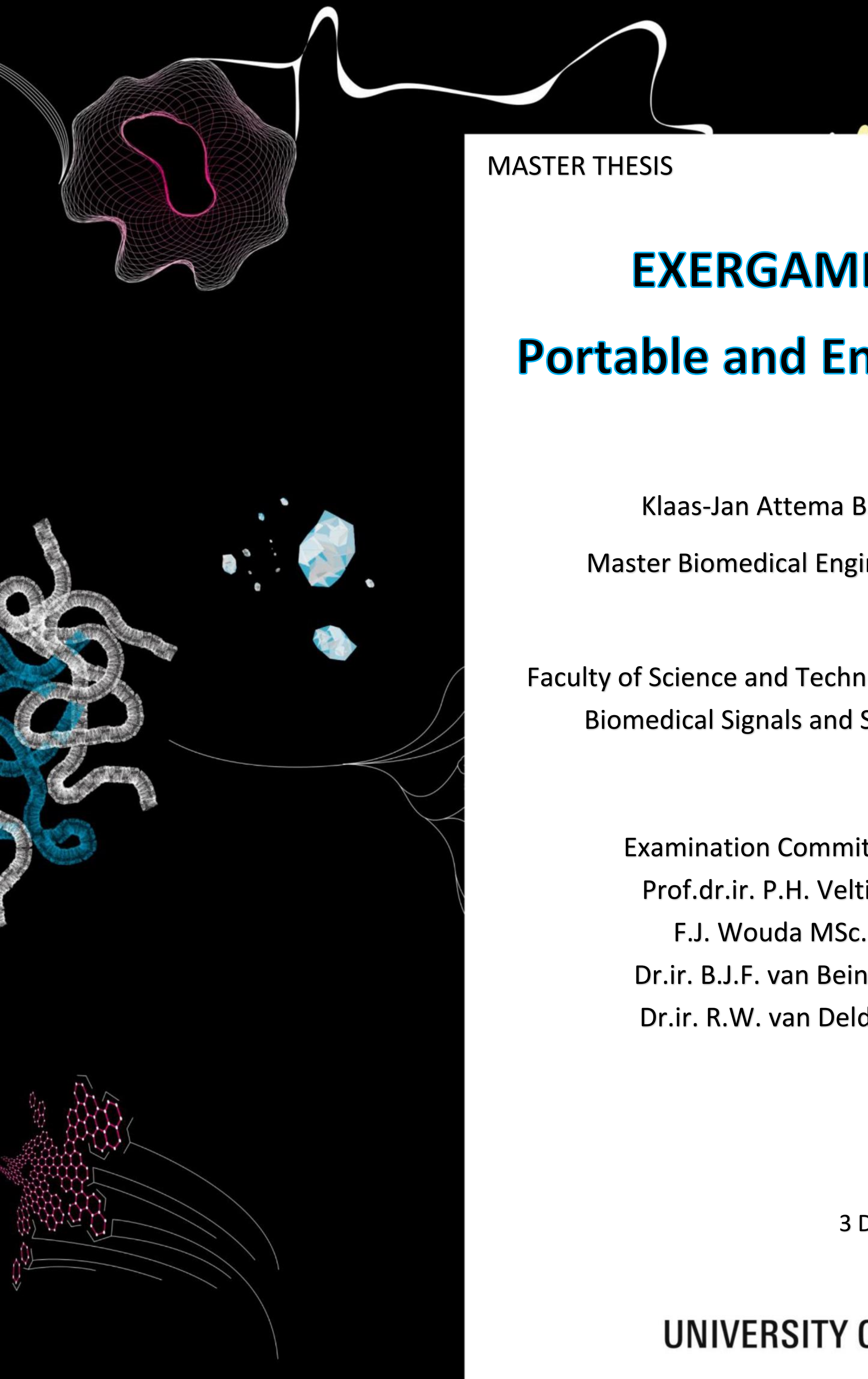

MASTER THESIS

EXERGAMES:
Portable and Enjoyable

Klaas-Jan Attema BSc.

Master Biomedical Engineering

Faculty of Science and Technology (TNW)
Biomedical Signals and Systems

Examination Committee:
Prof.dr.ir. P.H. Veltink
F.J. Wouda MSc.
Dr.ir. B.J.F. van Beinum
Dr.ir. R.W. van Delden

3 December 2019

UNIVERSITY OF TWENTE.

Preface:

This paper describes the results of my master thesis Biomedical Technology. Within the study Biomedical Technology, I've followed the master track "Neural and Motor Systems". I have therefore been working at the department of Biomedical Signals & Systems at the University of Twente during my master thesis. Hence, this research is conducted in collaboration with the University of Twente.

I would like to thank Peter Veltink for being my main supervisor. He helped me to think in solutions instead of problems and managed to always steer me to the correct path. Many thanks for Robby van Delden for being my external supervisor. He found time to help me and provide me with his scientific knowledge. Special thanks goes to Frank Wouda for being my daily supervisor. He helped me with the many problems I faced during my master thesis and has always been there to provide help whenever I needed. I also would like to give my thanks to Bert-Jan van Beijnum for being my supervisor, who helped me with the problems I faced during my master thesis after Frank Wouda left.

I would like to thank the rest of my colleagues at Biomedical Signals & Systems for the good time I've spend with them over the past year.

My thanks for the people who have been my voluntary test persons during my research. They managed to provide me with the necessary recorded data thanks to their willingness to strap themselves up with a ton of sensors.

I would like to thank my friends and family for the support and confidence they have given me. I especially want to thank Sytze Attema for repeatedly proofreading this master thesis.

I give my thanks to everyone!

Please enjoy reading my master thesis!

Klaas-Jan Attema

Abstract:

Exergames are a new method that stroke patients use to improve the rehabilitation of their gait. These exergames usually put little focus on the transportability of the hardware and the enjoyment of the user. This study seeks to create an exergame that optimizes the transportability and user enjoyment while being a solid tool for a stroke patient's gait rehabilitation.

Based on literature research a first set of mock-ups has been created and presented to physiotherapists. Using their commentary, a final prototype was created and subjected to a feasibility test.

The exergame in the prototype has the user walk over platforms while trying to keep his center of mass steady. The position of the user and his center of mass is calculated with X-sens Analyse motion capture. The platforms and center of mass are displayed to the user through Microsoft Hololens. At the end of the exergame the user is given feedback about his gait speed, the steadiness of his center of mass and the number of platforms he correctly stepped on.

The exergame is considered feasible if it fulfills four requirements. Unfortunately, only the second of the four requirements was fulfilled:

- The amount of orientation drift occurring in the exergame is 3.91%, which is higher than the maximum threshold of 1%.
- The maximum measured latency was 60.95 milliseconds, below the maximum threshold of 150 milliseconds.
- The accumulation of drift over multiple exergames was 32.8-36.2 centimeters after two exergames, and 52.3-59.2 centimeters after three exergames. The maximum allowed accumulation after three exergames is 25 centimeters, which was topped.
- None of the three methods in which the difficulty setting could be altered was viewed favorably by the test persons. Drift caused problems for two of the difficulty settings, and the limited screen size of the Hololens prevented the third difficulty setting from working properly.

Based on the limited fulfilment of the requirements with this specific implementation, we are not yet able to conclude that the created exergame is feasible. Changes are proposed to prevent drift and decrease the focus on user precision, the creation of a feasible exergame based on the requirements of this research might be possible.

Key Words: Augmented Reality, Exergame, Gait rehabilitation, Microsoft Hololens, Mixed Reality, Stroke patient, Unity, Xsens MVN.

Contents

1: Introduction

Stroke is the second commonest cause of death and a major cause of disability world-wide. Kumar & Clark define stroke as “a syndrome of rapid onset of cerebral deficit lasting >24 hours or leading to death, with no cause apparent other than a vascular one”. The death rate following stroke is 20-25%, and survivors of stroke require rehabilitation for the disabilities caused by stroke [1].

People who are rehabilitating from stroke often suffer from mobility symptoms that may persist even after acute treatment. Many stroke patients become unemployable and lose their independency due to these symptoms, resulting in a decrease of their quality of life. Rehabilitation by way of physiotherapy, occupational therapy and speech therapy have a vital role in assessing and facilitating the care pathway of the patient [1].

One disability caused by stroke is a disabled gait. Stroke usually causes hemiparesis, which can lead to a weakness, loss of skilled movement and defects in cognitive function on one side of the body [1]. Because of this weakened side of the body an asymmetry between the stride of both legs is created. This asymmetry decreases the quality of the gait of stroke patients [2]. Rehabilitation by physiotherapy is required to help the stroke patient recover to a normal gait.

One of the tasks of physiotherapy is to help patients regain mobility and balance. This could be done by making them play exergames [3]. Exergames are video games that require physical exercise of the player and have the intention of being a form of workout. They provide beneficial effects to people who have experienced a stroke:

1. Exergames can allow the stroke patient to improve their balance and increase cognitive functions [3]. The user is more active during the exergame, which helps them with maintaining and improving their health [4].
2. Exergames also help the mental state of the patient. According to Reis, et al., “Participants enjoyed playing the exergames, their depressive symptoms decreased, and they reported improved quality of life and empowerment” [5].

The rehabilitation treatment can be gamified by using exergames. This gamification approach should ensure an easy adoption of the system as well as a user readiness by the patients [6].

Though research into the use of exergames for stroke rehabilitation is limited, there are several different exergames that help with rehabilitation [6] [7] [8] [9]. An example of an exergame is Mystic Isle. Mystic Isle helps the stroke patient with making reaching movements with their upper extremities. A Microsoft Kinect camera measures the movements of the stroke patients, which affects the game the stroke patient can see on a monitor or projector [6]. This exergame has been shown feasible as an intervention for people after a stroke. Using Mystic Isle as an in-home intervention improves the motor function and daily activity performance of the stroke patient [7].

Exergames don’t need to have their output limited to a screen. One of these comprehensive systems is the Gait Realtime Analysis Interactive Lab (GRAIL). The stroke patient walks on a treadmill while being surrounded by a virtual reality environment projected on a 180° semi-cylindrical screen. As the user walks through the virtual environment a motion capture system measures the motion data and combines it with the force data from the treadmill’s force platforms to calculate joint kinematics and kinetics based on the human body model [8]. The GRAIL proves to be an apt training exergame that is beneficial for improving the balance and the gait of the user [9].

Both systems have their own advantages over the other system:

1. Mystic Isle is capable of a larger variety of exercises thanks to the wider variety of detected motions by the Microsoft Kinect. The GRAIL's exercises are all focused on making the user walk over a treadmill while stepping on platforms projected on the floor, only able to vary on this concept by implementing obstacles or perturbations during the gait.
2. The GRAIL is better capable of making minute changes to its own exercise compared to Mystic Isle thanks to the projected feedback and captured data being more independent from one another.

The earlier mentioned exergames show an improved rehabilitation of stroke patients. They show that usage of the exergame results in improved motor function for stroke patients, which is a major goal of rehabilitation [7][9].

All exergames have their own (dis)advantages. Exergames that focus on relearning the movement gait usually make their user walk on the spot or on a treadmill. [8][9] Those that do allow freedom of movement are usually limited to a single room that has been completely modified for exergame itself [6][7]. An exergame where the user can use the exergame wherever and whenever they want does not yet exist.

Another problem of exergames is that most of the studies that research exergames for medical purposes focus on showing the functionality of the proposed exergame on patient education and rehabilitation. Few studies try to optimize the effectiveness of the exergame. According to Bork, "To maximize the benefits of such systems it is necessary to find out about the best use cases and start an iterative optimization process of these systems [10]".

According to Widmer, research into the optimization of the stroke patient's education and rehabilitation should focus on the feedback of the game and how it rewards the person playing the exergame [11]. Optimization of this feedback system is done by optimizing the reward [12]. The reward is the incentive for the patient to keep using the system and wanting to excel the exergame. This incentive will help to keep the user motivated and help push to rehabilitate him/herself with the exergame.

This leaves us with the following primary research question:

Is it possible to design an exergame for the rehabilitation of the gait of a stroke patient that can be used <u>anywhere</u> yet also still be <u>fun</u> for the user?

Rehabilitation is defined by an improvement in the body functions and structures, activities and participation [13]. The exergame designed by this research mainly creates improvement in the activities by increasing the exerciser's walking speed, body balance and gross motor control for a reciprocal gait [14].

Three secondary research questions need to be answered before we can design an exergame that fulfill the primary research question:

1. What kind of exergame do we want to make the stroke patient perform?
2. Which tools do we use that translate the stroke patient's gait movements into an exergame which maximize the range of the exergame?
3. What reward systems of the exergame optimizes the fun for the stroke patients?

We expect to be able to create an exergame that fulfills the primary research question by giving answers to these questions.

In the first part of this research we explore the possible answers to the secondary research questions based on the current knowledge that can be found in scientific literature. In the second part of this research we determine the requirements that the proposed exergame needs to fulfill to satisfy the primary research question based on the secondary research questions and literature knowledge. In the third part we create mock-ups of exergames based on the requirements and literature knowledge and present them to physiotherapists for review. In the fourth part we create a final prototype and test out its proof-of-function. With all the knowledge gathered in these parts we can give an answer to the primary research question in the conclusion.

2: Research into scientific literature

In the introduction we asked ourselves three secondary research questions:

1. What kind of exergame do we want to make the stroke patient perform?
2. Which tools do we use that translate the stroke patient's gait movements into an exergame which maximize the range of the exergame?
3. What reward systems of the exergame optimizes the fun for the stroke patients?

In this part of the research we delve into scientific literature to obtain answers for these questions. We hope that we can reach a conclusion for all of these.

Types of exergames for stroke patients

What kind of exergame do we want to make our stroke patient perform? In this part of the literature review we seek to answer this question.

As said in the introduction, exergames are video games that require physical exercise of the player. They have the intention of being a form of workout. As said in the introduction, the exergame designed by this research mainly creates improvement in the activities by increasing the exerciser's walking speed, body balance and gross motor control for a reciprocal gait [14]. Literature has shown that training with a focus on these points will lead to an improved gait for stroke patients [14] [15].

We want the patient to train on these specific improvements. To do so the exergame must be composed out of exercises that each train on one of these ways of improvement. In this research we seek to find the best method to train walking speed, body balance and gross motor control for the exergame of this research.

Improving walking speed

Improving someone's walking speed appears obvious. Walking speed is the distance someone traverses over a set amount of time. By either fixing the distance to be traveled or the time spend walking you can get an estimate of the gait speed of the user.

Not all training methods to improve walking speed utilize real walking. Sometimes the user instead walks on the spot, called Walking-In-Place (WIP). This method utilizes step detection to estimate the number of steps per minute a user makes. By making an estimation for the step length of the user they can determine the walking speed of the user [16] [17].

We therefore need to consider two things to determine the optimal way to implement a method for walking speed improvement:

- Are Walking-In-Place exercises or Real Walking exercises preferable for the gait rehabilitation of stroke patients?
- Are exergames with a set distance or exercises with a set duration preferable for the gait rehabilitation of stroke patients?

When we compare Walking-In-Place and real walking, both WIP and real walking have their own advantages:

- Walking-In-Place does not need as many tools for measurement as real walking. No proper motion tracking system is needed to calculate the user's walking speed. The only thing that is necessary is that you can detect contact between the feet and the ground. Furthermore, this method doesn't limit the size of the virtual world by the available size in the real world [16]. One form of WIP, Gait-Understanding-Driven WIP, produces more consistent walking speeds that respond to variations in the step frequency of the user. This method comes close to obtaining the actual gait speed of real walking [17].

- Real walking's main advantage over WIP is that this method is much more precise and natural. WIP generates an estimation of the walking motion. This is a non-perfect representation of the gait, and the calculated gait motion is not the same as what is produced [17]. Another problem with WIP is that the perceived speed of someone walking in place is different from his actual speed. Users underestimate their perceived walking distance, and they change their gait behavior in an unnatural way [16].

As for comparing set distance with set time, Bijleveld-Uitman et al. compared these two predictors after stroke. They could not find a significant difference between set distance and set time for predicting how well the stroke patient can rehabilitate back into walking unsupervised within their own community. They do consider it pragmatic to choose for a set distance instead of a set amount of time. Measuring the exergame duration is easier to measure than the walking distance and can also be measured easily when space is limited [18]. From this we conclude that utilizing a set distance is preferable.

Improving body balance

Body balance is the stroke patient's ability to stand steady and not fall. The sense gets affected by stroke, but there are two specific methods for rehabilitating this type of stroke:

- <u>Balance Stabilization</u> is a training method that directly focuses on having the stroke patient keep his balance. The stroke patient tries to keep his center of gravity in control. This can be done using movement exercises like Tai Chi [19] or by performing weight-supported treadmill exercises [20].
- <u>Muscle Strengthening</u> is a training method focused on improving the muscle strength lost during the recovery from stroke. Nejc et al. found that there is a positive correlation between muscle strength and body balance [21]. By strengthening the muscles on the affected side of the stroke patient you increase the posture and weight transfer of the stroke patient, improving balance. Usually these types of exercise have a specific focus on certain muscle groups. Some exercises focus on improving the core muscles in the torso [26], others on strengthening the limbs [22] [23].

Both balance stabilization and muscle strengthening are important exercises that help the stroke patient. Balance stabilization helps improve the reaction speed to unwanted perturbations of the body and can lean further without falling [19] [20]. Muscle strengthening focuses on improving the muscular ability of the affected side of the body. This not only helps balance, but also weight bearing and gait velocity [22] [23] [24]. Both types of exercise are helpful for the patient and recommended for the recovery process. The exergame of this research could use either of the two methods to improve their body balance.

Improving gross motor control:

The point of improving gross motor control is to help improve the use of the affected half of the body while minimizing compensatory movement by the less affected half. In the case of improving gait this means that we seek to make the gait of the stroke patient reciprocal again [25].

The improvement of motor control consists out of the parts. First the stroke patient trains to strengthen his muscles. This helps with improving the posture of the stroke patient's gait, decrease the amount of weight placed on the affected leg and increases the symmetry of the gait [22] [23].

After the muscle strengthening it can be improved by focusing on improving the motion of the stroke patient. This can be done in two ways:

- Step Length Symmetry seeks to ensure that the length of each step is the same. A stroke patient is trained in this by having step towards a fixed point that is marked on the ground. By making all steps the same distance from one another you can help the patient with making his gait more reciprocal [9] [10].
- Cadence Symmetry focuses on ensuring that the duration of each step is the same. This can be done by utilizing rhythmic auditory stimulation (RAS). RAS has been shown to increase the stride, speed and symmetry of the stroke patient's gait [26] and has been used in modern gait rehabilitation [27] [28].

Both step length and cadence are important factors of someone's gait cycle. If possible, we would prefer to train the user in both. However, people who had a brain injury like stroke usually have problems with processing complex stimuli [29]. It would be better not to overstimulate the stroke patient. It is best if multiple variations of the exergame are tested in which one of the two methods are implemented.

Conclusion

We have three main objectives in the gait rehabilitation of the stroke patient: Gait speed, body balance and finer motor control. After looking at the possibilities for the implementation of these objectives we can come to conclusions about which are preferable to be implemented:

The main advantage of Walking-In-Place is that the necessary measuring tools for measuring walking speed are minimized. However, we do not merely seek to measure walking speed, we also want to measure body balance and finer motor control, for which more tools are needed. In that case it is preferable to utilize real walking for its precision and natural movement. With already having deduced that a set distance is preferable, we want the exergame to have real walking with a set distance.

For body balance we must look at how it can be implemented into a walking exergame. Muscle strengthening provides more benefits compared to balance stabilization, but most of the exergames we found did not perform muscle strengthening in a way that can be easily combined with walking [22] [23] [24]. On the other hand, focusing on balance during a walking movement did show up in balance stabilization exercises [19] [20]. We seek to improve the stroke patient's body balance using balance stabilization instead of muscle strengthening for this reason.

Gross motor control can be improved both by looking at Step Length Symmetry and Cadence Symmetry [9] [26]. Neither method has distinct advantage over the other, so we choose based on what better fits with the other exergame method. Our method for improving walking speed requires the user to walk over a fixed distance. Because of this it is simpler to implement Step Length Symmetry than Cadence Symmetry due to the former also utilizing fixed distance.

