# GROOVE STUDIO

exploring
action observation therapy
in virtual worlds

by Nick Wellwood

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# "The Implementation of Action Observation Therapy in Virtual Worlds"

# Abstract

Upper limb rehabilitation after stroke is vital to the recovery of a patient's range of motion, dexterity and strength (Jauch et al, 2010, p. 824). Rehabilitative practises are diverse and met with varying levels of success (Brewer et al, 2012, p. 11). This research is concerned with action observation therapy and its potential for neural reorganization through consistent repetition of prescribed physiotherapy exercises.

Action observation utilizes mirror neurons to stimulate neural strengthening and recovery (Ertelt et al, 2007, p. 172). The observation of an expert completion of an action by either the patient, a representation of the patient or someone else fires the corresponding mirror neuron (Fogassi et al, 2005, p. 662). Mirror neurons' ability to be fired under multiple conditions allow a patient who is unable to complete an action, in this case a physiotherapy exercise, to still receive the neural benefit just by observing the action (Ertelt et al, 2007, p. 165).

In collaboration with sensory devices in a virtual medium, action observation will be used to create a dynamic and engaging simulation with the intent of providing a physiotherapy experience that progresses in difficulty. Incremental difficulty will ensure patients are being pushed to their limits in a controlled and monitored environment (IJsselsteijn, 2007, p. 27).

Neural reorganization requires a large number of repetitions of exercises over extended periods of time creating rehabilitative experiences that have traditionally been tedious and mundane (Merians et al, 2002, p. 898; O'Dell, Lin & Harrison, 2009, p. 55). Gamification of traditional methods can engage the patient over an extended period of time By masking the repetitive nature of the exercises with a fun experience, patients can receive the full benefit of the treatment while performing enjoyable tasks (Muzzaffa et al, 2013, p. 69).

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# Introduction

Approximately 15 million cases of stroke are recorded to the world population annually with an approximate survival rate of 60% (World Health Organization, 2014). Of those survivors many are left with disabilities ranging in severity that impact their daily lives. Post stroke rehabilitation is imperative to the recovery process aiding in both the mental restabilization of the person's life as well as regaining functional use of motor control, range of motion and dexterity (Young & Forster, 2007, p. 86).

Mirror therapy primarily used in the treatment of phantom limb pain (Ramachandran, Rogers-Ramachandran, 1995, p. 489) has been used in the treatment of stroke due to the overlap in targeted neural rehabilitation (Muzzaffa et al, 2013, p. 64). By integrating existing mirror therapy techniques with modern technology I hope to add another layer of user engagement and make the process of visualizing the affected limb neurologically stronger.

Action observation is a young field of medical research that has not yet been fully explored, its potential in a rehabilitation environment even less so. The hypothetical human mirror neuron system presents an exciting opportunity to create rehabilitative simulations that a user can receive neurological and physical benefit from even if they lack functional use of their upper extremities (Garrison, Winstein & Aziz-Zadeh, 2010, p. 404).

Mirror and action observation therapy, while different in their physical applications, do overlap in their use of neurological psychology. Mirror Visual Feedback (MVF) and action observation are both thought to activate the mirror neuron system (Deconinck, 2014, p. 351). Given the overlap in these two therapies, I can design an application that can implement both therapies through minor adjustments to the physical design output.

Evolving technology presents an opportunity to explore the potential of these emerging rehabilitative techniques in a new medium. A virtual simulation can provide diverse activities and environments to engage the user (Muzzaffa et al, 2013, p. 69) while also giving a modern platform for mirror and action observation therapy to be showcased on and further explored.



# RQ

- How can emerging rehabilitative methods be combined with technology to aid in the recovery of stroke survivors?
- How can mirror therapy be combined with virtual reality to provide a rehabilitative experience for stroke survivors?
- How can action observation therapy be combined with sensory devices to provide a rehabilitative experience for stroke survivors?

This project aims to gain further insight into creative techniques for providing rehabilitative experiences for users suffering from a stroke induced injury. I propose to explore the use of virtual simulations in collaboration with sensory and virtual reality devices as alternative forms of mirror and action observation therapy, techniques used to aid in the mental and physical rehabilitation of stroke related disabilities. Promising advances in the field of neurological recovery post stroke indicate a need for further study into current models and investigation into new and innovative ways to treat stroke (Brewer et al, 2012, p. 17).

# Literature Review

## What is Stroke?

Stroke is the result of cell death in the brain and can occur in one of two forms: An Ischemic stroke is induced through restricted blood flow caused by a blood clot in the brain while Hemorrhagic strokes are the result of ruptured blood vessels that cause bleeding into the brain; A Transient Ischemic Attack (TIA) is a "mini-stroke," caused by a temporary blood clot and is typically identified by the retreat of common stroke symptoms several hours post stroke (National Heart Lung and Blood Institute, 2016). The death of brain cells and subsequent damage to neural pathways can cause weakness in parts of the body that the affected brain area is assigned to. Weakness typically occurs on one side of the body and is commonly referred to as hemiparesis. Hemiparesis can affect a person's range of motion, strength, dexterity, and motor control (Weiss, 2010).

The initial months following a stroke have a rehabilitative focus on impacting neuroplasticity to promote the reattainment of motor control, while subsequent rehabilitation draws on educational and psychological theory to improve the patient's ability to adapt to their changed circumstances and cope with day to day living (Young & Forster, 2007, p. 86).

Traditionally, rehabilitation after stroke is done through physical therapy (PT), occupational therapy (OT) and speech-language pathology (SLP). PT is focused on regaining a patient's range of motion and strength (O'Sullivan, 2007, p. 737), OT is concerned with the patient's ability to perform day to day tasks (Steultjens et al, 2003, p. 676), and SLP is generally used to aid patients suffering speech disorders such as aphasia (Brady et al, 2012, p. 2). For high repetition rehabilitation, PT primarily uses constraint induced therapy to assist in motor learning and recovery (O'Sullivan, 2007, p. 740). This research is focused on providing an alternative rehabilitation option to traditional PT practises.

Rehabilitative stroke methods can generally be categorized as either conventional or neurophysiological (Dickstein, Hocherman, Pillar & Shaham, 1986, p. 1233). Conventional methods have a focus on promoting the use of a patient's unaffected motor capabilities as a means of compensating for the loss of their impaired ones (Friedland, 1975; Mcdowell, 1976). Neurophysiological methods, in contrast, are concerned with the revitalization of the lost motor capabilities (Bobath, 1978; Kabat, 1952; Knott, 1968). This research is concerned with neurophysiological approaches for post stroke upper extremity rehabilitation.

"Population based studies of stroke recovery have shown that the time taken to achieve best functional performance for mild, moderate, and severe strokes averages 8, 13, and 17 weeks respectively." (Jørgensen et al,1995, p. 406). While recovery time varies between patients on an individual basis these averages provide a good indication for the optimal duration of rehabilitative action. "There is a higher focus on lower limb rehabilitation due to the complications involved with upper extremity disabilities. Walking, for example, requires nearly automatic rhythmical movements, whereas functional use of the upper limbs requires complex, fine graded motor movements." (Merians et al, 2002, p. 900). Given the impact a loss of upper extremity functionality can have on a person's ability to complete simple day to day tasks, rehabilitation that focuses on the rejuvenation of those lost motor capabilities is critical. This research seeks to improve upon existing upper limb rehabilitation concepts in collaboration with emerging virtual reality and sensory devices.

## Virtual Reality for Stroke Rehabilitation

Virtual reality (VR) systems have been successfully implemented in a range of rehabilitative models have proven to aid in stimulating patient motivation and improve the effectiveness of the rehabilitation. Henderson, Korner-Bitensky & Levin (2007, p. 52) discovered a link between a patient's level of visual immersion in a virtual reality system and the rejuvenation of lost upper extremity motor function. They concluded that a patient's level of immersion promoted a more intimate relationship with the rehabilitation and subsequently resulted in a higher frequency of participation in rehabilitative exercises. Rand et al (2012, p. 489) found that by replacing conventional therapy environments with video games they were able to monitor an increase in patient motivation and discovered that patients' use of their affected upper extremities increased.

A Study of 312 stroke patients revealed that only 31% of people with motor disabilities perform their prescribed exercises as recommended (Shaughnessy, Resnick, & Macko, 2006, p. 15). Given that adapting neural organization requires consistent performance of recovery exercises (Merians et al, 2002, p. 898), patient engagement is imperative to the recovery process. Recovery after stroke is directly influenced by the patient's level of synaptogenesis, which has a direct correlation to frequency and intensity of exercises performed (O'Dell, Lin & Harrison, 2009, p. 55).

Modern technology presents the opportunity to create dynamic instances in which a patient's recovery experience can be monitored and progressively targeted towards rehabilitating their unique conditions (Merians et al, 2002, p. 900). Furthermore virtual simulations can provide diverse activities and environments to engage the patient (Muzzaffa et al, 2013, p. 69).

A study conducted last year (Epure et al, 2014, p. 119) concluded that virtual reality systems that utilize head mounted displays (HMDs), are subject to inadvertently causing postural instability. Further studies (Just, Stapley, Ros, Naghdy & Stirling, 2014, p. 328) have found that actions performed in VR were slower than what the user could accomplish in real life and were performed with far less precision suggesting that the virtual disconnect causes a level of uncertainty in an unfamiliar environment. Limitations such as these should be considered in the design outputs of this research.

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## Mirror Therapy

Mirror therapy is defined by (Muzaffar et al, 2013) as

> The mirror provides patients with visual input. The mirror reflection of the moving good arm looks like the affected arm moving correctly and perhaps substitutes for the often decreased or absent proprioceptive input. Use of the mirror may also help recruit the premotor cortex to help with motor rehabilitation. (p. 64)

Mirror therapy is believed to enhance bimanual spatial coupling (Franz & Pacman, 2004, p. 174-175). The precuneus, a small part of the human brain responsible for visuospatial processing, has been found to play an important role in a patient's ability to reconcile visuo-motor shifts (Dohle et al, 2010, p. 543). This presents an opportunity to explore the potential benefits of implementing mirror therapy within a virtual world where the traditional illusion of a physical mirror is instead replaced by the patient's level of visual immersion.

The promotion of plasticity is responsible for motor function recovery in patients and is driven by the intensity of performed exercises. (Kwakkel et al, 1997; Langhorne et al, 2009; Luft et al, 2004). The observation of movement, either our own or others, causes neurons in the brain to activate at an increased rate. Areas of the frontal, parietal, and temporal lobes, are affected by this neural activation and subsequently can prompt cortical reorganization. Critical nodes located in impacted areas are often activated at the same time that these neurons are firing, stimulating recovery (Buccino et al, 2006; Celnik et al, 2006 & Rizzolatti et al, 2008).

