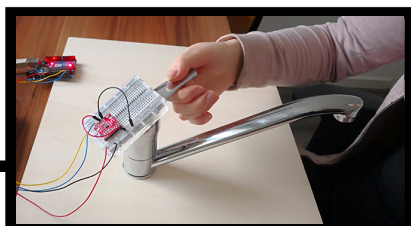
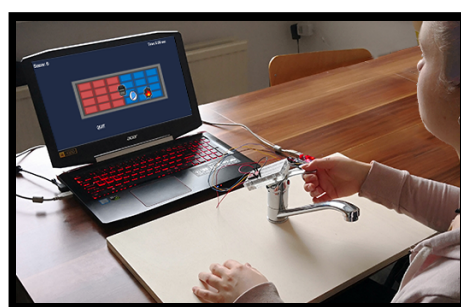
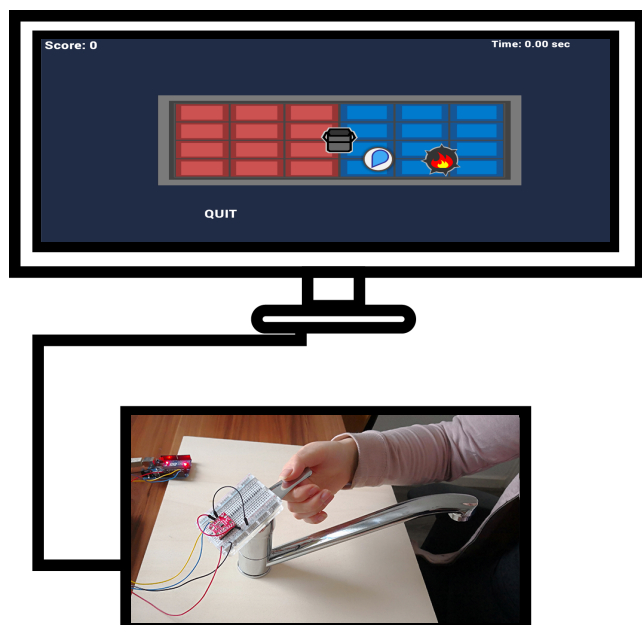


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# *Training Fine Motor Skills in the Hands with Game Elements*

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## **Abstract**

This thesis describes the development of a prototype for task-specific training of the fine motor skills in the hands. The prototype consists of a physical faucet as training object and a digital training that implements game elements. Evaluations showed problems with the sensors that could partially be solved by using appropriate filters. Expert evaluations of the user interface and game mechanics revealed that the visual elements and movement objectives had to be simpler than one might expect initially.

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## 1. Introduction

Fine motor skills are used to control and coordinate the small muscles in the fingers of our hands. People who are affected by illnesses such as cerebrovascular accident, also known as stroke, can have problems with these skills; grasping objects or making specific hand gestures and motions become difficult. Lack of control in the hand and finger movements can cause problems performing everyday activities, such as getting dressed, and picking up cutlery. While rehabilitation methods to train fine motor skills are available to help these people to regain control over their hands and fingers. However, conventional rehabilitation methods can be repetitive. This can cause patients to lose motivation or lose interest. Boosman et al. [29] have shown that motivation is a key factor for the rehabilitation process; the less motivated the patient is, the more time and energy is needed to attain the rehabilitation goals.

Silverfit<sup>1</sup> seeks to create playful and interesting rehabilitation methods to train the fine motor skills in the hands to prevent people from losing interest during their rehabilitation. Silverfit is a company that is specialized in rehabilitation technology for older people. The target group of this training consists of people who have lost the ability to use fine motor skills due to illnesses such as stroke.

A prototype of a training method was developed in this project that combines a digital game with a *single handle* faucet as a controller by attaching a motion sensor to determine the faucet's position. Operating and controlling a faucet was used as the task-specific aspect as people need to use faucets frequently in their daily routine that require controlling the temperature settings and the water flow, such as: brushing their teeth, washing their hands after using the bathroom, and doing the dishes.

A *single handle* faucet was used to act as the controller in the system that people can manipulate to change the position of the player in a game specifically designed for this training. The choice of using an actual faucet is to ensure that the motions that they use in the training reflect the motions they would make on a faucet in their own home environment. A *single handle* faucet was chosen as users who had no grip strength or could not open their hands could still operate the faucet.

A digital training was built around showing the current position of the faucet handle and the target position the faucet handle should move to. Gamification elements were implemented that determined what movements the player had to make and what effect these had inside the game.

Evaluations of the prototype were performed with two experts that have experience with rehabilitation and training of stroke patients. The results from the evaluations indicated that the level of difficulty of the game had to be set lower than we initially expected. It was determined that smaller movements should be used in the training that could be built up to larger movements in later stages of the game. From the expert evaluations we were also able to establish a base for statistical information that would be useful for therapists in future implementations.

Technical evaluations were performed throughout the development process to test how the sensors worked in combination with the game. The sensors consistently formed one of the biggest problems in the technical evaluations as inaccuracies were present in the readings. We identified the causes of the irregularities and determined that the inaccuracies were caused by random noise in the sensors as well as digitizing errors that were caused by the sensors. We could partially resolve such problems by using appropriate signal filtering like a moving average filter or a more complex exponentially moving average filter.

## **2. Assignment & Research Questions**

### **2.1 Assignment**

This assignment was done for Silverfit; a company that designs innovative technology with the goal to improve rehabilitation and elderly care to enable older people to retain health and independence for as long as possible. Silverfit wanted to create a rehabilitation method for people who have lost the ability to use fine motor skills in the hands due to illnesses, such as stroke, and help these people to regain the control over their fine motor skills so these people can be more independent again.

The rehabilitation method should make use of actual objects as training objects that patients would use in their home environment to ensure that the trained skills are directly applicable. Setting up the system should take as little time as possible as this time is deducted from the therapy time. As Silverfit designs rehabilitation methods in the form of games, the prototype would also preferably be designed in the form of a game or should at least include gamification elements.

### **2.2 Research Questions**

#### 1.2 Research questions

The following research questions were compiled based on the aim of the project.

*R1: How can a task-specific training for fine motor skills in the hands be designed that incorporates gamification elements and a physical object from a normal living environment?*

*R2: What type of sensor techniques are appropriate for monitoring training progress?*

## **2. Analysis**

The analysis consists of three parts; a literature research, a survey and a feasibility of sensing methods. The literature research gives insight that was needed to develop the prototype. The survey gives an overview of what technologies could potentially be used in the prototype as future reference as these have not been implemented in the current prototype. The feasibility of sensing methods gives an overview of the sensing methods that have been considered in the design of the prototype with all the advantages and disadvantages of each sensing method.

### **2.1 Literature research**

Research was done to give an overview of the aspects that had to be considered to design a training method for stroke patients with fine motor skill impairments. The physical limitations of stroke patients with fine motor skill impairments are defined to give an indication of what hand movements can be used. It was decided to use task-specific training as the type of training method in this project, therefore, research was done to see what positive effects it has on rehabilitation, and what aspects make task-specific training effective. As feedback is an important part of the learning process, it was researched what aspects make feedback effective. Furthermore, it was researched how gamification is applied in rehabilitation.

### **Physical limitations stroke patients**

Three impairments that affect the movements of the upper limbs of patients after a stroke are mentioned in the following section with an explanation of the effects of each impairment. The three impairments are taken from Lang et al. [42]; they mention three common upper extremity impairments that occur after a stroke: paresis, loss of fractionated movement, abnormal muscle tone, and changes in somatosensation.

Paresis causes patients to have a decreased ability to activate muscles and sets of muscles in a timely, coordinated manner with sufficient force. Mild paresis can make the patient appear to have slower, less accurate, and less efficient movements compared to healthy individuals, while severe paresis can result in patients being unable to move at all.

Fractionated movement is the ability to activate individual muscles volitionally. Reduced or loss of fractionated movement results in patients having a decreased ability to selectively activate muscles, this appears as involuntary flexing of additional muscles when only one is flexed volitionally.

The abnormal muscle tone is explained by Lang et al. [42] as the limb being harder to move with less range of motion, which is called hypertonicity, while the opposite is called hypotonicity. They state that hypotonicity is typically seen first after a stroke, while the patient develops hypertonicity during the first few weeks and months after a stroke.

The patients can also have a reduction or loss of somatosensation. The somatosensory system is responsible for processing information about the status of the muscles, such as the contraction and degree of stretch, as well as the joint position, temperature, pressure, and pain [43]. A reduced or loss of somatosensation would mean that the nervous system is less capable of monitoring and correcting muscle movements.

Based on the physical limitations, smaller precise movements are difficult for upper limb impaired stroke patients. Paresis and reduced fractionated movement limit the accurate movements of the hand, while abnormal muscle tone causes the movement to be more difficult to make. Big and less precise movements might be more suitable for the training, especially in the beginning stages of the rehabilitation.

### **Task-specific training**

Task-specific training is a method to relearn motor skills practice through the practice of context-specific functional motor tasks. Teasel et al. [2] explain the definition of task-specific training as training where patients 'practice context-specific motor tasks and receive some form of feedback'. Hubbard et al. [1] agree with this definition and add that the focus of task-specific training in rehabilitation is on improvement of performance of the associated functional tasks, which is facilitated through goal-directed practice and repetition. Hubbard et al. [1] state that while task-specific training is the most closely related to the motor relearning approach, the two are not identical. The motor relearning approach lets the patient practice the isolated impaired movements before letting them practice the specific functional task, while task-specific training lets the patients directly practice the specific functional task.

Multiple authors agree that there is strong evidence that suggests that some form of task-oriented training is effective in improving motor function rehabilitation. Van Peppen et al. [8] found that there is strong evidence that is in favor of task-oriented training being used to strengthen the paretic limb. Hubbard et al. [1] support this with their findings, but state that most of the evidence is limited to post-stroke recovery. Based on the evidence from a systematic review they concluded that some form of task-specific training improved global motor function, and function in both arms and lower limbs. Although, they mention that there was insufficient good-quality evidence for the upper limb interventions to have a clear view of this result. Additionally, evidence that was reviewed by Rensink et al. [6] suggested that functional outcomes and overall health-related quality of life would be improved for stroke survivors if task-specific training was used in their daily nursing care.

Additionally, two authors agree that there is strong evidence that supports using task-specific training to treat people affected by neurological disorder to have positive effects on motor relearning. Hubbard et al. [1] conclude that mounting evidence is available that are in favor of using task-specific training to treat people affected by a neurological disorder. Takeuchi and Izumi [7] support this as they state that there is strong evidence that demonstrate that functional motor recovery can be assisted with task-specific training as it induces long-lasting motor learning and associated cortical reorganization.

### **Effective task-specific training**

Multiple authors agree that repetition is needed to learn the skills to perform a task, while others argue that other factors might be more or equally important. According to Hubbard et al. [1], task-specific training should be repetitive; repetition of tasks results in better performance. However, Hubbard et al. [1] mention that it is suggested by Page [4] that from a clinical perspective task-specificity is more significant than the intensity of the time duration of the repetition. According to Page [4], it is still worth considering task-specific training even when high-intensity training routines are not within the capability of the patients.

Repetition of a given task may not be enough to cause sufficient changes in the brain to relearn that task. Bayona et al [3] state that usefulness or meaning in terms of function is needed aside from repetition to produce meaningful functional improvements. Takeuchi and Izumi [7] support this statement; based on the evidence they conclude that changes in the neural plasticity are greater when the practice is not only repetitive, but also meaningful.

The opinions of the authors are divided on the factors that influence the applicability of the learnt tasks. Authors agree on needing similarities between training scenarios and the 'real world' scenario to increase generalization of the learnt task's skills, but mention different types of similarities. Hubbard et al. [1] conclude from the reviewed papers that the evidence indicates that tasks should be context specific and should conform as closely to the 'real world' where possible. The actual objects that would be used in the given situation should be used in a similar context in the task-specific training. The results from the study of Bonney et al. [12] agree with the statement that there should be similarities, but focuses on the similarities between the skills in the task-specific training and the skills in the 'real world' situation. They suggest that having an increased number of common elements of the trained skills and the evaluated skills on motor tests is the reason why the subjects

in their study found it effortless to apply the learnt skills from the game to their 'real world' environment.

Moreover, the opinions are divided on whether task-specific training should have randomly ordered practice where possible to increase the task's applicability. Hubbard et al. [1] conclude that learned skills could potentially not be as readily applicable across similar tasks and alternate settings when task-specific training is too specific in task or movement, and are only applied in one context or sequence. However, findings of Bonney et al. [12] contradict this as they found that there were no differences between the transfer effects on learning in the variable and the repetitive training protocols. They suggest that, especially in the early learning process, repetitive or blocked training might be more effective as indiscriminate training might overload the system in cases of high attention, memory and motor demands, which results in disrupting the potential benefits of random practice. Moreover, Dithmer et al. [11] warn that unknown elements, such as new challenges, might form problems for patients in early rehabilitation stages. The patients might have a difficult time to keep track of all the different mechanics that are needed for each challenge.