- The preferable method for improving gait speed is to have the stroke patient train to walk a set distance over time and help them to decrease the duration of this walk.
- The preferable method for improving body balance we seek to include an exercise for balance stabilization.
- The preferable method for improving gross motor control is to implement an exercise that trains on Step Length Symmetry.

Tools to translate the stroke patient's movements into an exergame which maximizes range?

An exergame needs hardware tools to correctly translate movements of the person playing the exergame into changes in the game on the output that the player sees. However, this is not usually doable with a single tool. Therefore, we break it down to smaller components for which we can compare different pieces of hardware with one another.

First, we look at how an exergame translates movements into game changes. The motion capture system measures the movements of the user, and depending on the system calculates the position, velocity and/or acceleration of the body segments. This is then sent to the game engine, which processes the data and calculates which kind of actions it creates within the game. After that the Interface system displays to the user the results of these actions. Thus, the exergame consists out of three parts: A motion capture system, a game engine and an interface system. A schematic of how this system works can be found in figure 1.

We can go over each of them separately and see what the best options available to us are in all three categories.

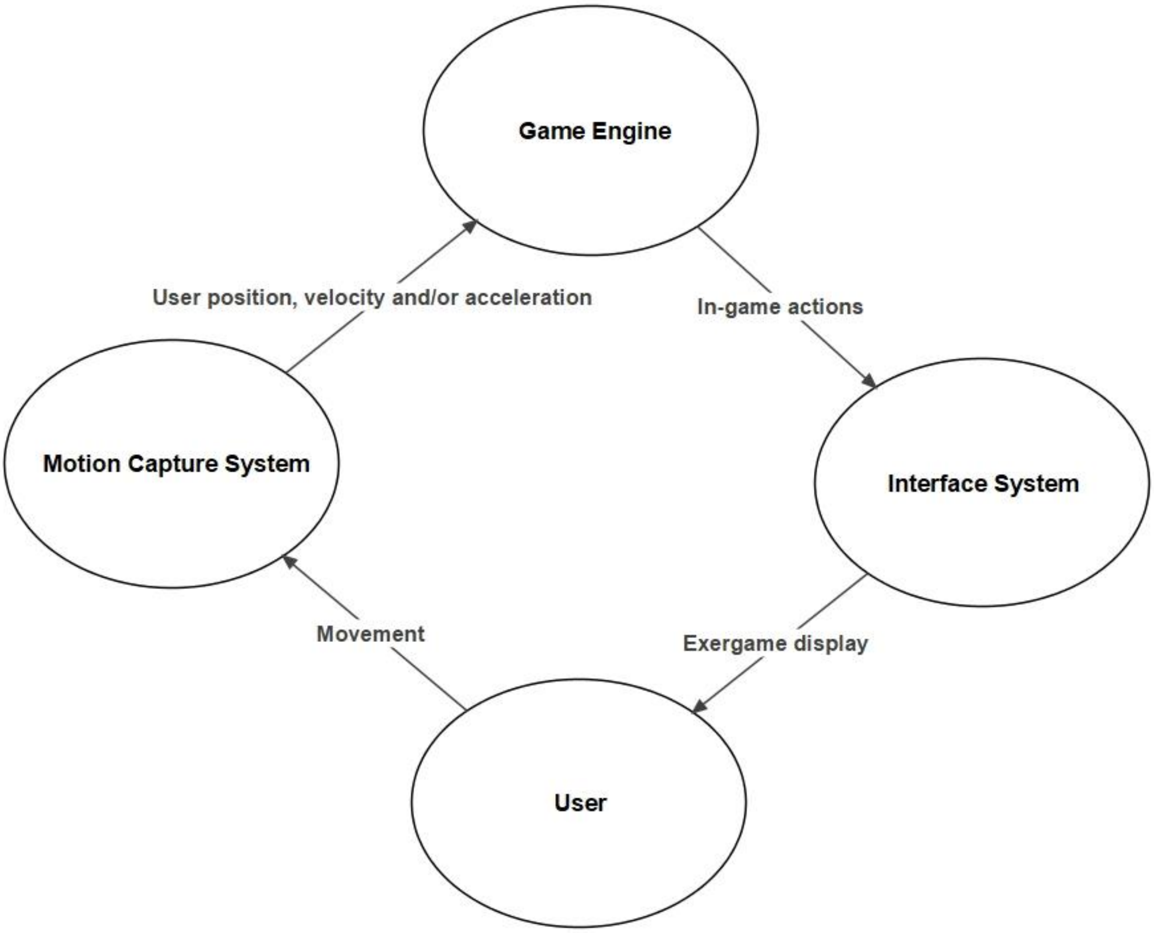

Figure 1: Schematic of the exergame feedback loop

Motion Capture Systems

Motion capture systems allow for the recording and processing of movement in people. There are multiple methods with which one can capture human movement:

> Optical Systems utilize data from two or more calibrated cameras to triangulate the three-dimensional position of a subject between the cameras. Some systems measure the location of markers to calculate the location of the body, like Vicon; others use a system without markers that track the silhouette of a person, like Kinect [30] [31].
>
> Inertial systems are based on miniature inertial sensors. Inertial motion capture usually uses inertial measurement systems that consist out of an accelerometer, gyroscope and magnetometer. These measure the rotational rates, which are translated to a human body skeleton with biomechanical models and fusion algorithms. Examples of inertial motion capture are Moven [32] and X-sens [33].
>
> Mechanical motion capture systems utilize an exoskeleton with rigid components of straight rods linked with potentiometers that articulate the joints of the body. An example of such a system is Dexmo [34] [35].

The problem with optical systems is that they're often bulky and require a large amount of set-up before they can be used [31]. It makes them unsuited for being moved around, limiting the area in which they can measure.

Mechanical motion capture systems are relatively cheap and lightweight, but their main weakness is that they're better suited for measuring only parts of the body, like hands and feet, rather than the entire body [34] [35].

This leaves us with inertial systems. They don't have the restricted movement of optical systems because they're worn on the body; since each inertial measurement system measures independently they can more easily be used for full-body measurements, unlike mechanical motion capture systems. This doesn't mean that inertial sensors don't have their own weaknesses: gyroscopes have drift errors over long periods of time, limiting the duration of the measurement.

Out of these three systems the one that is most likely to work according to our research question is the inertial motion system. Optical system's lack of range goes against our wishes of having an exergame with a maximized range. The exercises we want for our exergame according to "Types of Exergames for stroke patients" cannot be measured using the partial body measurement of the mechanical motion capture systems. Inertial measurement sensors have problems with the duration of the exercise due to drift, but this limit can be overcome. The development of inertial measurement is far enough that there exist systems that have limited the effects of this downside. With an average drift of 5% of the distance walked means that there will most likely be no problems with the drift for this exercise [36].

Interface Systems

Games like video games and exergames primarily focus on three senses: Hearing, sight and the hidden sixth sense of proprioception. The proprioception is part of the input, using it to issue commands in the game world that make the user function as an agent in the game world, thereby receiving feedback via hearing and sight [37]. This means that an interface system for an exergame would need to be audiovisual.

Yoo & Kay has compared the effects of three common interface systems for exergames [38]:

> Desktop displays show the exergame on a desktop monitor, e.g. a television screen, smartphone or a laptop screen. An example of exergames that use these types of displays are Nintendo Wii's fitness applications [39].
>
> Large displays project the exergame on one or multiple large flat surfaces. Examples of exergames that utilize this kind of display are the GRAIL and Mystic Isle mentioned in the introduction. Mystic Isle projects the exergame on a large screen in front of the user for ease of use [7]. The GRAIL utilizes multiple screens, displaying a virtual environment on screens in front and to the sides of the user as well as projecting platforms on the treadmill [9].
>
> Head-mounted displays make the user wear a device on the head with special glasses in front of the eyes. The device then projects the exergame on these glasses. Shaw et al. created such an exergame for cycling, using an Oculus Rift to display the exergame while they were performing on a home trainer [40].

According to Yoo & Kay, the users of desktop displays performed worse at the exergame compared to those with large displays and head-mounted displays. The downside of the large display was that it was considered impractical for everyday use compared to a desktop display or a head-mounted display [41].

It is not merely important that the data is displayed on an interface system. What is equally important is that the user can see and interact with the exergame display at any time. The exergame has a live output, and the game can force the player to react at any moment. If the user cannot interact with the system, they cannot respond to the exergame well. With a stationary interface this is not possible, as the locations where you can gaze at the interface are limited. The large display becomes impractical and does not fulfill the requirements. The only displays that fulfill this requirement are handheld desktop displays like smartphones or a head-mounted display.

These possibilities bring another danger to light: using a portable interface can decrease gait performance [41]. As the purpose of the exergame is to improve gait performance this decrease needs to be minimized.

Sedighi et al. compared the difference in gait performance between head-mounted devices, smartphones and paper-based dual-task walking. Of the three methods the one that had the least amount of loss in gait performance was the head-mounted device [41]. The research of Kim et al. did not find a decrease in the gait performance for people using a head-mounted interface. The only noted major difference was that the obstacle crossing speed decreased with three percent [42].

From this it appears that the best option for the user is to utilize a head-mounted display. These head-mounted displays can be further separated into Augmented Reality (AR) systems and Virtual Reality (VR) systems:

Augmented Reality uses a head-mounted display with transparent glasses. The exergame is projected on top of the real world and can combine both the real world and the virtual world. Because it combines the real world with the virtual it's not necessary for the augmented reality to be displayed with a head-mounted display, as it can be done with e.g. a desktop or large display [43]. If the user cannot carry around a desktop display or needs to look in multiple directions a head-mounted display for AR is preferable, like with HOLOBALANCE [44].

Virtual reality uses a head-mounted display with opaque glasses. The entire simulation of the exergame is virtual. The user is not aware of his surroundings in the real world, and completely focused on what is happening in the virtual one. Examples of these kinds of exergame are VRun [38].

The problem with virtual reality is that you are not aware of your surroundings. A lack of surrounding awareness would be dangerous for the user, potentially causing harm to them. The solution is to perform the exergame in an empty room, but this would limit the mobility and range of the exergame. Augmented reality is therefore preferable over virtual reality.

There are multiple possible augmented reality devices that can be used for exergames: Both Hololens and Magic Leap are examples of interface displays currently used in the medical world [45][46]. We have enough possibilities of choice that acquiring and utilizing a head-mounted augmented reality display should be possible.

Game engine

In figure 1 we see that the game engine must be able to utilize the data about the position, velocity and/or acceleration from the motion capture system and translate that to in-game actions on the interface system. This means that the game engine should be judged is whether it's compatible with both the motion capture system and the interface system. We cannot say which system to use right now, because we first need to know which motion capture system and interface system we want to use. We can only decide which game engine we're going to use after we know the brand of inertial motion capture and head-mounted augmented reality display we want to utilize.

Preferable combination

We've compared the possible pieces of hard- and software for our exergame. The combination that appears to be function best as an exergame without limiting range and mobility is an inertial motion capture system, a head-mounted augmented reality display and a game engine compatible with the other two.

Reward systems that optimize the fun for stroke patients

One of the most important requirements of an exergame that helps rehabilitate stroke patients should be its ability to be fun [13]. If the exergame provides a fun training environment it would be an intrinsic reward as compensation for the performed work. On the other hand, if the exergame is not enjoyable for the stroke patient, he requires an outside reward as additional compensation for the performed work [13]. If this reward cannot be obtained or is not worth the work, continuation of the exercise becomes more unlikely. An example of this difference has been found in exercises for people with arthritis: People who exercise regularly described that they enjoyed the exercise and found it fun, while non-exercisers find that the negative effects of arthritis during the exercise have more weight to them then the fun and improvement obtained from the exercise [14]. Therefore, it is important that the proposed exergame provides fun for the user so they will keep performing the exercise.

Rewards motivate people to keep excited over the course of a game [47]. Although the direct purpose of any reward is to provide a goal, a well-designed reward mechanism can push players by maintaining positive gaming experiences and motivation. This helps the player endure through the entirety of the rehabilitation independent of how long the rehabilitation takes [48]. Putting this in the perspective of exergames means that a reward system optimized for the respective exergame might create these gains for the user during his rehabilitation.

Rewards in video games have been classified by Salen & Zimmerman into four categories: *glory, sustenance, access,* and *facility* [12].

> Rewards of glory are those that provide the player with status or achievement without having an impact on the gameplay itself. Examples include leader boards for high scores or trophies for achievements.
>
> Rewards of sustenance are those that allow the player to maintain their status quo in the game and keep objects and rewards acquired up until that point. Examples include health packs, potions and armor.
>
> Rewards of access allow the player to access new locations or resources that were previously unavailable to them. Examples include keys, passwords or new weapons.
>
> Rewards of facility allow the player to do things they could not do previously or to enhance existing abilities. Examples include modifications to improve vehicles used in the game or the ability to jump higher [12].

According to Philips, Johnson & Wyeth the classification of glory was too broad and unspecific. They divided glory into three new forms of reward: *Positive feedback*, *sensory feedback* and a revised form of glory [49]:

> Rewards of positive feedback is flattery or praise received from the game, communicated in the form of language. Examples include an agent thanking the player and calling them a hero, or the word ‘perfect’ appearing on the screen when the player performs a successful action.
>
> Rewards of sensory feedback use visual or audial feedback rather than language to communicate with the player. These types of feedback are primarily used as a celebration of event and provide a feeling of positive affect or empowerment. A good example of sensory rewards can be seen in the game ‘Peggle’, in which, at the end of a level, the uplifting song ‘Ode to Joy’ plays while the player’s ball gains a rainbow-like trail and emits fireworks [49].

Revised glory utilizes the rewards of glory not mentioned in Rewards of positive feedback and rewards of sensory feedback. The focus of these types of reward are leader boards for high scores and trophies for achievements [49].

Another way to separate reward systems is to sort them on the duration of the reward. Philips Johnson & Wyeth identified 4 different sorts of durations: *Timed, Transient, Permanent* and *Consumable* [49]:

Timed rewards are videogame rewards in which the awarded artifact exists for a fixed period. An example would be giving the player invulnerability to damage for a fixed period.

Transient rewards are videogame rewards in which the awarded artifact exists in a non-permanent state. Transient rewards may exist until the occurrence of certain in-game events. For example, access to a weak version of a weapon is a transient reward – when the player gains access to a more powerful version of the weapon the weak weapon is wholly replaced. Another example is a power-up that may exist until the player receives damage from an enemy.

Permanent rewards are videogame rewards that exist in perpetuity. For example, a permanent reward is awarded when the reward applies a permanent enhancement to a player's avatar, such as leveling up. Another prominent example is gaining access to a new area or level in a game.

Consumable rewards are videogame rewards that the player has the option to use or not to use. For example, the player decides when the effect of the reward artifact should be applied. The reward artifact is then removed from play. A prevalent example of a consumable reward is in-game currency that allows players to purchase game items through a shop interface based on their personal preferences [49].

Rewards can also be separated on how the reward is utilized by the user. Utilization can be defined using a dual-axis classification system, as seen in figure 2. The horizontal axis emphasizes the idea that rewards may be oriented to personal satisfaction or to other players within a community. The vertical axis reflects how seriously players view their gaming activities and accumulated rewards.

Based on this classification there are four different angles for reward usage: *Advancement, Cooperate/Compete, Review* and *Sociality* [50]:

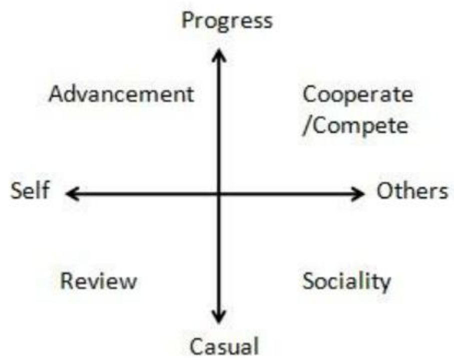

Figure 2: Dual-axis reward usage classifications [50].

Advancement. Players use rewards to make game progress—for example, building avatar strength with powerful *World of Warcraft* items. Rewards in this category mitigate challenge levels so that players can advance and gain feelings of increased skill and power.

Cooperate/Compete. Examples include sharing resources with teammates and hoarding powerful items to maintain advantages over other players. *Diablo II* encourages cooperation in order to accumulate pieces of equipment called "set items" as bonuses. It is not easy to collect all items in a set. Therefore, many *Diablo II* players possess multiple items belonging to different sets. The game design encourages player interactions to make item exchanges.

Sociality. Examples of using rewards as social tools include giving *World of Warcraft* avatars funny appearances, sharing information about rewards with other players, and showing off rare achievements or powerful weapons to establish status. These kinds of activities reflect the growing importance of player interaction via online forums or informal gatherings of gamers for single-player games.

Review. Players like to check their achievement collections, view their avatars wearing powerful items, and watch animations presented in games. Reviewing rewards provides entertainment, a sense of accomplishment, and memories linking play events to specific rewards. Thus, making rewards accessible for review is an important aspect of game design [50].

The reward needed for an exergame for stroke patients is different than the reward system for ordinary video games. The main goal of the video game is to generate fun for the user, while the exergame seeks to improves the physical capabilities of the stroke patient.

Because the purpose of an exergame is to improve the capabilities of the stroke patient, rewards that are utilized for progress are more valued than rewards utilized for casual gains. If the rewards do not grow with the skill of the user, then the enjoyment the user obtains from the reward decreases. As it is hoped that the results from the rehabilitation are permanent, rewards that have a permanent in-game effect to reflect this growth are preferred. [50]

While rewards of sustenance are usually utilized to help the exerciser progress and improve with the game their duration is usually not of a permanent form. Because permanent rewards are preferred this type of reward cannot be used as the only reward form. Sustenance might be useful if the level of sustenance can be objectified and classified as a reward of glory, creating a permanent form of reward. Further research is needed in this direction.

Rewards of Access usually provide content that requires a certain amount of effort to be unlocked. Unlocking this content grants unrestricted access to new locations and resources. While this type of reward usually leans more towards the casual side of the casual-progress bar it might be usable as a progressive type of reward if obtaining these rewards requires the user to progressively get better at the game.

Rewards of Facility grant permanent rewards that allow the user to do more within the game itself. This is a reward type that leans heavily on the progressive side of the progress-casual axis. However, the goal of exergames is to improve the physical capabilities of the user. This gives the exergame an in-born form of this type of reward. Rather than rewarding the player by giving him increased ability for the same level of exercise, the exergame seeks to give the player increased ability because he increased his level of exercise. Because of this redundancy, rewards of facility will not be included in further steps of this research.

Rewards of Positive Feedback have been scientifically proven to be important for rehabilitation by exergames. It is crucial that the stroke patient does not get frustrated by failure and quits the exercise. By handling failure in a positive way, the rehabilitator is more likely to remain engaged and not feel that failure in the game stems from their impaired physical abilities [51].

Rewards of Sensory Feedback are given as celebration of events utilizing visual or audial feedback. These forms of reward are transient, given out at specific moments when the user performs a specific successful action. They do not create permanent rewards, nor do they help the player stay engaged during failure like positive feedback does [51]. This form of reward is therefore dropped from this research.

Rewards of Revised Glory have a transient effect on gameplay as they only show up momentarily. The scores from this type of reward are usually stored to form a permanent form of reward. The problem with this is that it leans towards the casual side of the casual-progress axis where progress is preferred. However, this is the type of feedback used by current exergame systems as a golden standard thanks to its ease of use and implementation, making this reward required for this research [52] [53].

Preferred reward systems

The rewards reviewed in this research can be seen in table 1. Rewards of facility and sensory feedback are not part of this research. As mentioned before, rewards of facility are redundant when the goal of the exercise is to improve the user's physical capability. Rewards of sensory feedback are dropped because they are non-permanent rewards that do not keep the user continuously engaged.

Salen & Zimmerman	Philips Johnson & Wyeth	Utilized for stroke patients
Glory	Positive Feedback	Positive Feedback
	Sensority Feedback	
	Revised Glory	Revised Glory
Sustenance	Sustenance	Sustenance
Access	Access	Access
Facility	Facility	

Table 1: Rewards for exergames

Currently the golden standard for exergames are rewards of revised glory thanks to their ease of use and implementation. Positive feedback is certainly utilized while rewards of access and sustenance are compared with this golden standard. We do not yet know what effects implementing these rewards have on the user experience and rehabilitation of a stroke patient, but it might be possible to utilize these in gamification of walking exercises [54].