## Action Observation Therapy

Mirror neurons are neurons that can fire under two conditions, when the action is performed or when the action is observed being performed by someone else (Fogassi et al, 2005, p. 662). First discovered in primates (Gallese, Fadiga, Fogassi & Rizzolatti, 1996, p. 593) it is believed mirror neurons could allow for the owner to train, strengthen and reconnect existing neural pathways even if they can't perform an action themselves. Studies of brain activity in the frontal and parietal regions suggests the existence of a homosapien version of mirror neurons or a system that exhibits similar traits (Molenberghs, Cunnington & Mattingley, 2009, p. 979).

The difficulty associated with studying individual neurons in the human brain has resulted in a predominant focus on functional magnetic resonance imaging (fMRI) to study large regions of the brain (Gazzola & Keysers, 2009, p. 1252). These studies have shown strong activity in the inferior frontal cortex and superior parietal lobe of the human brain when an activity is both performed and observed thus suggesting the existence of a mirror neuron system (Lacoboni et al, 1999, p. 2526). A recent study in 2010 was able to take a closer look at individual neurons by working in collaboration with another research team at Ronald Reagan UCLA Medical Center. 21 Patients had intracranial electrodes implanted in their brains to study epileptic conditions. (Mukamel et al, Current Biology, 2010) were able to use the same electrodes to test for mirror neurons; they found a small group of neurons fired under both conditions and others that only fired under one.

The potential for a mirror neuron system in rehabilitation is significant, specifically for the recovery of lost motor control, range of motion, and dexterity. A person who has suffered a stroke resulting in hemiparesis ideally wants to recover as much control as they can to ensure that their quality of life is impacted as little as possible. Traditional therapy can present a physical and mental obstacle in that the patient is required to fulfil exercises that they may not be able to perform to completion (Garrison, Winstein, & Aziz-Zadeh, 2010, p. 404) and with little to no observable progress patients may become unmotivated resulting in an incomplete recovery. Action observation therapy proposes that the patient can observe an exercise being done to completion and still receive the neural benefit (Celnik, 2008, p. 1818).

Action observation therapy has been used experimentally with stroke patients to test its efficacy. Ertelt et al (2007), conducted research on 15 stroke patients to test the effect an implementation of action observation would have on simple physiotherapy exercises. Patients were split into "Action Observation" and "Control" groups. The "Action Observation" group were shown videos of someone performing various exercises and tasks such as picking up a cup, the "control" group were shown geometric sequences with no visual human involvement to eliminate the potential of mirror neurons being inadvertently activated (Ertelt et al, 2007, p. 165). Patients from both groups would watch their respective videos without moving their arms and then attempt to perform the same tasks themselves. Patients participated in 90 minute sessions over 18 consecutive working days (Ertelt et al, 2007, p. 165). fMRI's were used to measure changes in brain activity while a combination of Frenchay Arm Test—FAT (DeSouza et al, 1980) Wolf Motor Function Test—WMFT (Wolf et al, 1989) and subjective scales Stroke Impact Scale—SIS (Duncan et al, 1999) were used to measure changes in range of motion, time to complete, dexterity and strength (Ertelt et al, 2007, p. 165). Patients who participated in the "Action Observation" group reported significantly more improvement than the "Control Group" on all scales. They exhibited increased brain activity, specifically in the bilateral ventral premotor cortex, bilateral superior temporal gyrus, supplementary motor area (SMA) and contralateral supramarginal gyrus which together make up the regions of the brain where the mirror neuron system is believed to exist (Ertelt et al, 2007, p. 168-169). Ertelt et al (2007), concluded that the variation in improvement between the groups was a direct result of the implementation of action observation. This data provides the criteria for implementing action observation techniques within a digital medium where the therapy can be gamified to explore the creation of both a rehabilitative and enjoyable experience.

## Sensory Devices

Sensory devices have been used in rehabilitation for years, from custom built technology to commercially available systems the diversity and potential for innovative use cases is extensive (Patel, Park, Bonato, Chan, & Rodgers, 2012, p. 1). This research is concerned with using a commercially available device, the Kinect for Windows v2 (Kinect 2, Microsoft, 2014). The device uses technology such as skeletal tracking and depth cameras to motion capture a user's movements and build a virtual representation of them (Microsoft, 2014).

Sensory devices, in particular, entertainment oriented ones ( Shih et al., 2010, p. 1052) show research evidence that they are useful as physical rehabilitation tools. Motion-based games that combine motion sensor technology and video games can motivate people to engage in exercises that have been designed to be fun to perform (Alankus et al., 2010, p. 219).

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Webster & Celik (2014) describe the Kinects biggest limitations as:

> 1. The Kinect is unable to accurately assess internal joint rotations of the shoulder and instead utilizes a much less clinically viable single-point estimation. Use of the Kinect for specific shoulder-based functionality requirements have yet to be shown to be clinically viable.
>
> 2. Rehabilitation goals which include fine motor skills can not be captured by the Kinect alone; however initial studies suggest fusion systems of Kinect and inertial sensors can be a feasible alternative.
>
> 3. Kinect systems are usually not suitable for severely disabled patients, as gross movements that remain extremely small in their entirety are difficult for the Kinect to accurately capture. (p. 20)

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Exergames utilize sensory devices to drive gameplay, Tanaka et al (2012) summarises the interaction as:

Existing games do not allow for easy access to user data for research or feedback for rehabilitation purposes. Therefore, it is necessary to customize applications. The need for controllers and interfaces that report position and motion should be clear. The nature of the sensors and software involved dictate how accurate the results are and how quickly they can be acquired, which would seem to be the key aspects of controllers for exergames.(p. 77)

University of Utah Masters graduate Acosta (2012) conducted research into upper limb stroke rehabilitation using the Kinect. A game was designed to aid in the recovery of range of motion and reduce spasticity of the upper extremities. The game encouraged users to use their affected limb to move a cursor on screen (Acosta, 2012, p. 2). The Kinect captured real world movement and translated it to on screen cursor movement, each user's range of motion was calibrated at the beginning of each session so they would be able to move the cursor across the entire screen no matter their physical range of motion (Acosta, 2012, p. 9). Users were directed to hover the cursor over pictures that would appear in a 6x6 grid. Patients were observed to improve their overall range of motion over the course of the study with patients who participated ten times scoring significantly better than patients who only participated six times (Acosta, 2012, p. 22). Patients also noticed an increase of use of their affected limbs in their daily lives even when they weren't playing the game suggesting it had a positive influence on motivating them with their own independant rehabilitation (Acosta, 2012, p. 22).

## Exergames

Richards & Graham (2016, June) conducted research into how exergames can balance user interaction with prescribed exercises. The research generated four primary conclusions:

The timing of agency is important; designers should consider what type of agency is appropriate during and between exercises. Physical movement should be decoupled from avatar movement. Agency can be used as a mechanism to incent good form, reducing the risk of injury. And, illusion of agency can be combined with real agency. (p. 919) The strategy card game Brains & Brawn was user tested with eight participants who had little to no previous experience with muscle strengthening exercises (Richards & Graham, 2016, p. 917). Timing of player interaction was identified as an important design consideration. Richards & Graham (2016, June) discussed the implications of allowing a user complete freedom of interaction. They suggested that users' cognitive focus should not be split between performing the exercise and interacting with gameplay mechanics to ensure each was performed as successfully as possible. Fast paced games were not suited to this type of interaction as they favour user interaction. Turn based games comparatively are better suited to balancing a user's own interaction with the game and the performance of exercises (Richards & Graham, 2016, June, p. 919).

Decoupling the user and avatars movement was appropriate for Richard & Grahams (2016, June) game as it allowed for more precise control over the game's controls. They suggested that coupling the user and avatars movement in rehabilitation games had mostly negative effects resulting in games that were restricted in the complexity of user input the game could understand. Weakness in the extremities was also defined as a limitation of a perfectly mirrored system as the weakened extremities poor range of motion may result in imprecise data (Richards & Graham, 2016, June, p. 920).

Incentive to perform exercises correctly was identified as integral to a rehabilitation program's success. Richard & Grahams (2016, June) explored the use of visually rewarding feedback to ensure users knew when they were performing an exercise correctly. Furthermore the implementation of in game consequences can motivate a user to focus on correct form when performing exercises. Beyond simple identification of whether an exercise was performed correctly or not, the quality of the exercise performed can also be evaluated and rewarded appropriately to encourage users to improve their form and to guide them on what parts of their form they need to focus on

(Richards & Graham, 2016, June, p. 920). Richard & Grahams (2016, June) discussed how assisting the user without their knowledge can be a valuable tool when designing rehabilitation games. Assistive mechanics should be used sparingly and only when the user is incapable of performing an action to completion. By helping the user in small amounts a greater percentage of goals can be achieved resulting in increased motivation and satisfaction with the system (Richards & Graham, 2016, June, p. 920).

## Engagement in Games

Engagement in video games is important to how the game builds a relationship with the user, the user needs to be interested in the experience to ensure they dedicate the time and effort necessary to understand the game and receive the physical, mental and emotional rewards that the game is offering (Hoffman & Nadelson, 2010, p. 246). Active interest in an activity improves motivation and adds replayability to the game. Hoffman & Nadelson (2010), describe motivation in this context: “Several motivational variables have been found to be associated with video gaming. Gamers experience positive affect, competence, enhanced self-esteem, vitality, and when successful, ascribe higher ratings of value to gaming tasks (Gee 2003; Ryan et al. 2006; Wang et al. 2008; Warren et al. 2008)”(p. 246). Given that a rehabilitation game needs to be played repeatedly over an extended period of time (Merians et al, 2002, p. 898), qualities such as user engagement and enjoyment are imperative to that game’s long term viability. Hoffman & Nadelson (2010) discuss the advantage multiple level games have for engaging the user “Multiple-level games become increasingly complex and challenging as a player progresses (Habgood et al. 2005; Garris et al. 2003) and are of particular interest because the escalating difficulty requires persistence, overcoming in-game obstacles, and application of strategies to be successful at accomplishing game objectives.” (p. 246).