Authors agree that goals should be patient centered and relevant to achieve better results. Hubbard et al. [1] conclude that the evidence infers that it could be counterproductive to spend large amounts of time and effort on tasks and activities that have no value for the patient. They state that the objective of mastering the eventual skills of the whole task should be clearly implemented in the activities. Takeuchi and Izumi [7] supports this, they found that motivation and engagement in therapy has been shown to be encouraged by patient involvement in setting goals that are patient centered. Maclean et al. [14] agree that relevant goals should be set, more than half of the interviewed professionals thought that relevant goals had a positive effect on the motivation. Some professionals added that small and achievable goals demonstrate the progress to the patients. Lam et al. [10] noted that a participant indicated that assurance of therapeutic improvement was motivating to keep them going.

### **Effective feedback**

Feedback is mentioned in multiple papers and has shown to be valuable if used correctly. Dithmer et al. [11] state that the participants found that the feedback was valuable as it allowed them to measure their progress. There are a few factors that play a role in the effectiveness of feedback; frequency and content of feedback, and the timing of feedback. These factors define different aspects that contribute to how well the information is processed.

In the first category, frequency and content of feedback, the opinions are divided about whether the frequency influences the learning process or not. Gawlowska et al. [18] state that as feedback frequency increases, the amount of information the subjects must process and respond to increases which, in turn, consumes more of the available cognitive resources. Walker et al. [20] agree with the statement, saying that limiting the external knowledge that is given to the subjects could encourage the subjects to use intrinsic information that is produced by the movement itself, and therefore could enhance the learning process. Timmermans et al. [15] support this statement based on the negative consequences of giving feedback after each trial as mentioned by Winstein et al. [19]; it discourages variety in learning strategies, leads to feedback dependency and could possibly also lead to an attention-capacity overload. Timmermans et al. [15] state that the feedback should fade over

time as this might decrease dependency of the performance feedback. Additionally, they state that fading feedback over time might result in better retention of learning effects and better transfer effects. Hubbard et al. [1] share the opinion that feedback should fade over time to prevent potential dependency.

The outcomes of the following studies seem to not show any concrete evidence to support that frequency influences the learning process. In accordance with the statement, Takeuchi and Izumi [7] reported that the test group who received a lower frequency of feedback had higher scores on retention tests compared with the test group that received feedback after every trial. However, Merians et al. [16] state that researchers from Winstein et al. [17] found no difference in the learning of the subjects in their study, whether they received very frequent feedback or more limited feedback; the subjects seemed to not show signs of detrimental learning in either case.

Evidence that suggests that extrinsic feedback seems to be a better choice when it comes to stroke patients. Timmermans et al. [15] state that intrinsic feedback, feedback through experience, can often not be processed by stroke patients because of brain damage. This means that they rely more on extrinsic feedback, feedback from an outside source. Additionally, Timmermans et al. [15] mention that according to Cirstea et al. [30], there is some evidence that using knowledge of performance extrinsic feedback during repetitive movement practice for persons after stroke results in better motor skill learning outcomes. The data from Bonney et al. [12] supports this statement; results suggest that people with stroke might be able to learn implicit motor skills by using extrinsic feedback.

Additionally, according to multiple studies, performance feedback should be based on motor control knowledge as this has positive influences on motivation, self-efficacy and compliance, and enhances motor learning [15]. Merians et al. [16] point out that, based on their own study, specific feedback was suggested to be of importance based on the difficulties that were displayed by the subjects when receiving feedback that was not clear enough in showing how to correct the error.

It seems that in this case it would be more appropriate to use extrinsic knowledge as the target group consists of stroke patients. The feedback should be based on motor control knowledge and be specific. The frequency of feedback can be reduced in the later stages of the rehabilitation to increase the intrinsic learning process of the patients.

Lastly, the role of the timing in the effectiveness will be discussed. The timing of when feedback is given seems to influence the learning process. Feedback on incorrect performance seems to have more effect on the learning process of skill improvement when compared to feedback on correct performances. Gawlowska et al. [18] found that subjects who were presented with feedback after incorrect responses had a faster learning process than subjects who were presented with feedback after correct responses. Similarly, Timmermans et al. [15] state that according to the sources Lintern [31] and Wallace and Hagler [32], feedback on incorrect performances is more effective in skill improvement. This suggests that loss is motivationally more significant than the equivalent gain.

Negative feedback might not be the best option when it comes to working with patients. Based on the reviewed papers, Hubbard et al. [1] concluded that the evidence indicates that positive reinforcements should be used in task-specific training in the form of timely and positive feedback. In practice, negative feedback can discourage both patients and therapists. From the research of Kivihalmé [41], it came forward that patients switched from the affected hand to the healthy hand as they got exhausted and gave up trying. As patients were not aware of their skill and progress,

they said that they were unable to complete the task at hand. Giving negative feedback would reinforce this attitude. There was a negative and frustrated attitude towards long-term lack of positive rehabilitation results.

### **Gamification of rehabilitation**

Deterding et al. [13] propose the definition of “gamification” as using game elements in non-game contexts based on their research. Conventional therapy can be repetitive or cause the patient to lose interest due to low variety. For instance, a patient in the study of Lam et al. [10] expressed that typical prescribed therapy was “boring” as it was only repetitively doing one single action. They add that discussion revealed that technology was used by the clinician to motivate or reduce boredom during therapy sessions.

Perry et al. [21] state that patients experience difficulties as challenges to overcome gradually in the subsequent level while they are engaged in the gameplay. Additionally, training specific skills and performing task oriented movements are not perceived as a repetitive rehabilitation exercise by the users while they are exercising in a game environment.

While implementing gamification seems to be able to improve motivation, virtual reality and video games alone seem to also have potential as rehabilitation tools. Szturm et al. [5] suggest based on the results of several studies that virtual reality and video games have benefits in rehabilitation tools and have tremendous potential as rehabilitation tools. Bonney et al. [12] show results that also seem to favor virtual reality as they found that skills that are acquired in a virtual reality environment can transfer to real life contexts.

Multiple authors agree that games should be challenging and have adjustable parameters based on the opinions of both participants as researchers to be enjoyable. The patients in the study of Hung et al. [22] voiced that games should be challenging and Hung et al. [22] argue that this is a criterion that is highly correlated to the successfulness of existing video games that are designed for entertainment. Lam et al. [10] also found that the games should be challenging; according to the adult participants in the study of Lam et al. [10], game-based therapy should be challenging but also implement competitiveness. Hung et al. [22] state that based on therapists’ knowledge, in general, patients may lose motivation to continue game rehab without any challenge even though easier games are more compatible with rehabilitation.

Additionally, the adjustable parameters are a factor to make games more challenging and fit individual needs. The participants in the study of Lam et al. [10] expressed that they desired to be able to adjust their therapy according to their individual needs; change in resistance, assistance, and different motions. Szturm et al. [5] agree with using configurable adjustable parameters as they state that the interviewed professionals indicated that this made the exercises challenging, which allowed the participants to be competitive and contributed to the enjoyment of the games.

While the parameters should be adjustable, it might be good to consider that this process should take little time. Lam et al. [10] indicated that the adult participants stated that it was important that setting up the system should take a minimal amount of time, and that the games were simple to initiate, understand, and play.

Real-time multiplayer games seem to be a preference of the participants and could play a part in the motivation of the participants. Lam et al. [10] stated that the participants expressed that the games

should be multiplayer, but did not care whether these “players” were people they knew or random opponents found online. They did indicate that they liked the idea of playing with others who had similar physical challenges. Deutsch et al. [9] support using multiplayer, they observed that introducing new players that the patient could play against in the multiplayer games, in reaction to a decline in the patient’s enthusiasm and interest in the gaming system, caused the patient to maintain their interest in the task without interruption and requiring verbal cues.

Dithmer et al. [11] state that based on observations and interview responses of the participants, achievements in the form of medals were not as engaging as the points. However, there was an indication that the recognition of the medals meant something as a few teams mentioned that they were actively trying to earn the medals, and some of the teams were even aiming for the entire set of medals. Dithmer et al. [11] state that the element of having new challenges everyday was positively received, but warns that unknown elements might form problems for patients in early rehabilitation stages.

## **Conclusion**

Task-specific training is a method that uses context-specific functional tasks to relearn motor skills for which strong evidence is available that indicates that this method has positive effects on relearning motor skills, mainly for patients in post-stroke recovery. There is evidence that suggests that task-specific training can be used in neurologically disordered people as task-specific training induces cortical reorganization. Task-specific training can still be used on patients that are unable to train for long periods at a time.

Repetition seems to be an important aspect of the effectiveness of task-specific training that is needed to learn a task, however repetition alone might not be sufficient. It is suggested that repetition of a task should be combined with the meaningfulness of a task.

The task’s generalizability seems to increase when there are common factors between the task in the training environment and the task in the ‘real world’. While limiting the diversity of the tasks may result in a lower generalizability, using randomly sequenced tasks with a higher diversity might form a problem for patients in early rehabilitation stages as it has a chance to be too overwhelming.

Feedback with extrinsic knowledge is more appropriate for the purpose of this prototype as the target group consists of stroke patients. The feedback should be based on motor control knowledge and be specific. The frequency of feedback can be reduced in the later stages of the rehabilitation to increase the intrinsic learning process of the patients and reduce the feedback dependency. While feedback on incorrect responses seems to be more effective in skill improvement, it seems that this would negatively impact the motivation of the patients. It would therefore be better to implement positive feedback.

Gamification of rehabilitation can motivate and stimulate the participants more than conventional therapy. When participants are engaged in gameplay, they don’t experience the difficulties of the usual training exercises as problems and don’t see these as repetitive. The game-based therapy should be challenging to motivate the participants. Having adjustable parameters are both a

requirement of the patients as the professionals as these make it possible to adjust the difficulty to suit the patient’s physical capability. This has an influence on both the motivation and how challenging the patient experiences the therapy. It should be considered that adjusting these parameters should take minimal time to complete.

Game elements such as real-time multiplayer and achievements seemed to be liked by participants. Multiplayer games seem to be a factor that plays a role in motivating the participants. There seems to be no preference on whether the patients are familiar with these ‘players’, but it is suggested that they would like to play with people with similar physical limitations. Achievements seem to work as a middle of recognition and were liked by the participants, however there is not enough scientific evidence to support this.

## 2.2 Feasibility of Sensing methods

This section gives an overview of the sensing methods that could be used to capture training progress. The sensing methods that are discussed are: objects with sensors, removable sensor attachment piece, environment sensing, and sensing gloves.

### 2.2.1 Objects with sensors

The users manipulate an object as part of their rehabilitation exercise. One possible method to detect the manipulations of the object and the hand is by implementing sensors in the objects that the users train with to detect the changes that directly impact the object.

Object with sensor (non-removable)	
Advantage	Disadvantage
<ul style="list-style-type: none"> <li>- No restriction in hand sizes</li> <li>- Sensor can be robustly placed</li> </ul>	<ul style="list-style-type: none"> <li>- Wires of the sensors could restrict movement</li> <li>- Would need to make a range of objects to train different aspects</li> <li>- Would need a range of objects when an increase in resistance is needed</li> <li>- Not able to measure precise movements of individual fingers in every direction, only movements that impact the object itself</li> </ul>
Possible measurements	
<ul style="list-style-type: none"> <li>- Pressure sensors (measuring strength of grip)</li> <li>- Heat sensors (measure location of fingers)</li> <li>- GPS (to track location of the object in horizontal plane)</li> <li>- Distance sensor (tracking height of object)</li> <li>- Accelerometer (tracking rotation of object)</li> <li>- Measuring time (taken from the data of the sensors above)</li> </ul>	

## ReJoyce

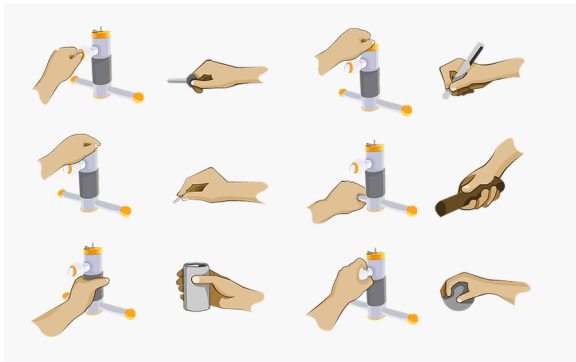


Figure 1: ReJoyce integrated objects, from [28]



Figure 2: Rejoyce being used, from <http://www.vancouver.sun.com/>

The ReJoyce [28] simulates AD and integrates these into exercise therapy disguised as fun and motivating games.

Advantages	Disadvantages
Quick setup time	No grip strength measuring
No hand size limitation	
At-home use possible	

### 2.2.2 Removable sensor attachment piece

This method detects the manipulations of the object and the hand is by making an attachment piece with sensors that fit on specific objects that the users train with to detect the changes that directly impact the object.

