MIRRVR

The design of a fully immersive virtual reality game for upper limb rehabilitation post-stroke using mirror therapy

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Mirror VR: The design of a fully immersive virtual reality game for upper limb rehabilitation post-stroke using mirror therapy

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Abstract

Motor rehabilitation post-stroke requires practice that is high-intensity, repetitive, task-specific, challenging, and goal-oriented to promote neuroplasticity to maximise functional recovery outcomes. There is concern that people with stroke (PwS) are not engaging in sufficient therapy dose to induce significant neuroplastic changes. PwS can utilise motor priming techniques, such as mirror therapy (MT), that are low-cost adjuncts to conventional physical rehabilitation proposed to induce neuroplasticity. However, the repetitive and perceived boring elements of conventional physical therapy exercises are potential reasons for low adherence in home-based independent rehabilitation. Interactive rehabilitation-focused video games have shown initial promise for facilitating engagement in rehabilitation. Virtual reality (VR) games focus on movement and promote increased immersion in virtual environments compared to 2D interfaces. The recent emergence of low-cost and standalone consumer-based VR headsets opens the accessibility of VR to new audiences. VR, in combination with interactive gaming, affords opportunities to extend the visual and proprioceptive feedback employed in MT and use gamification to facilitate engagement in rehabilitation.

This thesis involved the design of a fully immersive VR game based on MT. The research comprised three stages: empathic design through a design thinking workshop, iterative prototyping, and expert review of game design with clinicians. A design thinking workshop involving PwS and stroke rehabilitation experts informed the construction of design criteria for the game. Research through design, using the design criteria, was conducted iteratively. An expert review by clinicians evaluated the potential usability of the game as well as validated the game against our design criteria. VR enhanced the visual illusion employed in mirror therapy and could provide an immersive and novel self-management tool for PwS to positively engage with their rehabilitation. Future directions will include testing how VR could facilitate engagement in rehabilitation through qualitative and quantitative analysis of the user testing with PwS.

List of Abbreviations

Abbreviation	Term
HMD	Head-mounted display
HCD	Human-centred design
IMI	Intrinsic motivation inventory
MT	Mirror therapy
SUS	System usability scale
PwS	People with stroke
UI	User interface
VR	Virtual reality

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Chapter 1
Introduction

1.1. Stroke

Stroke is a brain injury and a significant cause of serious adult disability in New Zealand. About 9000 New Zealanders suffer a stroke each year (Hogan & Siddharth, 2018, p. i). Stroke primarily affects the elderly, with one in twelve people over the age of 75 suffering from stroke (Ministry of Health, 2015, p. 23). According to the 2016 Global Burden of Disease Study, it is the second most common cause of Disability Adjusted Life Years, and there were estimated to be more than 80 million people with stroke (PwS) (Johnson et al., 2019, p. 452).

People with stroke are likely to suffer from sensory, perceptual, cognitive, and motor impairments depending on the regions of the brain-damaged (Teasell & Hussein, 2018). Damage to the primary motor cortex on one side of the body leads to motor impairments on the opposite side of the body, including hemiparesis (muscle weakness) or hemiplegia (paralysis) (Aqueveque et al., 2017). Motor impairments lead to reduced balance, loss of fine motor control, and learned non-use of the upper and lower limbs, which can drastically impact activities of daily living.

Motor rehabilitation post-stroke requires exercises that are high-intensity, repetitive, task-specific, challenging, and goal-oriented to engage neuroplasticity to maximise functional recovery outcomes (Teasell et al., 2018). Neuroplasticity refers to the brain's ability to reorganise neural pathways (Sasmita et al., 2018). Motor priming techniques can facilitate neuroplasticity by activating the brain before training to create an environment more responsive to accompanying training.

1.2. Motor Priming and Mirror Therapy

Motor priming promotes behavioural change based on a previous stimulus (Stoykov & Madhavan, 2015). If the brain is in a state of activation (primed), it is more responsive to accompanying training. Healthy adults who carried out mirrored symmetrical movements with both hands (motor priming) before subsequent motor training showed enhanced motor learning (Byblow et al., 2012). PwS can utilise motor priming techniques as an adjunct to conventional physical therapy when they cannot use their affected upper limb (Deconinck et al., 2015). Mirror therapy (MT) is a priming technique that utilises a visual stimulus of movement followed by accompanying training (Ramachandran & Rogers-Ramachandran, 1996; Stoykov & Madhavan, 2015).

Mirror therapy (MT) leverages the brain regions involved in motor planning and intention to move, to prime the primary motor cortex (Deconinck et al., 2015). In MT, patients view the reflection of their unaffected limb performing exercises in a mirror, while a mirror blocks their affected from view (Figure 1.1). The illusion tricks their brain into thinking their affected limb is moving symmetrically and synchronously with their unaffected limb. This illusion capitalises on the brain's preference for visual feedback over proprioceptive and somatosensory feedback about limb position in space (Lamont et al., 2011, p. 370).

A Cochrane Review concluded that MT was effective for improving motor function after stroke when used as an adjunct to conventional physical therapy if the patient was unable to fully use their affected limb (Thieme et al., 2018). However, there are a variety of implementations of MT including moving only the unaffected limb, moving both limbs synchronously, or having movement of the affected limb supported by a therapist (Rothgangel & Braun, 2013). Also, MT is limited by the participant's ability to experience the illusion due to inter-individual variability (Brunetti et al., 2015). Brunetti et al. (2015) conducted a study to find potential determinants of response to MT in PwS. People who had a certain degree of initial motor function in their hands or showed positive activity shift in the precuneus, a brain region involved in self-body representation, were shown to be more responsive to MT, compared to those with poor initial motor function or a negative activity shift of the precuneus. For these non-responders, digital solutions like virtual reality (VR) may be able to enhance the visual feedback needed to create the illusion.

Figure 1.1. Mirror therapy. The left affected limb is hidden from view behind a mirror, or in a mirror box, while the person watches movements made by the right unaffected limb in the mirror to create the illusion of their affected limb moving.

1.3. Engagement in Rehabilitation

There is concern that people with stroke are not engaging in a sufficient therapy dose to induce neuroplastic changes. Lang et al. (2009) conducted an observational study of 312 therapy sessions for PwS at inpatient and outpatient rehabilitation sites and recorded movement practice and number of repetitions. They observed that PwS practised 32 repetitions on average daily for a given upper limb movement, which is insufficient compared to the hundreds of repetitions suggested to drive lasting neuroplastic changes (Lang et al., 2009, p. 1692). To complicate this issue further, Miller (2017) reported low adherence to post-stroke rehabilitation at home. This cross-sectional study of 55 PwS found that of the 89% that received a home exercise program, approximately 65% reported adhering to their program (Miller et al., 2017). One of the most reported reasons for non-adherence was that prescribed exercises were painful or boring. There is a lack of research exploring boredom in stroke rehabilitation and how to design rehabilitation programs to avoid boredom (Kenah et al., 2018, p. 2720).

Video games are accessible and engaging and have proliferated in terms of reach and demographics. The American Association of Retired Persons and Entertainment Software Association conducted a survey of American adults over the age of 50 (Anderson, 2016). They found four in ten owned a games system that they used at least once a month. Games have evolved to cater to many different purposes beyond entertainment, for example, serious games for physical exercise or cognitive challenge (Deterding et al., 2011, p. 10). Games have been used to allow therapy-relevant movements to be practised in the context of immersive and enjoyable games to facilitate engagement in rehabilitation (Lohse et al., 2013). Therefore, this thesis investigated the design of an immersive VR game based on MT to support stroke rehabilitation.

1.4. Thesis Overview

How might the design of an immersive virtual reality game based on mirror therapy facilitate engagement in upper limb rehabilitation post-stroke?

Chapter 2 (Literature Review) explores and critically reviews the literature and design precedents to position the research project within the body of knowledge.

Chapter 3 (Methodology) discusses the research methodology and outlines the key aims and objectives mapped to the methods used to achieve them.

Chapter 4 (Design Workshop) outlines the findings of a design thinking workshop conducted with people with stroke and stroke rehabilitation experts. Discusses the construction of themes for the VR game that formed the basis for design criteria.

Chapter 5 (Design Process) documents the iterative design process from concepts to a testable VR game informed by design criteria.

Chapter 6 (Expert Review) discusses how the game design met the design criteria by validating the game with clinicians through expert review of designs.

Chapter 7 (Design Output) produces the final VR game based on design suggestions from the expert review.

Chapter 8 (Discussion) is a critical evaluation of the project in terms of the research question, design criteria, limitations of the design process, and future directions.

Chapter 9 (Conclusion) summarises the findings from the research.

Chapter 2
Literature Review

Virtual reality-based therapies are an emerging support tool for stroke rehabilitation. VR in combination with interactive gaming affords opportunities to extend the visual and proprioceptive feedback employed in neurorehabilitation motor priming techniques and facilitate engagement to participate in rehabilitation (Laver et al., 2017; Rizzo & Kim, 2005). VR presents the opportunity for virtual limbs controlled by a patient's limbs to be visualised in an immersive virtual environment, to mimic the concepts used in MT. Immersive VR involves the presentation of an artificial environment that replaces the users' real-world surroundings using a head-mounted display (HMD). The design of virtual environments convinces the user to suspend disbelief and fully engage with the created environment. Additionally, a gamification framework used in a rehabilitation context can be a powerful way to positively reinforce PwS to carry out their prescribed therapy (Deterding et al., 2011).