Bastos et al (2016), conducted research into video game immersion and engagement, and how they interrelate with user cognitive and physical interactions. Using a Mixed Reality (MR) game, Beach Pong (Bastos et al, 2016), participants were evaluated on their cognitive and physical exertions. Bastos et al (2016) noticed that users while having consented to taking part in the study were primarily concerned with playing the game. They hypothesised that users may not have played the game at their highest physical and mental level instead opting to engage with it in a casual manner. They found this an important point of observation and suggested that this sort of attitude could skew results in a study intended for a specific target audience (Bastos et al, 2016, p. 954). To assess cognitive interactions in relation to physical, users were instructed to play beach volleyball while also making sure they didn’t step on areas of the floor covered in ‘lava’. The digitally superimposed lava constituted the introduction of digital technology into the MR experience and Bastos et al (2010) were able to identify the following conclusions, we see that visible evidence of engagement (both physical and cognitive) correlates well with IEQ score. This suggests that both physical and cognitive aspects of the game are related to immersion, which differs from the findings of Cox et al. [7] for desktop games. These measures were not correlated with game score, suggesting that the immersion may have been due not to mastery or a match of challenge with skill, but out of understanding how the game functions by doing—by acting in and enjoying the MR experience. (p. 954-955)

# Precedent Analysis

Figure 5. Toyra. 2011. Retrieved from http://www.fitness-gaming.com/images/Markets/Health_and_Rehab/1103_toyra_introduces_virtual_reality_to_occupational_therapy/013_toyra_rehabilitation.jpg

Toyra combines the skeletal tracking capabilities of the Microsoft Kinect with custom built wearable motion capture devices to create a rehabilitative experience. The aim of Toyra is to provide patients leaving the hospital with a device that they can use at home to complete their prescribed physiotherapy exercises. The Toyra communicates with the hospital and can be monitored to ensure patient participation (Toyra, 2011). While Toyra boasts excellent motion capture and networking capabilities, it is a cumbersome piece of equipment and depending on the patient's stage of recovery and/or degree of disability may require the assistance of a carer or family member to set up (LaBelle, 2011, p. 10).

The strongest point in this design is the networking with the hospital. If an application can be updated remotely you allow for a physiotherapist to monitor and progressively increase the difficulty or type of exercises for their patients which eliminates the need for clinic or home visits and allows the physiotherapist to more efficiently monitor a larger number of patients (Alshurafa, 2015, p. 126).



Figure 6. Tsoupikova. EVL. 2012. http://newsarchive.medill.northwestern.edu/uploadedImages/News/Chicago/Images/Science/patient.jpg

Project EVL is a virtual reality simulator aimed at rehabilitating fine graded motor control of the upper limb extremities. A virtual headset works in collaboration with a custom made sensor glove to place a user in a simulation where they perform their exercises under the guise of a tea party. The therapist sits across from them at the virtual table and shows them which exercises to perform creating an immersive user to user interaction (Kamper et al, 2012). Like the Toyra this piece of hardware provides an interesting experience but is limited in its commercial viability and ease of use due to the complex technology required.

The relationship that this design creates between therapist and patient is an innovative exploration into combining physical and mental therapy. By placing the therapist in the virtual world with the user it creates a more intimate and supportive environment where even in an unfamiliar virtual world the patient can feel connected. The quality of the patient-therapist relationship has been found to have heavy bearing on the success and extent of rehabilitation (Hall et al, 2010, p. 8).

Devices such as these while expensive and complicated to setup justify their cost by boasting capabilities that off the shelf devices such as the Kinect can't facilitate. For a patient that requires fine graded motor control rehabilitation, the Kinect would not be able to pick up their movements accurately enough to create any sort of rehabilitative experience or feedback (Galna et al, 2014, p. 1067).

Figure 7. Mindmaze. 2016. Retrieved from http://assets.bwbx.io/images/users/iqjWHBFdfxIU/icqcQQlkhktA/v2/-1x-1.jpg

Mindmaze's VR headset Mindleap is custom built, utilizing 32 neural nodes, it detects brain activity and uses the input to drive virtual rehabilitation. Users can command their arm to raise a glass of water or their leg to kick (Mindmaze, 2016). The application is interesting in that it removes any secondary sensory technology allowing the user more freedom when wearing the headset, however small advances in the field of using brain activity as input data constrain the application to simple actions. The custom built nature of this piece of hardware and the relatively new technology of VR headsets means this experience is not commercially viable to the average consumer and is at the moment only being trialed in hospital environments (Mindmaze, 2016).

Reading direct brain activity will eventually become standard among these types of rehabilitative devices as the importance of repairing of neural pathways is putative in stroke recovery (Cramer, 2008, p. 272). The direct connection between brain activity and visual performance is of great interest to this research as both mirror and action observation therapy are predominantly concerned with the repairing and strengthening of neural pathways in rehabilitation, specifically with the use of mirror neurons (Garrison, Winstein & Aziz-Zadeh, 2010, p. 405).

Direct brain activity should be a point of discussion when analyzing the final application and its potential future iterations.

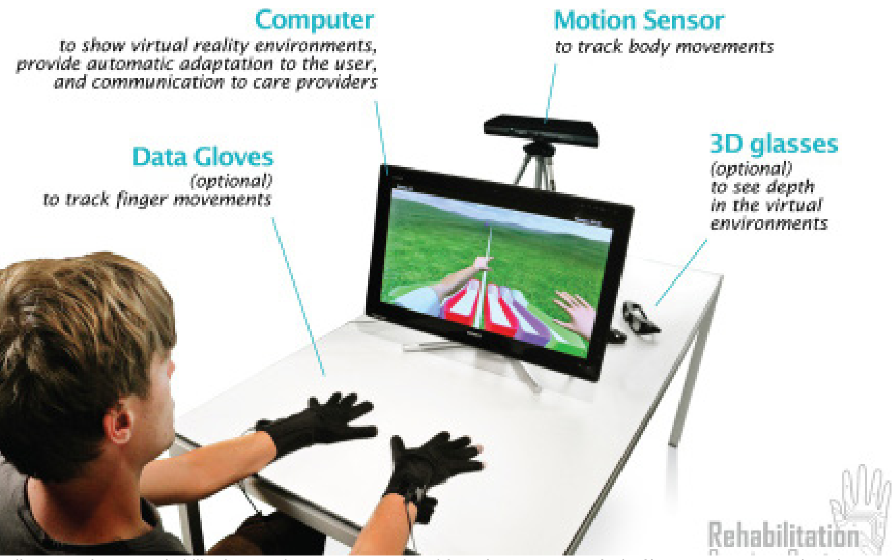


Figure 8. Ballester et al, 2015. Rehabilitation Gaming System. Retrieved from http://specs.upf.edu/files/rgs-system-overview_.jpg

The Rehabilitation Gaming System utilizes the Microsoft Kinect to track hand movements which then correlate to a virtual representation on screen. Users are instructed to reach for and grab targets. Data gloves and 3D glasses are optional pieces of hardware available to further improve the accuracy and enjoyment of the experience but are not required making this a commercially viable and easy to use product. The application utilizes assistive code to help push the on-screen hands to reach the target regardless of the extent of movement of their real life counterparts.This assistive technology is scaled back with every repetition allowing the user to progressively use their affected limbs to a greater degree (Ballester et al, 2015).

This application uses progressive difficulty (IJsselsteijn, 2007, p. 27) to ensure the user is constantly extending their range of motion. The use of assistive code means the user never fails to hit a target even as they tire. Essentially this removes the mechanic of failure from the game, improving motivation and working in synergy with progressive difficulty to ensure the user always experiences the rehabilitation at the most effective level.

Design considerations and implementations from these precedents will be used to inform the back end design of the application I am co-developing. The Toyra (Toyra, 2011) is an interesting exploration into home based rehabilitation technology but lacks the ergonomic qualities that are so important for catering to its intended end users. The application I am co-developing will endeavour to take the concepts of home rehabilitation showcased by Toyra and refine them to meet the heuristic requirements of this research. The application I am co-developing should be an advanced in home peice of software that is both affordable, easy to setup, and use. EVL (Kamper et al, 2012) highlighted the inability for the Kinect to accurately read fine motor movements, considering this limitation my research is not aimed at specifically rehabilitating fine graded motor control instead focusing on the overall range of motion and strength that a patient could regain in their arm by using the application. The application I am co-developing will incorporate a version of the assistive technology used in Rehabilitation Gaming System (Ballester et al, 2015) in some capacity as it not only allows the patient to push themselves over a course of repetitions but removes the mechanic of failure from the applications experience. Someone who has lost control, range of motion or strength in their arms should be provided with a rehabilitative experience that promotes positive reinforcement and motivates them to continue with their rehabilitation by consistently showing them progression through success (Columbo et al, 2004, p.4).

# Research Overview

1

This aim ties into the primary research question, and looks to establish new knowledge on alternative techniques for the rehabilitation of stroke.

i. Conduct research into existing rehabilitative methods to assess strengths and weaknesses.

ii. Apply existing knowledge to a theoretical framework in order to inform conceptual iterations.

2

This aim ties into sub-questions (2 & 3), and looks to explore the potential implementations of mirror and action observation therapy in a virtual medium.

i. Utilise the Microsoft Kinect 2 and the Oculus Rift in collaboration with a virtual world to provide a rehabilitative experience.

ii. Build upon current mirror and action observation psychology through the exploration of participants' virtual experiences.

3

This aim ties into sub-question (2 & 3), and seeks to conduct a series of experiments to determine the validity of a completely virtual rehabilitation process.

i. Design interactive applications that create an ergonomic and aesthetically pleasing user experience

ii. Gauge and compare new participant experiences to established methods.

## Research Outputs

A dissertation exploring the use of action observation therapy in a virtual world

A virtual simulation that provides a rehabilitative experience for stroke survivors

# Methodology

## User Centred Design

Given the personal nature of the condition and the unique patient experiences that this research is concerned with, User-Centered Design (UCD) was well suited to assess how participants engaged with the rehabilitative experience. The inherent problem solving component of this design research was addressed through the application of heuristic methodologies.

### Background Research

*"Conduct research into existing rehabilitative methods to assess strengths and weaknesses"*

To gain an understanding of the field of research a review of published literature and an analysis of existing precedents was undertaken. Searches with the following terms in engines such as Google Scholar and the Victoria University Library generated results in databases including but not limited to ProQuest, Sciencedirect, various academic journal sites over the period July 2015 - March 2016.

> Stroke
> Stroke Rehabilitation
> Action Observation
> Mirror Therapy
> Mirror Neurons
> Sensory Devices
> Virtual Reality
> Serious Games
> Engagement
> User Interface

*"Apply existing knowledge to a theoretical framework in order to inform conceptual iterations."*

The design precedents sourced using the above methods were analysed for their strengths weakness and were used to inform the initial design and future iterations of the application. The considerations identified in these precedents were first ground in the literature to ensure they accurately represented the field of research.

### Qualitative Analysis

The analysis conducted throughout this research was qualitative in nature due both to the fact, there was not enough data to draw quantitative conclusions, and that the final outcome of the research was concerned with attaining a high level of usability and aesthetic appeal. Qualitative analysis is interested in the "Why?" and "How?" questions, it seeks to gain an understanding of human interaction and relationships (Strauss & Corbin, 1990, p. 11). Strauss & Corbin (1990) define qualitative analysis as:

> Basically, there are three main components of qualitative research. First, there are the data, which can come from various sources such as interviews, observations, documents, records, and films. Second, there are procedures that researchers can sue to interpret and organize the data. These usually consist of conceptualizing and reducing data, elaborating categories in terms of their properties and dimensions, and relating through a series or prepositional statements. Conceptualizing, reducing, elaborating and relating are often referred to as coding...(p. 11 & 12)

The elements of qualitative research discussed by Strauss & Corbin (1990) focus heavily on interaction with the user and were used to inform the methods this research adopted. Interviews, questionnaires, usability testing, and participatory design were all chosen to ensure this research engaged with the user constantly throughout the design process.