Removable sensor attachment for a type of objects	
Advantage	Disadvantage
<ul style="list-style-type: none"> <li>- No restriction in hand sizes</li> <li>- A range of objects would be able to be used with one attachment; different aspects can be trained by changing the object on the attachment</li> </ul>	<ul style="list-style-type: none"> <li>- Wires of the sensors could restrict movement</li> <li>- Not able to measure precise movements of individual fingers in every direction, only movements that impact the surface of the attachment the object is attached to</li> </ul>
Possible measurements	
<ul style="list-style-type: none"> <li>- Pressure sensors (measuring strength of grip)</li> <li>- Heat sensors (measure location of fingers)</li> <li>- GPS (to track location of the object in horizontal plane)</li> <li>- Distance sensor (tracking height of object)</li> <li>- Accelerometer (tracking rotation of object)</li> <li>- Measuring time (taken from the data of the sensors above)</li> </ul>	

### 2.2.3 Environment sensing

This method detects the manipulations of the object and the hand is by using sensors that are put on the walls surrounding the object and the user to detect the changes in placement of the object and the hand.

Environment that detects changes within its proximity	
Advantage	Disadvantage
<ul style="list-style-type: none"> <li>- No restriction in hand sizes</li> <li>- No wires that restrict movement</li> <li>- Freedom to use any physical object</li> </ul>	<ul style="list-style-type: none"> <li>- Hands and/or objects might block view of sensor; inaccurate measurements</li> </ul>
Possible measurements	
<ul style="list-style-type: none"> <li>- GPS (to track location of the object in horizontal plane)</li> <li>- Distance sensor (tracking height of object)</li> <li>- Accelerometer (tracking rotation of object)</li> <li>- Visual tracking system (track location in horizontal plane and vertical plane)</li> <li>- Measuring time (using the visual tracking system footage)</li> </ul>	

## Xbox One Kinect



Figure 3: Xbox One Kinect, from [34]

The Xbox One Kinect [34] is an optical sensor that can detect movement.

Advantages	Disadvantages
At-home use	No use of objects, these can block the hand and finger detection
Quick setup time	No grip strength measure
No limitation in hand size	

## Leap Motion Controller



Figure 4: Leap Motion Controller example use, from <https://edgylabs.com/leap-motion-hand-vr/>

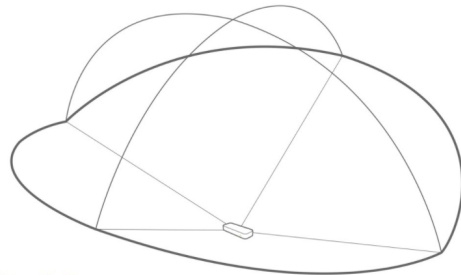


Figure 5, from <http://blog.leapmotion.com/>

The Leap [25] is a sensor that uses two cameras and three infrared LEDs to track infrared light with a wavelength of 850 nanometers. The viewing range is limited to roughly 80 cm above the device. It can detect hand and finger movements.

Advantages	Disadvantages
At-home use	No use of objects, these can block the hand and finger detection
Quick setup time of equipment	No grip strength measuring
No hand size limitation	wired
People with limited fine motor skills who cannot separate their fingers or open their hands enough to use this are included.	

## VirtualRehab 4.0



Figure 6: VirtualRehab 4.0 being used, from [26]



Figure 7: VirtualRehab 4.0 in-game, from [26]

VirtualRehab 4.0 [26] is complete hand & body video game therapy solution, CE approved, that helps patients to improve balance and fine motor skills using Microsoft's Kinect, Xbox One, and Leap Motion®, and clinically tested therapeutic games.

Advantages	Disadvantages
No limitation in hand size	No grip force measure
No uncomfortable cables and sensors	
Telerehabilitation is possible	
Short setup time	

### 2.2.4 Sensing Glove

This method detects the movements of the hands by wearing a wearable glove with sensors.

Sensing glove	
Advantage	Disadvantage
<ul style="list-style-type: none"> <li>- Measurements of individual finger movements</li> <li>- Freedom to use any physical object</li> </ul>	<ul style="list-style-type: none"> <li>- Restriction in hand sizes</li> <li>- Restriction of users (not everyone can separate individual fingers enough to wear the glove)</li> <li>- Setup time to put on the glove will differ per user (finger and hand mobility), might take a long time</li> </ul>

An overview of the existing sensor technologies are given that can track the movements of the fingers. While these sensors were not implemented in the final prototype of this project, these technologies could be interesting for future improvements of the prototype.

## Manus VR Glove



Figure 8: Manus VR Glove and VIVE Headset, from <https://manus-vr.com/#product-anchor>

The Manus VR Glove [23] uses two sensors in each finger to track its movements with a separate sensor in the thumb to measure its rotation, this is used to calculate the relative position of the hand. The gloves can be hand washed, gives haptic feedback, and can be used wirelessly lasting up to 3-6 hours of extensive use. Low computational power is required from a desktop or mobile device to use the Manus VR Glove. The gloves make use of a gyroscope, accelerometer and magnetometer.

As seen in figure 1, the gloves make use of topless fingers and fit the sizes M, L and XL using the adjustable strap.

Advantages	Disadvantages
Wireless	Limitation in hand size (smaller hands are excluded)
Waterproof and washable	People with limited fine motor skills who cannot separate their fingers or open their hands enough to use this are excluded.
Haptic feedback	No grip strength measuring
Accurate movement measurements of the fingers	

## SenseGlove



Figure 9: Developer model of SenseGlove[24]

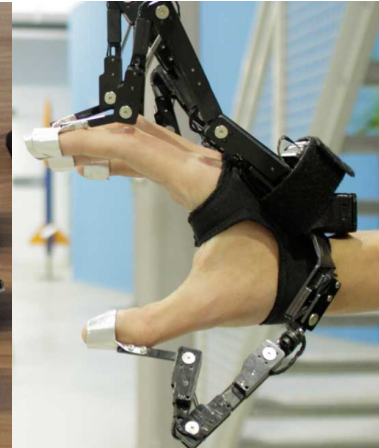


Figure 10: SenseGlove model taken from <http://www.senseglove.com>

The SenseGlove [24] is currently not a consumer product and is still in development. The glove makes use of an exoskeleton, as can be seen in figure 3, and uses reverse kinematics to calculate the position of each knuckle. It uses velcro strips to fit each finger to the glove. While the size of the glove is adjustable to the hand size, this requires a screwdriver to adjust the lengths of small plates in the fingers of the glove. There was a very minimal visible lag when transferring movements in the 'real world' to the digital visualization on the screen during the tests. The BETA version of the glove has a wireless connection, but the developer model in figure 2 does not have that yet. It is stated on the website that the Sense Glove DK1 would be launched by the end of 2017 and would have full force feedback.

Advantages	Disadvantages
No limitation in hand size	Not wireless (developer version)
Very accurate movements of each knuckle in the finger	Setup time might be long depending on hand size
	It is quite bulky to wear on the hands
	No grip strength measuring
	People with limited fine motor skills who cannot separate their fingers or open their hands enough to use this are excluded.

## RAPAEL Smart Glove



Figure 11: RAPAEL use example, from [35] brings-



Figure 12, from <http://technode.com/2015/12/14/rapael-smart-glove-gamification-rehabilitation/>

The RAPAEL Smart Glove [35] captures the hand and wrist movement. The product is smaller, cheaper, and lighter than the products available on the market according to the CEO of Neofect, Hoyoung Ban [36].

Advantages	Disadvantages
At-home use possible	No grip strength measuring
Quick setup time	Hand size limitation
Lighter materials than other products	

## VIVE Tracker

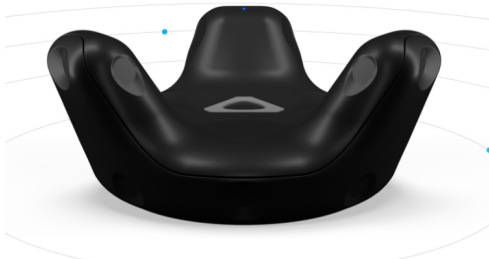


Figure 12: VIVE Tracker, from [33]



Figure 14: VIVE Tracker placement, from [33]

The VIVE Tracker [33] is an attachable tracker that can be used in combination with one of the gloves to keep track of both hand and wrist position.

Advantages	Disadvantages
Portable	Needs to be combined with other sensors to be effective in rehabilitation
Wireless	
No limitation in hand size	

## **Conclusion feasibility of the sensing methods**

Based on the results of the feasibility of the sensing methods, it can be concluded that the object with sensor method or the removable sensor attachment piece would be the most appropriate for the purpose of this prototype. Finger detection of the environment sensing method can be obstructed by the objects that are used in the training. Sensing gloves have a limitation in hand sizes which could take a longer setup time. Additionally, sensing gloves would exclude people that are not able to fully open their hands or separate their fingers.

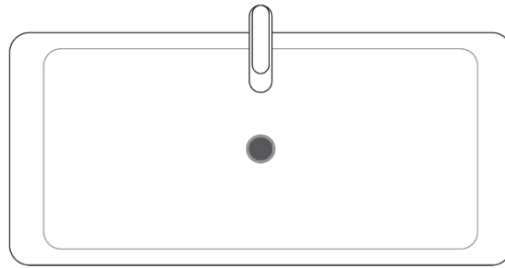
## **3. Ideation Designs**

The aim of the ideation phase is to create different ideas from which the final idea can be selected for the prototype. At this point it had been decided to use a faucet as the physical training object. The ideation was centred around how to implement a physical faucet in the prototype. The ideation phase of the design is split into two sections: the design of the system as a whole, and the design of suitable games. In the design of the system setup, it is described what different screen placements have been considered.

### **3.1 Design of the system setup**

Different screen placements can influence what the user is viewing and could bring their own limitations regarding visual elements. This section discusses what options have been considered, giving the advantages and disadvantages of each option.

### Screen under faucet – View from above



*Figure 15: Screen placed under the faucet showing view of sink area on the screen*

In this setup, the screen would be placed underneath the faucet, giving the user a view of the “sink”. A tablet or another screen that can be laid flat on the surface would be used in this scenario.

<b>Pros</b>	<b>Cons</b>
It mimics how an actual sink would work	Visuals are limited to sink only
Water can be mimicked in the sink to give visual feedback to the user when they reduce or increase water flow	Hands and arms might obstruct the view
Animations can be shown in the water	
Water level can be shown to rise and drop	
The physical faucet is used as the actual faucet where the water comes from	

### Screen behind faucet 1 – Front View

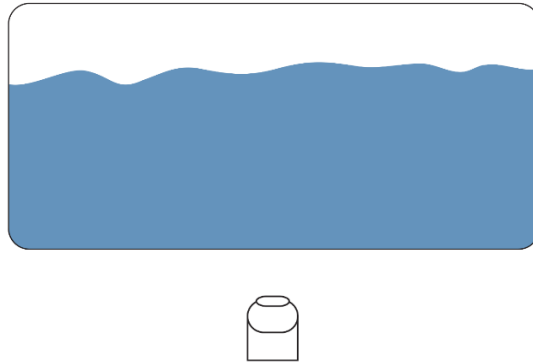


Figure 16: Screen placed behind the faucet showing view of water level on the screen

In this setup, the screen would be placed behind the faucet, showing the changes in water level due to changes with the physical faucet on the screen.

Pros	Cons
Water level can be shown to increase accurately	It might confuse the user as the water level starts to rise above the faucet
Arms and hands cannot obstruct the view (if screen is placed high enough)	It does not give the user a real-world feeling as the sink should be under the faucet
Animations can be shown in different heights of the water (for specific ques)	
This could work in a more pc style game	

### Screen behind faucet 2 – Front view

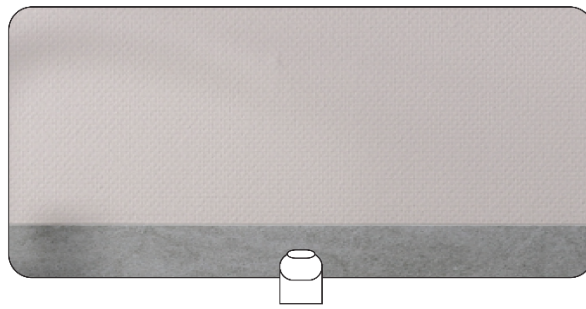


*Figure 17: Screen placed behind the faucet showing a virtual faucet on the screen*

In this setup, the screen is placed behind the faucet, a digital faucet would be implemented on the display of the screen, showing the changes of the physical faucet on the digital faucet.

<b>Pros</b>	<b>Cons</b>
Water can be shown flowing from the digital faucet	Having two faucets could cause confusion
This could work in a pc style game	Water level cannot be shown with this option, it would have to be combined with the “screen under faucet” option
Arms and hands cannot obstruct the screen	If combined, user would have to keep track of multiple screens

### Screen behind faucet 3 – Front view



*Figure 18: Screen placed behind the faucet showing the wall area on the screen (without a virtual faucet)*

In this setup, the screen is placed behind the faucet, the display would not directly show increase of water on the screen.