3: Requirements

Before we can design an exergame we first need to know what the requirements of the exergame are. By taking another look at the research question we can split up the categories for the requirements. In the research question "Is it possible to design an exergame for the rehabilitation of the gait of a stroke patient that can be used anywhere yet also still be fun for the user?" We've underlined five parts that can be used as aspects to define the requirements:

1. Rehabilitation: The goal of the exergame is to help the patients with rehabilitating their original gait. In the literature research we discovered the types of exercise we want the stroke patient to perform to help with their rehabilitation. We now must set requirements to define how these exercises must be implemented in the exergame.
2. Stroke Patient: The target group of the exergame are stroke patients. We need to ask ourselves what requirements the stroke patients have of the proposed exergame.
3. Exergame: We want to design an exergame. If the exergame does not function properly, then there is no point in having a stroke patient train with it. In chapter two we declared what combination of exergames we preferred, which requirements do we set for the technology of the exergame?
4. Used anywhere: One of the two focus points of this research is that we seek to improve the mobility of the exergame, both in ease of transportation and utility. What are the requirements we set before we are satisfied with the mobility?
5. Fun: The other focus point is that we want to ensure that the fun the user feels is optimized. We've defined in the literature research what type of reward systems we want to include, what are the requirements for these reward systems?

By looking at each of these points in more detail we can create a list of requirements that our research needs to fulfill. We prioritize these with the Kano model [55]. The Kano model splits the requirements into three groups:

1. Basic Needs: These are the requirements that the user expects and takes for granted. If they're poorly implemented the user will be dissatisfied. No praise is given if these are done well.
2. Linear Needs: Also called performance needs, these are requirements with a linear correlation between performance and satisfaction. If done well, they satisfy the user. If done poorly they cause dissatisfaction.
3. Delighters: These are the requirements that are not expected by the user. They are satisfying for the user when done well. They cause little to no dissatisfaction if implemented poorly.

A table of all the requirements can be found in Appendix A.

Requirements for stroke patient rehabilitation

The ultimate goal of the exergame is to ensure that the stroke patient rehabilitates his gait. In the introduction we defined rehabilitation as an improvement in the body functions and structures, activities and participation [56]. In chapter two we determined that we can achieve the best improvement by training the stroke patient in real walking, balance stabilization and step length symmetry. For the implementation of each of these three exercises we can set up requirements:

Requirements for the real walking exercise

The real walking exercise is one in which the user trains their walking speed. This is done by making the user walk forward for a set distance, which they try to do in as little time as possible. The goal of the exercise is that through the training of this exergame the user's walking speed will improve.

Basic: The walking speed of the stroke patient is higher after continuously training with the exergame than before he started to use the exergame.

Basic: The user must be able to walk from the starting point of the exergame to the end point of the exercise.

Basic: The end point of the exergame can be reached from the starting point by walking in a straight line.

Linear: The user must be able to manually choose the distance between the starting point and the end point.

Basic: The exergame must be able to measure the duration of the exergame.

Delight: The exergame must be able to measure the movement speed of the user as he is performing the exergame.

Linear: The user is given his overall walking speed at the end of the exergame via audial and/or visual feedback.

Delight: The user must be able to see his current walking speed during the exergame via audial and/or visual feedback.

Requirements for the balance stabilization exercise

The balance stabilization exercise focuses on making the user aware of their center of balance and training them to keep it stable. The goal of this exercise is that the user obtains more control over the stability of the balance of his body through this exergame.

Basic: The stroke patient has better control over the stability of the balance of his body after continuously training with the exergame than before he started to use the exergame.

Basic: The exergame must be able to continuously measure the center of balance of the user when the exergame is active.

Basic: The user must be able to differentiate between good control and bad control of his own center of balance through audial and/or visual feedback.

Linear: The user must be given a visual representation of his center of mass in the exergame.

Linear: At the end of the exergame the user is given a representation of how stable his balance is through audial and/or visual feedback.

Requirements for the step length symmetry exercise

The step length symmetry exercise focuses on making each step of the user the same length. By making the step length symmetrical the user's gait pattern improves, increasing his ability to walk. The goal of this exercise is to increase the user's step length symmetry by training with the exergame.

Basic: The step length symmetry of the stroke patient is higher after continuously training with the exergame than before he started to use the exergame.

Basic: The exergame must be able to show in an audial and/or visual way what the correct step length is that the user must bridge with his step.

Basic: The exergame must be able to calculate the step length of every step the user makes.

Linear: The exergame must give audial or visual feedback whenever the user successfully manages to make a step of the correct length.

Linear: At the end of the exergame the user must be able to see how many correct steps of the right step length he took.

Requirements from the stroke patient

The user also has expectations of the exergame. In the section we look at what the stroke patient wants out of the exergame. The main reason why a stroke patient would play the exergame is that he wants to improve his gait. The objective part of rehabilitation has been covered above in “Requirements for stroke patient rehabilitation”. We now need to look at rehabilitation subjectively from the view of the stroke patient.

The main thing the stroke patient wants is to improve his gait. Therefore, he should be able to understand where and how he is improving. This is more difficult than it sounds, as stroke patients often suffer from cognitive impairment. According to Sun et al., twenty to eighty percent of all stroke patients suffer from cognitive impairment, which varies for the difference between countries, races and the diagnostic criteria. Stroke with cognitive impairment have problems with learning, remembering and concentrating [57]. Stroke patients with severe cognitive impairment, to the point they cannot perform daily activities by themselves, are not the target group of this exergame. Stroke patients with mild cognitive impairment, where the impairment is not severe enough to prevent their ability to perform everyday activities, should be able to use this exergame to rehabilitate their gait.

The exergame may also not cause any harm to the user. The purpose of the exergame is to improve the gait of the stroke patient, and not to increase the amount of impairments he has. It won’t do if the user ends up worse off because of the rehabilitation.

Another thing to consider is that no two stroke patients have the exact same impairments. Exercises that might be too difficult for one patient could be no challenge at all for another. It is important that an exergame can be modified to best suit the patient’s needs. As Wüest, et al. puts it, “An exergame-based rehabilitation program warrants individually tailored balance progression in a learning environment that allows variable practice and hence optimizes the recovery of walking ability” [58].

Basic: The exergame must be simple enough that a stroke patient with mild cognitive impairment can understand and use it.

Linear: The stroke patient must be able to understand in layman’s terms that this exergame is going to help him rehabilitate.

Linear: The stroke patients can see during the training period that his gait is improving.

Basic: The exergame may not endanger or cause any form of harm to the user.

Basic: The exergame can be tailored to the patient by a medical caretaker.

Delight: The exergame can be tailored to the patient by the patient themselves.

Requirements for exergame design

In chapter 2 we determined that an exergame needs to have an inertial motion capture system, a head-mounted augmented reality display and a game engine compatible with the two. We can split up the requirements based on each of these parts.

Requirements for the inertial motion capture system

The inertial motion capture system's main purpose is to read the movement of the user and send this data to the game engine, as seen in figure 1. As we are using an inertial-based system, we should expect that the only limitation to the range being the receiver. We should be able to expect a minimum radius of at least twenty meters for the inertial motion capture system [36]. Within that distance there should be no problems with the transmission of data.

With inertial motion capture we need to watch out for drift during the exergame. The expected amount of drift we expect to occur is five percent of the distance walked [36]. Recalibrations take time and effort that is preferably spend by having the stroke patient perform the exergame. Therefore, it would be preferred if the number of necessary recalibrations is limited.

Basic: The inertial motion capture system can read the movement of the user and store this data as position, velocity and acceleration.

Basic: The inertial motion capture system can send out the position, velocity and/or acceleration of the user to the game engine.

Basic: The inertial motion capture system must be able to measure the movement of the user independent of the user's current location within a radius of 20 meters.

Basic: The average drift occurring in the system may be no more than five percent of the distance walked.

Basic: The exergame should only force the user to calibrate the inertial motion capture system at the start of the session and not in-between.

Requirements for the head-mounted augmented reality interface display

The main purpose of the head-mounted augmented reality interface display is to read the data it receives from the game engine and turn this into an exergame to display to the user via audiovisual output. Furthermore, we want the user to be able to see and interact with the head-mounted augmented reality interface display at any time during the exergame.

Basic: The head-mounted augmented reality interface display should be able to read and apply the data it receives from the game engine.

Basic: The head-mounted augmented reality interface display displays the exergame to the user.

Basic: The head-mounted augmented reality interface display displays both visual and audial output.

Basic: The user must be able to see and interact with the head-mounted augmented reality interface display at any time during the exergame.

Requirements for the game engine

The game engine's purpose is to create a game. Without a game there is no exergame, just a regular exercise. The other requirement for the game engine is its compatibility with the rest of the tools for the exergame. This means that it can read the data given by the inertial motion capture display. It then translates this data into changes within the game that the head-mounted augmented reality interface display receives.

Basic: The game engine creates a game that can be used in the exergame.

Basic: The game engine should be able to read the position/acceleration/position given by the inertial motion capture system and utilize it in the game part of the exergame.

Basic: The game engine must translate the data from the inertial motion capture system into changes in the game.

Basic: The game engine must send information about the in-game changes to the head-mounted augmented reality interface display.

Requirements concerning usability and transportability

In the research question we put extra emphasis on the exergame being used anywhere. With this we mean that we want the system to give as little problems with the location of use, the ease of use of the exergame and the transportation of the hardware.

With regards to the location, the exergame should not be hindered by where it is used. We want the exergame to be used anywhere. There shouldn't be made any significant modifications to the location of use other than installing the hardware. Installing the hardware on location should be doable for a single layman following written-down instructions.

We also want the exergame to be easy to use. Setting up the hardware on location (e.g. equipping a sensor or activating a camera) shouldn't require outside help for a user without cognitive impairment. If the user has a cognitive impairment a single layman can provide the set-up for the exergame by following instructions on how to use the exergame, though it would be nice if the stroke patient would be able to do this without help.

The ease of use should also appear within the exergame. The interface should be simple enough to understand for a stroke patient with mild cognitive impairment when to start or stop the exergame. Commands and other messages (both verbal and non-verbal) that appear on the interface of the exergame must be easy to understand for someone who is recovering from stroke. While it would be preferable if the stroke patient could also change the settings menu, it is a difficult task for them. It is considered enough if at least a layman can make changes to the settings.

With regards to transportation, we want to ensure that it is portable. A single healthy person should be able to carry everything in one trip without problems. According to Waters et al. an average person can lift up to 23 kilograms for a sustainable amount of time without problems [59]. Therefore, the maximum weight of the entire hardware system is 23 kilograms. Its size should also not be too big. It needs to fit through most of the doors. Most doors are built with a standard width of 80 cm [60]. Therefore, the packed-up hardware should fit through a basic door with a width of 80 cm.

Linear: There should not be made any significant modification to the location where the user wants to use the exergame.

Basic: A single layman can install the hardware following written-down instructions.

Linear: A single layman without cognitive impairment can set up the exergame without outside help.

Delight: A stroke patient with mild cognitive impairment can set up the exergame without outside help.

Basic: A stroke patient with cognitive impairment must be able to start and end the exergame by themselves.

Linear: Commands and other messages (both verbal and non-verbal) that appear on the interface of the exergame must be easy to understand for someone who is recovering from stroke.

Basic: A normal person must be able to change the settings of the exergame.

Delight: A stroke patient with cognitive impairment must be able to change the settings of the exergame.

Linear: The maximum weight of the entire hardware system is 23 kilograms combined.

Linear: The hardware should fit through a door with a width of 80 cm when it is packed up.

Requirements concerning fun

Exergames are essentially games. Games are usually played for fun. Few people continue playing a game that they do not find fun. The same goes for exergames. If the person performing the exergame does not obtain fun from the exergame or doesn't believe the fun is worth the effort, they will likely not continue the exergame [61] [62]. Therefore, we seek to optimize the user's fun.

We want to increase the fun by including rewards for performing the exergame. In the literature research we determined the types of rewards we want to include: Rewards of revised glory, sustenance, access and positive feedback were seen positively to include. When the user does something well during the exergame they should obtain one of these forms of reward to make the exergame more fun for them.

The exergame should also keep the user focused on the exergame. Negative effects that the user was not responsible for can cause irritation and frustration. Issues like latency problems can make the user lose focus. In case of latency, the maximum amount of latency that can be considered acceptable is 150 milliseconds. An average human has a visual processing speed of 150 milliseconds. If the latency is longer than this amount of time the human will recognize the latency [56]

Linear: The user receives a reward of positive feedback for doing well at certain parts of the exergame with rewards of positive feedback in mind.

Delight: The user can obtain rewards of revised glory for doing well at certain parts of the exergame designed with rewards revised glory in mind.

Delight: The user can obtain rewards of sustenance for succeeding at certain parts of the exergame designed with rewards of sustenance in mind.

Delight: The user can obtain rewards of access for succeeding at certain parts of the exergame designed with rewards of access in mind.

Basic: The game must only cause negative effects by the actions of the user, and not because of circumstances outside the user's control.

Basic: The maximum amount of latency that can occur during the exergame is 150 milliseconds.

4: Design of Exergame Mock-Ups

Introduction

Several steps in the design of the exergame have been made during the literature review. In the literature review we have determined the types of exercises that should be included in the exergame, the hardware to use for our exergame and which types of rewards are best used for an exergame:

- Exercises: Three forms of exercises must be included in the exergame. One of them must help the stroke patient improve their walking speed, another must help with his body balance and the last must help with the gross motor control.
- Hardware: We want to utilize an inertial-based motion capture system and a head-mounted augmented reality display, supported by a compatible game engine. Based on the literature research and the supplies available at the university of Twente we chose to use X-sens and Hololens, supported by a Unity game engine.
- Rewards: From the research towards reward systems we have concluded that the best possible reward methods are rewards of glory, sustenance, access and positive feedback. We want to include all four of them in these mock-ups.

Our current knowledge is not enough for sufficiently designing an exergame that fulfills the primary research question. We have two major questions left unanswered:

- What is the complete form of the exergame we want to let the stroke patient perform?
- How do we implement the reward system into the exergame?

It is important to find answers to these questions to create an exergame best suited for stroke patients. To do this we first create mock-ups of the exergame so we can have them be reviewed later.

Mock-Up design of the Exergame

In the introduction and literature research we pointed out that there are three different types of exercises that need to be implemented into the exergame: One of them must help the stroke patient improve their walking speed, another must help with his body balance and the last must help with the gross motor control. This means that the exergame in the mock-up needs one exercise for each of these three types.

Exercise for improving walking speed

In the literature research we concluded that the optimal way to train walking speed is to have the patient walk a set distance forward and try to do it as fast as possible. This type of training could directly be implemented into the exergame.

At the start of the exergame the user is placed at the start of a path, demarcated by two wooden bars at the sides of the path. At the end of the path they can see the word goal hanging in the sky. This can be seen in figure 3. The user is encouraged to walk towards this goal until he sees a checkerboard-colored line on the floor, as seen in figure 4. The mock-up ends when the user crosses this line.

Time is used as the method of feedback for this exercise. While no timer is shown during the exercise when the exercise is completed the user is told how fast they managed to complete the exergame. By pushing the user to improve their time we expect them to keep up a continuous movement and improve their walking speed.

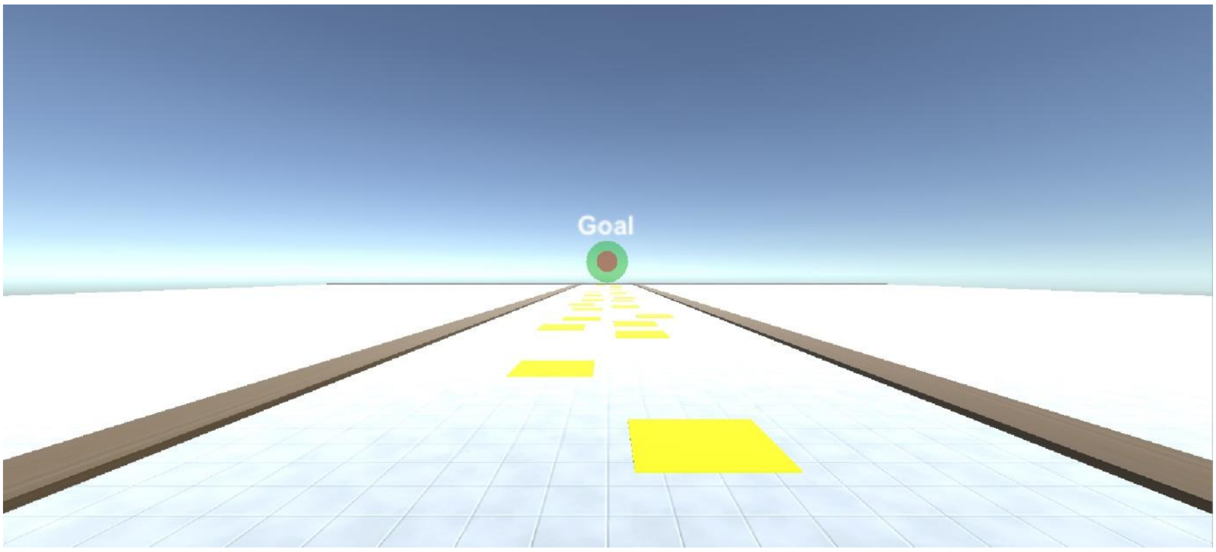

Figure 3: Basic Walkway mock-up. The camera is currently located at the starting point of the exergame

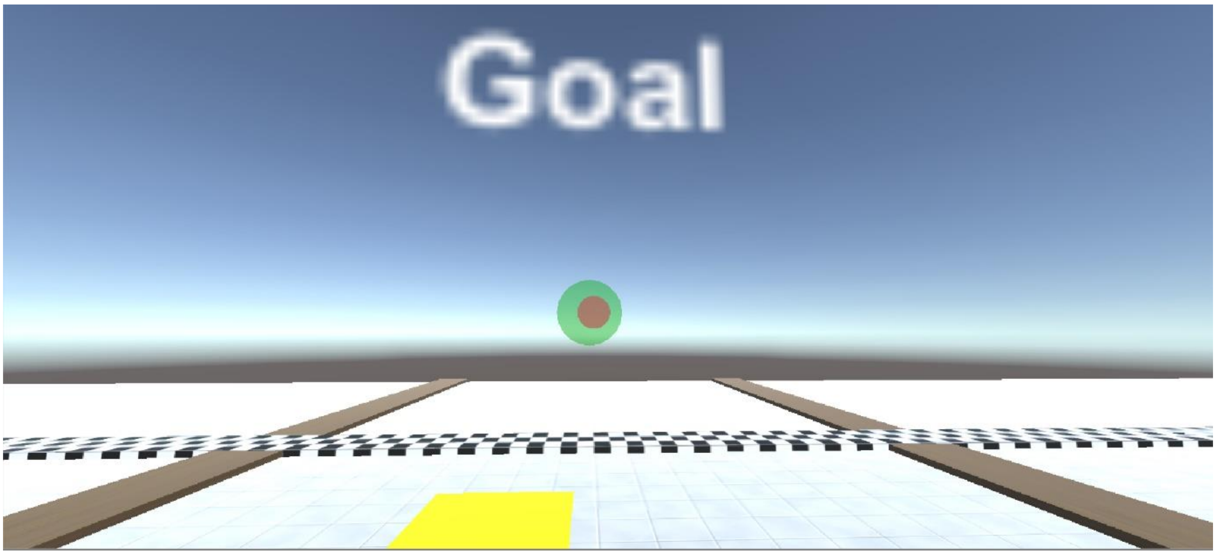

Figure 4: End of the basic walkway mock-up. At the end of the exercise the user reaches a finish line. Crossing the finish line causes the exergame to end and go to the results screen.