There is a growing body of evidence that immersive virtual environments employing interactive games may provide a promising tool in post-stroke neurorehabilitation (Demers et al., 2018; Laver et al., 2017; Palma et al., 2017). However, there is debate as to whether VR-based MT provides enough value over conventional MT to justify the cost and technical requirements of VR (Darbois et al., 2018). A Cochrane Review on mostly non-immersive VR for stroke rehabilitation reported that VR is no more effective than conventional rehabilitation in terms of functional outcome (Laver et al., 2017). However, this review also reported a significant benefit when VR was an adjunct to conventional rehabilitation. Also, there was no subgroup analysis conducted on non-immersive versus fully immersive VR (Laver et al., 2017, p. 25). A recent pilot study showed that immersive VR-based MT was well-tolerated by chronic stroke patients, which provides preliminary evidence for its feasibility and safety (Weber et al., 2019). Therefore, studies on the potential of fully immersive VR to facilitate engagement and therapy dose as an adjunct are required. This review outlines current research into VR-based upper limb rehabilitation for stroke, analyses design precedents of VR applications based on the motor priming techniques and highlights the opportunities for immersive VR-based rehabilitation to facilitate engagement. The review identified immersion and presence, and gamification of rehabilitation as themes to support the use of a VR game in upper limb rehabilitation post-stroke. These themes formed a game design strategy for a VR game to support upper limb stroke rehabilitation.

2.1. Immersion and Presence

Immersive VR can increase immersion and enhance presence in mirror therapy by overcoming the spatial and creative limitations of the conventional mirror box. Immersion is dependent on the technology that creates the virtual environment and the level of immersion influences the presence, which is the perception of being physically present in a virtual environment (Slater & Sanchez-Vives, 2016). A difficulty that arises in the literature is a loose definition of the term 'virtual reality'. VR becomes more immersive as the virtual environment takes up more of the user's field of view.

Figure 2.1. The Shapes and Rhythm prototype. Players move their left hand to the rhythm of the music to match hand gestures represented in the virtual environment, while their right-hand remains still. Reproduced from "Mirror Therapy, Reinvented: PreviewLabs at De Krook" by H. Geeroms with photo by H. Demeulemeester, 2017, Retrieved from September 4, 2019, from http://previewlabs.com/mirror-therapy-previewlabs/. Copyright 2019 by PreviewLabs. Reproduced with permission.

Immersive VR requires a head-mounted display (HMD) to replace the users' real-world surroundings. HMDs provide the user with continuity in their virtual environment that, in turn, enhances presence. In MT, the physical constraints of the mirror box require the patient to maintain the reflected image of their non-paretic limb in the mirror at all times to perceive the illusion, which limits the possible range of movements (Murray, 2009). However, in fully immersive VR-based MT using HMDs and sensors for hand tracking the patient can freely rotate their head and move their virtual limbs. Examples include the Shapes and Rhythm prototype (Figure 2.1) and Rewellio (Figure 2.2) (Demeulemeester & Geeroms, 2017; Rewellio GmbH, 2018). Therefore, HMDs increase immersion beyond the conventional mirror box through the creation of virtual environments and representations of the body, which are not constrained in the physical world, extending the types of exercises and movements that are possible.

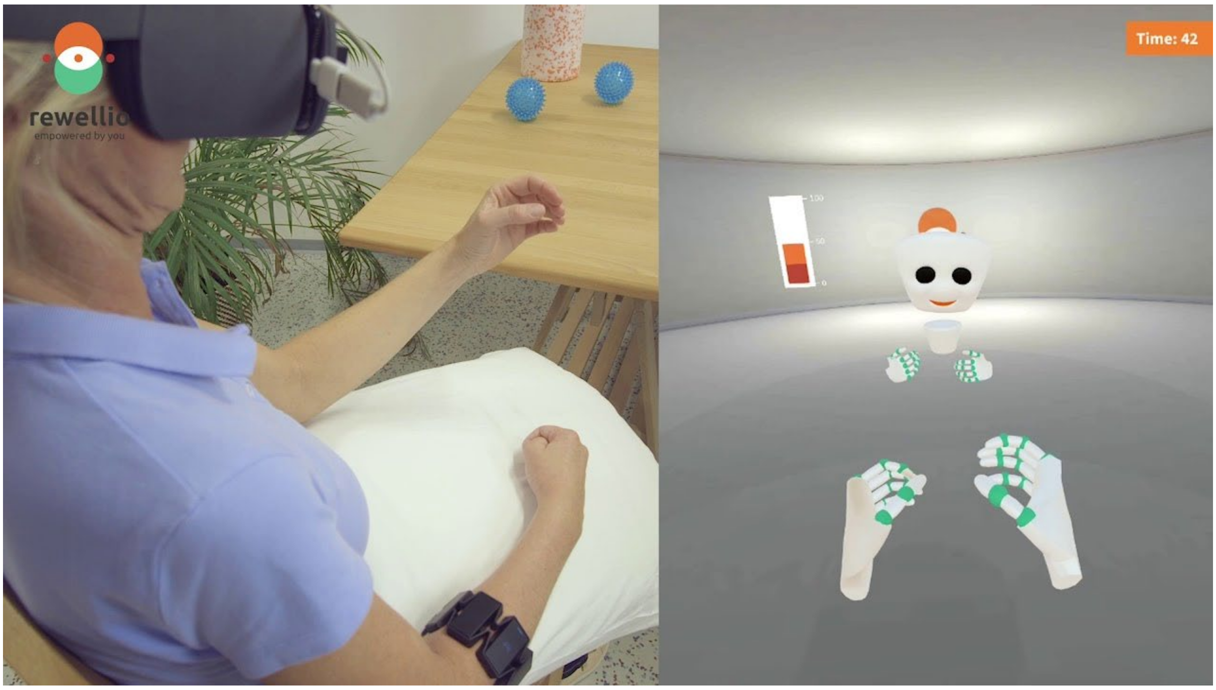

Figure 2.2. Rewellio's VR stroke therapy software. In addition to mirroring the non-paretic movement, an electromyography biofeedback monitor on the paretic arm detects small movements and visualises them onto the virtual representation of the affected hand. Reproduced from "Virtual Reality (VR) and Rewellio's innovative stroke therapy software" by Rewellio GmbH, 2019, Retrieved June 1, 2019, from https://www.youtube.com/watch?v=y3tWWIVG0zA. Copyright 2019 by Rewellio GmbH. Reproduced with permission.

The embodiment in VR-based therapies is facilitated by tracking hand movements and visualising movement superimposed onto virtual hands. Embodiment illusion refers to the patient transferring their perceived body image onto a virtual avatar (Slater & Sanchez-Vives, 2016). Schüler, Santos, and Hoermann (2015) propose that patients also need to be able to identify with movements that are visualised by the virtual body in the virtual world. The Augmented Reflection Technology (Figure 2.3), uses video capture of a patient's hands performing exercises and projects this movement on a video display as the opposite limb (Hoermann et al., 2017). Two randomised control trials comparing this system with the conventional mirror box on healthy subjects highlighted that using realistic representations of the users own hand lead to an increased mirror illusion and similar perceived ownership of the virtually mirrored limb respectively (Hoermann et al., 2012; Regenbrecht et al., 2011). In both studies, participants were not blind to which type of mirror box they were using, which could lead to bias towards the VR-based MT over the mirror box. They also used a monitor-based VR fixed in the physical space, which would lead to spatial limitations similar to the mirror box. Nonetheless, the studies show that having realistic tracking of hand movements and realistic graphical representations of the hand facilitate embodiment.

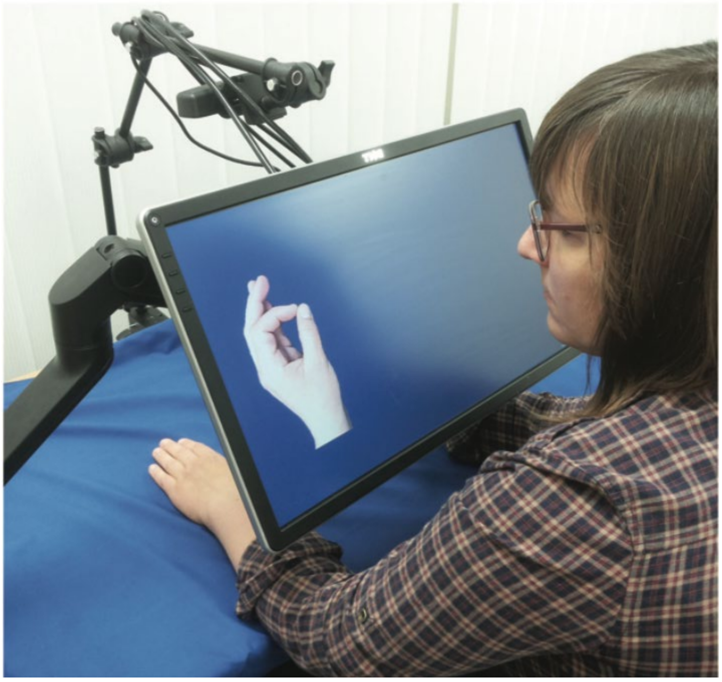

Figure 2.3. Augmented reflection technology system showing the mirror functionality for a person with an impairment on the left side: the unimpaired right hand is mirrored to the left side of the screen. Reproduced from "Computerised MT with Augmented Reflection Technology for early stroke rehabilitation: clinical feasibility and integration as an adjunct therapy," by S. Hoermann et al., 2017, Disability and Rehabilitation, 39(15), p. 1505. Copyright 2017 by Taylor & Francis Group, www.tandfonline.com. Reproduced with permission.