### Heuristics

*"Design interactive applications that create an ergonomic and aesthetically pleasing user experience "*

The following heuristics (Nielsen, 1995) are the result of an initial study (Molich & Nielsen, 1990) in heuristic evaluation and a further "factor analysis of 249 usability problems" (Nielsen, 1994; Nielsen, 1995) to create a set of ten heuristics that user interface designers can use to make sure their product is an ergonomic and intuitive user experience. The application I am co-developing can be extrapolated as one large user interface making these heuristics perfect guiding stones for its development.

**Visibility of system status**

The system should always keep users informed about what is going on, through appropriate feedback within reasonable time.

**Match between system and the real world**

The system should speak the users' language, with words, phrases and concepts familiar to the user, rather than system-oriented terms. Follow real-world conventions, making information appear in a natural and logical order.

**User control and freedom**

Users often choose system functions by mistake and will need a clearly marked "emergency exit" to leave the unwanted state without having to go through an extended dialogue. Support undo and redo.

**Consistency and standards**

Users should not have to wonder whether different words, situations, or actions mean the same thing. Follow platform conventions.

**Error prevention**

Even better than good error messages is a careful design which prevents a problem from occurring in the first place. Either eliminate error-prone conditions or check for them and present users with a confirmation option before they commit to the action.

**Recognition rather than recall**

Minimize the user's memory load by making objects, actions, and options visible. The user should not have to remember information from one part of the dialogue to another. Instructions for use of the system should be visible or easily retrievable whenever appropriate.

**Flexibility and efficiency of use**

Accelerators unseen by the novice user may often speed up the interaction for the expert user such that the system can cater to both inexperienced and experienced users. Allow users to tailor frequent actions.

**Aesthetic and minimalist design**

Dialogues should not contain information which is irrelevant or rarely needed. Every extra unit of information in a dialogue competes with the relevant units of information and diminishes their relative visibility.

**Help users recognize, diagnose, and recover from errors**

Error messages should be expressed in plain language (no codes), precisely indicate the problem, and constructively suggest a solution.

**Help and documentation**

Even though it is better if the system can be used without documentation, it may be necessary to provide help and documentation. Any such information should be easy to search, focused on the user's task, list concrete steps to be carried out, and not be too large.



By consistently cross referencing the feedback generated by interviews and questionnaires with these core heuristic concepts I was able to assess them for their efficacy and ensure that user focus remained prevalent throughout the design process. User focus is defined by Gulliksen, Göransson, Boivie, Blomkvist, Persson, & Cajander (2003) as

> All members of a project must understand the goals of the activity, the context of use, who the users are, their situation, goals and tasks, why and how they perform their tasks, how they communicate, cooperate and interact, etc. This helps in creating and maintaining a focus on the users' needs instead of a technical focus. Activities, such as identifying user profiles, contextual inquiries and task analysis, must be a natural part of the development process. (p. 401)

## Recruitment Protocol

Participants were contacted through a variety of means. I attended a Kapiti Stroke Club meeting to give an overview of my project and gauge participant interest. Various stroke clubs from the Wellington region were contacted by phone and were sent information sheets on my research. I investigated a retirement village, Summerset at Aotea, but found no eligible candidates. Information sheets were set via Robinson, B. (Private communication, June, 2016) to two participants one of whom was chosen as the research participant. The recruitment process was diverse and explored multiple options despite the final use of a single participant.

## Inclusion/Exclusion Criteria

The inclusion criteria for this rese rch was broad with no requirement on age, gender or ethnicity. Ideally participants had suffered a stroke in the past year that had resulted in left or right side hemiparesis. A class was taken at Wellington Hospital on Maori culture and health so that I would be able to conduct research with a Maori participant in an ethical and culturally sensitive manner. Ideally research participants had participated in a range of rehabilitative practises not limited to traditional therapies in the hope that they would be able to give some insight into the comparative benefits or limitations of my research.

The exclusion criteria was primarily focused on mental health. Participants needed to be able to communicate clearly enough that participatory design could be achieved. Participants needed to be mentally stable enough to play the game without becoming distracted or otherwise disengaged.

## Questionnaires

Questionnaires were used to gain an understanding of the study participant, their past rehabilitative experiences, their current physical condition and state of mind. Questionnaires provide insight into a participant's character, ideology and history and can be used in conjunction with other forms of data gathering to adequately equip the researcher with the information needed to generate discussion (Turner III, 2010, p. 754).

The following questionnaire was used to generate a participant profile

> When did you experience your first major stroke?
>
> What sort of stroke was it?
>
> How did the stroke affect you? Did you experience left or right side hemi-paresis?
>
> Were you offered any rehabilitation following the stroke?
>
> What form did this rehabilitation take?
>
> How long was this rehabilitation offered for?
>
> Did you regain any lost movement or motor capabilities?
>
> Did you find the prescribed rehabilitation hard to maintain over a long period of time? Why?
>
> Do you do any rehabilitation currently, prescribed or not?
>
> How often do you do this rehabilitation and how long does each session take?
>
> Have you noticed any improvement from this rehabilitation?
>
> Do you use any devices to assist you with home/clinical therapy?
>
> How much time do you spend using computers, the internet, smartphones, or tablets each day?
>
> Do you find technology easy or difficult to use?
>
> Have you played digital games before?

Originally the intention was to test the application I am co-developing with a range of participants and use their feedback to improve the application. Due to strict time constraints a different method was necessary. A single participant was recruited and tested on multiple times. With no diversity in participants, participatory design was relied heavily on to investigate the applications potential. Participant X user tested the application over a series of sessions and played a pivotal role in the applications development through several iterations.



## Collaboration

*"Utilise the Microsoft Kinect 2 and the Oculus Rift in collaboration with a virtual world to provide a rehabilitative experience."*

The physical output of this research was produced through collaboration with Victoria University of Wellington Masters student, Patrick Kauraka. Patrick worked on the front end of the application designing the aesthetic components while I worked on the backend designing the gameplay, logic and reporting. Patrick's Thesis used the application to explore graphical styles in stroke rehabilitation (Kauraka, 2016). The application that I co developed was built in the Unreal Engine using the Microsoft Kinect as a game controller. Action observation was implemented within gameplay to provide an engaging rehabilitative experience.

## Usability Testing

*"Gauge and compare new participant experiences to established methods."*

Initial concepts were brought to the participant for usability testing. This constituted the second component of the user centred design process. Users have been found to understand and interact more precisely with products that have reduced their inherent learning curves through concept iteration. (Dumas & Redish, 1999, p. 14). Strengths and issues that initial concepts presented were built upon and resolved respectively until the rehabilitation was both an ergonomic and intuitive experience.The participant was able to compare the experience to other rehabilitative methods and use that knowledge to aid in its development, eliminating points of friction and enhancing the designs strengths.

## Participatory Design

*"Build upon current mirror and action observation psychology through the exploration of participants' virtual experiences."*

Participatory Design (PD) (Schuler & Namioka, 1993, p. 6) was then used to further refine designs to provide specific rehabilitative activities that effectively engaged the participant in an immersive experience (Shin, Ryu & Jang, 2014, p. 4). The participant was able to have a greater impact on the design of the application by providing feedback on the experience via iterative testing and interviews. This produced an experience that was tailored to the intricacies of rehabilitating their condition. THrough observation of the participant and the participants own admissions an action observation therapy implementation was explored and assessed for its efficacy.

# Design Process

For the design component of this thesis I will refer to development of the application in general as collaborative and cite Patrick's specific contributions.

The following images depict the game with and without Patrick's involvement. The left game incorporates all the game play mechanics and can still be used as a rehabilitative experience. The right game shows the dramatic change visual assets such as character models, environments, lighting, and interface design can make to a game.

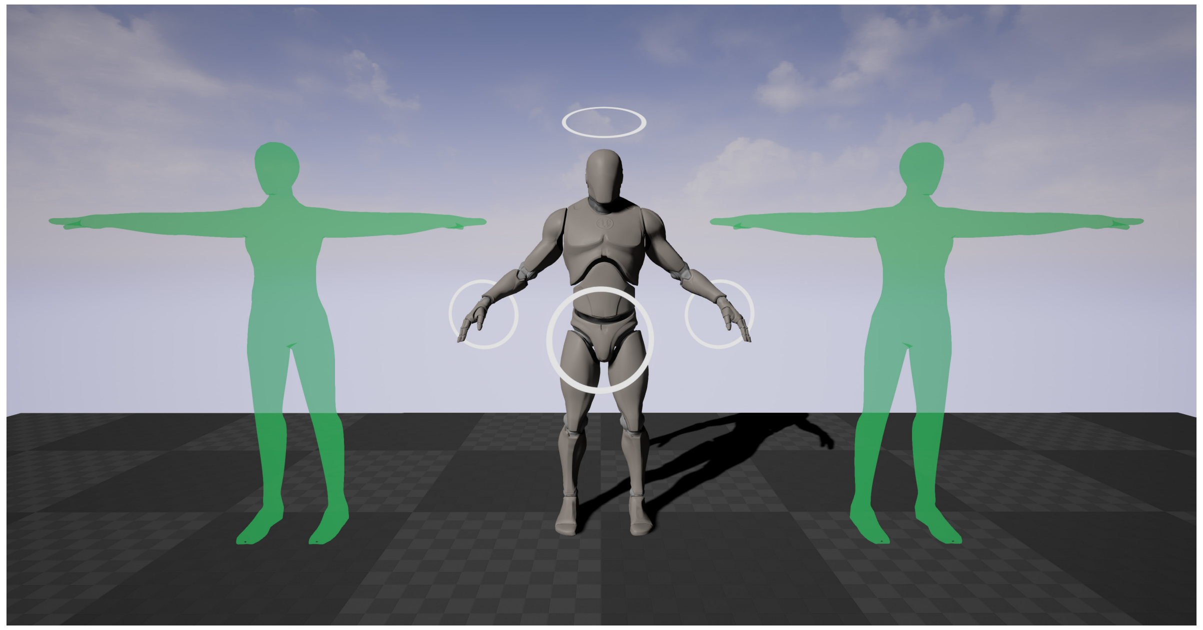

Figure 9.

Figure 10.



## Target Audience

Understanding the target audience played a significant role in the design of the application particularly with a focus on usability. Ideal end users had suffered a stroke resulting in left or right side hemiparesis which had left them with an impacted range of motion, level of strength or level of dexterity in their upper limbs.

Ethnicity, gender and age were not considered a major factor when designing the application because we didn't want to limit the applications potential to cater to a diverse demographic. Given that this research is looking very broadly at potential applications there was no criteria on the type of stroke that a person had suffered or the time that had passed since the stroke.

Previous involvement in stroke rehabilitation projects or activities was sought after in our user test participant as the person would be able to give good insights into the comparative benefits and/or disadvantages that our application provided.