Exercise for improving gross motor control

In the literature research we pointed out that we wanted to utilize step length symmetry to improve gross motor control. By fixing the step length of the user you help him to improve their walking pattern and control over their gross motor control [10]. This is implemented in the exergame with large array of platforms projected on the floor in a long, linear line. These are alternating on the left and right side of the body. In the mock-up these platforms have a variable step length and stride width. These distances can be changed before the exergame starts to suit the user. Implementation of these platforms can be seen as seen in Figure 3.

The goal of the user is to walk forward while only stepping on the platforms. When the user steps on a platform the platform will change in color and a sound will be played to indicate that the user has correctly stepped on the platform, as seen in figure 5. When the exergame ends the user is told how many of the platforms he correctly stepped on and how many he missed.

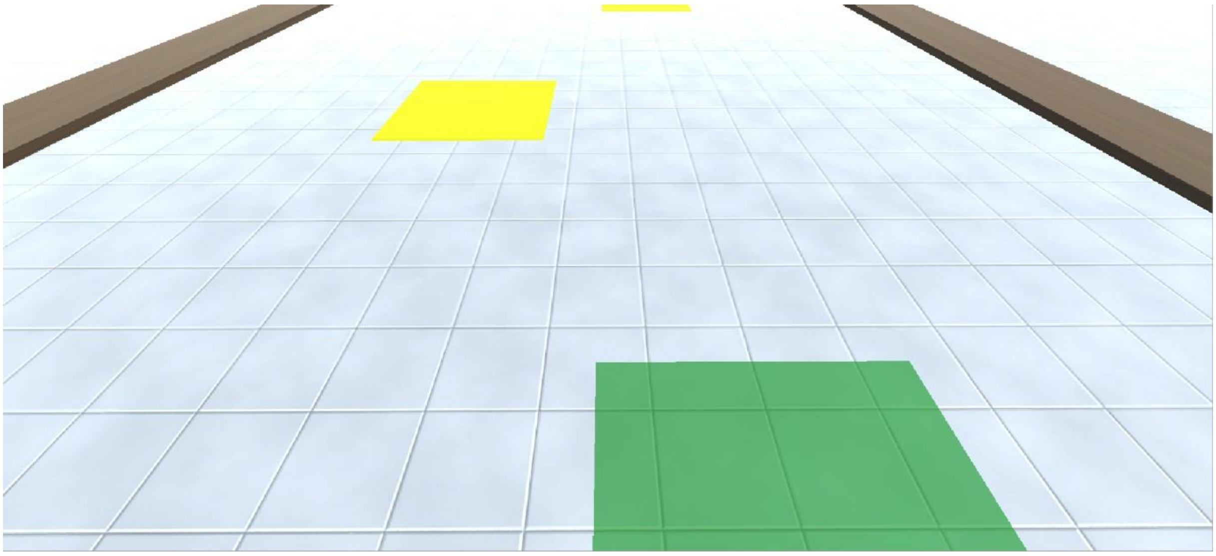

*Figure 5: Stepping on a tile in the basic walkway. The tile turns green and a *ping* sound plays.*

Exercise for improving body balance

In the literature research we found that it is preferable to train body balance by teaching a stroke patient to keep his center of mass (CoM) in control. We want to utilize this within our mock-up. Part of the exergame is therefore an exercise to keep your own CoM under control.

To teach the user about their CoM we need a proxy of this center of mass visible for the user, so they have a visualization. This is represented by a red circle located at the horizon in the direction the user looks towards at the start of the exergame, as seen in figure 3. When the user's CoM changes so does the position of the red circle. If the CoM shifts to the left the circle shifts to the left; If the CoM shifts up the circle shifts up etc. This way the user is aware of changes in his CoM in four directions.

A bigger, green outer circle can be seen around the center of mass. This green circle represents the boundary for the center of mass which may not be broken. The purpose of this exercise is that during the exergame the red circle, the proxy of the CoM, does not move out of the green circle. When the red circle moves out of the green circle a buzzer sound is played to indicate that their center of mass has exceeded the boundary. After the exergame ends the user is told how often the user caused the red circle to move outside of the green circle.

Mockup design of the rewards system in an exergame

Thanks to the earlier section of literature research, we know what kind of reward systems are good choices to implement in the final exergame. However, the optimal way to implement these reward systems needs to be decided upon. We still know relatively little about how we need to implement the reward systems. Therefore, we created multiple mock-ups all based on the same exergame implementation, but with different reward implementation.

According to our literature research there are four reward types which are interesting in for the use of exergaming: Positive feedback, revised glory, sustenance and access. Positive feedback was considered a standard inclusion in the final prototype. Positive feedback is considered essential for exergaming, as discussed in the literature research by Hallford et al. [52]. This reward has therefore been included in all three of the mock-ups and not been made into a separate mock-up. A total of three mock-ups were created with each mock-up focusing on a different type of reward.

Mock-Up with a revised glory reward system:

The first mock-up focuses on the reward of revised glory. This is accomplished with a results screen at the end of the exercise, as seen in figure 6. The results screen grades the user based on how many of the platforms they have stepped on, how often the user's center of mass has exceeded the boundaries of the center of mass, and how long the user took to complete the exercise. These gradings are being represented by graphs.

Figure 6: The credits. The bar on the left indicates how many of the tiles were correctly stepped on, while the circle on the right indicates the path the center of mass traveled and where it went past the boundary.

Mock-Up with a sustenance reward system:

The second mock-up utilizes a reward of sustenance. During the exercise the user can see a bar in the upper right corner of the screen, as seen in figure 7. This bar fills up as the user steps on platforms and decreases as the user exceeds the center of mass boundary. If the bar is full the user is awarded a point as well as some positive feedback (a small applauding sound is played for a short duration). At the end of the exercise the user gets notified how many points they have scored.

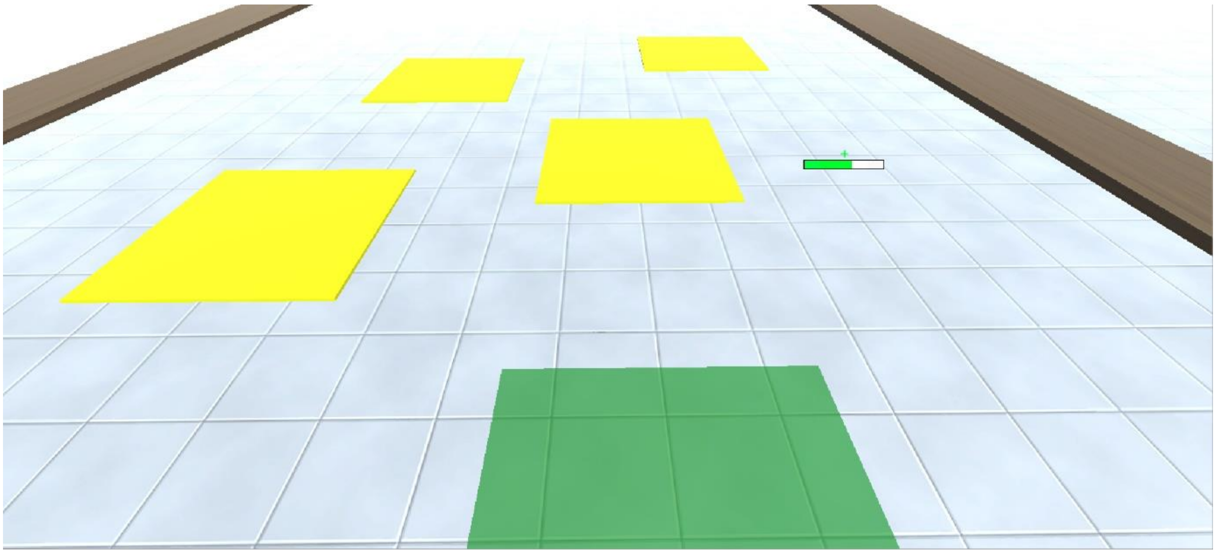

Figure 7: The sustenance bar can be seen in the upper right. A small plus appears when the user correctly steps on a tile, and a minus appears when the user exceeds the centre of mass boundary.

Mock-Up with an access reward system:

The third mock-up contains an example of a reward of access. Before the user starts the exercise, they can utilize a setting menu where they have the option to buy rewards using an in-game currency. This in-game currency can be earned by playing the game and excelling at the game, akin to the points scored in the second mock-up. The in-game currency allows the user to buy alternate colors for the platforms, an alternate appearance of the floor, or make ambient background music play during the exercise. An example of this can be seen in figure 8.

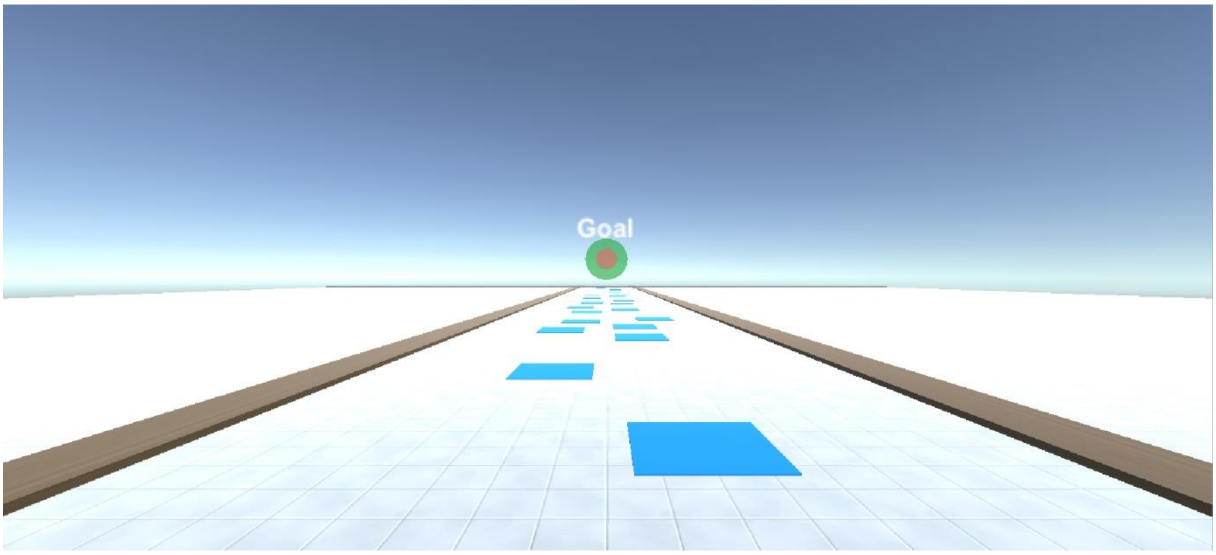

Figure 8: The reward of access chosen by the user in this picture is that the tiles have changed from a yellow to a blue color.

5: Physiotherapist review

Introduction

In chapter 4 we created mock-ups of the exergame. We would like to know what the opinions are of the stroke patients themselves. We want to know what their wants and needs are, and how they think this exergame would be able to help them. However, stroke patients can suffer from impaired cognitive and linguistic ability. It is discommended to ask them for their wants and needs directly. Therefore, physiotherapists who deal with the rehabilitation of stroke patients are involved instead.

The physiotherapists are presented with the mock-ups of the exergame. After showing the mock-ups we interviewed them on the mock-ups, where we extracted answers from them guided by a questionnaire we set up before the interview. This questionnaire can be found in Appendix B.

The feedback we obtained from the physiotherapists is then discussed. We determined how to implement the new information we obtained in this research, seeking answers to the following questions:

- Do we need to make adaptations to our exergame?
- Are there new requirements that we need to add to those we came up with in requirements?
- Are there other points of note that we cannot include in this research, but will be useful for future research?

Based on this discussion we can improve on our mock-ups to create an even better prototype.

Experimental protocol

Four physiotherapists were approached for this review. The physiotherapists have between eight and eighteen years of experience as a practitioner of physiotherapy. They treat people with stroke at least once or twice a week. The physiotherapists were chosen to ensure that they were responsible with different stages of the stroke patient's recovery process according to the stages of the Brunnstrom approach [63].

One physiotherapist mainly works with stroke patients in the early stages of rehabilitation (Brunnstrom stage I – V). Two physiotherapists mainly work with stroke patients who are in the later stages of rehabilitation (Brunnstrom stage V-VI) [63]. The last physiotherapist focuses more on his knowledge of research and development. This person is a manager at a research and development center for rehabilitation technology. His research focuses on human movement analysis with specific expertise in kinesiology (neuromuscular control and biomechanics) after stroke.

A questionnaire for the physiotherapist review was created to help guide the physiotherapist into answering the right questions. This questionnaire can be found in appendix B. All physiotherapist reviews follow the same procedure:

The physiotherapist will be asked to answer general questions about the physiotherapist's job and his experience at dealing with stroke patients.

The first mock-up is shown to the physiotherapist. This is the one that only includes the reward of glory. Explanation is given about the type of exercises the user needs to perform.

The physiotherapist is then asked to answer the second part of the questionnaire. This part is about the systems and specifications of the exercise, and how it needs to be implemented for stroke patients.

After this the second and third mock-up are shown, as well as the reward system of the first mock-up. The focus of this part is that the physiotherapist is explained how the reward systems of each mock-up works.

Afterwards they are asked to answer the rest of the questionnaire. This includes a section about the implementation of the reward systems, comparing the exergame to other rehabilitation techniques and systems currently on the market, as well as the option to make additional remarks about the mock-ups.

Results

Part 1: Design of the exercises in the exergame mock-ups

In the first part of the review we asked the physiotherapists about their opinion of the system in general and their opinion on the exercises that were implemented in the exergame. This includes the patterns projected on the floor, the projected center of mass and of the results screen.

The first impression of the physiotherapists is positive. All four physiotherapists are enthusiastic about the simplicity of the system. They compare it to other walking exercises currently in use: Two of them see similarities with a walking exercise for Parkinson that makes them walk over colored mats placed on the ground, while another sees more in common with a route of pillows made for stroke patients to relearn their gait. Most of them immediately noted that this system is easier to use and understand for the user compared to similar exergames.

The projected walking patterns are clear to see for the patient and make the exercise easy to understand for the patient. The way the tile changes color and starts playing a sound upon stepping on a tile is considered clear to understand and non-intrusive for the patient. The only recommendation given by the physiotherapists is that the sound played should be short and not overly complex.

One negative point of improvement that was almost immediately spotted by one of the physiotherapists is how the exercise is perceived entirely on the AR-goggles of the patient. With no physical markers on the floor the physiotherapist cannot see what is going on. A possible way for the physiotherapist to see what the patient is seeing on another screen would be preferred.

Two of the physiotherapists are wondering about the full effectiveness of this exercise for all stroke patients. Not all patients have enough recovery to regain normal gait. For those people this exercise is not effective. There should be a clear and simple method for the physiotherapist to determine if continuing to perform this exergame is futile or not.

The physiotherapists gave their comments about the center of mass and how it was utilized in this mock-up. The center of mass is known by the physiotherapists, though usually under the layman's term of centroid, but not used for the rehabilitation of stroke patients. The physiotherapists are evenly divided over the usage of the center of mass for rehabilitation. Some believe that the projected center of mass can help the patient with regaining their normal gait, while others believe that the center of mass is mostly interesting for the neurologist and not for the patient themselves. What they do agree on is that it should be presented in a simple manner that isn't too complex. The circle idea is considered good according most physiotherapists, but according to one of them it could be helpful if the center of mass is more realistic akin to a doll or torso.

The last thing the physiotherapists commented on in this part is the results screen. All physiotherapists agree that the results screen should not show too much data. The data shown should be clear and concise. This means that the screen should use large fonts and if possible easy to understand pictures. All physiotherapists agree that showing the number of correct steps, the movement of the center of mass and some simple positive feedback are essential to a results screen. Three of the physiotherapists believe that showing the required time is a good idea. The fourth one believes that the time can be scaring the patients into becoming hasty and imprecise. Though there are some differences between the opinions of the physiotherapists, they do agree that creation of a results screen should take the capacity of the stroke patient in mind.

Part 2: Design of the reward system in the exergame mock-ups

The second part of the review asks the physiotherapists about the reward systems. All the physiotherapists believe that it is important to add rewards into the exergame to keep it fresh and exciting for the patient. Some of them believe that the rewards to be provided should change as the patient improves their gait. According to this train of thought the system should focus first on patient recovery and learning the system. The rewards should come afterward, when the system is understood by the patient.

Rewards of sustenance are considered situational by the physiotherapists. All agree that not every patient would want this kind of reward. It might cause stress and sensory overdose. Caution should be applied when using this reward. According to some it should not be used on those in the early stages of recovery, while others believe that it should be patient-specific to see who is vulnerable to the negative effects of rewards of sustenance.

Rewards of access obtain a more positive opinion from the physiotherapists. All agree that such a system should be included. Slight differences exist with how they should be used. All agreed that the rewards should stay simple. One remarked that you should prevent a sensory overdose. Of the ideas shown in the mock-up changing the tile colors or the center of mass color was considered a good idea. Creating background music was not considered a good idea. It is also a bad idea to overload the world with visual objects. This would prevent the patient from keeping an eye on the real world to avert any collisions. These rewards of access should have a clear build-up, according to the physiotherapists. Some opted for a reward system where a room akin to an empty house gradually gets filled with non-intrusive, non-interactive objects like flowerpots or paintings as the user keeps playing. Others preferred the rewards to shift the projected world from chromatic and non-realistic to realistic as the patient progresses in his rehabilitation.

Part 3: Ease of use, system comparison and other remarks

Three of the physiotherapists admit to lacking the space to make the user perform the exercise inside their clinic. The physiotherapists with the greatest lack of space in their clinic would like for a way to combine the exergame with something that would allow the patient to walk in place, like a treadmill. The physiotherapists with more room prefer if the walking distance became more variable and can include corners and turnarounds.

When comparing the system to what is currently in use the physiotherapists see also other advantages. A commonly accepted advantage of this system is that this is more fun for the patient than ordinary walking. Other advantages which came up are that the center of mass can help the patient with obtaining a correct gait and that the AR-glasses allow the physiotherapist to continuously recreate the same circumstances and improve comparison between meetings.

At the end of the review the physiotherapists were asked for any other remarks about the system not discussed in the review. Two physiotherapists did bring up extra points: According to one of them the exercise should also include the possibility to step over or walk around objects. The other sees possibility for this system to work as an exercise not only for stroke patients, but also for people with Parkinson. He would like it if the system could also be compatible for them as well.

The physiotherapists believe that the proposed exergame is only suitable for people in the middle part of their stroke rehabilitation. According to the physiotherapists, gait rehabilitation has low priority in early stages of recovering from stroke. It is more important to focus on simple motions during this phase of the recovery. At the other end of the recovery spectrum is the lack of difficulty for people in late-stage recovery. The current mock-ups are only able to help the patient during a relatively small part of the recovery process.

One remark the physiotherapists gave is that the system should watch out for the fact that stroke patients have a single affected side. As a result, their gait will be weaker on one side than on the other.

Discussion

In the introduction of this part we had three unanswered questions that we wanted to solve with this review:

- Do we need to make adaptations to our exergame?
- Are there new requirements that we need to add to those we came up with in requirements?
- Are there other points of note that we cannot include in this research, but will be useful for future research?

Based on the physiotherapist reviews we believe to have come closer to the answer for all three questions:

Adaptations to the requirements

The physiotherapists brought up the subject of text size and readability. They want the text to be easily readable, and that what it says is clear and concise. This will help prevent sensory overload and keep the exergame clear for the stroke patient. This adds the following requirements that we did not think of:

Linear: Any written text must be easily legible for the stroke patient.

Basic: The exergame will not cause sensory overload for the user.

According to the physiotherapists the exergame should not restrict vision of the user. In other words, the stroke patient must still be able to see the real world around him during the exergame, for his own safety. While this is partially covered in "The exergame must not harm its user", it is specific enough to warrant its own requirement:

Basic: The user of the exergame must still be aware of the real world around him during the exergame.

The physiotherapists did look favorably upon the rewards of sustenance. They do not think that this type of reward should be mandatory when creating an exergame for stroke patients. We therefore remove the following requirement from the requirements list:

Delight: The user can obtain rewards of sustenance for succeeding at certain parts of the exergame designed with rewards of sustenance in mind.