Virtual environments can simulate realistic environments and tasks. Through context information, these environments can utilise elements and interactions which are plausible, achievable, and based on real-world functional behaviours to aid in rehabilitation and motor learning (Rizzo & Kim, 2005; Schüler et al., 2015). In the instance of stroke rehabilitation, standardised exercise movements used in conventional physical rehabilitation should form the basis for these interactions. However, VR also allows designing abstract or imaginative solutions to extend exercises to enhance patient motivation to engage in their rehabilitation programme. Therefore, providing gamified rehabilitation as a supplement to conventional rehabilitation may increase the dosage of therapy-relevant movements by integrating these movements into a fully immersive and interactive environment.

2.2. Gamification of Rehabilitation

Conventional rehabilitation can make use of serious games using gamification techniques to engage and motivate people. Gamification refers to the process of applying elements of game design principles and mechanics in a non-gaming context to enhance the players' motivation and engagement in the task (Deterding et al., 2011). Elements of gamification that may be useful in a rehabilitation context include progressive difficulty levels to provide a challenge and monitoring patient progress through point scoring to provide feedback (Afyouni et al., 2017; Schüler et al., 2015).

Utilising a gamification framework in a rehabilitation context could positively reinforce and potentially motivate patients to engage in their prescribed exercise therapy.

Sustained engagement in rehabilitation requires motivation. Engagement "*is a cognitive and affective quality or experience of a user during an activity*" (Rohrbach et al., 2019, p. 3) and motivation "*encourages action toward a goal by eliciting and/or sustaining goal-directed behaviour*" (Rohrbach et al., 2019, p. 3). In psychology, intrinsic motivation refers to doing something because it is inherently interesting or enjoyable, while extrinsic motivation is reward-driven (Deci & Ryan, 2000). To maintain a high level of intrinsic motivation requires elements such as competence, valuing the importance of the task and autonomy over choices. In contrast, extrinsic motivation relies on doing something because it leads to external rewards. Although extrinsic motivation may lead to short term engagement, it is more beneficial to focus on intrinsic motivation to facilitate engagement over a sustained period.

Human-computer interaction provides a model for sustained engagement with technology. Engagement with a device has four stages: the point of engagement, engagement, disengagement, and re-engagement (Lohse et al., 2013). The reinforcing nature of games could promote the initiation of engagement and re-engagement in gamified rehabilitation to avoid patient non-adherence to home-based exercise (Miller et al., 2017). The Information-Motivation-Strategy (IMS) model is a heuristic model designed to improve patient adherence to treatment (DiMatteo et al., 2012). The motivation component is derived from the Health Belief Model, which argues that to motivate people to adhere to their rehabilitation, they must believe in the efficacy of the intervention. Therefore, gamified systems must have their efficacy validated to promote sustained engagement.

Conventional rehabilitation requires repetitive and high-intensity exercises for people to regain functional independence. Randomised control studies using monitor-based VR games combined with conventional physical therapy have claimed to speed up functional recovery in acute and subacute stroke patients compared to conventional therapy alone (da Silva Cameirão et al., 2011; Wang et al., 2017). Da Silva Cameirão et al. (2011) used the Rehabilitation Gaming System (SPECS-lab, 2020), which adapts difficulty progressively by reducing the amount of assistance provided to the player's movements as the patient repeats tasks successfully in-game (Figure 2.4). VR training games can use creative and engaging tasks to target different movements and motor skills, for example, a ball swatting game to train gross motor skills (da Silva Cameirão et al., 2011) or a flower petal-picking game for fine motor skills and dexterity (Wang et al., 2017). VR-based training allows for exercises to be delivered in a variety of creative ways, at a range of difficulty levels, and to adapt to patient needs in real-time (Afyouni et al., 2017; Rizzo & Kim, 2005). Although monitor-based VR used in the Rehabilitation Gaming System is less immersive than HMDs, the game highlights how VR-based therapies can utilise the repetitiveness of conventional rehabilitation to its advantage to provide a scaling level of difficulty. Challenging exercises that increase exercise intensity and provide valuable feedback on progress could facilitate engagement in rehabilitation.

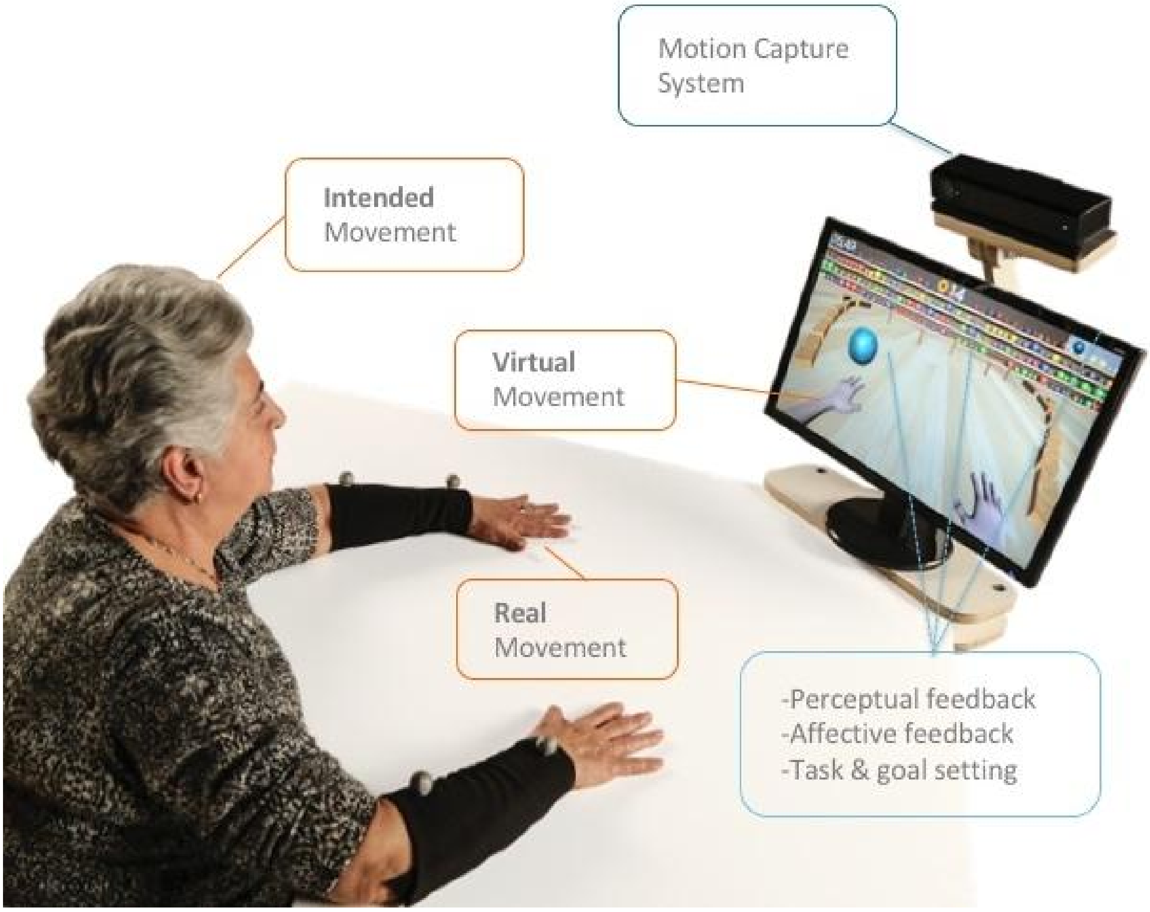

Figure 2.4. The Rehabilitation Gaming System. A clinically validated tool for upper limb rehabilitation post-stroke that monitors patient performance in task-oriented games. Reproduced from "NeuroRehabilitation" by SPECS-lab, 2019, Retrieved September 4, 2019, from https://specs-lab.com/portfolio-items/neuro-rehabilitation/. Copyright 2020 by SPECS-lab. Reproduced with permission.

Game design uses a set of fundamental principles such as interactivity, goals, challenges, and rewards. These principles are essential when designing games and experiences for rehabilitation. Barrett et al. (2016) highlight meaningful play/feedback, goals/rewards, and challenge/difficulty as shared game design principles for commercial and rehabilitation-focused games. Lohse et al. (2013) found six factors for understanding the engaging nature of video games: feedback, reward, challenge/difficulty, choice/interactivity, clear goals and mechanics, and socialisation. The principles of feedback, challenging activities and clear goals align the principles identified by Barrett et al. (2016). The following sections outline these game design principles and how they could be used to facilitate engagement in rehabilitation.

2.2.1. Feedback

Good quality patient performance feedback could facilitate sustained engagement. Feedback involves the immediate outcomes of the player's actions as well as on-screen progress identifiers, such as game scores, show progress towards a goal, or objective (Lohse et al., 2013). VR-based games can monitor and quantify patient performance to track therapy progression and help set therapy goals. The Rewellio (Figure 2.2) and Rehabilitation Gaming System (Figure 2.4) collect data from each therapy session to help guide and optimise the patient's future therapy sessions to enhance recovery (da Silva Cameirão et al., 2011; Rewellio GmbH, 2018; SPECS-lab, 2020). Afyouni et al. (2017) found through questionnaires that clinicians rated the ability to see real-time metrics to monitor patient performance and progress as a core strength of their VR game, while patients felt the main strengths of the game were its ability to keep them engaged in their exercises. The adaptive algorithm used in the game kept them motivated and challenged. A strength of technologies like VR and motion capture sensors used in these games is the capability to capture a digital record of motor performance (Rizzo & Kim, 2005). This data could assist clinicians in setting realistic and achievable goals for their patients. People are more likely to modify their behaviour to rehabilitation when they get valuable feedback on their therapy progress (MacDonald et al., 2013, p. 120). Clear feedback that aligns with the goals set by clinicians will likely lead to greater acceptance of the VR game and be a motivator for patients to engage in continued rehabilitation.