<b>Pros</b>	<b>Cons</b>
The physical faucet is used as the actual faucet where the water comes from	Water level is not shown with this, would have to be combined with the “screen under faucet” option
Animations would not be limited to water	If combined, user would have to keep track of multiple screens
Hands cannot obstruct the screen	

### 3.2 Design of the games

A brainstorm session was performed to form ideas of games that could be used to base the exercises on. In this brainstorming session the focus was put on giving the tasks consequences that involve the happiness of virtual animals and humans in an attempt to give the tasks more meaning to improve the user's interests in the rehabilitation training. The results of this ideation phase can be found in appendix A.

After some initial reviewing it was decided to not use all of these elements for the prototype due to the results of the online ethnography performed by Kivihalmé [41] that showed that stroke patients were unable to filter information and stimulations around them and could be overwhelmed by the information. Instead, elements were selected to create a game based on the movements that need to be performed by the user. The basic functions of the game were set up as a starting point.

<b>Basic functions</b>
Displaying faucet handle current position
Displaying faucet handle target position
Scoring system for correct faucet handle position
Scoring system for time to reach correct faucet handle position

After setting up the basic functions, the visual cue system was put together to give an idea of what basic visual elements would be needed to be implemented.

<b>Visual Cue system</b>
Gradient bar containing colours that are linked to the temperature of the water; Red-orange-green-blue
Horizontal movement of the player on the bar indicating the horizontal movements made with the faucet handle
Vertical movements of the player on the bar indicating the vertical movements made with the faucet
Target position is shown with a collectible item

Based on the visual cue system and the basic functions, the reward system was constructed.

<b>Reward system</b>
Points can be awarded by:
Length of time (receive points for the playtime of the game)
Collected item (a collected item indicates a reached correct position)

Finally, the potential uses of the reward system was put in a list for future use.

<b>(Optional) use of points from reward system</b>
Points can be used to customize the game:
Unlock new backgrounds (think different style kitchen/bathroom)
Unlock new music (this is played during the gameplay)
Unlock specific elements (new visual elements or decorations)

## 4. Product Specification

The product specification of the concept of the prototype is given in the following section.

### 4.1 Physical setup

The physical setup consists of a faucet and a frame. The faucet is placed on a frame to stabilize the faucet. Placement of the faucet on the frame ensures that the faucet is within arms-length and is in range of moving the handle without users having to strain. The frame of the faucet is secured to the table it is placed on using clamps as it needs to stay firmly in its place when the handle of the faucet is moved. Placements of the clamps should not hinder any movements; the frame should either be much wider or smaller to ensure this. To make the faucets interchangeable in order to provide multiple faucet possibilities in the future, the faucet is secured on the frame using a bolt that can be unbolted without damaging the faucet or the frame. A faucet with a longer handle is chosen so users have enough surface to hold onto the faucet handle.

### 4.3 Design of the game

The current position of the faucet is displayed as the player icon. A collectible item is spawned on the screen representing the target faucet handle. The player icon has to stay on the location of the collectible item for a set amount of time before the item is picked up. This ensures that the user cannot simply move the faucet handle from one side to the other side and pick up items without needing any precision. The range of movement that users have to make to reach the target faucet location can be adjusted by changing the x-range and the y-range parameters of the collectible item in the options screen. Picking up collectible items gives a score points. The score points are tracked on the play screen so users can see their progress. At the end of the game the users can see the statistics of how they performed during the game session.

### 4.4 Hardware

The sensors are able to measure the horizontal movements and the vertical movements of the faucet handle. When the user moves the faucet handle, its position is picked up with as little lag as possible. Placement of the sensor and other hardware does not hinder or limit movements of the faucet handle. The faucet handle remains free of hardware as much as possible to allow a user to freely use any hand position to operate the faucet handle.

## 5. Design

### Playfield



*Figure 19: First version of the playfield*

The playfield is a gradient bar that uses colours that are linked to the temperature of the water. The red and blue represent the hot and cold side of the faucet. The first version of the gradient bar contained seven different colours to make each column stand out and make the game look more

colourful and playful. The first version is shown in figure 19. After the evaluation, the gradient bar was changed to two colours as the amount of colours was deemed too distracting. The two colours that were used in the gradient bar were picked based on temperature representation: red for hot and blue for cold. The final version of the playfield is shown in figure 20.



Figure 20: Final version of the playfield

### Player icon & Collectibles

The movement of the player is represented by the player icon, the bucket, that moves with the faucet handle. The target position where the player should move to is represented by the waterdrop, this is a collectible item.

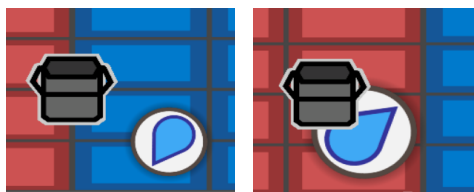


Figure 21: Waterdrop increases in size when the player is within pickup distance

To collect the waterdrop, the player needs to be within the pickup range of the waterdrop, which means that the player must be touching the waterdrop icon, for a set amount of time. After the evaluation, the collectible waterdrop also increased in size to indicate that the player was on the waterdrop. When the set amount of time has been reached, the player icon will turn green as is seen in the left image of figure 22 and a sound will play to indicate

that the waterdrop has been collected. The waterdrop also has a “fade time”; this is the time when the waterdrop becomes 50% transparent. The “fade time” initially indicated that the time to pick up the waterdrop was almost over and the waterdrop would soon disappear. After the evaluation, the “fade time” became an optional setting and would only to serve as an indication to the player that this waterdrop has been on the playfield for a set amount of time already. The range of movement that users have to make to reach the waterdrop can be adjusted by changing the x-range and the y-range parameters of the collectible item in the options screen.



Figure 22: Colour states of the player icon

If the player touches an obstacle, the bucket will turn red as is seen on the right image of figure 22 and a sound will play to indicate that an obstacle has been hit. The obstacle was first represented by a thermometer to warn users for the temperature, but after the evaluation with experts, the obstacle was changed to a spiked mine containing a flame to make it more intuitive that the obstacle should not be touched. The obstacle can be seen in figure 22.

### Score system & Statistics



Figure 23: First version of the Playscreen

Each waterdrop has a set amount of points. The total collected score is updated when a waterdrop is collected. It was initially set that waterdrops would lose a few points in value when the player had hit an obstacle. After the evaluation, this deduction in points was removed to avoid discouraging patients.

discouraging patients.

The average time is the average time it took the player to collect a waterdrop. The fastest time is the fastest time it took a player to collect a waterdrop. After the evaluation this information was no longer shown on the play screen, but was only shown on the end screen instead of showing on both the play screen and on the end screen. Instead of showing this information on the play screen, it was decided to show the elapsed time since the start of the game on the screen. The time is only updated when a waterdrop is collected to avoid continuously moving numbers on the screen that could be too distracting. All the texts are displayed in the TextMesh Pro [27] text resolution instead of the standard Unity UI text as it has improved visual quality and flexibility without additional performance costs.

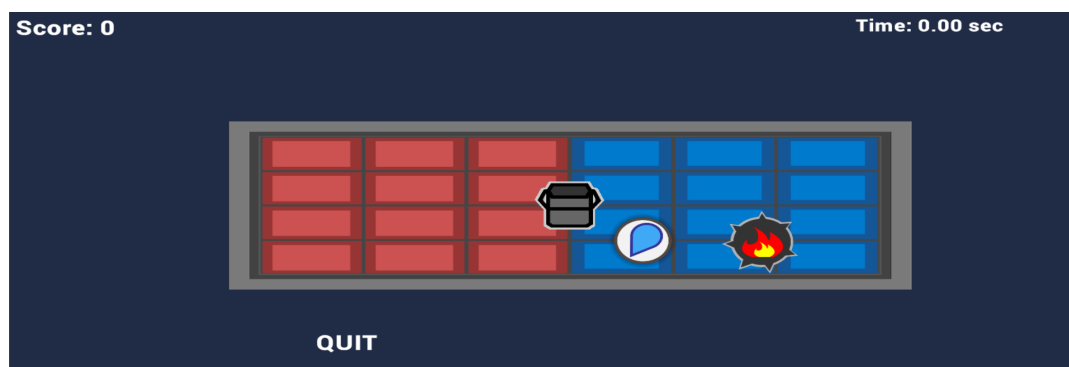


Figure 24: Final version of the Playscreen

When the game ends, the statistics of that game are shown on the end screen. It can be selected to go to the highscores and find the best statistics that are collected from multiple games. As it is assumed that only one patient plays at a time, no names or tags are added to these scores. It was

also considered that in the case that it was played by multiple patients, some patients could get discouraged if they were never able to get in the highscores.

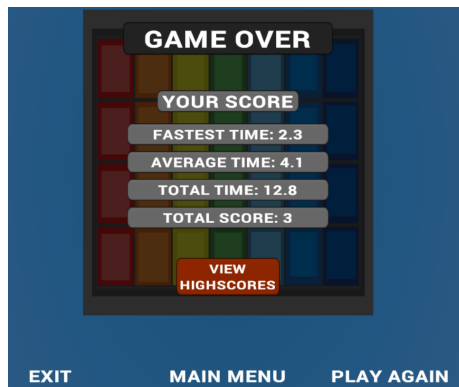


Figure 25: First version of EndingScreen

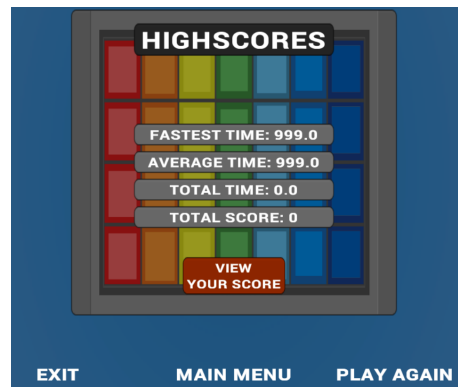


Figure 26: Highscores screen

After the expert evaluation, the “Game over” text was changed to “Game ended” to make the ending of a game sound less negative. The information on the ending screen was also divided into multiple screens; this was done as the amount of information could be overwhelming for a patient. Additionally, not everyone would be interested in seeing all of the information. Additional information was added that kept track of how much time it took to reach objects on the left side, how many obstacles were hit on the left side, and the same information was tracked for the right side. This information was mainly added to give therapists insight on the progress of their patients and for statistical implementations in the future. The final end screens can be seen in figure [x].

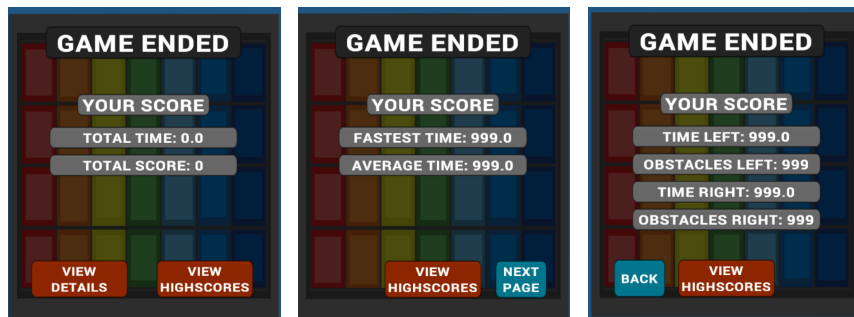


Figure 27: Final version of the EndingScreen

## 6. Realization

This section discusses how the prototype was realized. The realization is divided into the system setup, hardware & software, and sensors. The physical construction of the prototype is described in the system setup. The hardware and software that are used for the sensor technology can be found in the hardware & software section, this section also describes what software is used for the game. The sensor section discusses what sensor technology is used and how the sensors were tested, this section also discusses the filters that were used on the data and which filter was selected.

## 6.1 System Setup

### 6.1.1 Faucet

The faucet that is chosen is a brass single-handle kitchen faucet with chrome finish. The height of the faucet is 12 cm, with a width of 2,8 cm.



Figure 28: Selected single-handle kitchen faucet, from <https://www.gamma.nl/assortiment/l/sanitair/kranen>

Faucets that were rejected based on user limitations consisted of the faucets that required grip strength to operate the faucet. Examples of these types of faucets are shown in figure 29.



Figure 29: Rejected faucets requiring grip strength, from <https://www.gamma.nl/assortiment/l/sanitair/kranen>

The following faucets were rejected to prevent the sensor placement from restricting the faucet handle movements.



Figure 30: Rejected faucets limiting sensor placements, left from <https://www.gamma.nl/assortiment/l/sanitair/kranen> right from <https://www.praxis.nl/badkamer-keuken-wonen/kranen>

### 6.1.2. Frame

The base for the prototype consists of two 8mm triplex plates. The two plates are connected by four screws; one in each corner. The top plate has a hole that is the size of a bolt. The hole on the bottom plate is bigger so the bolt head of the bolt that is used to connect the faucet to the frame is sunken into the bottom plate while also leaving enough room around the nut for easier access during

disassembly. Having the bolt head sunken into the bottom plate ensures that the bottom of the base is level with the surface it is placed on. Easier access to the disassembly is done in consideration of being able to change the faucet that is used in the system. A plain washer is put between the bolt head and the bottom plate to minimize friction between the bolt and the bottom plate when the disassembly takes place.