Adaptations to the exergame

The physiotherapists want to see more flexibility in the exergame. They believe that if the exergame cannot be tailored to each specific stroke patient this exergame will not be useful for the majority of stroke patients. The exergame must therefore include a way to in- or decrease the difficulty so that it can be just challenging enough for the stroke patient.

According to the physiotherapists it is not good to reward the user for his duration of play. Rather, it is more effective to reward the user for an improvement in performance, as that is the end goal of the rehabilitation. The physiotherapists also wanted to see some parts of the exergame to become more realistic and human-like. This can be combined with the reward system to have the exergame become more realistic over time. In summary, the reward system will therefore become more human-like in appearance based on the user performance, instead of exergame duration.

The physiotherapists were also clear about the types of rewards to be included in the exergame. The system should be simple but show a clear, linear progression. The obtained reward should correlate with the improvement in the user's gait. This must be implemented in the exergame. The rewards obtained in the exergame will therefore change over time and improve as the stroke patient's gait improves.

Rewards of Sustenance were not received positively by the physiotherapists. This type of reward system can cause sensory overload and stress, which is not what you want to cause to the stroke patient. The physiotherapists recommend making this type of reward non-mandatory. Because of this the rewards of sustenance will not be included in the final prototype.

Rewards of Access were received positively by the physiotherapists. Their problem with the rewards of access is the form in which they appear. Not all the forms of rewards of access were seen in a positive light. Physiotherapists showed positive responses to the floor tiles and center of mass changing form and color as the chosen rewards of access., while the other rewards of access were less positively received. The final prototype will therefore only have rewards of access in the floor tiles and the center of mass.

Adaptations to future research

According to the physiotherapists this type of exercise is effective for stroke patients who are expected to make a full recovery. As full recovery is not expected for every patient the exercise is not effective for all stroke patients. This point will not be solved in this research as this research will not test out its research with live stroke patients. However, this is important for follow-up research involving stroke patients. For future design, results from the exergame should be stored and accessible by physiotherapists. This lets them help to determine what progression is reached through therapy by exergame. Based on the progression the physiotherapist can then decide to continue with the treatment or try something else.

The exergame engine, Unity, allows someone to see on screen what the patient is experiencing. The physiotherapists wish to see the actions of the patient so mistakes can be caught immediately. With Unity this can easily be implemented in the system. However, it is not to be expected that the computers or tablets of the physiotherapist run Unity. Further research needs to implement an application with which the physiotherapist can see along the user without needing to install Unity.

The physiotherapists would like for flexible exergame lengths, the ability to turn corners during the exergame or the ability to do the exergame on the spot. These will not be included in the final design. The flexible exergame length and ability to turn corners provide too many additional requirements for marginal gain and are better off implemented in potential follow-up research. The ability to do the exergame on a treadmill is not included because that would negate the advantages this system has over the GRAIL. If a treadmill must be included in this system, there is no reason not to use the GRAIL over this new exergame.

The exergame has the potential to be used for more than just normal gait rehabilitation, like relearning to step over obstacles. This is not the goal of this research. The goal of this research is to provide an exergame in which the user can be taught a normal gait. More complex parts of someone's gait, like stepping over objects, are not taught with this exergame. Teaching how to step over objects might be good for the rehabilitation of the patient, but it is not what this research focuses on. It might be possible to implement this into the final product of this research. Future research can be done in this direction.

Stroke patients aren't the only ones who could benefit from this type of exergame. While Parkinson patients might utilize this system as well the focus of this research is on stroke patients. It is not the goal of this research to create an exergame for Parkinson patients. Follow-up research needs to determine the effectiveness of the product of the current research for people with Parkinson.

6: Design of the exergame prototype

Introduction

Thanks to the physiotherapists who reviewed the mock-ups, we have obtained the knowledge to improve on the mock-ups we created. The type of exergame that the user performs with the final prototype is not much different from the exergame designed in the mock-ups. The physiotherapists agreed that such a system would work for stroke patients and had no objections to the use of this type of exercise. Instead the mock-ups have been given improvements based on the remarks of the physiotherapists.

Changes to the Mock-Ups

The physiotherapists agreed with the general idea of the exergame but saw room for improvement. We've included several of them in this final prototype.

- According to the physiotherapists the exergame should not overload the world with visual data. This keeps the user more aware of his surroundings and prevents overstimulation for the stroke patient. Parts of the exergame that weren't strictly necessary for the exercise have been removed in the final prototype. These are the guiding bars to the sides and the goal sign in the distance towards the finish line. To keep clear in which direction the user needs to walk, both the center of mass and the center of mass boundary are projected in the direction of the finish line.
- The original idea for the exergame length was to have the user walk 20 meters forward. The physiotherapists pointed out that there is usually not enough space in their clinic to walk that distance. They also weren't sure whether all stroke patients for which this system was intended could walk such a long distance. To placate the physiotherapists the length of the exergame has been shortened from 20 to 15 meters.
- The physiotherapists want more flexibility in the exergame. They want to see that the exergame can be challenging to stroke patients in different levels of their recovery phase. To do this a difficulty setting has been implemented in the exergame. More explanation about this can be found in the heading "Regarding patient specificity" below.
- The reward system should be implanted in a different manner and with different focus. Rewards of sustenance have been scrapped due to the physiotherapists having a negative connection to them, while rewards of access have been given a linear progression. More explanation can be found in the heading "Regarding reward method implementation" below.

Utilized tools for the exergame

In the literature research we explained what type of motion capture system, interface system and game engine we want to use and why they're the preferred choice for this exergame. Here we hope to explain more about the three systems that were chosen for this research:

<u>X-Sens Analyze</u> is an inertial motion capture system that focuses on being cost-efficient and easy to use for a full-body motion capture system. It is a completely portable system that can be used anywhere. The only limit in measurement is the wireless range. Indoors the range of X-sens Analyse is 20 meters, and outside it is 50 meters. It sends the data to an additional program, MVN analyze, to translate the inertial data into a human body model that can be implemented in other engines [36].

Hololens is a head-mounted interface display that offers the user an augmented reality experience. It does this by superimposing an image on the user's surrounding real-life environment to create a mixed-reality experience. It is comfortable to wear, easy to use, and compared to other augmented reality head-mounted displays it supports high-resolution imaging. It has shown to be usable as a tool in the medical field [46].

Unity is a cross-platform game engine designed to support and develop both 2D and 3D video games for computers, virtual reality, consoles and mobile device platforms. It is high quality for a game engine available on the market. Its ease of use and shorter rendering duration compared to other engines make it a valid choice for game development. The biggest issue with using Unity for this project is that there are no transformation tools for transferring the coordinate system from X-sens to that of Unity and needs to be created manually [64].

Implementation of the exercises in the exergame

The purpose of the exergame is still to perform three exercises focused on improving walking speed, stabilization of the body balance and step length symmetry. This is done by respectively real walking, keeping your center of mass steady and stepping on tiles with a fixed step length. This way the exergame wants to help rehabilitate the stroke patient in their gait speed, body balance and gross motor control.

An example of how the exercise looks can be found in figure 10. The tiles change color and make a small 'ping' sound when the user steps on a tile. The center of mass is represented with a green circle that responds to movement of the user, while the red circle around the green circle are the static boundaries of mass. If the movements of the user cause the green circle to leave the boundaries of the red circle a buzzing sound will play to indicate that the user exceeded the boundary. The exercise is finished the moment the user steps on the checkerboard-colored finish line, which causes the results screen to appear and tell the user how well they did.

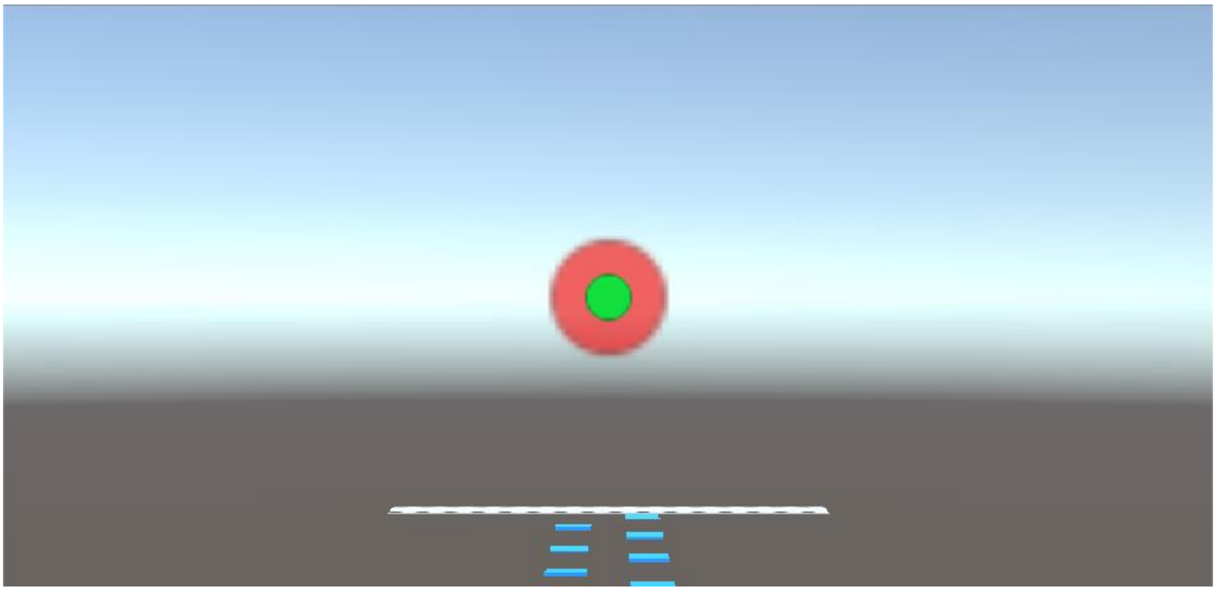

Figure 10: How the final prototype looks when used during the exercise. In the middle you can see the center of mass and the boundaries of the center of mass. On the ground you see the plain blue tiles and the long checkerboard-colored finish line.

Implementing a user-specific difficulty adjustment

One of the requirements we made during the exergame was that the exergame could be tailored to the user. The skill level of each person performing the exergame is different. Stage of recovery, capability to walk, level of cognitive impairment and experience are all examples of why stroke patients would have a different skill level compared to one another. To keep the exergame a challenge for all of them the exergame must be able to be tailored to each specific user.

The mock-ups we designed were not good enough at doing this, which was noted by the physiotherapists during their review of the mock-ups. We therefore want to include a difficulty adjustment in the exergame prototype.

Difficulty	Maximum center of mass deviation	Step distance	Tile Size
Easy	33 cm	70 +- 0 cm	50 cm
Medium	30 cm	70 +- 15 cm	40 cm
Hard	25cm	70 +- 25 cm	30 cm

Table 3: Differences between difficulty levels

We chose three ways in which the difficulty is adjustable: maximum deviation of the center of mass, the size of the tile which the user must step on and the variety in step length between each tile. The first increases the difficulty of training the stroke patient's body balance, while the latter two increase the difficulty of the gross balance control. We did not include a difficulty setting for the walking speed. While it is possible to do so by setting a time limit to the exergame the physiotherapists pointed out that such limits could cause stress for the stroke patient, something that is averse to our goals. For this reason, only these three difficulty ratings were chosen for this exergame.

A possible difficulty rating can be found in table 2. Three different difficulty levels have been created for the exergame. We shall call these difficulties easy, medium and hard. The easy difficulty is expected to take the least effort to complete, and the hard difficulty the most. A description of each variable can be found below:

- The center of mass moves during the exergame. To try and make the gait abnormal for the tester they need to try and keep their center of mass from moving. The less leeway the center of mass has before it is considered out of bounds, the harder it is for the tester keep their center of mass within the boundary.
- The step length of an average person is about seventy centimeters. The step length does not vary between steps in a normal reciprocal gait. If the step length does vary then the tester needs to make conscious effort to step the correct distance. This increases the difficulty of the exergame. The average step length does not change.
- To train the gross motor control the stroke patient tries to step on the projected tiles. If the tiles are made smaller the tester needs more precision to step on the tiles correctly. This increases the difficulty of the exercise.

Regarding reward method implementation

The mock-ups were designed with four different reward systems in mind. After the review by the physiotherapists three reward systems were implemented in the prototype because they were viewed positively by the physiotherapists: rewards of glory, access and positive feedback. Rewards of sustenance were not met positively and thus not included in the final prototype. The method of implementation is described below:

Glory is implemented in the results screen. At the end of the exercise the user is graded on how fast they performed the exercise, as well as the number of tiles they've successfully stood on. This can be seen in figure 11.

Figure 11: The basic result screen. The yellow background appears transparent when viewed with Alternate Reality.

Positive feedback is implemented during the test by making a pleasant sound occur whenever the user correctly steps on a floor tile. The other form of positive feedback occurs when the result screen comes up, which gives the user words of praise. This can be seen in figure 11.

Access is implemented in multiple forms: The physiotherapists believe that rewards of access should have a clear build-up. The idea from the physiotherapists is to make the rewards of access ramp from non-realistic to realistic. Three difference appearances of the exercise were created: Non-realistic, semi-realistic and realistic. The rewards of access change the looks of the tiles, the center of mass and the reward screen:

- The non-realistic reward of access is seen in figures 10 and 11. The tiles are plain, the center of mass is shaped like a circle, and the result screen shows no additional objects.
- The semi-realistic reward of access is seen in figures 12 and 13. The tiles are wood-colored, and they change to the color of grass when you step on them. The center of mass is shaped like a cup, a schematic representation of the human torso. The result screen is adorned with pictures of drawn flowers and sun.
- The realistic reward of access is seen in figures 14 and 15. The tiles appear to be made of wood, and they appear to be grass when you step on them. The center of mass is shaped like a human T-shirt, a more accurate representation of the human torso. The result screen is adorned with pictures of real flowers and sun.

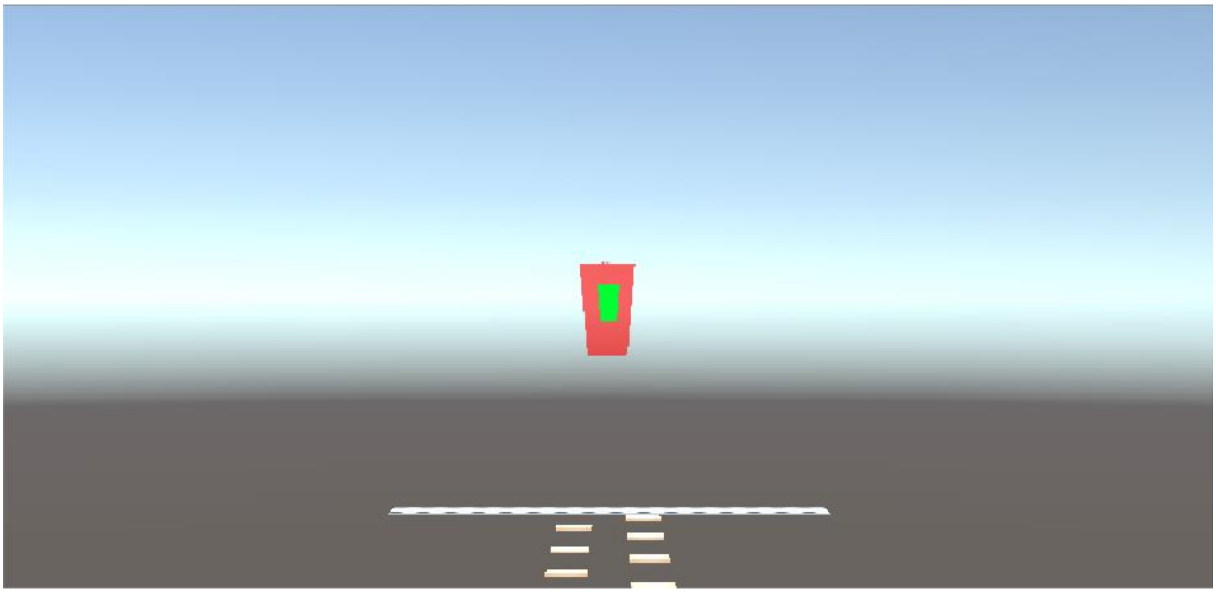

Figure 22: Appearance of the exergame with semi-realistic access rewards.

Figure 33: Appearance of the exergame result screen with semi-realistic access rewards.

Figure 44: Appearance of the exergame with realistic access rewards

Figure 55: Appearance of the exergame result screen with realistic access rewards.

7: Feasibility Study of the Exergame

Introduction

Thanks to the literature research and physiotherapist reviews we managed to come to a final set of requirements. With these requirements we managed to come from a mock-up to a prototype of the exergame. Now we want to perform a feasibility test to determine whether this prototype of the exergame fulfills all the requirements.

This feasibility test is performed with healthy test persons who have not suffered from stroke. This is because we are unable to obtain stroke patients to test this exergame. Testing out a prototype meant to be used by healthy persons can still be beneficial towards the creation of an exergame for stroke patients: The stroke patient seeks to rehabilitate by relearning his normal gait. In other words, the exergame focuses on teaching someone a new gait. Teaching a healthy person an abnormal gait is similar enough that it corresponds to the rehabilitation of stroke patients.

There is one downside to the lack of stroke patients: The optimization of the reward system requires stroke patients to judge whether they enjoy the ways the rewards have been implemented. As this feasibility test lacks people who can judge on the reward system, we will not explore this topic any further.

While we do not do any further research towards the requirements of user enjoyment, we still have other requirements we want to test in this feasibility study. In this test we want to find out if the following four requirements can be fulfilled by this exergame:

- The exergame can correctly translate movements of the person playing the exergame into changes in the game on the output that the player sees. This mainly concerns if the inability to transfer coordinate systems between X-sens, Unity and Hololens will not cause issues during the exergame.
- The maximum amount of latency that can occur during the exergame is 150 milliseconds
- The exergame should only force the user to calibrate the inertial motion capture system at the start of the session and not in-between. This means that the exergame can be performed multiple times before the system needs to be recalibrated.
- The exergame can be tailored to the patient by a medical caretaker. This means that the difficulty setting for the exergame must not cause additional problems,

This final prototype seeks to proof the feasibility of the concept by fulfilling all the requirements stated above.

Methods

The goal of this research is to determine if an exergame with a high focus on easy mobility is feasible. To determine this, we need to test out if the prototype we created fulfills the requirements we've set.

We seek the answer to the following hypotheses:

1. The transfer of data between X-sens, Unity and Hololens does not cause any problems that prevent the user from performing the exergame.
2. The exergame has a total amount of latency of less than 150 milliseconds.
3. The user can perform the exergame a second and a third time without needing a full-on recalibration.
4. Changing the difficulty setting access will not cause unwanted difficulties or problems for the user.

The following materials are used for the exergame:

- X-sens Analyse suit, to be worn by the test person.
- Hololens, to be worn by the test person.
- Laptop running Unity and the exergame.
- The University of Twente's eduroam network grid.
- Wooden board with bars attached to it, to ensure the starting position of the user.
- Paper circle, to ensure the starting orientation of the user.

Two people were approached for the experiment. Both test persons are healthy persons of adult age. They have not had any gait issues prior to the experiment. They received an information letter that explains the purpose of the exergame and an overview of what they are expected to do during the experiment before the experiment started. This information letter can be found in appendix C. Both test persons agreed to perform in the experiment. This research has been approved by the ethical committee of the University of Twente.

The test person puts on the X-sens suit and the Hololens. Before the exergame starts the X-sens suit is calibrated according to protocol of X-sens. The Hololens is connected to the laptop by the eduroam Wi-Fi. The test person steps on the wooden board, which has bars strategically placed on it to ensure that the test person always has his feet start from the exact same position. He looks towards the paper circle in the distance. This is done to ensure that the orientation of the Hololens and X-sens have the same initial orientation.

To ensure that the orientation of the Hololens and the X-sens suit are the same during the exergame we utilize an algorithm to compensate for any orientation drift and errors. A flow diagram of this algorithm can be seen in figure 16.