2.2.2. Clear Goals

Goal setting is a fundamental aspect of rehabilitation. Clinicians set rehabilitation interventions with specific goals focusing on the overall outcome of functional independence and recovery (MacDonald et al., 2013; Plant et al., 2016). Games set goals via the achievement of tasks, which can be as simple as completing a level or improving your score (Gilbert, 2016). These goals are effective because they are clear and meaningful in the game context. Salen and Zimmerman (2003) define meaningful play as occurring "*when the relationship between actions and outcomes in a game are both discernable and integrated into the larger context of a game* (p. 316)". Aligning the goals of the game with the goals of the player creates meaning for the player. Maclean et al. (2000) reported that unclear goals had a detrimental impact on patient recovery. Furthermore, more personally relevant goals based on mutual understanding between the patient and clinician lead to better engagement (MacDonald et al., 2013). Therefore, games for rehabilitation must be adaptive and align with a variety of patient goals and needs by providing players with a variety of choices. Choice in game design can refer to the variety of games available, the ways to complete a task or the level of difficulty. Providing players with interactive choices empower the player to determine their level of interaction. Chen (2007) advises that embedding adaptive choices inside the core interactions of games, ensures that users have the potential to enjoy the experience at their own pace without overwhelming the player with too many choices. Therefore, by clearly defining the interactions and tasks in the game, the player has tangible goals to achieve success. By providing a clear context for how the game translates into therapy goals, the player will likely be more accepting of engaging with the adjunctive virtual therapy.

2.2.3. Challenging Activities

Finding the balance between challenge and skill motivates the player to engage with and enjoy a game. The concept of 'Flow' in positive psychology, developed by Czikszentmihalyi (1990), encapsulates this balance between challenge and ability. 'Flow' is the mental state of operation in which a person has "*complete and energised focus in an activity, with a high level of enjoyment and fulfilment*" (Chen, 2007, p. 31). Challenges deemed beyond the user's ability can generate anxiety. In contrast, if the challenge is non-existent, then the user becomes disengaged, bored, and will likely end the game. This delicate balance between challenge and ability to maintain a 'Flow' state is compounded by interindividual differences in what people consider challenging, as well as their ability to complete a task. Games can provide choices or customisation to cater to different skill levels and preferences and enable players to progress gradually through levels of difficulty at a self-directed pace. Difficulty can also adapt based on player performance, as shown in the Rehabilitation Gaming System (da Silva Cameirão et al., 2011). The clinician and PwS can select the appropriate starting difficulty, and the game adjusts as necessary based on individual performance and goals.

These three game principles outlined above can be combined with the immersion of VR to inform design strategies for VR games to facilitate engagement. A human-centred approach to designing VR-based therapy games may support the adoption of these technologies in the clinic and the home. Rizzo and Kim (2005) highlight that public perception for the use of VR as a therapeutic tool has been consistent. However, they caution that it is crucial to temper unrealistic expectations with well-executed applications. Proffitt and Lange (2015) suggest that human-centred design strategies should be employed with clinicians when developing VR games for rehabilitation due to their expertise on the parameters of effective therapy interventions such as dose and amount of clinician input. VR-based therapy designed with a human-centred approach will ensure the games are reflective of the PwS's needs and goals.

2.3. Conclusion

VR-based therapy for upper limb rehabilitation after stroke shows promise through the ability of the immersive technology to enhance the MT illusion and to use interactive gaming to support engagement. Based on the current research, a VR-based therapy game utilising immersive VR technology for output and realistic hand tracking as an input, will likely provide an effective combination to enhance presence and allow for accessible interactions in virtual environments. However, for VR to be widely used for therapy, further work is required in the exploratory phase of design research. Using human-centred design and a therapy-driven approach will hopefully lead to a better understanding of the feasibility of VR-based therapy for upper limb stroke rehabilitation. Primary research with PwS and clinicians will be essential to help establish best practices when designing VR-based therapies that will be accessible and well-adopted. The literature supports the application of immersive VR to extend the creative possibilities of MT and potentially provide an accessible entry point for those with severe impairment to visualise their affected hand movement. The literature has also shown that principles of video games such as challenging activities, clear goals, and feedback align with the elements of effective rehabilitation. The subsequent research aims to gain comprehensive insights into best design practices for VR in rehabilitation. The goal is to facilitate the illusion in MT with fully immersive VR and to explore how VR games can support engagement in stroke rehabilitation through gamification techniques.

Chapter 3
Methodology

The research used a human-centred design (HCD) framework (Giacomin, 2014). HCD is an iterative methodology consisting of methods such as observations, ideation, rapid prototyping, and testing (Norman & Verganti, 2013). This research project consisted of three phases:

1. Empathic design through a design thinking workshop with people with stroke (PwS) and stroke rehabilitation experts, and VR usability testing with a single PwS
2. Research through the design of iterative prototypes of a VR game based on design criteria
3. Expert review of designs with clinicians to inform design changes

There was flexibility for the phases to overlap and run in parallel. The research allowed for a combination of design research methods that aimed to include PwS and clinicians as part of the design process as much as was feasible. This inclusive design process was essential as this game was for people with specific needs and limitations.

3.1. Research Question

How might the design of an immersive virtual reality game based on mirror therapy facilitate engagement in upper limb rehabilitation post-stroke?

3.2. Empathic Design: Empathise and Define

Empathic design involves engaging with the target audience early on without assumptions of a design solution (Skogsrød, 2014). Empathic design advocates for the designer to take a more active role within HCD by using design methods to help end-users more easily express their needs in the initial stages of the project to gain new insights. The multi-disciplinary design thinking workshop with PwS and stroke rehabilitation experts used empathic design research to develop a shared understanding of attitudes, experiences, and expectations of assistive technologies for stroke rehabilitation (IDEO, 2019; Martin & Hanington, 2012, p. 129). The qualitative data collected was analysed through thematic analysis to synthesise and define areas of further exploration (Braun & Clarke, 2012). The constructed themes framed the development of design criteria for VR development. Design criteria were used to assess designs systematically, without compromising creative freedom (Rodríguez Ramírez, 2017). Early-on a usability test of the chosen VR headset was conducted with a single PwS. This test was an opportunity to observe the usability of the device and interview the participant on their experience (Martin & Hanington, 2012, p. 194). The combination of approaches in the early stages of the research ensured the needs and goals of PwS informed the design process.

3.3. Research Through Design: Ideation and Prototyping

Research through design created new knowledge through a series of design experiments, iterative prototyping, and technology exploration (Krogh et al., 2015). The ideation phase involved developing design concepts for the VR game as well as an exploration of the various software tools and technologies for VR development. Three low fidelity prototype VR experiences with varying implementations of the MT interaction were developed using comparative research through design (Krogh et al., 2015, p. 45; Martin & Hanington, 2012, p. 138). The design criteria provided a systematic way to assess the prototypes at various stages of development (Rodríguez Ramírez, 2017). A higher fidelity prototype combined successful elements of the low fidelity prototypes to be validated by clinicians to identify the feasibility and usability of the game for PwS (Privitera, 2019, p. 173).

3.4. Expert Review: Testing and Evaluation

Formative design evaluation of the prototype with clinicians, in the form of expert reviews, was used to develop a refined prototype. The initial aim was to test the VR experiences developed with representative users with a supervising clinician. However, due to the COVID-19 global pandemic, there was restricted access to PwS for usability testing due to their vulnerability. Therefore, the focus shifted to the formative evaluation of designs with clinicians. Expert reviews are conducted with a representative user to identify possible issues with the user interface of a design (Privitera, 2019, p. 173). Reviews validated the game in terms of its potential usability with PwS, the game design (visually and mechanically), and the gamification of exercises. Semi-structured interviews with clinicians contributed feedback and opinion on the prototype and the research topic (Martin & Hanington, 2012, p. 102). Qualitative data was assessed against our design criteria to refine the prototype. The System Usability Scale (SUS) and the Intrinsic Motivation Inventory (IMI), were conducted following the expert review as validated outcome measures (John, 1996, p. 189; Martin & Hanington, 2012, p. 140; Popović et al., 2014). This quantitative data provided a preliminary evaluation of the VR prototype for usability and engagement. The initial validation of the game ensured the feasibility for testing with PwS in the future.

3.5. Aim and Objectives

The design investigation considered the following aims & objectives mapped to specific methods:

Table 3.1. Aims and objectives mapped to design research methods

Aims	Objectives	Methods
Aim 1: To explore the potential for immersive VR-based mirror therapy to facilitate engagement in upper limb rehabilitation post-stroke	**1a:** Investigate current applications of VR-based mirror therapy within the context of stroke rehabilitation	**Literature and Design Precedent Review (Martin & Hanington, 2012, p. 112)**
	1b: Conduct design research with people with stroke and clinicians to identify their needs and interests to engage with VR-based upper limb rehabilitation	**Design Workshop/Participatory Design with PwS and Clinicians** (Martin & Hanington, 2012, p. 129)
		Expert Review of Concepts with Clinicians (Privitera, 2019, p. 173)
		Exploratory Usability Testing of VR Hardware with PwS (Martin & Hanington, 2012, p. 194)
	1c: Establish design criteria for a VR game for upper limb stroke rehabilitation	**Thematic Analysis** (Braun & Clarke, 2012)
		Design Criteria (Rodríguez Ramírez, 2017)
Aim 2: To design, develop and validate a series of prototype immersive VR-based games designed for people with stroke	**2a:** Iteratively design and develop a series of VR prototypes based on developed criteria using appropriate technology	**Prototyping** (Martin & Hanington, 2012, p. 138)
		Comparative Research Through Design (Krogh et al., 2015, p. 45)
	2b: Critically evaluate and validate a high-fidelity VR prototype game with clinicians	**Expert Review of Prototype with Clinicians** (Privitera, 2019, p. 173)
		Semi-structured interviews (Martin & Hanington, 2012, p. 102)
		Questionnaires/Outcome Measures (John, 1996, p. 189; Martin & Hanington, 2012, p. 140; Popović et al., 2014)

3.6. Participants

The research involved multiple sessions with participants throughout the design process. There are ethical considerations for involving a vulnerable population with disabilities. The Health and Disabilities Ethics Committee provided an out-of-scope letter for this research due to the Therapeutic Goods Administration classification of VR headsets as a Class 1 medical device (see Appendix A). Therefore, ethics approval was received from the Human Ethics Committee at Victoria University of Wellington (Ref: 0000027728) to conduct workshops, interviews, and user testing with PwS and stroke rehabilitation experts. COVID-19 restricted access to PwS for user testing of the game. The revised ethics protocol (Ref: 0000023011) allowed remote expert reviews of designs with clinicians in place of user testing with PwS.