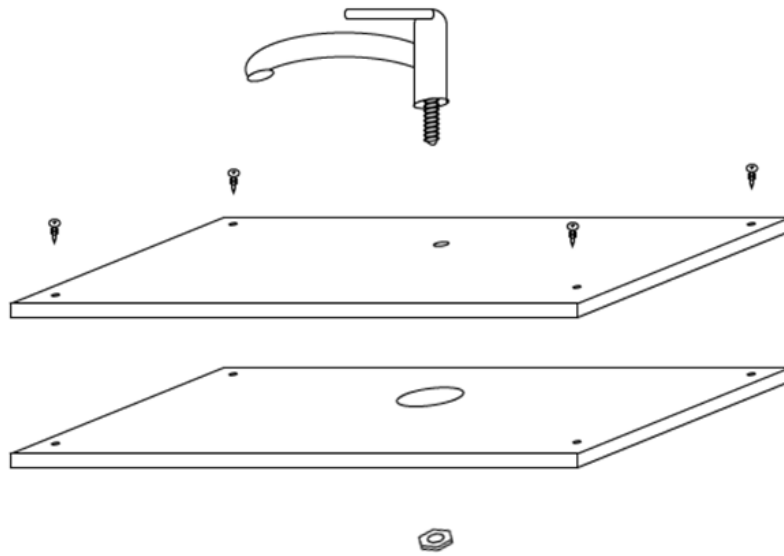


Figure 31: Disassembled frame of the prototype



Figure 31: Example Clamp that can be used to secure the frame to a table,  
From <http://www.bessey-ser.fr/outils-serrage/presses/presses-en-c/presse-en-c-ser-forgee-prise-de-masse-743/743-80/>

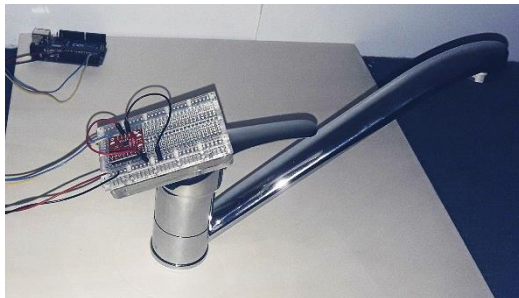
### 6.1.3 Sensor Attachment

The sensors are attached to a breadboard for the prototype as this made it easier to make quick adjustments with the sensors and the wiring.

For initial tests during the development, the breadboard was attached to the faucet using regular tape. During these tests, it was noted that it was important that the breadboard was firmly secured; as the tape was not strong enough to hold the breadboard in place while the faucet handle was moved, the sensors would also pick up on unwanted movements of the breadboard. Additionally, the breadboard had to be secured in a manner that it would not impact the movement of the faucet handle; if the tape was placed to close the bottom of the head of the faucet, it would increase the resistance in the movement.

Initial ideas to resolve these problems involved gluing pieces to the head of the faucet as extension pieces going towards the back, the breadboard could then be placed on top of that piece which would ensure stable sensor readings without limiting the movements of faucet handle. However, as the head of the faucet has a rounded shape, and the surface of the faucet is too slippery, gluing the breadboard on the faucet would be very difficult.

Instead, it was decided to drill a hole through the top of the head of the faucet and attach the sensors attachment piece with a screw and a nut. This would increase the stability of the sensor attachment piece while the user is operating the faucet handle. Using double-sided tape, the sensor attachment was glued on a plastic plate that had the size of the breadboard and was deep enough to have the head of the screw sunken into the plastic plate. Attaching the plastic plate to the faucet head seemed to be stable, however when a sensor had to be switched on the breadboard the plastic plate came loose. After switching the screw out for a bigger one (in diameter), the attachment has been stable, even after changing sensors. The plastic plate was doubled to fit the new screw head size.



*Figure 32: Sensor attachment setup on the faucet*



*Figure 33: Side view of the sensor attachment piece on the faucet*

## 6.2 Hardware & Software

### 6.2.1 Electronic Hardware

Arduino Uno<sup>38</sup> was used to connect the sensors. The final fritzing schematic with the motion sensor is shown in figure x. The schematics for both the sensor setups that were tested can be found in appendix B.

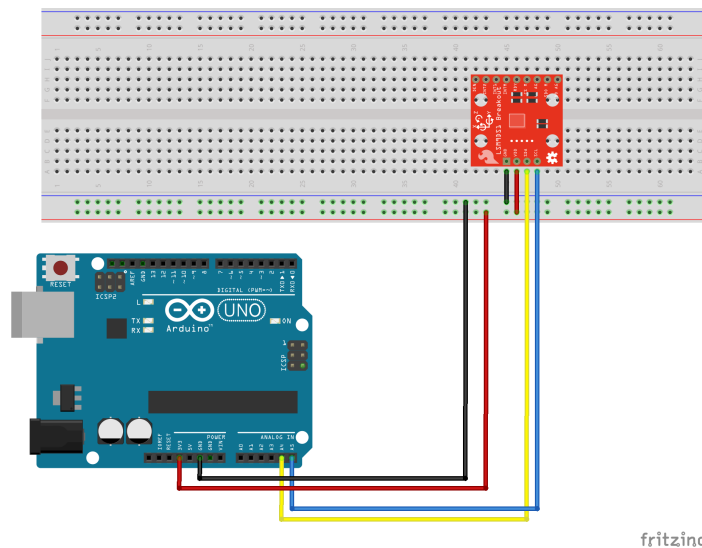


Figure 34: Fritzing schematic of LSM9DS1 motion sensor and Arduino Uno

### 6.2.2 Software

As the Arduino UNO is chosen as the hardware component, the coding for the Arduino UNO was done in Arduino C.

It was chosen to use Unity<sup>39</sup> (Unity 2017.3) as the game development platform as it is a widely used gaming engine and has an extensive database of available tutorials.

## 6.3 Sensors

Sharp [46] distance sensors were considered as a possibility to measure the faucet movements. However, from previous experience it was already clear that these sensors needed a good filter to get rid of the spikes that the sensor produces. Additionally, if this type of sensor would be used to measure the horizontal movement, a monochrome surface would be needed to reflect the IRED on.

Two versions of the distance sensor were considered: the GP2Y0A21YK0F with a range of 10 to 80 cm and the GP2Y0A41SK0F with a range of 4 to 30 cm. The reason that these two were chosen is because while the total range of the GP2Y0A21YK0F is bigger, the 10 cm minimum distance would cause the size of the prototype to be a minimum of 10 cm and measuring distance longer as well. If it turned out that the smaller sensor would have enough measuring distance, the preference would go out to the smaller sensor.

It should also be mentioned that only one distance sensor could be used. Using multiple distance sensors could lead to erroneous readings due to overlapping light emissions. As a precaution, no other light emitting object will be used if a distance sensor is chosen for the prototype.

Product code	GP2Y0A21YK0F
Company	Sharp
Measuring principle	Distance measuring unit using PSD, IRED and signal processing unit
Range	10 to 80 cm
Limitations	Needs monochrome surface to reflect IRED on, direct light will impact readings

Product code	GP2Y0A41SK0F
Company	Sharp
Measuring principle	Distance measuring unit using PSD, IRED and signal processing unit
Range	4 to 30 cm
Limitations	Needs monochrome surface to reflect IRED on, direct light will impact readings

The other sensor that was considered was the accelerometer. Such sensors are useful for measuring the vertical movement of the faucet.

Product code	MMA7361
Company	SparkFun
Measuring principle	Triple Axis Accelerometer
Range	$\pm 1.5g$ and $\pm 6g$ measurement ranges
Limitations	

The LSM9DS1 motion-sensor might be capable of sensing both the horizontal and vertical movement of the faucet, however as we had not worked with this sensor before, it would be hard to make a clear judgement.

Product code	LSM9DS1
Company	SparkFun
Measuring principle	Motion-sensing using 3-axis accelerometer, 3-axis gyroscope, and 3-axis magnetometer
Range	Accelerometer: $\pm 2, 4, 8, 16 g$ Gyroscope: $\pm 245, 500, 2000 \text{ }^\circ/s$ Magnetometer: $\pm 4, 8, 12, 16 \text{ gauss}$
Limitations	

### 6.3.1 Sensor movement compatibility

It was first tested whether the sensors were compatible with the detection of the intended movement. At this stage, the faucet was not available for testing yet. The tests were performed by mimicking the movements of a faucet handle.

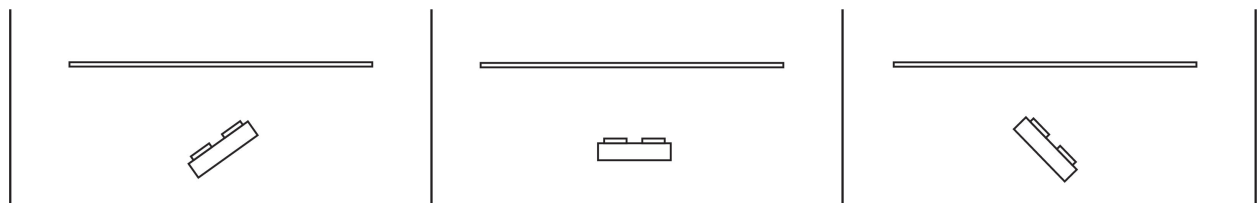
There were two different sensor setups that were considered for the prototype. The first sensor setup consists of the MMA7361 accelerometer for the vertical movements and the GP2Y0A21YK0F or the GP2Y0A41SK0F distance sensor for the horizontal movements. The distance sensors were

separately tested in the first sensor setup to see which range would deliver better measurements. The second sensor setup consists of using the LSM9DS1 motion-sensor for both the vertical movements and the horizontal movements.

### First Sensor Setup

The accelerometer in the first sensor setup was tested to see whether the sensor could measure the full range of the vertical movement. The sensor was attached to a breadboard, the vertical movements were then mimicked with the breadboard to test whether the sensor could register the movement. It was also tested whether smaller movements could be registered as well. Results from this test showed that the sensor could measure the full range of the movement and could register the smaller movements as well.

A comparison test was performed between the long-range and the short-range distance sensor to see which one would have the most accurate readings. It became clear from the test that the long-range distance sensor would be more appropriate for the intended range as the short-range distance sensor was not able to detect the movements on the full range as well as the long-range distance sensor. Since the accelerometer was used to measure the vertical movement, another sensor was needed to measure the horizontal movements. The theory was that the distance sensor could be used for the horizontal movements if the sensor was placed on the head of the faucet facing towards the back with some sort of wall-like structure behind the faucet to use as reflective surface as can be seen in figure 35.



*Figure 35, Top View Distance sensor movements with respect to the wall structure.*

A test was performed to test this theory and to see whether the sensor could measure the full range of the horizontal movement. The sensor was attached to a breadboard, the breadboard was then held vertical so the sensor would be parallel with the wall structure. Cardboard was used to mimic the wall while the horizontal movements were mimicked with the breadboard. The results of the test showed that the sensor could measure the movement and could register smaller movements as well, but had some issues that needed to be adjusted.

One issue that came forward is that the values of the sensor on the outer-left and the outer-right were the same; the range from left to centre and right to centre were identical with no way of differentiating whether a single value was from the left side or the right side. A potential solution was to change the placement of the wall; instead of placing the wall parallel behind the faucet, it would be placed diagonally with the distance of the wall being the shortest at the outer-left position of the sensor and furthest at the outer-right position of the sensor as can be seen in figure 36.

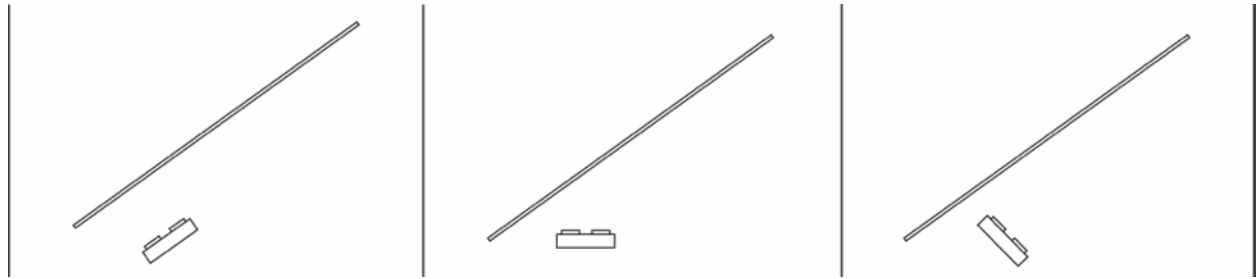


Figure 36, Top View Distance sensor movements with respect to the new placement of wall structure.