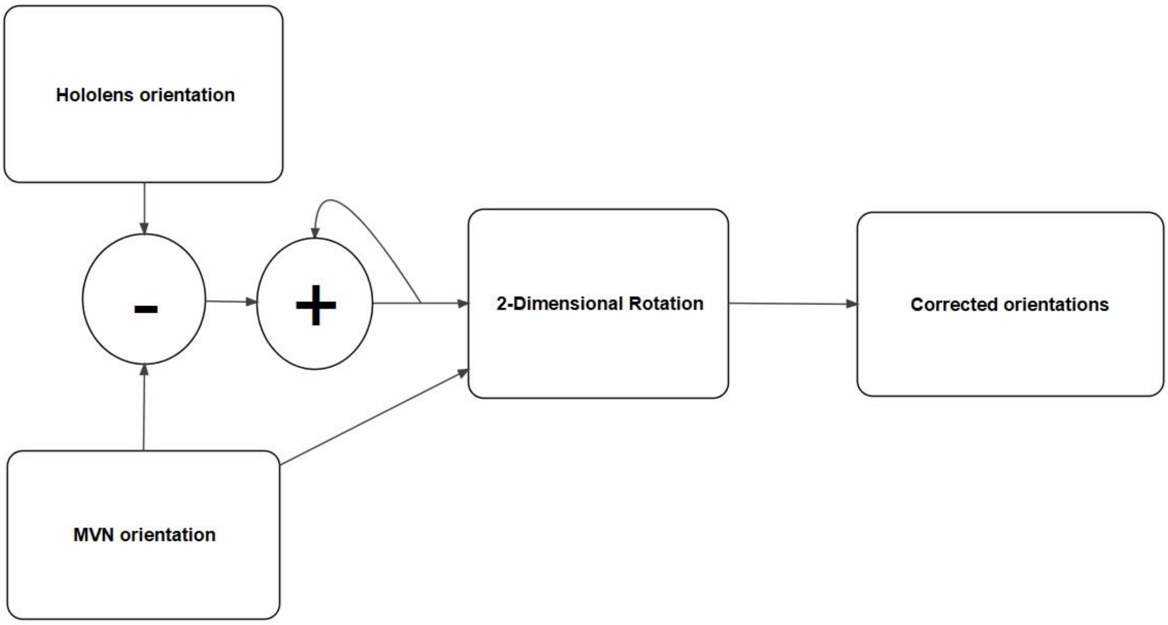

Figure 16: Flow diagram of the algorithm to compensate for X-sens' body segment orientation.

We calculate the difference in orientation between Hololens and X-sens for each iteration of the exergame according to the following 5-step algorithm.

1. Calculate the difference in orientation between Hololens and X-sens current iteration's orientation.
2. Use the calculated change in orientation together with the previous iteration's orientation to calculate a 2-dimensional rotation of the xy-position.
3. All body segments of X-sens are corrected using a 2-dimensional rotation of the xy-position.
4. A new iteration time is set.
5. A new iteration is started from step 1.

When the test person is ready the researcher starts the exergame. The test person then performs the exergame according to instructions he sees with the Hololens.

During the exergame the latency between the X-sens suit and Unity and between Unity and the Hololens is measured. By adding up all the different calculated latency lengths you can calculate the total latency between the X-sens suit and the Hololens.

Latency consists out of two parts: The connection time, how long it takes to send data from one piece of hardware to another piece of hardware, and processing time, how long it takes for a piece of hardware to utilize the data it received and prepare it for either use or sending it to another piece of hardware. There are three pieces of hardware, so there are three processing times and two connection times between the motions of the user and the interface display. This can be seen in figure 17.

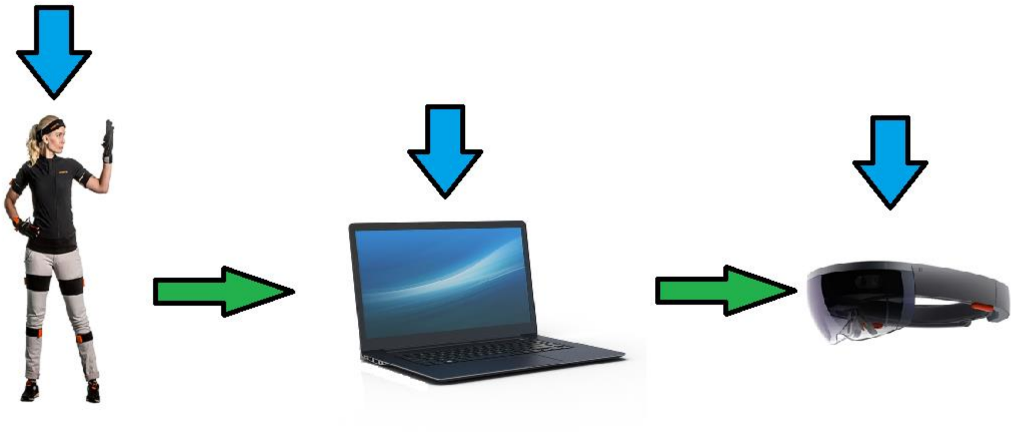

Figure 17: Locations of latency in the exergame. The blue arrows are where there is processing time in the system. In this exergame those are the X-sens motion capture system, the laptop running Unity and the Hololens device. The green arrows represent the connection time between devices. Here there is the connection time between X-sens and the laptop and the laptop and the Hololens device.

The connection speed between X-sens and Unity is normally limited by the update speed of X-sens of 60 Hertz. We can measure if there are any hold-ups in the upload of data from X-sens to Unity through the X-sens analyzing program. If there are none then we can conclude that the biggest limiter for the connection speed between X-sens and Unity is the update speed of X-sens.

The connection speed between Hololens and Unity can be measured in Unity. Unity sends out a signal from the laptop running Unity to Hololens and back. It can calculate how long it took to complete this process. As sending data from Unity to Hololens should take as long as sending data from Hololens to Unity, we can obtain the connection speed between Hololens and Unity by divinding Unity's calculated values by two.

The processing speed of the laptop running Unity and Hololens can be measured through Unity. The processing speed of the laptop can be calculated directly in Unity. We are unable to directly measure the processing speed of Hololens, but we can make an estimation by calculating the difference in processing speed between the laptop and Hololens.

We are unable to directly measure the processing speed of the X-sens inertial measurement units and are therefore forced to utilize the answer from literature research that the processing time of the inertial measurement unit is 30 milliseconds [42].

After the exergame is performed the user will walk back to the wooden board and repositions himself on the wooden board, looking at the center of the paper circle again. The exercise is then performed a second time. The third time is performed similarly. This allows us to answer the third hypothesis, "The user can perform the exergame a second and a third time without needing a full-on recalibration".

The system is recalibrated after these three exergames. A new exergame is performed once at medium difficulty with the semi-realistic rewards of access. After this the system is recalibrated once more. A new exergame is then performed at hard difficulty and realistic rewards of access.

After this exergame the user is done with exergame. He now takes off the X-sens suit and the Hololens and starts filling in a questionnaire about the exergame. This questionnaire can be found in appendix D. Once done the user is finished and can leave.

The expected duration of this experiment from putting on the equipment to unequipping everything is 45 minutes.

The data we obtain from this exergame are the movement data calculated by X-sens as well as two forms of the position of the center of mass, one obtained from X-sens and one calculated through Unity. These are stored as comma separated files. These files are uploaded in Matlab. The data is transformed into graphs, which are used to calculate whether the following requirements have been fulfilled:

- The transfer of data between X-sens, Unity and Hololens does not cause any problems that prevent the user from performing the exergame.
  Changing the difficulty setting access will not cause unwanted difficulties or problems for the user.

Results

Data Transfer between hardware

X-sens creates a model of the user's body, a human body model. This human body model gets correctly transferred from X-sens to Unity to Hololens. The only data that does not get transferred is the coordinate world of each piece of hardware.

The coordinate world is the orientation and position of the human body model according to X-sens or Unity. The worlds of X-sens and Hololens overlap at the start of the exergame, having the same orientation. During the exergame drift starts to occur in the inertial measurement unit. We expected that due to our algorithm no drift would occur. However, we did experience errors that causes the coordinate worlds to become estranged of one another and stop having the same orientation. The amount of orientation error is recorded in table 3.

	Minimum error	Average error	Maximum error
Orientation error	0.56°	2.23°	4.38°
Exergame disparity	14.6 cm	58.4 cm	114.9 cm
Error percentage	0.98%	3.91%	7.68%

Table 4: Amount of coordinate world estrangement, given in degrees, as well as how far to the left or right you would end up at the finish line of a 15-meter exergame course.

The orientation error was recorded over six measurements. The orientation error was between 0.56 and 4.38 degrees, with an average of 2.23 degrees. Put into perspective of the exergame this means that if you were to perform the 15-meter-long exergame with these orientation drifts you would end up 14.6-114.9 cm to the side of the finish, with an average disparity of 58.4 cm.

Latency determination

We calculated the processing speed for all pieces of hardware and the connection times between all pieces of hardware separately. The results can be found in table 4.

Location	Peak	Processing X-Sens	Processing Unity	Processing Hololens	Connection X-sens to Computer	Connection Computer to Hololens	Total Latency
	Minimum	30 ms	3,08 * 10^-4 ms	8.29 * 10^-4 ms	16.67 ms	5.26 ms	51.93 ms
Hallway	Average	30 ms	3.86 * 10^-4 ms	1.04 * 10^-3 ms	16.67 ms	5.80 ms	52.47 ms
	Maximum	30 ms	4.94 * 10^-4 ms	1.32 * 10^-3 ms	16.67 ms	8.00 ms	54.67 ms
	Minimum	30 ms	3.51 * 10^-4 ms	9.45 * 10^-4 ms	16.67 ms	8.33 ms	55.00 ms
Garden	Average	30 ms	3,59 * 10^-4 ms	9.66 * 10^-4 ms	16.67 ms	9.26 ms	55.93 ms
	Maximum	30 ms	4,18 * 10^-4 ms	1.13 * 10^-3 ms	16.67 ms	14.28 ms	60.95 ms

Table 4: List of the latency times found in the exergame. Processing speed of Unity and Hololens are so small tobe considered negligible, and not used when calculating total latency.

The processing speed of Unity and Hololens was between $3.08 * 10^{-4}$ and $1.32 * 10^{-3}$ milliseconds. Because this is more than thousand times as small as any of the other determined latencies, we consider these negligible. They're not included in the determination of the total latency.

The X-sens suit has a programmed sample size of 60 samples per second. This means that the update time between X-sens and the computer is a sixtieth of a second, or 16.67 milliseconds. It can happen that the necessary connection time is higher than 16.67 milliseconds, in which case these "spikes" can be measured. During the measurement no spikes were detected in the connection time between the X-sens suit and the computer, meaning that the X-sense suit never went above or below 16.67 milliseconds of connection time.

The connection time between the Computer and the Hololens device was not restricted by programming. It was dependent on the wireless connection. In a place with good wireless connection, in this case an indoor hallway, the connection time differed between 5.26 and 8.00 milliseconds. In the garden the connection time differed between 8.33 and 14.28 milliseconds.

The total Latency we calculated was between 51.93 and 60.95 ms.

When the test persons were asked to comment on the exergame after their test none of them noticed any form of latency during the exergame.

Need for recalibration between exergames

	First exergame	Second exergame	Third exergame
Exergame duration	24.7 s	23.7 s	22.4 s
Maximum drift to the left	10.1 cm	36.2 cm	52.3 cm
Maximum drift to the right	16.9 cm	32.8 cm	59.2 cm

Table 5: Amount of position drift of the center of mass that is formed over time during repeated exergames without renewed calibration. Given are the amount of drift calculated to both sides during the exergame as well as how long each exergame took.

Recalibration of the exergame is necessary if the drift becomes too high. The drift of the X-sens suit was measured during the exergame. A certain amount of drift was expected, but it was unknown how much. In table 5 the maximum drift to the left and the right are given for the drift test of the system, as well as the amount of time each exergame took. Over a period of 70.8 seconds, the maximum drift during the exergame was 59.2 centimeters.

User specificity and difficulty setting

The test persons performed the exergame at three different difficulty levels that represent the ability to tailor the exergame to user. The difficulty was changed by way of changing the size of the tiles, the distance between the tiles, and the leeway of the center of mass boundary.

The test persons commented that they had problems with performing the exergame when the size of the platform and the center of mass became smaller. They confirmed that a decrease in the size of the platforms they needed to step on and in the leeway with the center of mass led to an increase in difficulty of the exergame. This increase in difficulty requires more precision of the user than what they found themselves able to do. It was due to drift that the user became less precise as time went on. The test persons found that this made the exergame almost impossible at higher levels, which caused frustration amongst the test persons.

The test persons had a different problem with the variable step length. They considered the screen of the Hololens to be too small to see both the tiles and center of mass at the same time. According to them the easy difficulty had no variations in step length, so they could look at the center of mass and do their step length on instinct. At harder difficulties they were forced to look down at the tiles and were not as able to keep their center of mass in check. They did not find this comfortable. They would prefer to perform the easier difficulty because it would allow them to perform the exercise without constantly switching gazes.

Discussion

Feasibility Study Conclusion

In the introduction we stated that there were four requirements of which we wanted to know if they were fulfilled by this exergame. Now we can look back and see whether the requirements are made:

<u>The exergame has a total amount of latency of less than 150 milliseconds.</u> The latency of the exergame appears to be within bounds. The measured latency of the exergame was between 51.93 and 60.95 milliseconds, which is less than the maximum allowed latency of 150 milliseconds. While we couldn't measure the processing speed of the Inertial measurement units, the users answered that they did not notice any form of latency. It is likely that this requirement is fulfilled.

<u>Changing the difficulty setting access will not cause unwanted difficulties or problems for the user.</u> Of the three proposed possible ways in which the system could be adapted to change the difficulty for the user the test subjects found problems with two of them. Due to the naturally occurring drift within the inertial measurement units the position of the user in the virtual world becomes less precise. Changing the size of the tiles or the center of mass is only a good method of changing difficulty if good precision of the sensors is guaranteed. The third method of changing difficulty, altering the step length, is considered a problem because the Hololens couldn't let them focus on their center of mass and the tiles at the same time. All three methods that can tailor the exergame to the user were considered unusable by the testers. With no successful methods to make the exergame patient specific this requirement is not fulfilled.

<u>The user can perform the exergame a second and a third time without needing a full-on recalibration.</u> We found that after two rounds of exergames without recalibration the amount of drift had increased to be larger than 30 centimeters. After three rounds of exergames the amount of drift had increased to 50 centimeters. This means that if during the second round of exergames on the easiest difficulty you would step on the middle of a tile it would not recognize it as correct positioning. If it happened during the third round of the exergame then no location on the tile is considered correct anymore. A second try without recalibration makes this exergame nigh impossible, and a third try without recalibration makes it completely impossible. The exergame has failed to fulfill this requirement.

<u>The transfer of data between X-sens, Unity and Hololens does not cause any problems that prevent the user from performing the exergame.</u> While it's possible to overlap the coordinate systems of multiple systems at the start of the system position drift and orientation errors will eventually cause the skeletal model to stop overlapping with the Hololens. It was known from the start that drift could occur, and X-sens said that you can expect an average drift in position of 1% [42]. Regarding orientation degrees this means that X-sens expects an average error of 0.57 degrees. We found that the average error in orientation was about 2.23 degrees, or 3.91%, almost four times as much. Because the change in orientation is larger than we expected the exergame could sometimes not be completed. The algorithm that linked the coordinate systems did not manage to successfully stop orientation drift. We therefore conclude that the exergame failed to fulfill this requirement.

Since three of the four requirements were not fulfilled by the exergame, we can only conclude that it has not succeeded at fulfilling the requirements.

Solving drift problems:

We knew that some drift will naturally occur in the system. The drift was minimized so that the exergame would still be feasible: We implemented our algorithm to prevent orientation drift. The remaining position drift was expected to be low enough that there would be no issues with the requirements we wanted to test.

However, our algorithm did not fully work as intended. Orientation drift does still occur due to tracking loss. This occurs when the Hololens device cannot track itself in the global world. Unity will pause updating the data from Hololens until tracking is regained. Our algorithm was unable to adapt to this tracking loss. This caused errors in the orientation of Hololens compared to X-sens. These caused a disruption of the orientation of Hololens and X-sens, which made them stop overlapping with one another. This cause problems for the exergame in a similar way to orientation drift.

Regarding position drift, we expected it would stay within the range of one percent that we could expect from previous research [41]. If the drift stayed within this range the amount of position drift would be low enough that the precision required for the exergame would be high enough to be playable. However, the drift we measured did not consider that our algorithm couldn't withstand Hololens' tracking loss. This limited the precision of the exergame beyond just the drift that we calculated from the position drift. The errors from preventing orientation drift combined with the position drift prevented us from making a feasible exergame.

After finishing the feasibility test, we discovered that Selman believes to have a solution for both issues. [65]. Selman's research focuses on the development of a position aiding system for inertial motion capture using Hololens. They wanted to create a system in which they could decrease the drift from X-sens' inertial motion capture system using Hololens.

Selman had a solution that would decrease both the position drift and the orientation drift. Selman found a total amount of drift of 1.85 when no solutions were implemented against drift. This is smaller than our calculated drift of 3.91% but higher than X-sens' predicted drift of 1%. Thanks to his solutions he was able to bring the total drift below 0.1%, a much more acceptable level of drift.

The drift of a video-based measurement system is much lower than that of an inertia-based system. Selman used this by using a Kalman filter to decrease the amount of position drift. A flow diagram of the Kalman filter can be seen in figure X.

This discrete Kalman Filter consists of an ongoing correction and prediction loop. The inputs of the Kalman filter are the displacements over a single time step (the Δ-position) of the X-sens suit and the position of the Hololens. With this method the user's position is first estimated with the X-sens suit and then updated with the Hololens position. By constantly predicting and correcting the user's position you can get more accurate details of the user's position and decrease the amount of drift noticeable during the exergame. The output of the Kalman filter is an absolute position that is not susceptible to drift.

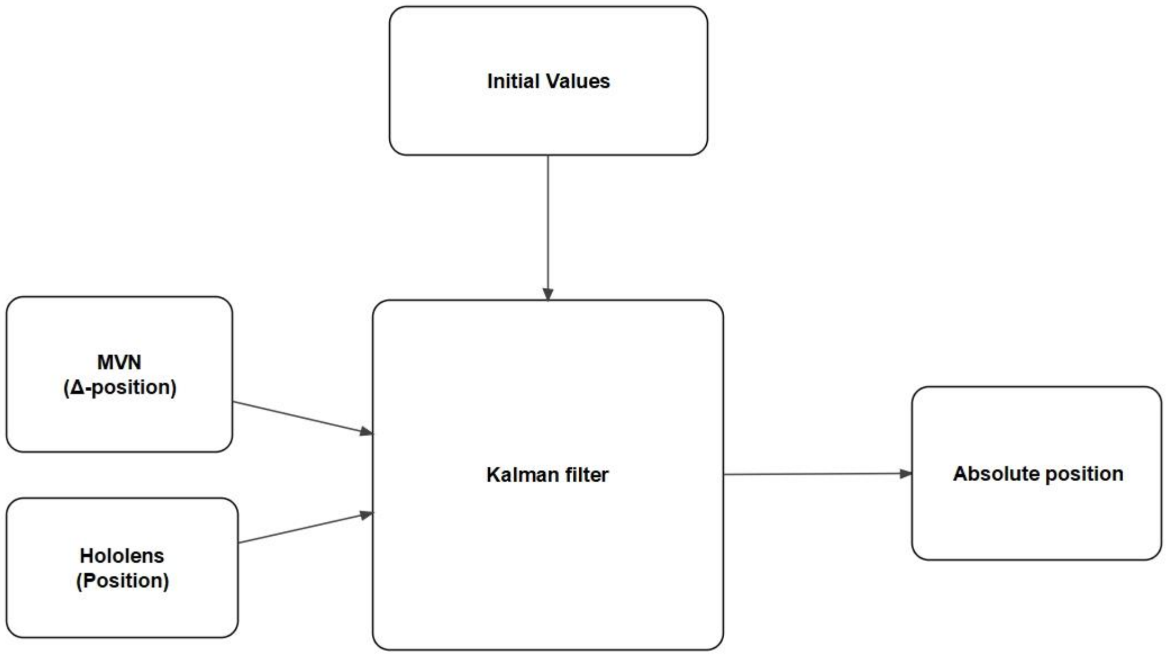

Figure 7: Flow diagram of the algorithm to determine absolute position from position updates using a Kalman Filter design.