3.6.1. Inclusion Criteria

3.6.1.1. People with Stroke

People with stroke (PwS) participated in the design thinking workshop (n = 4) and one PwS, absent from the workshop, tested the usability of the VR hardware before both the prototype development and COVID-19. The aim was to recruit PwS experiencing upper limb motor impairments. All the participants were PwS at the chronic stage (> 6 months post-stroke) who have hemiplegia or hemiparesis and are undergoing rehabilitation currently. Dr Nada Signal, our collaborator at Auckland University of Technology (AUT), recruited participants. AUT has a database of PwS who have participated in previous research and are willing to participate in clinical research. An email invitation was sent to the database, and participants were recruited from those who responded. Medical records were not accessed. The following inclusion and exclusion criteria helped to set a standard for screening participants to ensure they could safely participate in the research:

Inclusion Criteria:

- Aged > 18
- Greater than six months post-stroke
- Had experienced a stroke which impacts upper limb function

Exclusion Criteria:

- Significant cognitive deficit in the opinion of the screening physiotherapist
- Unable to follow a 1 step verbal command
- Unable to give informed consent
- Medically unsuitable in the opinion of the screening physiotherapist, G.P., or medical specialist; experiences excessive joint pain; suffering other conditions

that could impact results (e.g. substance abuse, significant mental illness such as major depression).
- History of significant motion sickness, active nausea and vomiting or epilepsy (VR specific)

3.6.1.2. Clinicians

Clinicians participated in the design thinking workshop (n = 5) prior to COVID-19 and expert reviews (n = 6) post-COVID-19. One clinician participated in both the workshop and expert review. For both activities, we aimed to recruit clinicians (physiotherapists and occupational therapists) who have experience working with PwS. Dr Nada Signal recruited clinicians at AUT through an email invitation. Two clinicians in the expert review were recruited by word-of-mouth through clinicians who participated. The following inclusion and exclusion criteria helped to set a standard for screening clinicians:

Inclusion Criteria:

- Aged > 18
- Qualified NZ physiotherapist or occupational therapist

Exclusion Criteria:

- Unable to give informed consent

Chapter 4

Design Thinking Workshop

The Smart Interactions design research team developed and conducted a design workshop over two days at Auckland University of Technology. Design thinking methods were conducted to gain a better understanding of the attitudes, experiences, and expectations of people with stroke (PwS) and stroke rehabilitation experts for assistive technologies to support stroke rehabilitation. The workshop was for two master's projects designing assistive technologies for stroke rehabilitation. The other project investigated the *'acceptability and design of a robotic device for upper limb rehabilitation'*. This workshop was only possible due to the collaboration of both projects to access such pivotal primary research. The following methods and analyses cover the aspects of the workshop relevant to the development of this thesis.

4.1. Goals

- Establish a user journey of PwS
- Construct themes for games to support stroke rehabilitation by consulting the target population of PwS and stroke rehabilitation experts
- Align themes with established game types to inform game design
- Establish design criteria for developing VR games for stroke rehabilitation

4.2. Participants

The workshop involved four PwS, five clinicians, and four engineers. All PwS were in the chronic stage of stroke. The clinicians were all trained physiotherapists and researchers at AUT with expertise in stroke rehabilitation and research. The engineers had expertise in developing games and devices for stroke rehabilitation through MedTechCore and Callaghan Innovation. Experts provided opinions on the delivery and development of assistive technologies for stroke rehabilitation that were essential to informing our design process. Seven out of the 13 participants were female. No other demographics about participants were collected.

4.3. Workshop Activities

The workshop involved four activities completed by three groups, each consisting of at least one PwS, one clinician, one engineer, and a designer facilitating the activities. Brief descriptions of the activities follow.

4.3.1. User Journey Map

User journey maps were used to understand how stroke rehabilitation was incorporated into the daily life of PwS (Endmann & Keßner, 2016). PwS and clinicians mapped out a typical day of a PwS based around three questions:

1. When you did rehabilitative exercise? (Rehabilitation)
2. When you had spare/leisure time? (Leisure)
3. When did you enjoy doing something? (Hobbies)

They filled out a card for each unique activity (see Appendix B) and placed them on a user journey map (see Figure 4.1). Each response required participants to indicate the location, duration of time spent, and variables that initiate (motivate) or stop (inhibit) an activity. PwS used their personal experience and experts used user personas (see Appendix C) for a motivated and unmotivated PwS (Pyae et al., 2013). User personas provide meaningful archetypes of people based on collective research to assess designs against (Martin & Hanington, 2012, p. 132). PwS recounted personal experiences in-depth, while clinicians captured a range of PwS experiences.

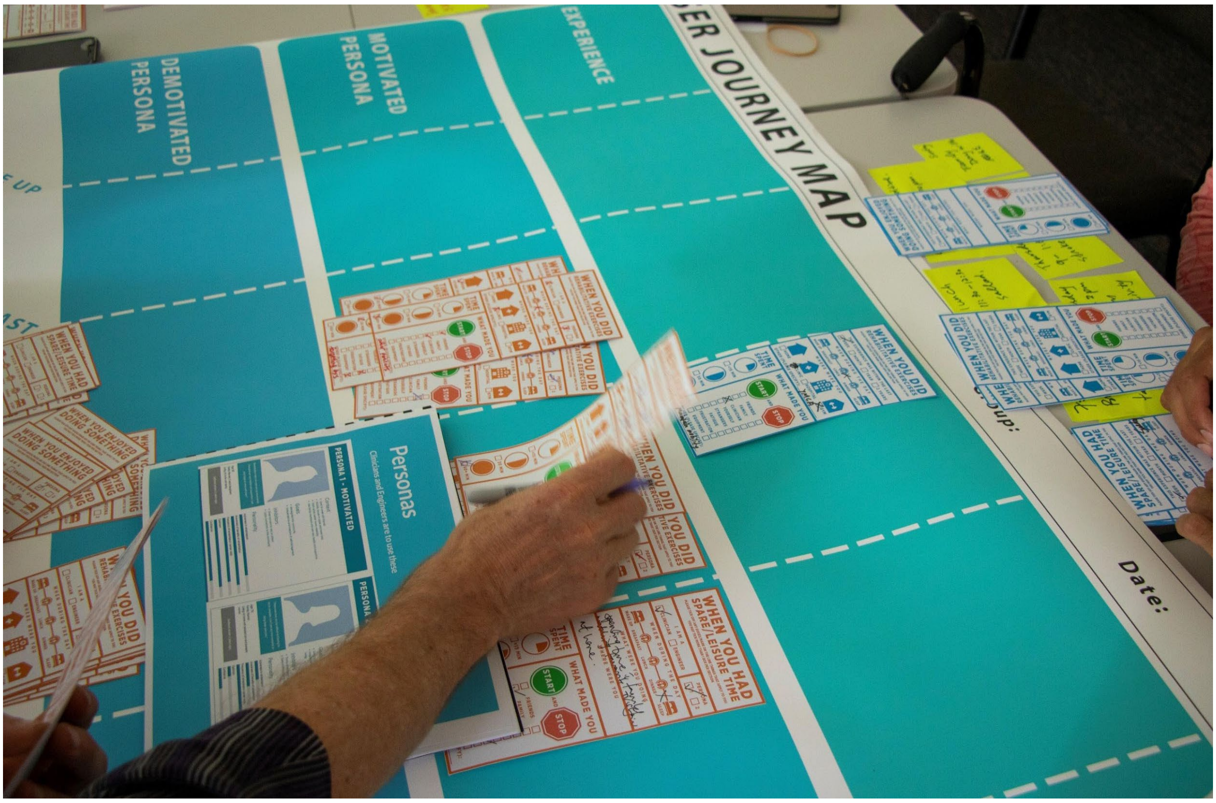

Figure 4.1. User journey map. Participants placed their cards in the relevant row.

4.3.2. Empathy Map

Empathy maps were used to gain insight into what mattered most to the target audience (Ferreira et al., 2015). For the empathy map, each participant responded to the prompt:

> *"Think of a time when you had a positive experience in a medical or rehabilitation setting."*

They organised their ideas into categories such as what they thought, did, saw, and heard during their personal experience. They also wrote down any challenges (pains) and the positives they took from their experience (gains). At the end of the first day, the research group conducted a thematic analysis of the empathy map responses constructed eight themes: *progress, simplicity, respect/trust, feedback, customisation, social connection, enjoyment,* and *motivation*. These themes were included in the subsequent card sort activity.

Figure 4.2. Empathy maps. Participants discussed their empathy maps.