## User Flow/Application Goals

Clear goals were set out at the beginning of the project to ensure the application did not grow too large or evolve past its originally intended use case.

The application needed to be designed in such a way that it could be used in a clinic or home environment. The application needed to incorporate some form of action observation therapy. The application needed to be ergonomic and simple to learn. Finally the application needed to be able to account for a user's condition and dynamically tailor itself to meet the user's needs.

The applications user flow needed to introduce the user to each aspect of the game in a logical order and give them enough time to learn the component before moving on. Transitions between gameplay components needed to be smooth and keep the user informed of changes to game elements and to the introduction new gameplay elements.

## Technology and Software

Familiarity with the software Unreal Engine 4 (UE4, Epic Games, 2014) led to its primary use in this project. I specifically worked with the Blueprint Node System in UE4 to produce the backend of the application.

The Kinect 2 was chosen as the applications primary controller as it was both available to me to use for testing and given its current availability to the general consumer, proved an affordable product should the project ever be commercialized.

Third party plugin Kinect 4 Unreal (K4U, Opaque Media, 2015) and software Brekel Kinect Pro Body (Brekelmans, 2013) were purchased and utilized in this project to allow the Kinect to provide input data to UE4 and to be used as a motion capture device.

## Considerations

Given the time constraint on the project it was not feasible to produce a system capable of handling a wide variety of existing rehabilitative techniques and translating them into the application. Exercises were explored that focused on improving range of motion, strength and dexterity across 3 axis of the human body. The exercises were simple to perform which both met the criteria of an ergonomic application and provided the Microsoft Kinect with easy to track movements, ultimately producing smoother more consistent data.

## Concept

The application needed to incorporate the users avatars as well as some sort of AI avatar whose movements the user could copy to ensure the action observation component of the research was demonstrated. The application needed to cater to a range of age groups, ethnicities and both the female and male genders. Given the demanding list of variables we needed an application that could provide options to cater to all potentially unique users. The application became Groove Studio, a dancing game which logically fit all of the requirements. The user could watch both their own and AI avatars dance on the screen. Music and dance are relatable across multiple cultures, generations, and are typically enjoyed by everyone in some way.

With the ability to digitally add, remove and modify music, avatar models and environments an experience could be tailored to any individual person given the right information was provided.


Figure 11.

# Prototypes

## Initial Prototype

This prototype was first intended to showcase a digital avatar within UE4 being controlled by data streamed from the Kinect in real time. This was achieved by using default assets shipped with UE4 and an implementation of the K4U plugin. The prototype was proof of concept enough to move forward with our own assets and to start designing a user experience.

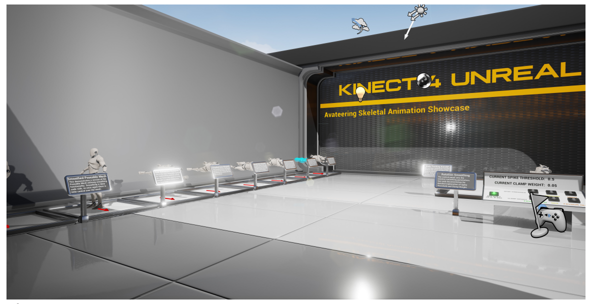

Figure 12.

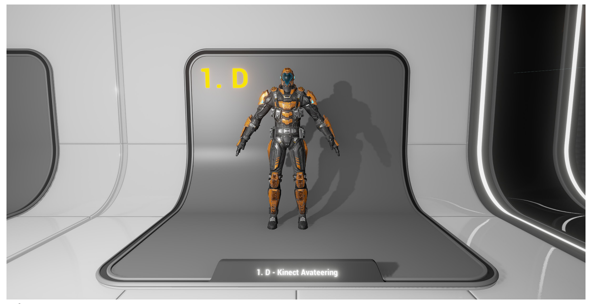

Figure 13.

The prototype was developed further to include a basic calibration of a user's range of motion. The application was made to work on a 3 axis understanding of a user's mobility. The user was instructed to perform 3 separate exercises, the Kinect tracked their left wrist, constantly storing the highest number they were able to reach in each direction, creating their limits.The left wrist data was then mirrored to give the right side the same limits.

Figure 14.

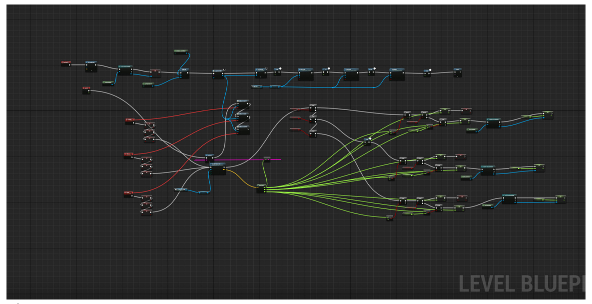

Figure 15.

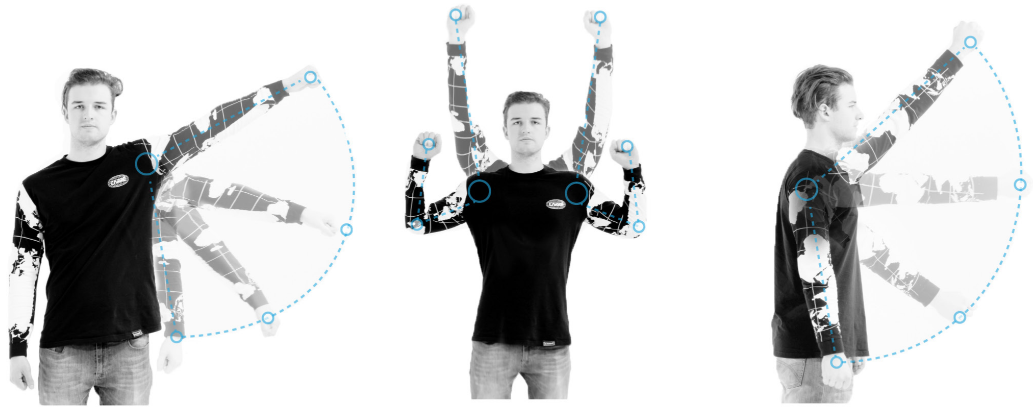

Figure 16.

The prototype then introduced the next component of gameplay. Once calibration had been completed the application set the player's limits in 3 dimensional space and again they were told to perform various exercises to hit those limits. With constant repetition the limits could slowly be moved further away to create incremental/progressive difficulty and in doing so ensured that the patient was consistently trying to extend their range of motion. A simple human figure and background assets were created to demo the gameplay (Kauraka, 2016). Simple exercise movements were motion captured and added into the application. The user looks at the top left of their screen to see what they need to do and then they perform the exercise themselves.

Figure 17.

## Mirror Therapy Prototype

This prototype implemented mirror therapy and pushed the applications aesthetic further. A placeholder environment was customized to show what the application might look like in a home setting (Kauraka, 2016; Epic Games, 2014). Dance animations were motion captured, refined and incorporated into the application. By utilizing the Kinect's gesture recognition capabilities a menu system was setup that could be navigated by the user by making open and closed fist gestures. A mirror was added to the application to complete the basic gameplay requirements needed for a mirror therapy implementation.

Figure 18.

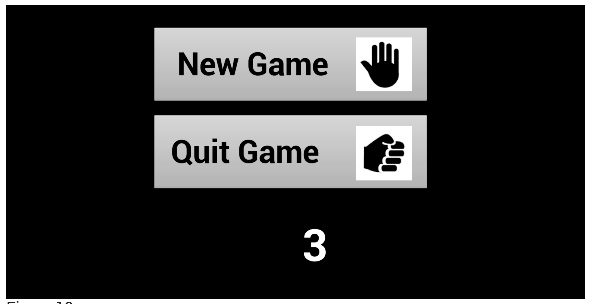


Figure 19.

Signal, N. & Taylor, D. (Private communication, October 14, 2015) were invited from Auckland University of Technology to review and provide feedback on the viability of the application in its current state. They suggested that the application should be able to be played both standing up and sitting down as stroke survivors may have impaired balance or weakness in their legs. Their second suggestion was that the mirror was not an accurate implementation of mirror therapy. Their critique on the implementation of mirror therapy suggested that we focus on action observation therapy instead as it was more inline with the design of our application.

## Revamped Prototype

Before implementing the feedback from the first review we decided to strip the application back and improve its core functionality. We had started developing aesthetic parts of the application too soon which resulted in multiple bugs and an unstable framework. This prototype included significantly more reporting functionality to improve the accuracy of calibration. I made the calibration level more advanced giving it the ability to track a user's arms independently of each other and set unique limits for each. This allowed for hemiparesis to be more realistically represented in the gameplay. I split the calibration and gameplay into their own respective levels, this improved the applications functionality and created a more logical user flow. Models were created and added into the application , a realistic female and male model with accompanying clothes and textures (Kauraka, 2016). To accommodate the introduction of male and female characters I added a new menu screen so the user could select the gender of their virtual avatar.

Figure 20.

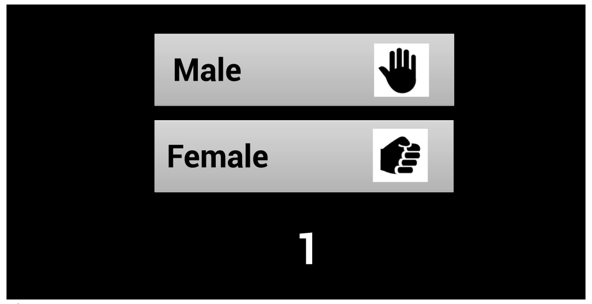

Figure 21.


Figure 22.



The way the application was calculating limits being hit by the user required more accuracy than the Kinect could reliably output. In response to this I added physical hit boxes into the application that could be dynamically placed in the world based on the user's limits. This allowed for a much larger margin of error and considerably improved hit accuracy. Our own environment was designed to replace the placeholder levels and establish a base for the application to be iterated from (Kauraka, 2016).


Figure 23.

## Action Observation Prototype

In response to the feedback given by Signal, N. & Taylor, D. (Private communication, October 14, 2015) I removed the mirror from the application and instead added a second character model in the same place as the user's avatar. This character model had a slightly translucent material giving him an "Onion Skin" effect. This model would perform exercises and the user could try to move their arms and copy the other model. Testing revealed that the Kinect was capable of capturing a user's input even if they were seated, minor adjustments to how that data was processed in the application allowed the application to be played seated or standing. I devised a system to count the repetitions performed by the user and upon completing a set amount of repetitions they were given a reward. The reward involved hiding the characters Kinect driven avatar and replacing it with an AI avatar playing a dance move animation. Once the animation completed the model would switch back to the user controlled avatar. This transition was masked by an exploding particle effect.


Figure 24.


Figure 25.