There is one major problem with using these Kalman filters to solve the drift issues in our exergame. Hololens can suffer from tracking loss, as described earlier. This causes the Kalman filter to temporarily become inaccurate until the Hololens has no more tracking loss. For Selman's research this was no problem because the data is not important for test persons. In our research we make the test person perform an exergame. The tracking loss will cause inaccuracies that make our test person temporarily lack the precision to correctly perform the exergame. A different method of implementing the Kalman filters might be needed to be successful in this research.

The solution Selman had for orientation drift functions akin to the one utilized in this research. Both of us utilized an algorithm to make the coordinate worlds of Hololens and X-sens overlap. Selman however managed to solve the problem that we discovered in our research. What we did not think of was that Hololens can suffer from tracking loss. Our algorithm is unable to compensate for this loss. His orientation compensation detects tracking loss and then recalculates the orientation compensation using the most recent known Hololens orientation. This method can be implemented into our system and probably solve the orientation drift.

While it is uncertain if Selman's solution for position drift can be implemented in an exergame, the solution for orientation drift can be implemented. What is important to note is that just the solution for orientation drift might be enough to make this exergame feasible. The measured drift when the drift of X-sens was eliminated was below 0.1%, while if only the orientation drift was eliminated was 0.32%. Considering that drift values below 1% were acceptable, it might be possible that the exergame is feasible with merely the implantation of Selman's algorithm for orientation drift.

Future research should implement Selman's solution for orientation drift, as it lowers the total amount of drift measured in the system. Selman's Kalman filters against position drift might be implementable in this kind of exergame, though this needs to be confirmed by a follow-up study [65].

Future Research

Using a combination of inertial motion capture sensors with an augmented reality headset failed to produce successful results in this research. However, this combination might succeed if one takes more care with the design of the exergame. We've found that it is not feasible to require exact positions of the user in a system utilizing inertial measurement and augmented reality. A different approach is needed to create a feasible exergame.

One possibility is to utilize cadence symmetry. In the literature research we discussed how cadence symmetry can be used for rehabilitating gross motor control as well as step length symmetry. With cadence symmetry the user must make steps guided by a regular beat. With this system the X-sens suit must measure when the feet contact the ground instead of the location relative to the world, which it is much better equipped to do. Drift will be less of an issue if the user must perform cadence symmetry instead of step length symmetry. If we change the step length symmetry exercise by a cadence symmetry exercise the current design would likely become more feasible.

If you want to keep the type of exergame like the one in this research, then another possibility is to use a virtual reality head-mounted display instead of one using augmented reality. Because the real world isn't included in the virtual reality exergame the coordinate system of the motion sensor's skeletal model can be directly implemented into the virtual world. This would prevent any orientation drift, allowing for greater precision. The requirement that would not be fulfilled is that the user cannot see the world around him, thereby endangering him to walk into obstacles he cannot see. This combination of hardware would therefore require a second person to oversee the stroke patient performing the exergame. Because most stroke patients perform their rehabilitation with the help of a physiotherapist this concession could be acceptable for some use cases if motion sickness is minimized. This makes virtual reality an option for exergames based on the movement of the stroke patient.

We also found a research paper that goes in-depth on some of the problems that occurred during the exergame. We discovered Isbister & Mueller's paper on the design of movement-based exergames after the feasibility test was done. This paper provided guidelines that an exergame creator should follow to optimize the game. By comparing the guidelines in this paper to the created exergame we found that several of these guidelines have been broken:

- <u>Instead of fighting the ambiguity of movement, embrace it.</u> According to Isbister & Mueller, "Trying to force precision may only frustrate the player and make the limitations of the sensor obvious in a very un-fun way". The precision we tried to force with the tiles and the center of mass proved to be difficult to implement, as we didn't fully know the limits of the sensors. Future exergame design should accept that the measured movement is ambiguous. They could try to work with it instead of forcing impossible precision.
- <u>Moving can demand a lot of mental attention, creating high "cognitive load," especially when learning new movements, so do not overload the player with too much feedback.</u> This guideline says that the feedback the user receives should be limited while learning a new movement. Our feedback during the exergame consisted of two visual sources (the center of mass projection and the tiles) located in visually different spots. This overloaded the cognitive load for the players, who were frustrated at trying to succeed at both types of feedback. Future exergame design should either start with only one type of feedback or overlay them into a single type of feedback. Only when the user is familiar with the exergame when it uses a single type of feedback should a second type of feedback be implemented.
- Help players identify rhythm in their movements. Movement is rhythmic. In our exergame we've seen rhythm only as a haptic feedback, something that occurs when your gait is

correct. It wasn't used as a rhythmic aid, even though we showed in the literature research that rhythm can be used to train cadence symmetry. A beat should be added that helps the user with obtaining a steady gait, not merely when they do it correctly.

- Facilitate social fun by making movement a social experience. According to Isbister & Mueller the exergame should be designed for multiplayer, as moving with others is more fun than alone. While the exergame focuses on rehabilitation and should not focus on having multiple users at once, we did overlook the effect of the audience of the exergame. There will likely be a physiotherapist, spouse, family member or other acquaintance overseeing the exergame. The user usually wants to show off his prowess to an audience. Because the exergame uses augmented reality the audience cannot see what the user is doing, and thus has a harder time participating. By including the audience into the exergame the user is given more drive to improve and show off.

With this research we recognize several guidelines that could further improve our approach to exergame design. Future research should keep Isbister & Mueller and others we used (Reis et al., Salen et al., Burke et al.) in mind when designing a new exergame [5] [12] [51] [66].

Conclusion

We asked ourselves whether it is possible to design an exergame for the rehabilitation of stroke patients that can be used anywhere yet also still fun for the user. This research shows that it is possible to create an exergame system that has great portability, ease of use and methods to implement an optimized reward system. However, because some of the requirements for the feasibility of the system haven't been fulfilled it is discommended to use the exergame produced in this research for further use. Future research should instead learn from this research and create an exergame where the drawbacks of the hard- and software chosen for the optimal portability of the system aren't affecting the exergame itself.

References

[1] Kumar, P., & Clark, M. Clinical Medicine. 2005. *Edinburgh: WB Saunders*, *5*.

[2] Li, S., Francisco, G. E., & Zhou, P. (2018). Post-stroke hemiplegic gait: new perspective and insights. Frontiers in physiology, 9, 1021.

[3] Verheijden Klompstra, L., Jaarsma, T., & Strömberg, A. (2014). Exergaming in older adults: a scoping review and implementation potential for patients with heart failure. *European Journal of Cardiovascular Nursing*, *13*(5), 388-398.

[4] Hurkmans, H. L., Ribbers, G. M., Streur-Kranenburg, M. F., Stam, H. J., & Van Den Berg-Emons, R. J. (2011). Energy expenditure in chronic stroke patients playing Wii Sports: a pilot study. *Journal of neuroengineering and rehabilitation*, *8*(1), 38.

[5] Reis, A., Lains, J., Paredes, H., Filipe, V., Abrantes, C., Ferreira, F., ... & Barroso, J. (2016, July). Developing a system for post-stroke rehabilitation: an exergames approach. In *International Conference on Universal Access in Human-Computer Interaction* (pp. 403-413). Springer, Cham.

[6] Proffitt, R., & Lange, B. (2015). Feasibility of a customized, in-home, game-based stroke exercise program using the Microsoft Kinect® sensor. *International journal of telerehabilitation*, *7*(2), 23.

[7] Ma, M., Proffitt, R., & Skubic, M. (2018). Validation of a Kinect V2 based rehabilitation game. *PloS one*, *13*(8), e0202338.

[8] Sloot, L. H., Van der Krogt, M. M., & Harlaar, J. (2014). Effects of adding a virtual reality environment to different modes of treadmill walking. *Gait & posture*, *39*(3), 939-945.

[9] Rooij, I. J. M. D., van de Port, I. G. L., & Meijer, J. W. G. (2017). Feasibility and Effectiveness of Virtual Reality Training on Balance and Gait Recovery Early after Stroke: A Pilot Study. *Int J Phys Med Rehabil*, *5*(417), 2.

[10] Bork, F. (2018). Interactive augmented reality systems. *Der Unfallchirurg*, *121*(4), 286-292.

[11] Widmer, M. (2017). The use of performance feedback and reward for optimization of motor learning and neurorehabilitation of motor functions (Doctoral dissertation, ETH Zurich).

[12] Salen, K., Tekinbaş, K. S., & Zimmerman, E. (2004). *Rules of play: Game design fundamentals*. MIT press.

[13] Eng, J. J., & Tang, P. F. (2007). Gait training strategies to optimize walking ability in people with stroke: a synthesis of the evidence. *Expert review of neurotherapeutics*, *7*(10), 1417-1436.

[14] Kollen, B., Van De Port, I., Lindeman, E., Twisk, J., & Kwakkel, G. (2005). Predicting improvement in gait after stroke: a longitudinal prospective study. Stroke, 36(12), 2676-2680.

[15] Lamontagne, A., & Fung, J. (2004). Faster is better: implications for speed-intensive gait training after stroke. Stroke, 35(11), 2543-2548.

[16] Nilsson, N. C., Serafin, S., & Nordahl, R. (2014). Establishing the range of perceptually natural visual walking speeds for virtual walking-in-place locomotion. IEEE transactions on visualization and computer graphics, 20(4), 569-578.

[17] Wendt, J. D., Whitton, M. C., & Brooks, F. P. (2010, March). Gud wip: Gait-understanding-driven walking-in-place. In 2010 IEEE Virtual Reality Conference (VR) (pp. 51-58). IEEE.

[18] Bijleveld-Uitman, M., van de Port, I., & Kwakkel, G. (2013). Is gait speed or walking distance a better predictor for community walking after stroke?. Journal of rehabilitation medicine, 45(6), 535-540.

[19] Au-Yeung, S. S., Hui-Chan, C. W., & Tang, J. C. (2009). Short-form Tai Chi improves standing balance of people with chronic stroke. Neurorehabilitation and neural repair, 23(5), 515-522.

[20] Yen, C. L., Wang, R. Y., Liao, K. K., Huang, C. C., & Yang, Y. R. (2008). Gait training—induced change in corticomotor excitability in patients with chronic stroke. Neurorehabilitation and neural repair, 22(1), 22-30.

[21] Nejc, S., Loefler, S., Cvecka, J., Sedliak, M., & Kern, H. (2013). Strength training in elderly people improves static balance: a randomized controlled trial. European Journal of Translational Myology, 23(3), 85-89.

[22] Chung, E. J., Kim, J. H., & Lee, B. H. (2013). The effects of core stabilization exercise on dynamic balance and gait function in stroke patients. Journal of physical therapy science, 25(7), 803-806.

[23] Noh, D. K., Lim, J. Y., Shin, H. I., & Paik, N. J. (2008). The effect of aquatic therapy on postural balance and muscle strength in stroke survivors—a randomized controlled pilot trial. Clinical rehabilitation, 22(10-11), 966-976.

[24] Aruin, A. S., Hanke, T., Chaudhuri, G., Harvey, R., & Rao, N. (2000). Compelled weightbearing in persons with hemiparesis following stroke: the effect of a lift insert and goal-directed balance exercise. Journal of rehabilitation research and development, 37(1), 65-72.

[25] George, S. H., Rafiei, M. H., Borstad, A., Adeli, H., & Gauthier, L. V. (2017). Gross motor ability predicts response to upper extremity rehabilitation in chronic stroke. Behavioural brain research, 333, 314-322.

[26]: Thaut, M. H., McIntosh, G. C., & Rice, R. R. (1997). Rhythmic facilitation of gait training in hemiparetic stroke rehabilitation. Journal of the neurological sciences, 151(2), 207-212.

[27]: Song, G. B., & Ryu, H. J. (2016). Effects of gait training with rhythmic auditory stimulation on gait ability in stroke patients. Journal of physical therapy science, 28(5), 1403-1406.

[28]: Kobinata, N., Ueno, M., Imanishi, Y., & Yoshikawa, H. (2016). Immediate effects of rhythmic auditory stimulation on gait in stroke patients in relation to the lesion site. Journal of physical therapy science, 28(9), 2441-2444.

[29]: Alwis, D. S., Yan, E. B., Morganti-Kossmann, M. C., & Rajan, R. (2012). Sensory cortex underpinnings of traumatic brain injury deficits. PLoS One, 7(12), e52169.

[30] Pfister, A., West, A. M., Bronner, S., & Noah, J. A. (2014). Comparative abilities of Microsoft Kinect and Vicon 3D motion capture for gait analysis. Journal of medical engineering & technology, 38(5), 274-280.

[31] van Diest, M., Stegenga, J., Wörtche, H. J., Postema, K., Verkerke, G. J., & Lamoth, C. J. (2014). Suitability of Kinect for measuring whole body movement patterns during exergaming. Journal of biomechanics, 47(12), 2925-2932.

[32] Cloete, T., & Scheffer, C. (2008, August). Benchmarking of a full-body inertial motion capture system for clinical gait analysis. In 2008 30th Annual International Conference of the IEEE Engineering in Medicine and Biology Society (pp. 4579-4582). IEEE.

[33] Karatsidis, A. (2018). Kinetic Gait Analysis Using Inertial Motion Capture: New Tools for Knee Osteoarthritis.

[34] Gu, X., Zhang, Y., Sun, W., Bian, Y., Zhou, D., & Kristensson, P. O. (2016, May). Dexmo: An inexpensive and lightweight mechanical exoskeleton for motion capture and force feedback in VR. In Proceedings of the 2016 CHI Conference on Human Factors in Computing Systems (pp. 1991-1995). ACM.

[35] Kosawa, H., & Konishi, S. (2018, November). Wearable Hand Motion Capture Device. In 2018 IEEE CPMT Symposium Japan (ICSJ) (pp. 129-130). IEEE.

[36] X-sens (2017) Xsens *MVN User Manual.* Retrieved from: https://usermanual.wiki/Document/MVNUserManual.1147412416.pdf

[37] Shinkle, E. (2008). Video games, emotion and the six senses. *Media, culture & society*, *30*(6), 907-915.

[38] Yoo, S., & Kay, J. (2016, November). VRun: running-in-place virtual reality exergame. In *Proceedings of the 28th Australian Conference on Computer-Human Interaction* (pp. 562-566). ACM.

[39] Bock, B. C., Dunsiger, S. I., Ciccolo, J. T., Serber, E. R., Wu, W. C., Tilkemeier, P., ... & Marcus, B. H. (2019). Exercise videogames, physical activity, and health: Wii heart fitness: A randomized clinical trial. American journal of preventive medicine, 56(4), 501-511.

[40] Shaw, L. A., Wünsche, B. C., Lutteroth, C., Marks, S., & Callies, R. (2015). Challenges in virtual reality exergame design.

[41] Sedighi, A., Ulman, S. M., & Nussbaum, M. A. (2018). Information presentation through a head-worn display ("smart glasses") has a smaller influence on the temporal structure of gait variability during dual-task gait compared to handheld displays (paper-based system and smartphone). PLoS one, 13(4), e0195106.

[42] Kim, S., Nussbaum, M. A., & Ulman, S. (2018). Impacts of using a head-worn display on gait performance during level walking and obstacle crossing. Journal of Electromyography and Kinesiology, 39, 142-148.

[43] Desai, K., Bahirat, K., Ramalingam, S., Prabhakaran, B., Annaswamy, T., & Makris, U. E. (2016, May). Augmented reality-based exergames for rehabilitation. In Proceedings of the 7th International Conference on Multimedia Systems (p. 22). ACM.

[44] Kouris, I., Sarafidis, M., Androutsou, T., & Koutsouris, D. (2018, July). HOLOBALANCE: an Augmented Reality virtual trainer solution forbalance training and fall prevention. In 2018 40th Annual International Conference of the IEEE Engineering in Medicine and Biology Society (EMBC) (pp. 4233-4236). IEEE.

[45] Hackett, M., & Proctor, M. (2016). Three-dimensional display technologies for anatomical education: a literature Review. Journal of Science Education and Technology, 25(4), 641-654.

[46] Hanna, M. G., Ahmed, I., Nine, J., Prajapati, S., & Pantanowitz, L. (2018). Augmented reality technology using Microsoft HoloLens in anatomic pathology. Archives of pathology & laboratory medicine, 142(5), 638-644.

[47] Hallford, N., Hallford, J., & LaMothe, A. (2001). *Swords and circuitry: A designer's guide to computer role-playing games*. Premier Press, Incorporated.

[48] Wang, H., & Sun, C. T. (2011, September). Game reward systems: Gaming experiences and social meanings. In *DiGRA Conference* (pp. 1-15).

[49] Phillips, C., Johnson, D., & Wyeth, P. (2013, October). Videogame reward types. In *Proceedings of the First International Conference on Gameful Design, Research, and Applications* (pp. 103-106). ACM.

[50] Lohse, K., Shirzad, N., Verster, A., Hodges, N., & Van der Loos, H. M. (2013). Video games and rehabilitation: using design principles to enhance engagement in physical therapy. Journal of Neurologic Physical Therapy, 37(4), 166-175.

[51] Burke, J. W., McNeill, M. D. J., Charles, D. K., Morrow, P. J., Crosbie, J. H., & McDonough, S. M. (2009). Optimising engagement for stroke rehabilitation using serious games. *The Visual Computer*, *25*(12), 1085.

[52] Desai, K., Bahirat, K., Ramalingam, S., Prabhakaran, B., Annaswamy, T., & Makris, U. E. (2016, May). Augmented reality-based exergames for rehabilitation. In *Proceedings of the 7th International Conference on Multimedia Systems* (p. 22). ACM.

[53] De Leon, N. I., Bhatt, S. K., & Al-Jumaily, A. (2014). Augmented reality game based multi-usage rehabilitation therapist for stroke patients. *International Journal on Smart Sensing & Intelligent Systems*, *7*(3).

[54] Schroeter, R., Oxtoby, J., & Johnson, D. (2014, September). AR and gamification concepts to reduce driver boredom and risk taking behaviours. In *Proceedings of the 6th International Conference on Automotive User Interfaces and Interactive Vehicular Applications* (pp. 1-8). ACM.

[55] Kano, N. (1984). Attractive quality and must-be quality. Hinshitsu (Quality, The Journal of Japanese Society for Quality Control), 14, 39-48.

[56] Thorpe, S., Fize, D., & Marlot, C. (1996). Speed of processing in the human visual system. *nature*, *381*(6582), 520.

[57] Sun, J. H., Tan, L., & Yu, J. T. (2014). Post-stroke cognitive impairment: epidemiology, mechanisms and management. Annals of translational medicine, 2(8).

[58] Wüest, S., van de Langenberg, R., & de Bruin, E. D. (2014). Design considerations for a theory-driven exergame-based rehabilitation program to improve walking of persons with stroke. European Review of Aging and Physical Activity, 11(2), 119.

[59] Waters, T. R., Putz-Anderson, V., & Garg, A. (1994). Applications manual for the revised NIOSH lifting equation.

[60] ICC, I. (2018). International Building Code. Lenexa, Kansas: International Code Committee.

[61] Werle, C. O., Wansink, B., & Payne, C. R. (2015). Is it fun or exercise? The framing of physical activity biases subsequent snacking. *Marketing Letters*, *26*(4), 691-702.

[62] Wilcox, S., Der Ananian, C., Abbott, J., Vrazel, J., Ramsey, C., Sharpe, P. A., & Brady, T. (2006). Perceived exercise barriers, enablers, and benefits among exercising and nonexercising adults with arthritis: results from a qualitative study. *Arthritis Care & Research: Official Journal of the American College of Rheumatology*, *55*(4), 616-627.

[63] Brunnstrom, S. (1970) *Movement Therapy in Hemiplegia: A Neurophysiological Approach.* New York, New York: Harper & Row.

[64] Buyuksalih, I., Bayburt, S., Buyuksalih, G., Baskaraca, A. P., Karim, H., & Rahman, A. A. (2017). 3d Modelling and Visualization Based on the Unity Game Engine–Advantages and Challenges. ISPRS Annals of the Photogrammetry, Remote Sensing and Spatial Information Sciences, 4, 161.