4.3.2. Card Sort

The card sort consolidated themes from the empathy map with values we had identified in our research (Faiks & Hyland, 2000). Each group had 32 cards to sort into the most important two values for assistive technology for stroke rehabilitation. Twenty-four words were values researched from the consumer technology, assistive technology, and performance sports industries, and the remaining eight values were from the empathy map. Participants were blind to which themes had come from the empathy map. Each group progressively culled values in half until there were two values per group. The top six values were voted on by all participants to identify the top three values for the subsequent mood board activity. The three values determined were: *engagement, progress,* and *simplicity*.

Figure 4.3. Card sort. Participants organised values on the card sort template.

4.3.3. Mood Board

Mood boards were used to ascertain the types of games that appealed to the target audience (Cassidy, 2011). This activity aimed to align game types with the themes discovered from the previous activities, to inform the game design of our prototypes. Each group got a deck of 70 cards containing images of games, products, and interfaces. Forty of the seventy images were relevant to this project specifically. Groups were shown one image at a time and placed the image on the Venn Diagram under themes from the card sort activity: *engagement*, *progress*, and *simplicity*. If they could not agree on the placement, they placed the image in a liked or disliked category.

Figure 4.4. Mood board. Participants debated where to place images.

4.4. User Journey

The following sections analyse findings from the user journey map under three key themes:

1. Location of Rehabilitation
2. Duration of Activities
3. Motivators and Inhibitors for Activities

4.4.1. Location of activities

The home was the most common location for rehabilitation to occur (18 responses). The next closest was the gym with seven responses, followed by the clinic with six responses. On a typical day of the week, rehabilitation occurred more than twice as much at home than at the gym and clinic, respectively. This finding highlights the importance of designing the game to integrate within the home environment to facilitate independence, self-management, and engagement.

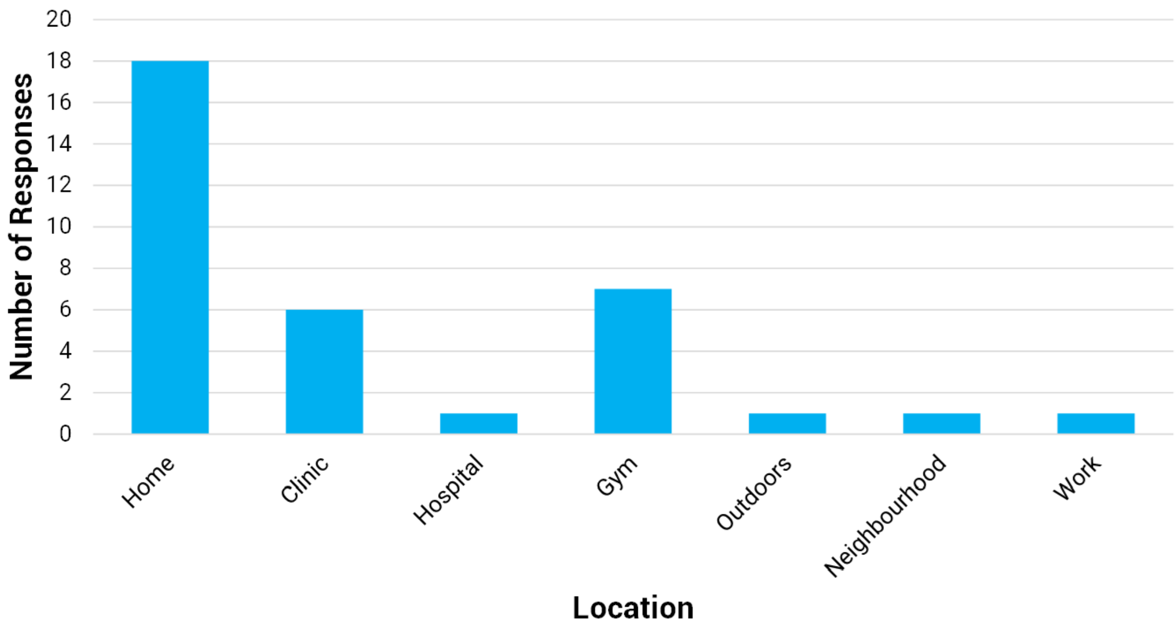

Figure 4.5. Frequency chart showing where stroke rehabilitation takes place

4.4.2. Duration of Activities

The PwS (n = 4) average self-reported time was 49 min of rehabilitation, while experts (n = 9) thought that motivated and unmotivated PwS spent less average time on rehabilitation (33 and 30 min respectively). There is insufficient data to identify whether the PwS are over-estimating their rehabilitation time, or the experts are under-estimating perceived rehabilitation time. The participants could represent highly motivated PwS.

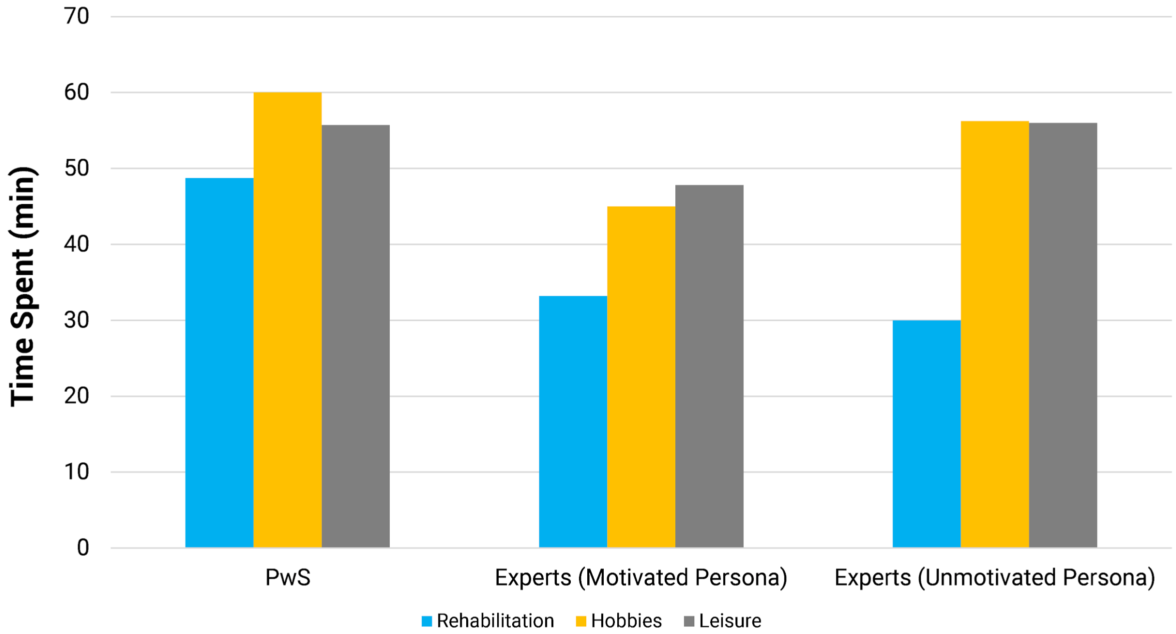

Figure 4.6. Mean reported time spent in minutes for PwS (n = 3) and experts using personas (n = 10) on rehabilitation, hobbies and spare time

The data was encouraging as the recommended time of a VR session is between 15 to 30 min, which fits within the time spent on rehabilitation of between 30 to 49 min. There is the opportunity to design the game to be incorporated into this rehabilitation time. There was minimal difference in the motivated and unmotivated personas in terms of rehabilitation time. However, experts' responses showed the unmotivated personas spent more time on average on hobbies and leisure time. A VR game could be used during this leisure time to extend the therapy dose for these unmotivated people.

4.4.3. Motivators and Inhibitors

The following figures separate the PwS (personal experiences) and experts (personas) for all activities (rehabilitation, hobbies, and leisure). There were more responses from the experts. Therefore, to compare each group, we looked at the percentage of total responses for each motivator or inhibitor.