Signal, N. (Private communication, March 16, 2016) was invited to review and comment of the applications progress. She recognized the intention of the "Onion Skin" character as a way of implementing action observation within the application but suggested that it was not clear enough with the user standing in the same place overlapping the model. She also made note that stroke rehabilitation requires extensive repetition and the application as it was setup in its current state was rewarding the user more than it was giving them an opportunity to perform the exercises.

## Final Prototype

At this point in the project virtual reality had still not yet been implemented. While the benefits of virtual reality are certainly promising it was no longer suitable to the project. Given time constraints and an already complicated integration of sensory devices with a virtual application, adding virtual reality on top of that was not feasible.

This prototype involved a big push on the front end. Patrick produced new models in two art styles, realistic and toon. UI and menu elements were created and implemented, environments were produced to accompany these models in their respective styles and new animations were produced for both exercises and dance moves (Kauraka, 2016). I inverted the skeletons of the models within the application so that they would mirror the user's movements. This had been an original benefit of the ingame mirror which had since been removed. I coded a UI for the application, a simple power up bar with stars that change colour from grey to gold provided the user with visual feedback every time they completed a repetition within a set. The visual assets for this UI were produced by Patrick (Kauraka, 2016). Once a set was completed the bar reset to 0 and the "Set" number was incremented inside the big star.

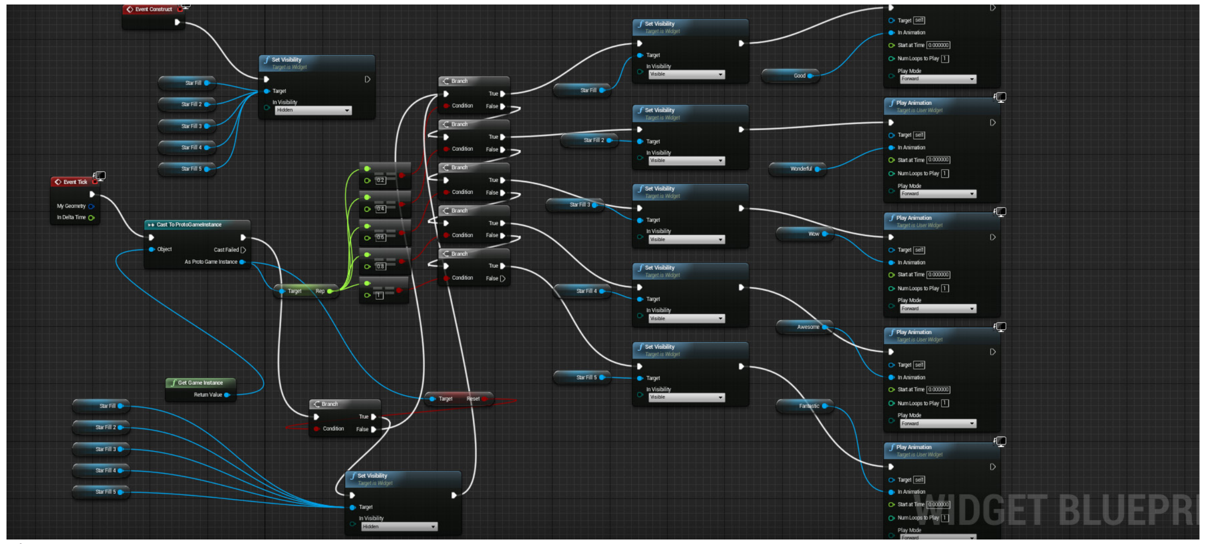
Figure 26.

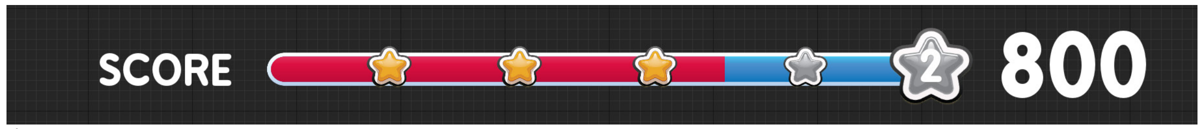

Figure 27.


Figure 28.

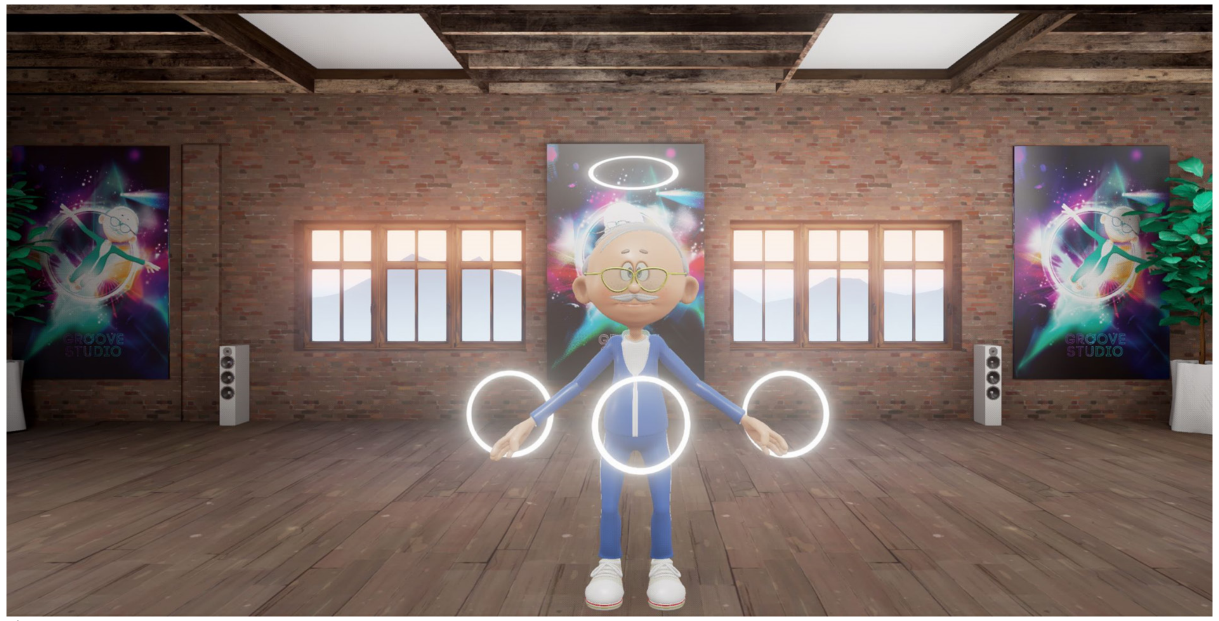
Figure 29.

Art style selection was added as another user defined option. Adjustments were made to hitbox size and the visual hitbox particle effect was replaced with a simple white circle. I wrote code to animate a second circle inside the hitbox circle when it was hit. This provided some nice visual feedback to the user that they had hit the target. Refined exercise animations were added to the application to provide a visually smoother experience (Kauraka, 2016).

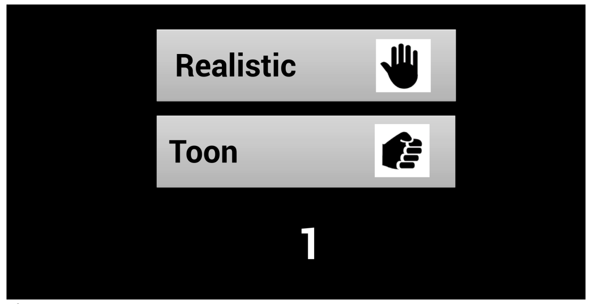

Figure 30.


Figure 31.

With the inclusion of toon and realistic levels the amount of user navigatebale screens was becoming a hindrance. The gesture recognition while mostly accurate was not the optimal solution for the issue of customization within the application . I instead coded a start menu with four options that the user could choose from including gender and the artstyle they wanted to play. Patrick produced the visual assets for this menu (Kauraka, 2012). Green "Onion Skin" models were added on either side of the player in place of the original "Onion Skin" model. A music track and sound effects were added to the application. Lighting and particle effect transitions were refined to be less dominating.

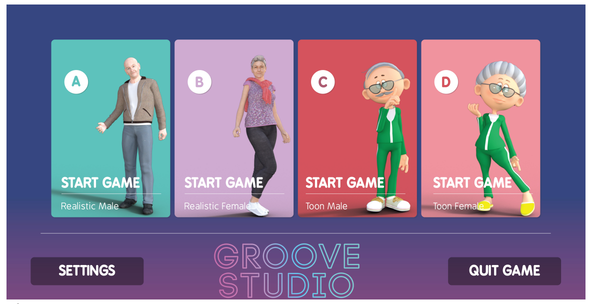

Figure 32.


Figure 33.

# Results

The information obtained in the questionnaire generated the following profile:

Participant X is a 74 year old female of European descent. She suffered an ischemic stroke in mid-January 2016 resulting in left side hemiparesis. She lost mobility and strength on her left side, particularly in her left hand. She was offered rehabilitation for one week at a local hospital during the acute stage followed by 3 in home physio visits from an occupational therapist and a physiotherapist. Goals were set for what Participant X wanted to be able to do independently again. Using public transport, minding her grandchildren and going for bike rides were a few of the items on this list.

Participant X started on a walker but regained the ability to stand on her own through a series of exercises focused on improving balance and stability i.e. stepping up and down on a box. Modified constraint induced therapy of her good hand was used to help regain strength in her affected arm by forcing her to use it. Participant X lost fine motor control in her left hand, exercises such as placing pegs on a peg board were aimed at regaining this lost control. Participant X was given a range of exercises to incorporate into her daily life to further rehabilitate her left side including the use of an elastic theraband.

Participant X regained most of the strength and control in her left side but still has some difficulty typing. Participant X attributes the extent of her recovery to being in good shape before the stroke and is still unsure if the recovery was the result of natural healing or forced rehabilitation. Participant X found the prescribed physio exercises hard to keep up over a long period of time due to exhaustion and the time that it took out of her day.

Participant X's good health and mobility makes her an ideal candidate for testing our application. With a longer exhaustion time and the ability to complete exercises without difficulty the iteration of the application through the participatory design stage can be completed quickly allowing for as much development as possible within the given time frame. Participant X ha s also participated in other research and alternative rehabilitative treatments including stationary bike riding and a neurological choir. This diverse involvement in the field of prospective rehabilitation means Participant X can also give insight into how our application compares to other emerging technologies and techniques.

Participant X was familiar with technology. Belonging to writing groups and using email were a part of her daily life. Participant X wasn't involved with traditional video games but did use Brain HQ, a computer game aimed at improving cognitive abilities.



## Usability Testing

The first user test constituted three parts. A preliminary interview about Participant X's history allowed for the above profile to be built around her stroke, recovery and rehabilitation prior to our interaction. Participant X then tested the application multiple times using both the realistic levels and toon levels. Finally Participant X participated in a second interview to give feedback on the application.