[65] Selman, K. J. R. (2017). Development and validation of a position aiding system for inertial motion capture using Microsoft HoloLens (Master's thesis, University of Twente).

[66] Isbister, K., & Mueller, F. F. (2015). Guidelines for the design of movement-based games and their relevance to HCI. Human–Computer Interaction, 30(3-4), 366-399.

List of Appendices

Appendix A: Table of requirements for the exergame

All requirements colored green were added after the physiotherapist review. All requirements colored red were removed after the physiotherapist review.

Requirements for stroke patient rehabilitation
Basic Needs
◦ The walking speed of the stroke patient is higher after continuously training with the exergame than before he started to use the exergame.
◦ The user must be able to walk from the starting point of the exergame to the end point of the exercise.
◦ The end point of the exergame can be reached from the starting point by walking in a straight line.
◦ The exergame must be able to measure the duration of the exergame.
◦ The stroke patient has better control over the stability of the balance of his body after continuously training with the exergame than before he started to use the exergame.
◦ The exergame must be able to continuously measure the center of balance of the user when the exergame is active.
◦ The user must be able to differentiate between good control and bad control of his own center of balance through audial and/or visual feedback.
◦ The step length symmetry of the stroke patient is higher after continuously training with the exergame than before he started to use the exergame.
◦ The exergame must be able to show in an audial and/or visual way what the correct step length is that the user must bridge with his step.
◦ The exergame must be able to calculate the step length of every step the user makes.
Linear Needs
◦ The user must be able to manually choose the distance between the starting point and the end point.
◦ The user is given his overall walking speed at the end of the exergame via audial and/or visual feedback.
◦ The user must be given a visual representation of his center of mass in the exergame.
◦ At the end of the exergame the user is given a representation of how stable his balance is through audial and/or visual feedback.
◦ The exergame must give audial or visual feedback whenever the user successfully manages to make a step of the correct length.
◦ At the end of the exergame the user must be able to see how many correct steps of the right step length he took.
Delighters
◦ The exergame must be able to measure the movement speed of the user as he is performing the exergame.
◦ The user must be able to see his current walking speed during the exergame via audial and/or visual feedback.

Requirements from the stroke patient
Basic needs
◦The exergame must be simple enough that a stroke patient with mild cognitive impairment can understand and use it.
◦The exergame may not endanger or cause any form of harm to the user.
◦The exergame can be tailored to the patient by a medical caretaker.
◦The exergame will not cause sensory overload for the user
◦The user of the exergame must still be aware of the real world around him during the exergame.
Linear needs
◦The stroke patient must be able to understand in layman's terms that this exergame is going to help him rehabilitate.
◦The stroke patients can see during the training period that his gait is improving.
Delighters
◦The exergame can be tailored to the patient by the patient themselves.
Requirements for exergame design
Basic Needs
◦The inertial motion capture system can read the movement of the user and store this data as position, velocity and acceleration.
◦The inertial motion capture system can send out the position, velocity and/or acceleration of the user to the game engine.
◦The inertial motion capture system must be able to measure the movement of the user independent of the user's current location within a radius of 20 meters.
◦The average drift occurring in the system may be no more than five percent of the distance walked.
◦The exergame should only force the user to calibrate the inertial motion capture system at the start of the session and not in-between.
◦The head-mounted augmented reality interface display should be able to read and apply the data it receives from the game engine.
◦The head-mounted augmented reality interface display displays the exergame to the user.
◦The head-mounted augmented reality interface display displays both visual and audial output.
◦The user must be able to see and interact with the head-mounted augmented reality interface display at any time during the exergame.
◦The game engine creates a game that can be used in the exergame.
◦The game engine should be able to read the position/acceleration/position given by the inertial motion capture system and utilize it in the game part of the exergame.
◦The game engine must translate the data from the inertial motion capture system into changes in the game.
◦The game engine must send information about the in-game changes to the head-mounted augmented reality interface display.

Requirements concerning usability and transportability
Basic Needs
◦A single layman can install the hardware following written-down instructions.
◦A stroke patient with cognitive impairment must be able to start and end the exergame by themselves.
◦A normal person must be able to change the settings of the exergame
Linear Needs
◦There should not be made any significant modification to the location where the user wants to use the exergame.
◦A single layman without cognitive impairment can set up the exergame without outside help.
◦Commands and other messages (both verbal and non-verbal) that appear on the interface of the exergame must be easy to understand for someone who is recovering from stroke.
◦Any written text must be easily legible for the stroke patient.
Delighters
◦A stroke patient with mild cognitive impairment can set up the exergame without outside help.
◦A stroke patient with cognitive impairment must be able to change the settings of the exergame.
Requirements concerning fun
Basic Needs
The maximum amount of latency that can occur during the exergame is 150 milliseconds
The game must only cause negative effects by the actions of the user, and not because of circumstances outside the user's control
Linear Needs
The user receives a reward of positive feedback for doing well at certain parts of the exergame with rewards of positive feedback in mind.
Delighters
The user can obtain rewards of revised glory for doing well at certain parts of the exergame designed with rewards revised glory in mind.
The user can obtain rewards of sustenance for succeeding at certain parts of the exergame designed with rewards of sustenance in mind.
The user can obtain rewards of access for succeeding at certain parts of the exergame designed with rewards of access in mind.

Appendix B: Physiotherapist Questionnaire

Algemene kennis:

- Hoe vaak behandelt u een patiënt met een beroerte? (x per dag/week/maand/jaar)
- Hoe lang bent u al fysiotherapeut?
- Welke technische hulpmiddelen gebruikt u op het huidige moment om patiënten die een beroerte hebben gehad om weer te revalideren met lopen? *
- Welke revalidatieoefeningen gebruikt u op het huidige moment om patiënten die een beroerte hebben gehad om weer te revalideren met lopen?
- Hoe houdt u uw kennis over beroertes (en algemene ziektekennis) bij?
- Bent u bekend met de HoloLens?

(Laat Systeem zien, beginnen met deel zonder Sustenance & Access rewards)

Algemene mening Systeem:

- Wat is uw eerste indruk over het nieuwe systeem zelf?
- Bent u bekend met vergelijkbare oefeningen voor de patiënt? Zo ja, welke?

Loopvlakken:

- Wat is uw mening over het lopen over de geprojecteerde vlakken?
- Heeft het leren lopen met gekleurde vlakken toegevoegde waarde voor de rehabilitatie van de patiënt?
- Zijn de vlakken duidelijk genoeg voor de patiënt om op te stappen?
- Is de combinatie van kleurverandering en geluid duidelijk genoeg voor de patiënt om te realiseren dat hij een goede stap heeft gezet?
- Leid de kleurverandering en geluid de patiënt af van de oefening?
- Heeft u nog verdere opmerkingen over de loopvlakken?

Center of Mass:

- Bent U bekend met de term Center of Mass? Zo Ja, gebruikt U deze kennis bij het rehabiliteren van mensen na een beroerte? *(Geef extra kennis voor fysiotherapeut bij antwoord nee.)*
- Wat is uw mening over het geprojecteerde Center of Mass?
- (Leidt de geprojecteerde Center of Mass af van de oefening zelf?)
- Hoe kan een patiënt het best geattendeerd worden op het overschrijden van het CoM?
- Welke vorm en grootte moet de Center of Mass boundary krijgen?
- Heeft U nog verdere opmerkingen over het Center of Mass?

Eindscherm:

- Bij welke data die verkregen wordt uit deze oefening is van belang dat de patiënt dit te zien krijgt?
- Hoe zou U de data uit de vorige vraag duidelijk presenteren aan de gebruiker?
- Hoe zou U de “positieve feedback” brengen aan de patiënt?
- Heeft U nog verdere opmerkingen over het eindscherm?

Overig 1:

- Heeft u nog enige verdere vragen of opmerkingen over het tot dusver gepresenteerde model?

(Laat nu ook deel Sustenance/Access zien).

Beloning:

- Hebben deze beloningsvormen toegevoegde waarde voor een revaliderende na beroerte?
- Zou een gebruiker van dit systeem behoefte hebben aan het vrijspelen van nieuwe onderdelen door middel van het gebruikmaken van dit systeem?

Zo Ja,

- Hoe zou U de puntenverdeling van “Sustenance” willen maken bij het gebruik van dit systeem?
- Hoe moet de “Sustenance” beloning worden gepresenteerd, zowel de continue progressie alsmede de momenten waarop punten worden gescoord?
- Wat voor “Access” beloning zou de gebruiker willen hebben voor in zo’n dergelijk systeem?
- Hoe zouden deze beloningssystemen moeten worden toegepast in het systeem?

Zo Nee,

- Waarom heeft een gebruiker hier geen behoefte aan?
- Wat voor andere beloning zou de gebruiker willen hebben om deze oefening te blijven oefenen?

Gebruiksgemak:

Deze oefening vereist dat de gebruiker loopt in een rechte lijn over een te specificeren afstand.

- Hoe lang zou een oefening als deze moeten duren om nut te hebben?
- Hoeveel ruimte om te kunnen lopen is beschikbaar in uw praktijk?

Indien Ruimte < Oefening:

- Als U dit systeem zou willen gebruiken in uw praktijk, aan welke eisen moet het dan voldoen om toch bruikbaar te zijn ondanks het gebrek aan loopruimte?

Vergelijken met standaard:

U gaf aan dat op het huidige moment *** gebruikt (zie vraag met *)

- Welke voordelen bevat dit systeem over wat u momenteel gebruikt?
- Welke nadelen bevat dit systeem over wat u momenteel gebruikt?
- Zou u overschakelen naar dit systeem als het gepubliceerd wordt?

Overige vragen 2:

- Hebt u nog enige op- of aanmerkingen op dit onderzoek?

Appendix C: Information letter Feasibility test

UNIVERSITY OF TWENTE.

Adres van de ontvanger:

Faculteit Technische Natuurwetenschappen

DOOR	DATUM	VAKGROEP	PAGINA
K.D. (Klaas-Jan Attema) T 06-40404560 k.d.attema@student.utwente.nl	26 Juni 2019	BSS	67 van 4

ONDERWERP
Deelnemer informatie: *"AR-assisted walking exercise for rehabilitation of stroke patients with optimized reward system."*.

Geachte heer/mevrouw,

U heeft aangegeven deel te willen nemen aan het onderzoek: *AR-assisted walking exercise for rehabilitation of stroke patients with optimized reward system.* Het doel van deze brief is om u meer informatie over het onderzoek te geven. Deze informatie kunt u gebruiken om een goede keuze te kunnen maken over uw mogelijke deelname. Wij raden u aan om de deelname te bespreken met uw partner, vrienden, familie of anderen. Mocht u na het lezen van deze informatie nog vragen hebben, neem dan gerust contact op met de hoofdonderzoeker. Contact informatie is aan het einde van deze brief te vinden.

Doel en achtergrond van dit onderzoek
Het doel van dit onderzoek is het testen van een systeem dat mensen na een beroerte helpt om weer spelenderwijs te leren lopen op een leuke manier.

Gedurende het experiment zal er een oefening worden uitgevoerd die de deelnemer forceert om een nieuwe loopstijl aan te leren. Het aanleren van deze nieuwe loopstijl kan worden getransleerd naar de rehabilitatie van het looppatroon van mensen met een hersenbloeding.

Geschikt voor deelname
Ieder gezond persoon ouder dan 18 is geschikt om deel te nemen aan dit onderzoek. In dit geval betekent gezond: geen bot-, gewricht-, hersen-, huid-, rug- of zenuwproblemen, die uw bewegingen kunnen beïnvloeden (dit mag ook recent niet het geval geweest zijn). Daarnaast is het belangrijk dat u geen medicatie gebruikt die uw balans en/of bewegelijkheid beïnvloedt. Ook mag u niet zwanger zijn.

Wat houdt dit onderzoek voor u in?
In bijlage I kunt u meer specifieke informatie over dit onderzoek vinden.

Wat wordt er van u verwacht?
Van u worden geen speciale voorbereidingen verwacht, maar u wordt wel verzocht kleding te dragen die niet belemmerend is voor uw bewegingen.

Welke bijwerkingen zou u kunnen verwachten?
Bij dit experiment gebruikt u een AR (augmented reality/toegevoegd realiteit) -bril. Sommige mensen kunnen zich oncomfortabel voelen door het gebruik van de AR-bril. Dit oncomfortabel gevoel kan bestaan uit tijdelijke gevoelens van misselijkheid, bewegingsziekte, duizeligheid, desoriëntatie, hoofdpijn, vermoeidheid, oogvermoeidheid of droge ogen.

Wat zijn de mogelijke voordelen?
U zult niet direct voordelen hebben van dit onderzoek. Maar uw bewegingen worden gebruikt voor de basis van de ontwikkeling van een systeem dat helpt om mensen na een beroerte weer spelenderwijs te leren lopen op een leuke manier.

Wat wordt er met uw data gedaan?
Alle gemeten data tijdens dit experiment zullen met discretie behandeld worden volgens internationale regels en wetten, inclusief de wet voor het beschermen van persoonlijke data. De data zal worden gecodeerd zodat deze niet herleidbaar is naar u. Deze codering zal niet gebaseerd zijn op uw initialen, geboortedatum of geslacht. De resultaten van dit onderzoek zullen worden gepubliceerd. De data in deze publicaties zal anoniem zijn en niet herleidbaar tot u.

Als u besluit deel te nemen aan deze metingen, geeft u toestemming tot het volgende:
- De gemeten data mogen gebruikt worden voor dit onderzoek en mogelijk toekomstig onderzoek (de anonieme data zal 7 tot 10 jaren bewaard blijven)
- Wanneer u aangeeft te willen stoppen met de metingen, zal u gevraagd worden of de tot dan toe gemeten data gebruikt mag worden voor dit en toekomstig onderzoek (of niet).

Bent u verzekerd wanneer u besluit deel te nemen aan dit onderzoek?
De Universiteit Twente heeft een aansprakelijkheidsverzekering. Er zijn geen hoge risico's verbonden aan deelname aan dit onderzoek.

Huisarts
Uw huisarts zal niet worden ingelicht over uw deelname aan dit onderzoek.

Wat gebeurt er wanneer u besluit niet deel te nemen aan dit onderzoek?
Deelname is geheel vrijwillig, dus u bepaalt zelf of u deelneemt aan dit onderzoek. Als u besluit niet deel te nemen dan hoeft u verder niks te doen. Wanneer u besluit deel te nemen, kunt u op elk moment uw besluit terugtrekken. U hoeft niet aan te geven waarom u niet meer wilt deelnemen aan het onderzoek.

Meer informatie
Voor overige vragen kunt u altijd contact opnemen met de hoofdonderzoeker van dit project.

Met vriendelijke groeten,

Hoofdonderzoeker
Klaas-Jan Attema BSc

Biomedische Signalen en Systemen

06-40404560

k.d.attema@student.utwente.nl

Toestemmingsverklaring

Korte titel van het onderzoek:
AR-assisted walking exercise for rehabilitation of stroke patients with optimized reward system.

Door deze toestemmingsverklaring te ondertekenen verklaar ik:

- Dat ik deze informatiebrief en de bijlage gelezen heb, en de inhoud hiervan heb begrepen.
- Dat ik voldoende tijd heb gehad om over mijn deelname aan dit onderzoek na te denken.
- Dat ik de mogelijkheid heb gehad om vragen te stellen, en dat mogelijke vragen naar tevredenheid zijn beantwoord.
- Dat ik weet dat mijn deelname geheel vrijwillig is, en dat ik mijn toestemming op ieder moment terug kan trekken zonder hiervoor een reden op te geven.

Door deze toestemmingsverklaring te ondertekenen geef ik toestemming voor het volgende:

- Mijn deelname aan het onderzoek zoals hierboven beschreven.
- Het gebruik van de anonieme data, voor het doel beschreven in deze informatiebrief.

Naam proefpersoon:	Datum:
Gaat akkoord met het anoniem (gezicht onherkenbaar) opnemen van een video/foto van de meting (omcirkel wat van toepassing is):	Ja/nee
Handtekening:	

Naam onderzoeker:	Datum:
Handtekening:	

Een kopie van de ondertekende toestemmingsverklaring en de informatiebrief zullen aan de proefpersoon overhandigd worden.

Bijlage I

Wat houdt dit onderzoek voor u in?

In dit experiment wordt de functionaliteit van het systeem getest. Hiervoor wordt u gevraagd om het spel uit te voeren zoals wordt aangegeven door de AR-bril te spelen en te voltooien. Het onderzoek zal plaatsvinden in de Zuidhorst van Universiteit Twente (Zuidhorst, De Horst 2, 7522 NB Enschede, Nederland). Dit onderzoek zal plaatsvinden in een sessie die 60-120 minuten zal duren.

Het volgende zal er tijdens de metingen gebeuren:

1) Uitleg over het doel en de uitvoering van het onderzoek zal worden gegeven.
2) Uw lichaamsmaten en gewicht zullen worden gemeten.
3) U wordt gevraagd om een lycra shirt te dragen, zoals aangegeven is in figuur 1. Passieve sensoren worden met straps aan het lichaam bevestigd.
4) U wordt gevraagd om de AR-bril op te zetten, zoals te zien is in figuur 2.
5) U wordt gevraagd om het spel uit te voeren zoals wordt aangegeven door de AR-bril. Het doel is dat u naar de finishlijn loopt over de vlakken geprojecteerd op de grond terwijl u probeert uw heuppositie stabiel te houden.
6) Tussen en na afloop van de oefeningen wordt u gevraagd om feedback te geven over het systeem. U wordt gevraagd of u enige gebreken bent tegengekomen in het systeem en richting het gebruiksgemak van het apparaat.

Figuur 1: MVN motion capture pak.

Figuur 2: Microsoft Hololens AR-bril

Appendix D: Questionnaire for after the exergame

Thus far you've participated five times in a walking exercise. We would like your opinion about the exercises:

1. Did you notice a difference in the appearance of the exercises you've walked thus far?

   ☐ Yes

   ☐ No (Go to Question 6)

2. Which differences between the games' appearances did you notices?

3. Which exercise was in your opinion the best looking?

   ☐ The first three exercises

   ☐ The fourth exercise

   ☐ The fifth exercise

4. Why did you find this exercise the best looking?

5. What would you like to add to the appearance of the exercise?

6. Did you notice a difference in the difficulty between the exercises you've done thus far?

   ☐ Yes

   ☐ No (Finish this questionnaire)

7. Which exercise was in your opinion the most difficult?

   ☐ The first exercise

   ☐ The second exercise

   ☐ The third exercise

   ☐ The fourth exercise

   ☐ The fifth exercise

8. Why did you consider this exercise more difficult than the other exercises?

9. Do you have prior experience with Hololens or a similar AR-system?

☐ Yes

☐ No

10. Can you explain how difficult it was to utilize the Hololens?

Very easy						Very difficult
☐	☐	☐	☐	☐	☐	☐

11. How comfortable is the use of Hololens when compared to the usual circumstances?

More comfortable						Less comfortable
☐	☐	☐	☐	☐	☐	☐

12. How difficult was learning a new walking gait with this exercise?

Very easy						Very difficult
☐	☐	☐	☐	☐	☐	☐

13. How clear was the explanation of the exercise?

Very clear						Very unclear
☐	☐	☐	☐	☐	☐	☐

14. Summarize what was in your opinion the purpose of this exercise.

15. Did you notice any bugs appearing during the exercise?

☐ Yes

☐ No (Go to question 12)

16. Which bugs did you identify?

17. Do you have any final remarks?

General questions:

What is your gender?

- ☐ Male
- ☐ Female

What is your age?

- ☐ 16-24 years
- ☐ 25-40 years
- ☐ 41-55 years
- ☐ 56-70 years
- ☐ 71 years or older

What is your highest completed level of education?

- ☐ Elementary school graduate
- ☐ Vocational education (lbo/ vmbo)
- ☐ Intermediate general secondary education (mavo)
- ☐ Intermediate vocational education (mbo)
- ☐ Higher general secondary education (havo)
- ☐ preparatory scientific education (vwo)
- ☐ Higher professional education (hbo)
- ☐ Bachelor’s level of university studies
- ☐ Master’s level of university studies
- ☐ Doctoral level of university studies
- ☐ No Answer