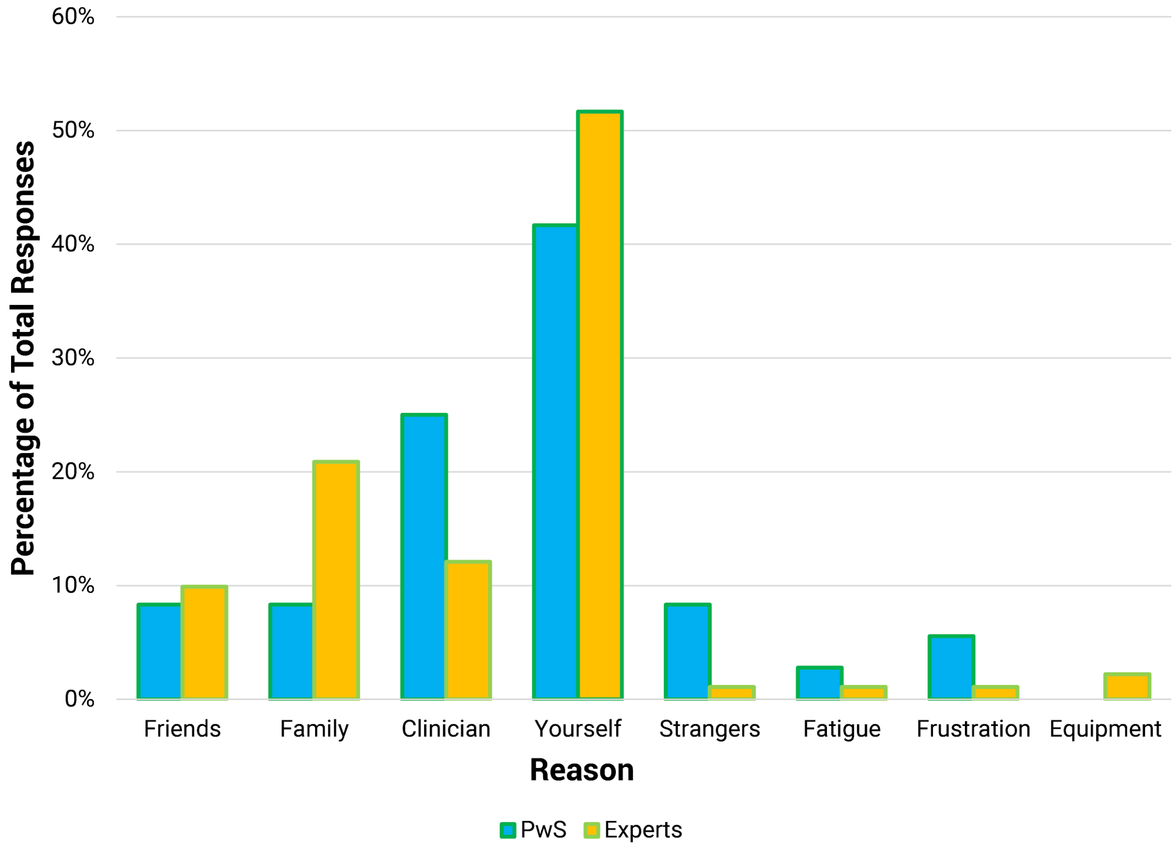

Figure 4.7. Main motivators for all activities for PwS (N = 36 responses) and experts using personas (N = 91 responses).

PwS and experts assigned 'yourself' as a critical motivator for doing activities (42% and 52% of responses respectively), while PwS saw 'clinicians' as more of a motivator (25%) than experts did (12%). The findings indicate that it is essential for clinicians to be involved in the use of any device to provide validation and to motivate PwS to engage with the device. The patient-clinician relationship is a crucial motivator for patients. Positive feedback and support from clinicians give PwS confidence that they are completing exercises correctly and to ensure they are progressing (Pyae et al., 2015, p. 103).

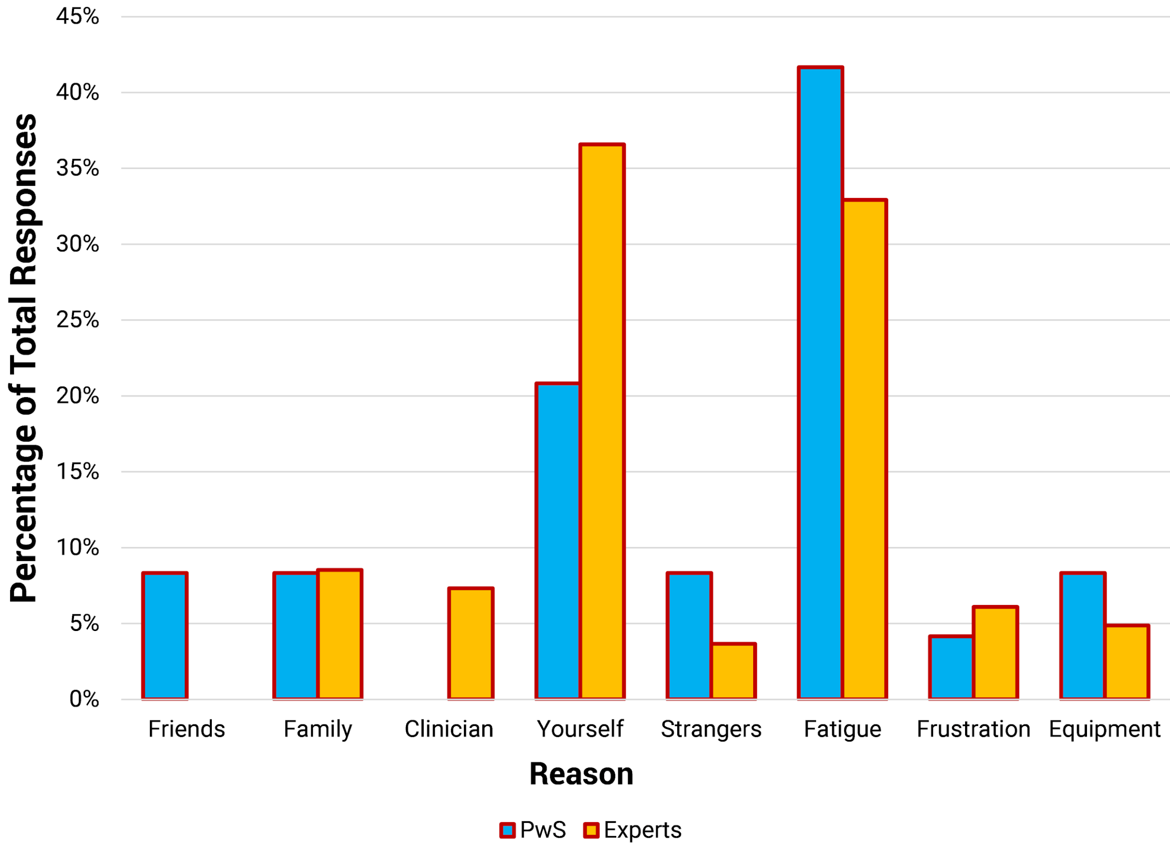

Figure 4.8. Main inhibitors for all activities for PwS (N = 24 responses) and experts using personas (N = 82 responses)

'Fatigue' was the biggest inhibitor of activities for both PwS and experts (42% and 36% respectively), while experts saw 'yourself' as more of an inhibitor (39%) compared to PwS (21%). Self-efficacy to start an activity aligns with the concept of intrinsic motivation, while external motivators include clinicians and family members. Therefore, a design opportunity is to involve clinicians and family members in the initiation of using a VR game. 'Yourself' and 'fatigue' were identified as inhibitors. These two inhibiting factors are likely dependent on each other. 'Fatigue' could refer to physical or mental fatigue. Physical fatigue is *"physically felt exhaustion, with coexisting symptoms such as bodily pain"* (Buunk et al., 2018, p. 1114). Mental fatigue is *"a sustained feeling of exhaustion, lack of energy and reduced initiative resulting from performing mentally demanding activities"* (Buunk et al., 2018, p. 1113). For rehabilitation, it is critical to increase physical activity and cognitive stimulation but to limit physical and mental fatigue (Gordon et al., 2004). Therefore, since low-level physical exercise is a possible way to lessen the impacts of fatigue, a VR game should target physical exertion without inducing cognitive overload.

4.5. Thematic Analysis

A thematic analysis was conducted after the workshop to construct themes in the data. Five key themes were constructed from the workshop activities and discussions following thematic analysis of the data:

1. Accessibility and simplicity
2. Communication and feedback
3. Engagement
4. Progress
5. Social connection and wellbeing

These themes and associated evidence from the workshop are discussed.

4.5.1. Accessibility and Simplicity

Accessibility involved ensuring that assistive tools retain simplicity. Participants wanted *“something relatable, and that seems achievable”*. Clinicians wanted to know that the healthcare experience would meet their patients’ needs as they progressed through the rehabilitation journey. A clinician said a successful rehabilitation device *“would have to be kind of iterative in a sense. That it could change for me over time”*. Therefore, games should be designed for ease of use, minimal setup time, and provide customisation to the individual to facilitate engagement.

4.5.2. Communication and Feedback

Clear communication empowered people to make informed decisions about their health. One clinician recounted that they were *“relieved we were heard and understood. Confident that the care plan was robust. Empowered with a new plan and info to deal with the situation”*. Most participants see empathy as a critical feature of positive clinical care. Concerning a positive medical experience, a participant said it was important to *“just treat me with respect”* and recounted that when communication was poor, it led to uncertainty. Another participant stated that *“[they’d] have felt more supported through more information”*. In contrast, a clinician wanted *“the ability for the device to meet the needs of my patient but also the needs of the plan that we’ve collectively decided.”* Therefore, if the technology provides clear goals and training to support the rehabilitation plan set by the clinician, then the game is likely to be more effective.

Appropriate and clear feedback was important. One clinician stated that a critical feature of good health care was *“getting the information when you want, at the level you want at the time you want”*. Information should be at a level that is understandable and not overwhelming to cater to the patient’s needs. Therefore, a VR game for rehabilitation must provide meaningful and timely feedback to PwS.

4.5.3. Engagement

Engagement leads to participation in the process of recovery and rehabilitation. A PwS recalled that rehabilitation classes *“made her happy because she was doing something about her rehabilitation and said that it made her feel good when she was engaging in it”*. In this example enjoyment in the task leading to greater engagement. A topic that came up with PwS was the concept of comparing themselves to others to gauge their level of function. One PwS stated that *“unfortunately, you compare yourself to other survivors”*. Comparing their situations to others seemed to help the PwS value their progress and potentially motivate themselves to work harder as one PwS stated that they are *“quite competitive”* in-group stroke therapy. Opportunities for competition in a group environment or against yourself may help PwS motivate each other and themselves. For example, a clinician recounted that *“some people get really motivated by repetitions. Whereas somebody else might need to be more gamified.”* Gamifying repetitions through scoring could facilitate engagement.