The theory behind this is that the value measured on the outer-left would be the smallest while the value on the outer-right would be the biggest; the values would be on a scale of outer-left to outer-right which would make it possible to differentiate what position a single value would be representing. However, it became apparent that this setup would not work; the angle that would be needed to ensure that the outer-left would have the smallest value and the outer-right the biggest value would mean that the wall had to be very long in length for the sensor to be able to reach the wall at the outer-right position. Instead, the shape of the wall was changed to a curve; the curve could be adjusted precisely so the outer-left would be the smallest while the value on the outer-right would be the biggest without needing as much length.

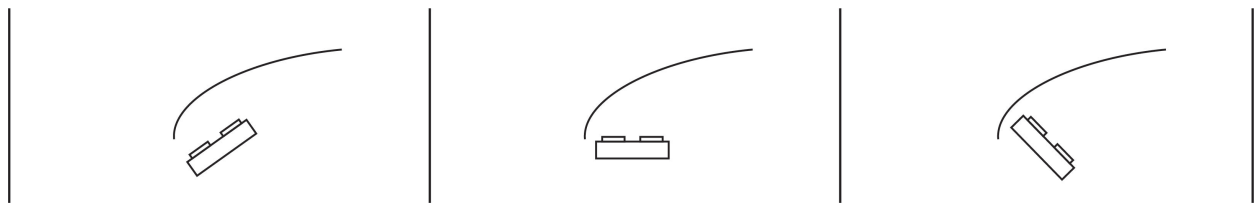


Figure 37, Top View Distance sensor movements with respect to the curved wall structure.

Another issue that became apparent from the test is that the sensor values showed irregularities that caused spikes in the data. To remove these irregularities, several filters were tested to see if the data could become smoother. The filters that were used are discussed in more detail in section 5.3.2. While the filters reduced the amount of irregularities in the readings, the readings still contained a lot of noise.

## Second Sensor Setup

For the second sensor setup, the motion sensor was tested for both the vertical as well as the horizontal movements. This sensor consists of an accelerometer, magnetometer and a gyroscope. As the motion sensor consists of multiple sensors, it was first tested which sensors were suitable for which measurements. From the test, it was clear that the gyroscope readings were too irregular to implement in the system, while the accelerometer and the magnetometer had more stable readings. The accelerometer of the motion sensor was chosen for the vertical movements, while the magnetometer was chosen for the horizontal movements.

A test was performed to see whether these sensors had enough sensitivity and range to measure the intended movements. The sensor was attached to a breadboard, the vertical movements were then mimicked with the breadboard to test whether the sensor could register the movement. This sensor setup was capable of measuring both the vertical as the horizontal movements with more stable readings than the first sensor setup.

## Sensor Selection

The Sparkfun LSM9DS1 motion sensor was selected for the prototype; using the magnetometer for the horizontal movements of the faucet handle, and the accelerometer for the vertical movements of the handle.

### 6.3.2 Filter

The next step was to make a filter for the data of the sensors to get a smoother reading that could be used to move the player in-game. Different filtering methods are described in this section. The best filtering method was selected by testing the filters on the distance sensor as this sensor showed the most irregularities in the measurements during the movement compatibility test.

#### Averaging

The first filter used a method called "Averaging". The method adds several measurements together, then divides the total by the number of measurements. More noise is reduced when a greater number of measurements are included in the average. The downside is that this method would need more memory as it makes multiple measurements to calculate the average.

The formula of this filter is given below.

$$y_n = \frac{\sum_{m=1}^m x_m}{m}$$

$y_n$  is the new averaged value,  $x_m$  is the new measurement and  $m$  is the number of measurements.

#### Moving average using a buffer

Another method that is similar to averaging is the moving average. A single measurement is done each time and that value is added to a buffer while the oldest value is removed. The average is calculated by adding all the values in the buffer and dividing the total by the amount of values that the buffer contains. Each measurement is related to the previous measurements that causes more continuity in the values. The downside to this method is that the response time will be longer as it must go through the whole buffer each time.

The formula for this filter is given below.

$$y_n = \frac{\sum_{m=1}^m x_{m+(n-1)}}{m}$$

$y_n$  is the new averaged value,  $x_m$  is the new measurement and  $m$  is the number of measurements.

#### Exponential moving average

The exponential moving average filter calculates a new smoothed moving average by using the last smoothed moving average and a new measurement. The amount of smoothing can be controlled by adjusting parameter  $w$ . When this parameter has a high value, there is less smoothing, but the response time would be quicker. When this parameter has a low value, there is more smoothing, but the response time would be slower.

Formula of this filter is given below.

$$y_n = w \times x_n + (1 - w) \times y_{n-1}$$

$y_n$  is the new smoothed value,  $y_{n-1}$  is the last smoothed value,  $x_n$  is a new measurement and  $w$  is the weighting parameter that controls the amount of smoothing.

### **Exponential moving average with sleep function**

This filter is a variation on the exponential moving average filter and is designed by Damien Clarke [45]. This filter uses a sleep function in addition to the regular exponential moving average calculation. Another exponential moving average is used to keep track of the error estimation, if the error estimation is smaller than the threshold, the function sleeps until the threshold has been reached. While the function sleeps, the value of the previous measurement that reached the threshold is outputted. By using a sleep function, the function can show bigger changes in values quicker by ignoring values that don't meet the threshold.

### **Filter selection**

The exponential moving average with sleep function is selected as the filter for the prototype. In comparison to the other filters, the exponential moving average filter with sleep function can smooth data while causing the least amount of lag in data.

## **7. Evaluation**

This section explains the steps that have been taken to evaluate the prototype and the results that came forward. Two types of evaluations were performed: expert evaluations of the system, and technical evaluations of the movement sensing of the system.

### **7.1 Methods of evaluation**

The expert evaluation consisted of two evaluations. The first evaluation was performed in the form of an informal assessment with two experts in the field of physiotherapy. The participation in this assessment was on voluntary basis. The assessment was mainly focused on testing the concept of the system and the user interface.

The second evaluation was performed in the same manner, but with only one expert in the field of physiotherapy. The focus of the second assessment was on testing the adjustments that had been applied based on the first evaluation.

The assessment started with an explanation of what the system does and who it is intended for, followed by stating what kind of information was needed from the experts. The functionalities were explained to the experts while showing these in-game with the system. Afterwards, the experts were asked to play the game once on level "Easy" and "Medium". Lastly, a guided interview was performed to get an idea of how the experts experienced the system and whether they had any remarks or suggestions, the interview questions can be found in the appendix C.

## 7.2 Results First Expert Evaluation

This section contains the results of the first evaluation. The results of the evaluation are divided into four categories to give a better overview of the information; User Interface, Game Mechanics, Statistics for the therapist, and Faucets.

### User Interface

The very first remark came when the system was still being explained: the background music had to be switched off. They explained that having background music while simultaneously having to focus on performing a task would be too distracting for most people who have had a brain injury. On the other hand, the sound effect that can be heard when you pick up a waterdrop in game was received very positively. The sound of the sound effect was nice and clear. Hearing the sound was perceived as positive feedback; giving a clear indicator of when they were doing well. The sound effect that can be heard when you hit an obstacle, which is only available on the “Medium” level, gave very clear feedback of when you were doing something wrong.

The colours in the background had clear contrasts and were well distinguishable. However, the amount of “colour bars” that are displayed in the background had to be reduced to two or three; this would make the background less distracting. Another suggestion was to reduce the background to one colour so all the focus would be put on the task that needs to be performed.

The experts both agreed that the icons of the player, the waterdrop, and the obstacles needed to be bigger to make it easier to track. It was also suggested to increase the size of either the player icon or the waterdrop once the player is within pickup range of the waterdrop. Additionally, the bucket image that was used to display the player on the screen was perceived to not be very intuitive. The suggestion to change the purpose of the bucket by using it as background item instead of player icon was well received; by placing a bigger version of the bucket at the bottom of the screen and let the waterdrops fall into this upon collection it felt more intuitive and fit better with the idea of a faucet. The icon of the obstacle also needed to make it more obvious that it had to be avoided, a suggestion was to make it a fire icon as that is the opposite of water.

The experts suggested to use a more neutral tone instead of “Gameover” when the game ends as it might sound too negative. The results at the end of the screen had too much information; the amount of information could be too overwhelming if it was shown directly after the game ended. Additionally, not all the users would be interested in seeing this information. It was suggested to put this in on a separate screen that the users could open if they wanted to.

### Game Mechanics

It was mentioned that the experts would rather have the game with a time limit over the whole duration of the game with the total score showing the amount of collected waterdrops than having each waterdrop timed. While having a timer on each waterdrop made it more exciting from a game perspective, the experts would rather not have a patient be discouraged by missing waterdrops after having put in a lot of effort because the time was up.

Another aspect to change to make it easier for the patients to use was to increase the pickup range of a waterdrop; patients who are recovering from a brain injury would have a hard time getting the player to the location of the waterdrop with a small pickup range. The experts explained that especially in the beginning stages of the rehabilitation, people who have had a brain

injury have difficulties making controlled small movements. Therefore, it would be better to start off with big movements. One suggestion was to divide the playfield in two, each half of the playfield would represent one waterdrop.

### Potential Statistics for the therapist

This section covers the statistical data from the game that the experts indicated to have potential use in their treatment and how they would like to see this data. Data showing whether the patient had more difficulties with moving from right-to-left or vice versa was viewed as useful. The experts would also like to see whether it was easier for the patients to move in the horizontal plane or the vertical plane. The amount of time that the patient has played the game and the amount of waterdrops they have collected during this time is the most basic information that the experts would want to see. If the patient practiced at home with different game settings, the experts would like to be able to see what kind of settings they had used during their practice and how the patients performed.

The experts stated that they would prefer the data to be shown in the form of a graph over time. Having the data displayed in the form of a graph over time is easy to read and would give a clear overview of the performance of the patients.

### Faucets

The experts appreciated that the position of the faucet handle was measured without needing specific finger placements; this makes it possible for people to operate the faucet who have limited hand function. It was even possible for someone to lean their wrist on the spout of the faucet while manoeuvring the faucet handle which lowered the strain that was put on their wrist.

Additionally, the experts stated that patients who are recovering in a nursing home setting usually have a thermostat-controlled tap. To use this type of faucet, training in grip strength is needed to make the patient able to rotate the handle. Patients who are recovering at home would have different kinds of faucets. The experts stated that it would be ideal if the patients could practice with the faucet that they have in their own home as this would ensure that their learned skills would be applicable at home when they need it. The experts were very enthusiastic about the idea of a sensor attachment piece that could be adjusted to different faucets.

## 7.3 Adjustments First Evaluation

This section discusses the adjustments that were made based on the feedback of the first expert evaluation.

### User Interface

The background music was removed from both the game as well as the options screen as this was pointed out as undesirable in the first evaluation.



Figure 38: Final playfield

The background of the playfield was changed from seven colours to two colours. Using a two-coloured background instead of using a one-

coloured background is based on implementing the temperature related representation that was also intended for the original background. The choice to use the two colours, red and blue, is to make the background represent the two temperature settings on the faucet: warm and cold.

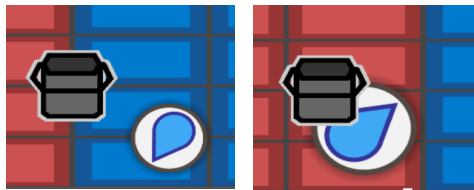


Figure 39: Waterdrop increases in size when the player is within pickup distance

The icons of the player, waterdrops and obstacles were increased by 50% to increase the visibility of each icon. The waterdrops increased by an additional 50% if the player was close enough to the location of the waterdrop to pick

it up, the waterdrop lost the additional 50% of its size if the player left the pickup range. Additionally, gravity was activated for a waterdrop if the player picked it up, this caused the waterdrops to fall for a few seconds before it disappeared. Making the waterdrops fall adds to the resemblance of water dripping from the faucet.

The player icon of the bucket received a light grey background to add contrast between the bucket and the background. The bucket was not placed under the background image instead of being as the player icon as it was decided that doing so might cause there to be too many visual elements which could potentially be too distracting to a patient.

The obstacles received a new icon with spikes to make it clearer that users should not touch the object. A fire icon was put in the middle of the obstacle to represent the opposite of water to more intuitively show users that it should not be picked up as is suggested in the evaluation. A light grey background was given to the obstacle icon to add contrast between the obstacle and the background.



Figure 40: Original EndScreen displayed on the top image, Final EndScreens on the bottom images

The title of the game ending screen was changed to “Game End” instead of “Gameover” to make the screen feel more neutral. It was decided to separate the data that was shown on the game ending screen and to only show additional data if the user chose to view these as the experts indicated in the evaluation that there was too much data. The ending screen showed the score, which was the amount of collected waterdrops, and the total

playtime. As the average time and the fastest time became optional information, this information was removed from the play screen as well. The total elapsed time was displayed on the screen instead. The total elapsed time would be displayed on pickup of the waterdrop instead of continuously updating the time as it could be too distracting for the user to see the continuous change of numbers.