The participant liked the use of the Kinect in the application but struggled to see the application as a video game. Participant X associated games with hand held devices or consoles. Participant X felt that the calibration level was very rehabilitative and suggested that we remove the text prompt "Let's get warmed up" as the calibration level is very short and not reflective of a traditional physical "Warm up". The participant, given her good range of motion, did not find the application very challenging and suggested that it should be made longer to induce fatigue. The participant enjoyed the novelty of having her movements drive the movements of the avatar on screen but suggested we make it clearer to the user that it was a gameplay mechanic as she had not realized the avatar was mirroring her until well into the play session. Participant X suggested that the calibration level should use a Kinect driven avatar as well. Participant X suggested that more visual feedback would make the application feel more like a game. Participant X found the calibration level confusing because she was not sure if she was supposed to be reading the text or copying the movements of the avatar on screen.

Figure 34.

Using Participant X's feedback I made some adjustments to the application before our second user test. The text prompts and animations on the calibration level were altered so that the text prompt would display for a few seconds and then the animations would start playing. This gave the level a more logical flow and helped to pace out the exercises. New "+100" score assets were created and added to the application to provide better visual feedback when a participant hit a circle (Kauraka, 2016). The applications rounds were increased from 3 to 5 and the "Let's get warmed up" was changed to "Let's get started".

Figure 35.

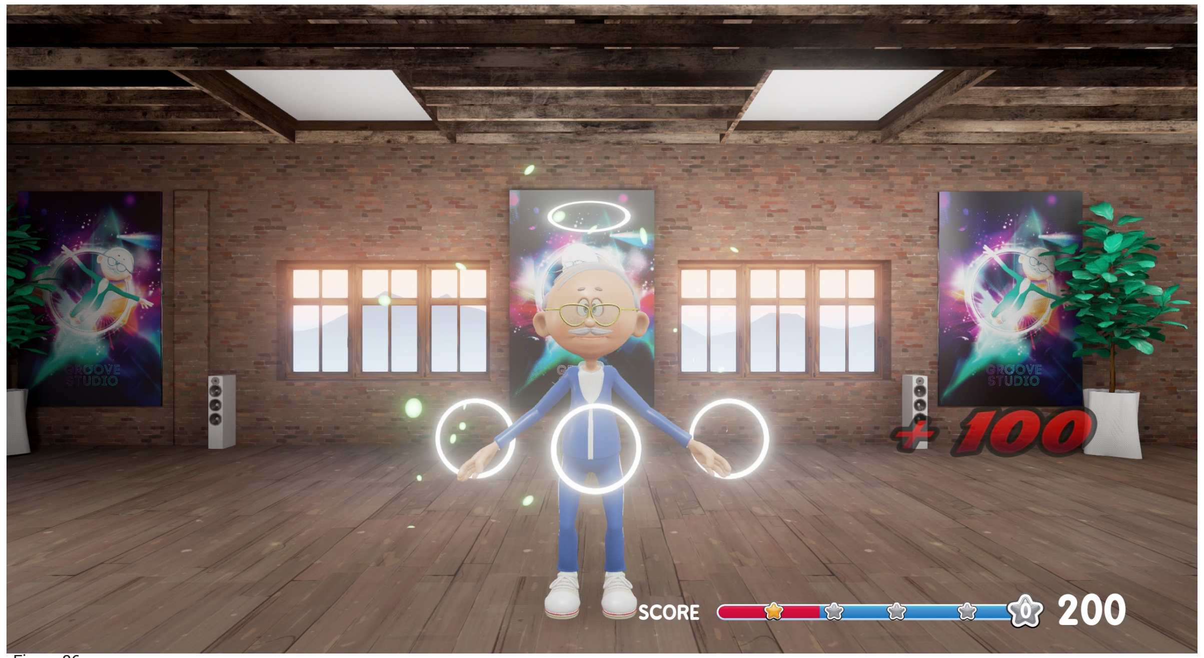

Figure 36.

## Participatory Design

The second user test constituted two parts. First Participant X tested the application multiple times in both the realistic and toon levels. An unstructured review was then carried out to gather Participant X's feedback on the changes that had been made to the application and to provide any additional ideas or criticism.


Figure 37.

Participant X thought the adjustments made to the calibration level made it easier to understand. I noticed that while she was performing the calibration level however, that she was raising her arms immediately to copy the "T-Pose" of the green men on screen. When asked she confirmed that she thought she was supposed to copy them. A note was made that the green men should have an idle position with their hands at their side so that users would not inadvertently put themselves out of position before the calibration had even started. Participant X liked the visual changes to the UI but suggested that we add a text prompt telling the user to hit the white circles as it was not immediately obvious that they were targets. Participant X suggested that we change the music because the rhythm did not match the speed of the gameplay. As someone who did scottish dancing she felt that having music that matched the speed of the dance was vital to its ability to feel natural. Participant X had not previously noticed that the targets were placed at the limits set in the calibration. Participant X re-did the calibration and tried setting her limits so that they would reflect someone who had lost range of motion on one side. Participant X played the application with the new limits and commented on the cleverness of the system.

In response to criticism from the first user test I changed the main model in the calibration level to be a Kinect driven avatar. By having the Kinect driven model in the calibration level users are introduced to the concept more quickly and the translation into the dance level should feel more natural. Additional music tracks were sourced to provide different rhythms to accompany the dancing (Kauraka, 2016). The green men in the calibration level were given an idle pose to eliminate confusion on what the user should be doing at the start of the calibration level and in between exercises.  A text prompt was added to the start of the dance level instructing the user to hit the white circles to gain points.

The third user test constituted two parts, First Participant X tested the application multiple times in both the realistic and toon levels. An unstructured review was then carried out to gather Participant X's feedback on the changes that had been made to the application, to provide any additional ideas or criticism and to verify that all the information we had recorded over the course of our testing was accurate.

Participant X felt that the slower paced relaxation music track was better suited to the applications speed and allowed for a more fluid experience. Participant X preferred having the Kinect driven avatar in both the calibration and dance levels because she was able to familiarize herself with the concept earlier and it wasn't such a drastic change going into the dance level. The green mens idle pose, while a minor change, did stop Participant X from attempting to assume a "T pose" straight away which allowed for a more natural entry into each of the exercises . Participant X liked the text prompt that instructed her to hit the white circles and believed that would be sufficient to inform a user what the aim of the application was. She suggested moving the text prompt a few seconds further into the level though so the user had time to take the level in before having to register a text prompt.

The applications final iteration involved implementing the changes from the second iteration consistently across the application. Those changes had only been implemented in the realistic level of the application so the user could compare to see what they liked best. The "what to hit" text prompt was moved further into the dance level and minor tweaks were added to the placement of trigger boxes within the level.

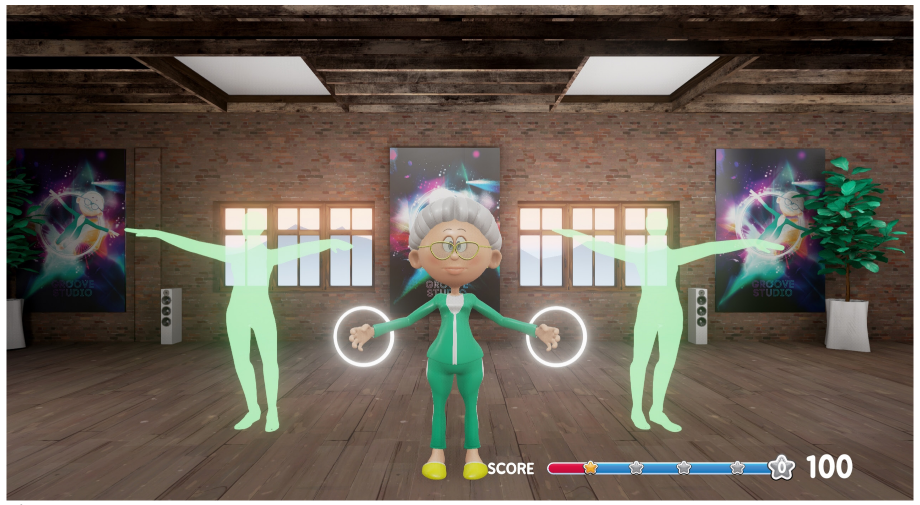

Figure 38.

Figure 39.

Figure 40.

Figure 41.

# Conclusion

This project developed further insights into creative ways to rehabilitate stroke. Mirror therapy and action observation therapy were explored in virtual mediums using sensory devices as game controllers.

*i. Conduct research into existing rehabilitative methods to assess strengths and weaknesses.*

Experimental technology, devices and concepts were researched prior to undertaking this research in an attempt to identify strengths and weaknesses in existing rehabilitative devices. Toyra (Toyra, 2011), EVL (Kamper et al, 2012), Mindmaze (Tadi, 2015) and Rehabilitation Gaming System (Rubio, 2015) were all analyzed for their efficacy in stroke rehabilitation and several of their concepts or strengths were utilized or built upon in this research.

*ii. Apply existing knowledge to a theoretical framework in order to inform conceptual iterations.*

Toyra's in home rehabilitation model provided the framework for the proposed affordable and easy to setup aftermarket application (Toyra, 2011). EVL's exploration in fine graded motor control helped to limit the scope of the research by ensuring a realistic understanding of the technologies capabilities was enforced (Kamper et al, 2012). EVL's focus on patient comfort informed several design decisions that led to virtual environments that had a homely feel (Kamper et al, 2012). Rehabilitation Gaming System's assistive code technology was interpreted in our application in the form of calibrating to a user's needs so they could always hit the target at their limits (Rubio, 2015).

Private communication with Signal, N., Taylor, D. (2016) highlighted the benefits of exploring action observation therapy over mirror therapy while time restraints delayed the implementation of virtual reality headsets ultimately leading to both of their exclusions from the research.

*i. Utilise existing sensory and visually interactive devices in collaboration with a virtual world to provide a rehabilitative experience.*

Using a Kinect as a game controller, an application was developed in UE4 that used 3D motion data from the Kinect to drive gameplay. The virtual simulation used the Kinect's skeletal tracking capabilities to calibrate the application to a user's range of motion.The simulation placed targets at the user's limits and used to the Kinect's motion tracking data to determine if the user hit the target in-game.



*ii. Build upon current mirror therapy and action observation psychology through the exploration of participants' virtual experiences.*

The participant was observed to follow the actions of the instructive green avatars on screen even when it meant putting themselves out of position. Adjustments were made to streamline this interaction and it was noted by the participant that despite the novel appeal of having their movements mirrored by their avatar on screen they found themselves trying to copy the green men most of the time. The split in participant attention potentially means they can enjoy the interaction with the Kinect avatar but not focus on the representation of their own range of motion instead looking to the green men as an example. This was a promising response to the implementation of action observation and combined with the dynamically placed targets it can be assumed that the user would feel like they were consistently accomplishing something while progressively getting better.