### **Game Mechanics**

A time limit was put on the entire game as was suggested in the evaluation. The time limit could be adjusted in the option screen with a range of one-ten minutes. The minimum of one minute was selected as it was considered that this would be enough to give the users some time to make several attempts to get at least one waterdrop, without ending the game while the user is still in their first attempt.

The time limit of each waterdrop was removed, the idea of having a waterdrop disappear while a patient is trying hard to reach it was not desirable. The number of waterdrops was set to 999 as it would be unlikely that this number would be reached during the evaluation. In the unlikely case of reaching the maximum number of waterdrops, the game would end prematurely with a shorter total time to prevent errors.

The point system was adjusted for the collected waterdrops to award different amount of points based on the level of difficulty instead of being time related. It was mentioned in the evaluation that the experts cared more about their patients collecting the waterdrops, how fast the patients collected the waterdrops would be extra information. The decision to no longer make the points affected by time is to give the users less time-related performance pressure, and to represent the value of effort with each collected waterdrop. One point would be awarded for each collected waterdrop on Easy mode and two points for each collected waterdrop on Medium mode as there was an increased difficulty of not hitting the obstacles.

The fading of the waterdrops was changed to not affect the score, but merely serve as a signal for the user that they were not within the target time to collect the waterdrop. The thought behind this was to add a bit of a challenge element of making them try to reach each waterdrop within the target time, but to not discourage them if they are not capable of doing that. The fading was optional, it could be turned off in the options menu if the users found it undesirable.

Hitting the obstacles no longer affected the score, it only caused a sound effect to be played. It was theorized that having a sound effect could possibly be annoying enough on its own to discourage the user of hitting the obstacles.

The pickup range was increased along with the waterdrop object; an increase of 50%. As both the player object and the waterdrop object were increased in size, it was speculated that it would be easier to get the player in pickup range in comparison to the previous version of the prototype, while still needing some precision in the movements to make it more challenging for the users.

### **Potential Statistics for the therapist**

Information that could be useful to the therapist was taken from the feedback of the evaluation; these consisted of the total time of the waterdrops on the playfield that were placed left of the player, the total time of the waterdrops on the playfield that were placed right of the player, and

keeping track of the number of obstacles that were hit on each side of the player. This information was not yet functioning in the prototype, but it was displayed on the details screen after the ending screen to show how it would look like.

The time of the waterdrops on the playfield was tracked for each side to show at the end of the game which side was the most difficult for the user. A higher time on the left side would mean that the user has more difficulties moving to the left side than the right side.

The number of obstacles that were hit on each side of the player is tracked to determine on which side the user has more difficulties with precise movements. As the obstacles are placed further away from the player than the waterdrops, hitting more obstacles on a certain side could show that precise movements were more difficult for the user on to that side.

It was suggested that it might be better to limit the information for the user on the ending screen to only the total time and the total score. The information of time and obstacles on each side could be displayed on the details screen, but it would be preferred to show these in a bar chart so the users could instantly see which side was higher to point out the side with the most difficulties. The other information, average time and fastest time to reach a waterdrop, could be shown to the therapist, but was deemed to not likely be relevant to the user.

## **7.4 Results Second Expert Evaluation**

A second evaluation was performed with one expert to get feedback on the adjustments. The results from this evaluation are discussed in this section.

### **User Interface**

Reducing the background to two colours was less distracting. The representation of temperature by the chosen two colours was a nice link to the faucet. It would be preferred if the “bars” that were used in the background could be used in the game mechanics; using the “bars” to indicate what the pickup range of the waterdrops are for example.

Having increased icons made it clearer to track the icons, however it was preferred to make these even bigger. The falling effect of the waterdrops was a nice touch. There was a clearer contrast between the bucket icon and the background because of the light grey background of the player icon. The obstacle icons made it clear that it should not be touched.

### **Game Mechanics**

Upon expressing concerns about reaching the maximum amount of waterdrops during the game, it was suggested to place the number of waterdrops in the options screen as well so therapists could adjust this, or to make this a very high number to ensure that users would not reach this during the gameplay.

The fact that the time no longer affected the points that were collected was a positive point. Changing the awarded points to one per collected waterdrop on the Medium level as well could be a fairer point distribution, the highscores would then be divided into Easy and Medium to differentiate between difficulties.

The increase of pickup range made it easier to get the player into pickup range, however, it was deemed too difficult for patients in the beginning stages of rehabilitation of brain injury. This current setup could be used for the patients in the more advanced stages of rehabilitation of brain injury and had more control of their fine motor skills to make the precise movements that were needed for this setup.

It was suggested to limit the range of the faucet handle so a small movement was enough to move the player across the playfield in the easier modes. It was also suggested to make the range of the faucet handle an adjustable option in the options screen so a therapist could manually adjust the range.

## **7.5 Results Technical evaluation**

The sensors had irregularities in the sensor values causing spikes in the data. The distance sensors had the most unstable readings in comparison to the accelerometer and the motion sensor. Filter techniques were applied on the readings of the distance sensor to determine which filter resulted in the most stable and accurate readings. While all of the filter techniques were capable of removing the spikes in the data, they differed in the ability to output a smooth transition of the values and varying degrees of delay between making the movement and showing the corresponding reading. Using the averaging filter on the readings resulted in values “jumping” from one to the other with little continuity between the values. The moving average using a buffer filter improved the continuity between the values in comparison to the averaging filter, but still had the “jumping” between the values. While using the exponential moving average filter resulted in the smoothest transitioning of the values, it had a clear delay between the movement and the readings. The exponential moving average with sleep function filter reduced this delay considerably, but had a slightly less smooth transitioning of the values that was barely noticeable. As the delay formed a bigger hindrance for the purpose of the prototype, the exponential moving average with sleep function filter was deemed as the more appropriate choice of filter. The exponential moving average with sleep function filter was selected as the filter as applying this filter on the readings resulted in the smoothest possible transition of the values with the least amount of delay between making a movement and showing the corresponding reading.

The distance sensor contained more irregularities in the data and had a worse performance in comparison to the motion sensor. Due to this result, it was decided to disregard the first sensor setup that consisted of the distance sensor and the accelerometer, and to use the second sensor setup that consisted of only the motion sensor in the prototype.

After applying the exponential moving average with sleep function filter on the motion sensor, it became clear that there were still irregularities present in the data that could not be filtered. The irregularities that remained occurred periodically in specific steps. It was determined that the irregularities in the data were caused by both random noise in the sensors as well as digitizing errors in the sensors. The random noise was removed by the filter, however the digitizing error in the sensors could not be removed by the filter.

After selecting a filter, it was discovered that the filtered data of both the magnetometer and the accelerometer of the outer left and outer right side showed a slight difference. One side consistently

caused a higher reading than the other side, which was visible in the game as the player icon would not be able to hit the bottom of the playfield on that side. The difference also caused the player icon to move slightly to the left side in addition to moving downwards when the faucet handle was moved straight down. It became clear that the side with the higher reading was positioned slightly higher. It was unclear whether the difference in height was caused by the modification of the faucet head for the sensor attachment piece, construction of the frame, or unlevelled surface the prototype was placed on. However, it was clear that the difference in height affected the magnetometer readings, although it was not as significant as the changes in the accelerometer readings.

## 8. Conclusion

### 8.1 Conclusion & Discussion

A task-specific training for fine motor skills in the hands was developed in this project by combining a physical *single handle* faucet and a digital training with game elements in the form of a game. A physical faucet handle is used as the controller of the game so the user learns movement skills that are directly applicable to an actual faucet from a normal living environment. A *single handle* faucet allows stroke patients of varying stages of rehabilitation to operate the faucet as moving the faucet handle does not specifically require grip strength, which especially patients in the beginning stages of rehabilitation lack.

Game elements were implemented in a digital training that was built around showing the current position of the faucet handle and showing the target position the faucet handle should move to. From the expert evaluation it became clear that patients should only see minimal information about their progress as too much information could be overwhelming. It became clear that smaller movements should be used in the training that could be built up to larger movements in later stages of the game as these would be difficult enough especially for patients in the beginning stages of the rehabilitation. A simpler visualization of the background would complement the decrease of movement difficulty and reduce the possibility of overwhelming the user with the visual elements.

A base for statistical information was established with the information that came forward from the expert evaluations. By tracking the time it takes to reach a target position from the previous position, it can be established which side is the most difficult for the user and thus requires more training on that side. In a higher difficulty where obstacles are added, it can also be tracked whether the user moves past the target position and therefore has problems with precision rather than lack of strength to move the faucet handle. The experts have indicated that they would like to see this information in the form of a graph so they can easily see the progress that a patient has made and whether the problem areas have been improved.

Several sensor techniques were tested to see which one would be appropriate to monitor training progress. It was determined that the readings of the Sharp GP2Y0A21YK0F and GP2Y0A41SK0F distance sensors were not stable enough to use in the prototype even after applying filters to reduce the irregularities in the readings. Subsequently, the Sparkfun MMA7361 accelerometer was eliminated from the selection as this sensor had to be used with one of the distance sensors to read the faucet handle movements. The Sparkfun LSM9DS1 motion-sensor was selected as the sensor to

monitor the faucet handle movements. The magnetometer of the motion-sensor was used to measure the horizontal movements and the accelerometer in the motion-sensor was used to measure the vertical movements.

While the physical prototype that was created with this sensor technique was able to show what the intention of the training method was, there were inaccuracies in the readings that could partially be resolved by using an exponential moving average with sleeping function signal filter. The irregularities in the data that were caused by both random noise in the sensors were removed by the filter, however the digitizing errors in the sensors could not be removed by the filter.

Another issue that came forward after filtering the readings was that there was a height difference between the left side and the right side of the faucet handle that caused higher readings on the side that was positioned slightly higher. While it was unclear what the exact cause of this difference in height was, the problem areas were narrowed down to the faucet head, the triplex plates of the frame and the surface where the prototype was placed on. The difference in height affected the magnetometer readings, with more significant changes in the accelerometer readings.

## **8.2. Recommendations future work**

Adjustments need to be made to get rid of the problems that occurred with the sensor before the prototype can be used with actual patients. One of the options to make the sensor more accurate is to calibrate the sensor at the start of each training session to off-set the height difference that can occur due to either the prototype's frame or the surface it is placed on. Choosing a motion sensor with higher precision could reduce the digitizing error that occurred with the current motion sensor. Another option is to use a different sensor technique for the faucet handle movement.

Based on the expert evaluations, there are several functions that would be interesting for future implementations. Research can be done on how the statistical data should be displayed for the therapists. Determining what scales should be used to properly display the information and how detailed the information should be would lead to the information giving better insight for the therapists in what adjustments should be made in the training.

The experts would like to be able to use different types of faucets in future versions of the prototype and preferably be able to attach sensor attachments to the faucets that the patients have at home. Faucets are interchangeable on the frame as the current faucet can be unbolted from the frame to bolt a new faucet on it. The problem that needs to be researched is what sensor techniques would fit the operating techniques of the other types of faucets as the current setup of the sensor technique is not appropriate for rotational faucet operations. Another aspect that would require research is how the sensor attachment could be applied to faucets that people have at home. The current sensor attachment is bolted into the head of the faucet as the surface of the faucet was too slippery to simply attach it on the surface. Additionally, bolting the attachment piece ensured that the sensor could not move unintentionally. Attaching a sensor attachment without bolting it to the faucet would require research into methods that ensure that the sensor is placed securely while also being removable.

Research into implementing correct finger and hand placements could be done to improve the training. The prototype that is developed in this project is not capable of sensing finger or hand placements on the faucet handle as it is focused on making the user *able* to operate the faucet handle rather than *how* they operate it. Adding this function could improve the training as it would be able to correct hand positions of the patients to ensure that they learn the correct positions from the start of the training instead of adjusting the position later in the training. Research can be done on sensors that can be placed on the faucet handle itself to sense the placements of the fingers or that can sense the fingers regardless of whether they touch the faucet handle. Sensing gloves have been discussed in the feasibility of sensing methods, and while at this stage they might not have been deemed appropriate for the prototype developed in this project, they are worth considering in the future once they are more easily adjustable to different hand sizes.