*i. Design interactive applications that create an ergonomic and aesthetically pleasing user experience*

User testing revealed extensive information on the ergonomics, aesthetics and practicality of the application. Ease of use made up a large portion of the participants feedback which should come as no surprise given the inherent learning curve associated with new technology (Russell, 1995, p.177). Participant X was able to consistently identify points of friction within the application that if left untreated would have had detrimental effect on the applications usability and replayability (Bateman, 2009, p. 199).

The applications aesthetic didn't change dramatically throughout user testing. Participant X was impressed by the quality of the levels both realistic and toon, likening them to movies such as Toy Story (Pixar, 1995). Aesthetic development came in the form of better visual feedback. Participant X wanted to be told more clearly how to accomplish things and to be rewarded for accomplishing them. Visual feedback such as this is important to user engagement specifically when the gameplay is aimed at beating a personal best (Bateman, 2009, p. 4).

Usability for end users was a clear goal of the application and user testing with Participant X provided invaluable insights into how someone who had suffered a stroke may interact with the system. Communication of the applications mechanics underwent significant revision as a result of participant feedback and observation. The calibration level lacked systematic integrity and the progression into the dance level was not logical. Altering elements such as the ordering of text and animation cues allowed the participant better comprehension of what they were expected to do (Nielson, 1995, p. 1).

Given its simplicity, the applications user flow required little revision. Adjustments to the soundtrack improved the pacing of the application and allowed the participant to engage more naturally. Games that use soundtrack to harmonize player actions and gameplay mechanics allow for more relatable and emotional connections (Bateman, 2009, 34). Introducing dance level mechanics on the calibration level made the transition smoother and gave the participant more time to assimilate the varying aspects of the application.

*ii. Gauge and compare new participant experiences to established methods.*

The lengthy setup of the prototype was a concern raised by the participant both as someone who was not familiar with the latest technology and as someone who lived alone and could not rely on assistance if something went wrong. It was explained that an aftermarket version of the system would ideally be optimized to a level of plug and play. The system would also be affordable as it already used the commercially available Kinect device and a final version would be compatible with most TV's or computer screens found in the average home. The participant agreed that provided the setup required minimal work and included some sort of clear and concise instruction sheet the system would be suitable for in home use. A study conducted into the use of in-home rehabilitation devices found a correlation between the user's level of impairment and the willingness to use a device, they concluded that the more impaired the user the more ergonomic the device needed to be (Mann, Hurren, & Tomita, 1993, p. 985).

The participant enjoyed using the application and if given another chance said she would use it again. The participant believed the strongest point of the application to be the use of the Kinect to drive the movements of the on screen avatar, she found the experience novel and engaging.

In contrast to the rehabilitative practises that the participant had experienced including but not limited to constraint induced therapy, task oriented exercises, stationary bike riding and a neurological choir, she found our application to be an innovative and relaxing way to perform rehabilitative exercises. Mental Practise (MP) has been shown to aid in stroke rehabilitation through the use of visual and audio techniques to help patients relax their muscles prior to commencing physical therapy (Page, 2005, p. 401).

**This research sought to answer the following questions:**

*"How can mirror therapy be combined with virtual reality to provide a rehabilitative experience for stroke survivors?"*

While a much smaller and less developed component of this research mirror therapy in a virtual medium was explored in the early prototypes of Groove Studio. A mirror was placed in the virtual world for the participant to look at and observe themselves completing the action. This was a very convoluted and ultimately redundant implementation of mirror therapy given that it wasn't innovative, merely a virtual version of real life mirror therapy. The integration of the simulation with a VR headset was never achieved but would likely have allowed for an implementation of mirror



therapy that was innovative and provided a novel user experience.
*"How can action observation therapy be combined with sensory devices to provide a rehabilitative experience for stroke survivors?"*

Action observation therapy constituted the primary focus of this research after mirror therapy and virtual reality were excluded for technical and practical reasons. The integration of the Kinect with a simulation produced in Unreal Engine 4 allowed for a unique take on action observation therapy. Using bright green avatars as "Guides" within the application, the participant could perform exercises alongside the green avatars looking to them for instruction. Participant X claimed that she spent most of her time consciously focusing on following the green avatars actions and not on whether her avatar was performing the exercises to completion. This interaction hit the primary psychology behind action observation therapy precisely and allowed the participant to consistently perform exercises without directly focusing on the physical effort required. With less focus on the physical contribution to the rehabilitation session It is hoped that the participant directed that energy to her brain, reforging and strengthening the neural connections associated with the actions she was performing.

To inform the design of the application Nielsen's ten user interface usability heuristics were applied to create an intuitive and ergonomic experience.

**Visibility of system status**

*The system should always keep users informed about what is going on, through appropriate feedback within reasonable time.*

This heuristic was applied in the design of our user interface and was a consideration behind the implementation of sound and particle effects. The primary goal of the game was for users to hit designated targets. Visual feedback for the successful hitting of a target was supplied through several methods. Animated white circles would activate at the point of contact with the target to give the user immediate feedback that they had entered the correct area. Sound effects were used to provide auditory feedback to further reinforce the completion of the action. A score meter on the bottom right of the screen made up the main component of the UI and would charge up and fill grey stars with gold to signify the completion of a repetition. A "+100" text asset would also appear on screen to further reinforce the completion of the action and to give the user a feeling of reward. Finally the green onion skin models on either side of the the user's avatar would come together in the middle of the screen and explode into green particles to further reinforce the completion of the action and to provide a transition into the next required action.

**Match between system and the real world**

*The system should speak the users' language, with words, phrases and concepts familiar to the user, rather than system-oriented terms. Follow real-world conventions, making information appear in a natural and logical order.*
This heuristic was primarily observed in the calibration level where users were instructed on exercises to perform. These instructions used simple english and were

timed so the user had ample time to read and perform each action before moving on. Introducing users to dance level mechanics in the calibration level created good, logical user flow.

**User control and freedom**

*Users often choose system functions by mistake and will need a clearly marked "emergency exit" to leave the unwanted state without having to go through an extended dialogue. Support undo and redo.*

The application does not support any undo/redo functionality however this heuristic was re interpreted and implemented through application fail safes. The user can not perform an action incorrectly, they can not fail. The system waits for the user to perform each action before it moves on and ensures that each of the actions are within the user's capabilities.

**Consistency and standards**

*Users should not have to wonder whether different words, situations, or actions mean the same thing. Follow platform conventions.*

The application is careful in its introduction of new gameplay mechanics and elements, ensuring consistency across all levels in instruction and visual feedback so that the user is never unsure of the purpose or requirements of an aspect of the game.

**Error prevention**

*Even better than good error messages is a careful design which prevents a problem from occurring in the first place. Either eliminate error-prone conditions or check for them and present users with a confirmation option before they commit to the action.*

This heuristic was initially applied in the application fail safes but was further explored in user testing when points of friction were discovered. Alterations to the application such as giving the green onion skin models T poses eliminated the possibility of the user assuming incorrect positions.

**Recognition rather than recall**

*Minimize the user's memory load by making objects, actions, and options visible. The user should not have to remember information from one part of the dialogue to another. Instructions for use of the system should be visible or easily retrievable whenever appropriate.*

The game's aesthetic is simple and steps were taken to ensure there was no visually confusing elements to the experience. Plain white circle targets and a clear user interface were implemented to provide the user with clear static instruction on their progress within the game. Visual effects such as particles and lighting were kept to a minimum so as not to distract the user from objectives.



**Flexibility and efficiency of use**

*Accelerators -- unseen by the novice user -- may often speed up the interaction for the expert user such that the system can cater to both inexperienced and experienced users. Allow users to tailor frequent actions.*

This heuristic was reinterpreted as user tailored experiences. The calibration level allows the application to adjust its difficulty to suit the capability of the user. This means a user with poor range of motion or strength in their arm can experience the application and perform exercises at the same level of progression and difficulty as someone who has comparatively good range of motion or strength in their arm.

**Aesthetic and minimalist design**

*Dialogues should not contain information which is irrelevant or rarely needed. Every extra unit of information in a dialogue competes with the relevant units of information and diminishes their relative visibility.*

The application considered this heuristic in all its aesthetic development. Text prompts were kept clear and concise, universally recognized symbols were used for menu and heads up display (HUD) elements. Particle effects within the game were refined to appear subtle and music and sound effects were chosen carefully to ensure clear auditory feedback without being annoying.

**Help users recognize, diagnose, and recover from errors**

*Error messages should be expressed in plain language (no codes), precisely indicate the problem, and constructively suggest a solution.*

This heuristic was not explored in depth due to the game removal of failure mechanics. Guide trails were an early concept that got left behind in an effort to keep the gameplay from being too visually confusing. The trail's showed the path that the users arms were moving in and could change colour to show the user if they were performing the exercise within the recommended margins.

**Help and documentation**

*Even though it is better if the system can be used without documentation, it may be necessary to provide help and documentation. Any such information should be easy to search, focused on the user's task, list concrete steps to be carried out, and not be too large.*

In its prototype state the application had very little in the way of documentation. The proposed aftermarket version of the application would include industry standard troubleshooting and setup guides to ensure an easy user experience.

# Discussion

Stroke rehabilitation is a complex field of study that owes much of its development to new and innovative technologies. The aftermath of a stroke can be very debilitating, making the return to full health a mentally taxing and physically exhausting task. This research sought to investigate ways that existing emerging techniques could be combined with innovative technology to create a rehabilitative experience. This experience was focused on providing the same or greater benefits than that of traditional methods while eliminating the laborious and uninteresting qualities so often associated with them.

Groove Studio combined the Microsoft Kinect with a virtual game engine to create an experience that promoted the performance of physiotherapy exercises while engaging the user in a video game environment. The requirement for repeated action over an extended period of time meant the application had to exemplify replayability, ease of use and an aesthetic experience that could immerse the user and mask the feeling of rehabilitation with fun.

Besides the obvious aesthetic and content improvements, this application would benefit from integration with direct brain monitoring technology to either aid in providing the application with input data or to monitor whether the split attention between the participant's avatar and the green avatars created increased activity in the mirror neuron system. This application would further benefit from a quantitative study of participant interaction to determine how much the application could aid in the recovery of range of motion, strength and dexterity.  Features that didn't make it into the final prototype but showed promise in earlier stages would ideally be developed to a point of functional use and included in the application.

In conclusion this research set out to conduct a qualitative analysis of user experience with a integration of emerging stroke therapy techniques and innovative technology. The produced application used commercially available technology in an effort to give the application feasibility for in home use. A series of user tests revealed the applications strengths, weakness and potential. This research has produced criteria for exploring games using action observation further with more advanced technology and further innovation in integration.

# Appendix





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## Glossary

UE4 - Unreal Engine 4 is a game development engine produced by Epic Games
Kinect 2 - A sensory device produced by Microsoft
PT - Physiotherapy
OT - Occupational Therapy
SLP - Speech Language Pathology
UI - User Interface
MP - Mental Practise