## 9. Appendix

### A. Ideation

#### Tablet screen (portable) placed under the faucet -> viewing sink area

Name	Aquarium game
Objectives	-each fish tank needs to be filled and re-filled up to a certain level at the right temperature (just like with real fish, too warm and too cold are both not ok)
Visual Feedback	-fish grow bigger in size -fish become larger in numbers -fish become more active when the water gets filled to the adequate level and gets refreshed often  If fish are in a cartoonlike style: -emotions on fish show how you are doing (happy, angry, sad etc) -colour of fish corresponds to water temperature (red for too warm, blue for too cold - > in ice cube for more comical visual indication)  Direct feedback possible as fish can react immediately on changes in the water
Unlockable	fish breeds (colours and species) aquarium styles aquarium decorations number of fish allowed in the tank (bigger tank size)
Training aspect	+Precision temperature  Optional: Time restricted (based on the water reaching the desired level)

Name	Pond game
Objectives	-fill the pond with water -avoid hitting the animals in the pond with water by turning faucet off at the right moment
Visual Feedback	-animals grow bigger in size -animals become larger in numbers -animals become more active when the water gets filled to the adequate level and the least amount of animals are hit (preferably none)
Unlockable	Pond animals Pond decorations (plants) number of animals allowed in the pond
Training aspect	+Reaction speed +Speed repetition switching on and off of faucet  -No precision

Name	Puppy bathing game
Objectives	-get the water to the right temperature before the sinks flows over
Visual Feedback	-more soap bubbles -puppy becomes cleaner -puppy becomes happier (wagging of tail etc, cheerful barking, licking screen)
Unlockable	Puppy breed Puppy accessories (collar) Soap colours

Name	Quick flush
Objectives	-turn up the flow of the faucet (attached to a water gun in the game) at the right times to shoot the dirt off your sink
Visual Feedback	-water gun lights up every time it hits a spot -sink becomes cleaner
Unlockable	water gun types sink colours/materials

**(Tablet) screen placed behind the faucet->viewing wall area/kitchen area**

Name	Gardening game
Objectives	giving water to the plants by filling up water buckets of different sizes depending on flowers
Visual Feedback	-flowers bloom depending on how close the water level is and how often it gets watered (tracks both accuracy and motivation (seen in frequency))
Unlockable	flower types flower colours colours/styles of pots bucket styles/colours

Name	Babysitting game
Objectives	You need to take care of a kid, the kid will request things such as water, tea, lemonade or maybe some coffee for their parents when they get back, fill up whole sink so the kid can play with toy boats (the whole idea is to give the user the idea that they themselves are in control and are doing this to help someone else, to help them feel like someone can depend on them again)
Visual Feedback	if done correctly: kid will make drawings and give it to them, kid compliments them ("it's so much fun being around you!", "Thanks! You're the best!"), kid will make little artistic crafts for them (something out of clay or paper and glue)
Unlockable	different kid different parent different drawing/craft styles different houses

Name	Farm game
Objectives	Automatic watering system is down at the farm, you need to help water the crops and give water to the animals by filling buckets of water
Visual Feedback	if done correctly: the specified farm animal will pass by, either alone or with their babies, farmer or farmer's wife comes by with food dishes that can be prepared with the farm's harvest (milk, cheese, pies, bread)
Unlockable	different farmhouse animals crops food dishes

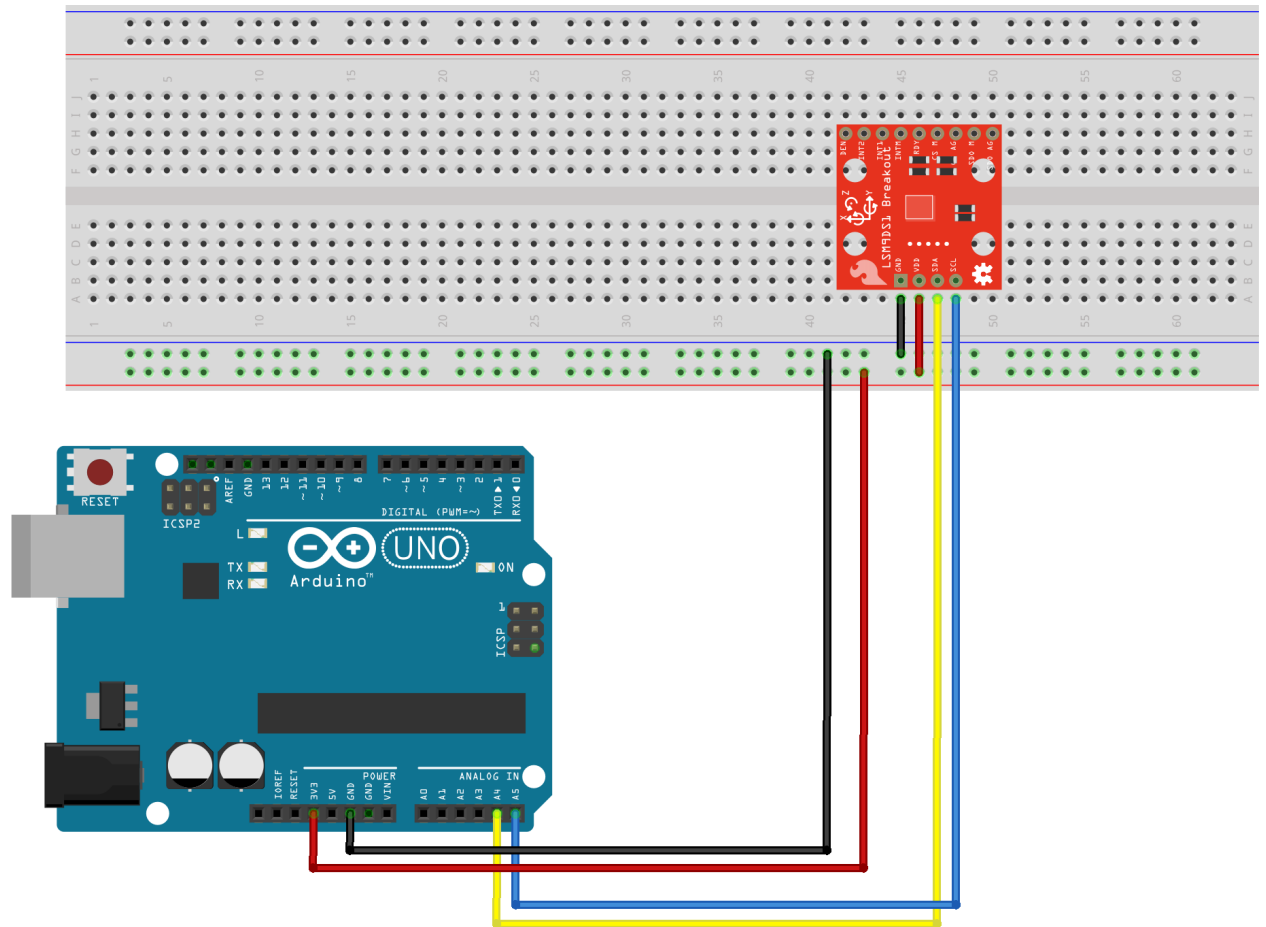
Name	Zoo game
Objectives	You need to help the zookeeper by filling food bowls with water for the animals, you can choose the animal habitats (certain animals need more water and some are quite picky about the temperature of their water!)
Visual Feedback	if done correctly: animals are cheerful and more active, you will see more animals in the habitat, they will do funny poses
Unlockable	special habitats special animal poses
Name	Restaurant game
Objectives	Chaos at this Italian restaurant as several parties are planned on the same day, you have to help them out by filling big pots with water so they can boil the pasta on time  water must be filled to a certain point, the cooking time will be shorter if you use hot(ter) water instead of cold
Visual Feedback	if done correctly: you will see the dishes that they make, restaurant owner will come by and thank you with special dishes, you can see the guests complimenting you
Unlockable	restaurant décor special guests party themes

Name	Fire-fighter game
Objectives	Fire-fighting training!: Fire hydrants are not working and their truck is not functional either, you need to run through buildings and open as many faucets as you can to help collect water to stop the fire
Visual Feedback	if done correctly: you will see the fire going out and the people in the building that are saved come out and thank you
Unlockable	change buildings change environment change firefighting clothing

Name	Animal rescue game
Objectives	A forest fire has caused many animals to be homeless, without food and drinking sources. You and your friend decide to help by bringing water and food to these animals.  Your friend oversees bringing food, you are in charge of the water; fill enough buckets so the animals can drink. (might also be combined with washing the animals and giving the trees etc water too)
Visual Feedback	if done correctly: animal families happily eating and drinking together, special family moments (grooming and other interactions)
Unlockable	different friend special animals

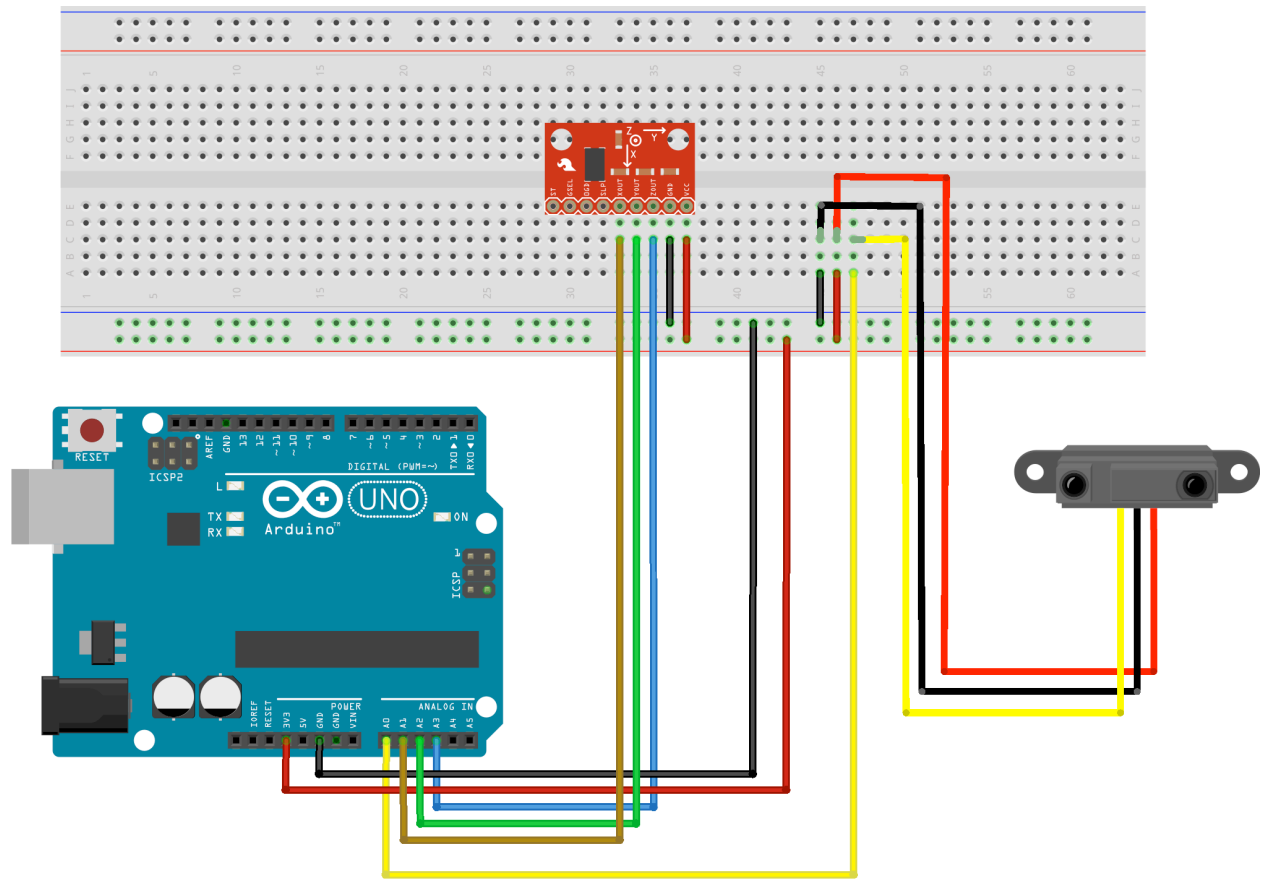
## B. Schematics

### Connecting Sparkfun LSM9DS1 Breakout to Arduino UNO



fritzing

## Connecting Sharp distance sensor and Sparkfun MMA7361 to Arduino UNO



fritzing

## C. Interview Questions

1. Welke aspecten moeten voorkomen in een oefening?
2.
  - a. Wat voor soort oefeningen zouden fysiek en mentaal passen bij de targetgroep?
  - b. Zou leeftijdscategorie effect hebben op hoe zij de oefening ervaren?
3.
  - a. Hoe uitdagend moet het zijn voor de doelgroep?
  - b. Hoe zou het spel uitdagender/ makkelijker gemaakt kunnen worden? (afhankelijk van antwoord op 3.a)
4.
  - a. Hoelang en hoe vaak zullen de patienten de oefening kunnen doen?
  - b. Wat zijn de redenen voor deze limieten?
5. Zouden patienten dit leuk vinden (met zicht op hun eigen patienten)
6. Is het spel visueel aantrekkelijk of storend
7. Zou het gebruik van meerdere elementen tegelijk te afleidend zijn?
8. Wat voor soort elementen zouden beter zijn (druk, rustig, kleurrijk, hoog tempo muziek, laag tempo muziek)
9. Hoe storend zijn de gamemechanics?
10. Zou het spel beter taakgericht of fungericht moeten zijn of juist afwisselend?
11.
  - a. Welke elementen zijn handig voor therapeuten? (wat voor soort feedback + welke records van gamegegevens)
  - b. Liever feedback van alleen deze sessie of liever feedback van een langere periode?
  - c. Hoeveel data zouden jullie willen en in welke vorm (grafiek, cijfers, visualisatie)

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