Another aspect of engagement was empowerment. One clinician stated *“there's so much with stroke… that your ‘autonomy’ is removed from you. So, if that device can increase ‘autonomy and independence’ then … you just get so much better at ‘engagement’ and your ‘motivation’ to use it.”* Therefore, assistive technologies to support stroke rehabilitation must strive to provide independence. One clinician outlined the differences between independence and autonomy for a support tool for rehabilitation. *“Independence is around the ability to use the device by yourself, so to do more exercise for longer”*, while *“autonomy would be doing it when I want to do it and how I want to do it”*. The more independent the person is using the game, the more engagement and therapy they are likely to get from the game. However, one participant stated that *“you’re not going to engage with it if you don’t trust it. If you don’t trust it, it’s not going to be engaging.”* People will only engage with technology when they trust it to perform. Therefore, to increase trustworthiness will require validation by clinicians to ensure the game is of value to end-users.

4.5.4. Progress

Participants needed to see evidence of progress in their health care and recovery. The pace of recovery time was a recurring sub-theme. One participant was “*concerned with the speed of recovery and possible loss of condition if it takes too long*”, while another PwS was concerned that *“It took a long time to see big improvements in her rehab”*. Lack of empathy and the internal and external pressures to recover were cited by participants who said *“friends/boss don’t see pain … they don’t get it”* and that there is *“pressure from teammates to make a good recovery soon”*. This lack of understanding from their peers may hinder progression. External pressure, which may have the potential to provide motivation, risks being perceived as a lack of empathy by the PwS. This pressure could be detrimental to recovery if PwS are pressured beyond their current level of capacity. Some participants expected to progress at an attainable pace. They wanted to *“get back* *to what [they were] doing before", "become good again", "without loss of condition"*. Participants wanted to be challenged, but they also wanted to be paced correctly with achievable goals. One participant stated that *"[they] think [they] want to be able to move with the experience … with the full journey to get the most benefit out of it"*. Therefore, games should be accessible, provide realistic goals, and adapt throughout the recovery process. One clinician admitted that *"we sometimes don't recognise progress very well and certainly any of the clinical things we do don't always recognise progress''*. Therefore, a game may provide more tangible measures of progress.

4.5.5. Social connection and wellbeing

Social connection and wellbeing referred to the importance of key relationships during the healthcare journey and how this supports positive wellbeing. A PwS recounted that *"I was with a group of people that knew what I was going through"*, which highlights the importance of the shared experiences. One clinician questioned, *"whether what [we're] trying to do with this technology is replace [their] relationship that [they] have had with this person I have been working with for months"*. This fear must be alleviated as it should be made clear that assistive technologies will support clinicians, not replace them.

A common theme of positive health care was family inclusion and support. One PwS saw their *"family included and also looked supported"*, while a clinician recounted a doctor visit where *"[they] wanted [their] husband to be part of that and he was, [their] dignity was well respected"*. The importance of support networks was supported in the user journey map, as evidenced by the clinician and family being primary motivators to engage in rehabilitation. A PwS reflected that *"all the therapies, programmes could help me to find the positive and have wellbeing again*". If games can stimulate positive attitudes and emotions, it may become an additional tool to help people through difficult situations.

Figure 4.9. Coding and thematic analysis of transcript evidence.

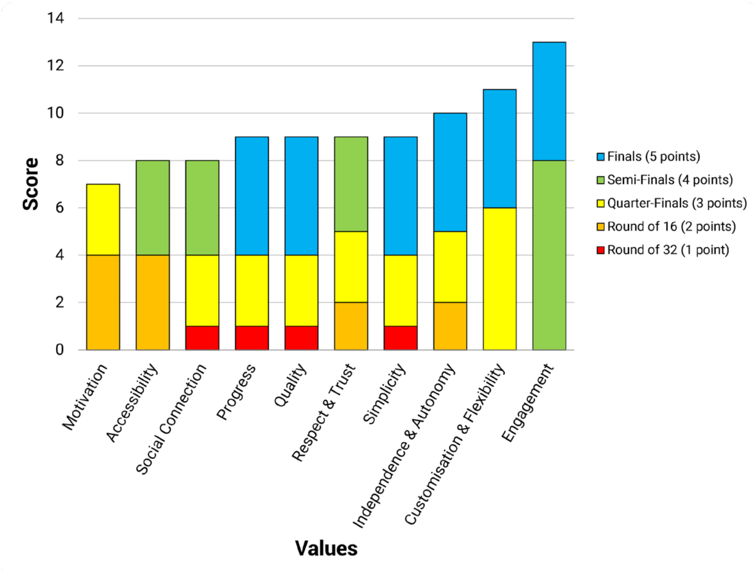

Figure 4.10. Card sort weighting. Top 10 weighted values from card sort in ascending order based on the combined weighted score from all three groups in the workshop. Values were weighted based on how many stages each value moved through in the card sort.

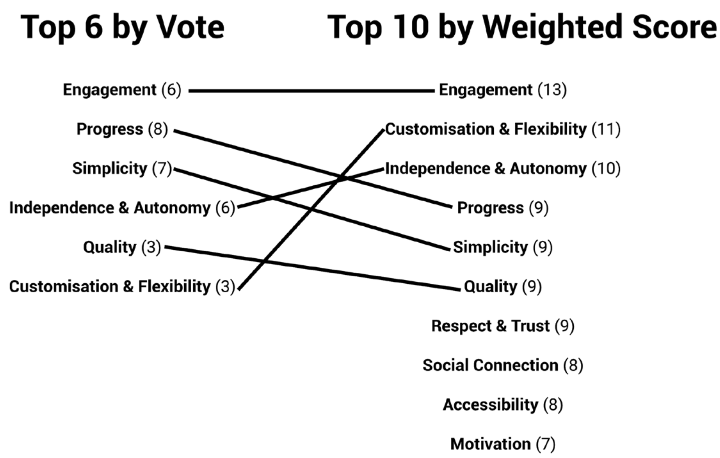

Figure 4.11. Comparison of top 6 themes voted by groups versus the top 10 by the weighted score during analysis post-workshop.

4.6. Game Genres

The mood board activity helped to guide the game design strategy by aligning the most popularly identified themes of *engagement, simplicity*, and *progress* with established game types. The 40 relevant images used in the mood board covered three categories: traditional games (12), rehabilitation-focused games (13), and entertainment-focused video games (15). Traditional games included physical board games such as chess. Rehabilitation-focused games include serious games designed for rehabilitation and exercise. Entertainment-focused video games were video games designed for pure entertainment. Participants were blind to the categories of the images when they completed the activity. Categories were only for analytical purposes. The three group mood boards are colour coded by category:

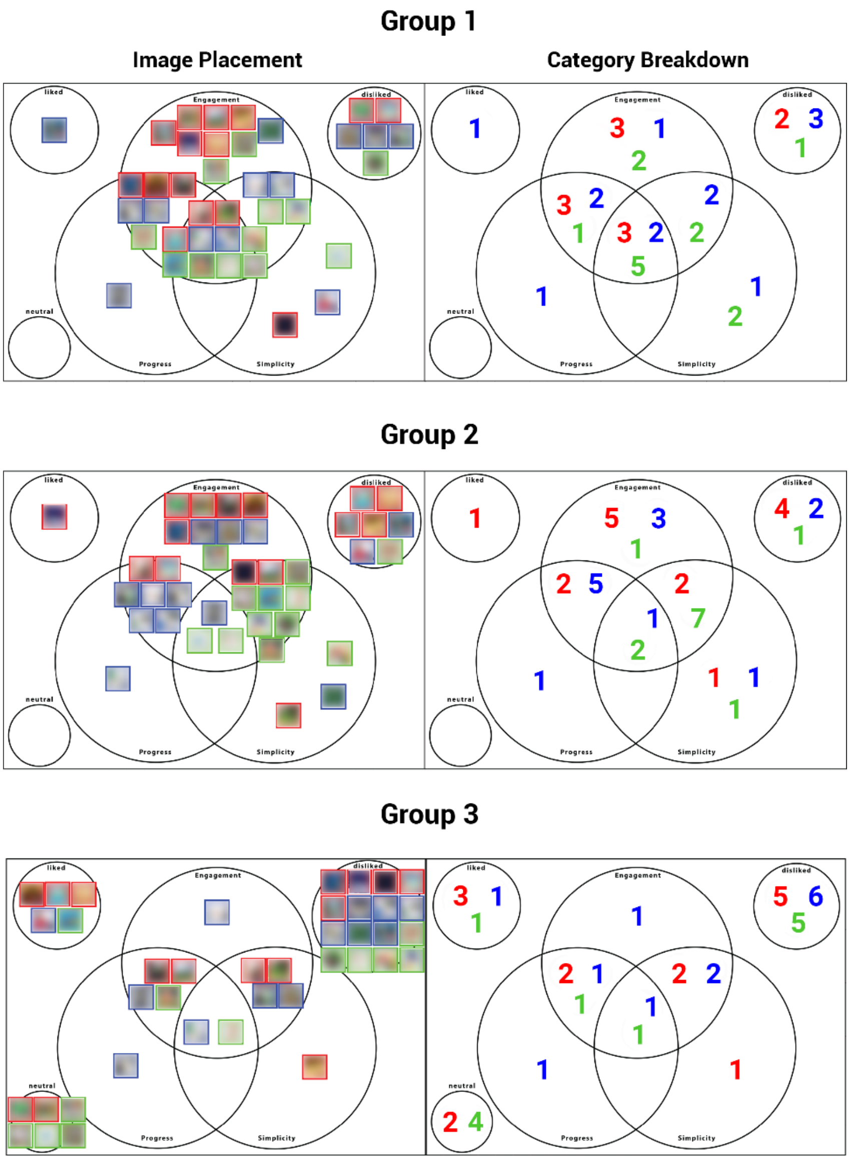

Figure 4.12: Mood board for each group showing image placements (left column) under each theme from the card sort as well as image category breakdown within each theme (right column). Images are colour coded into traditional games (green), rehabilitation-focused video games (blue), and entertainment-focused video games (red).

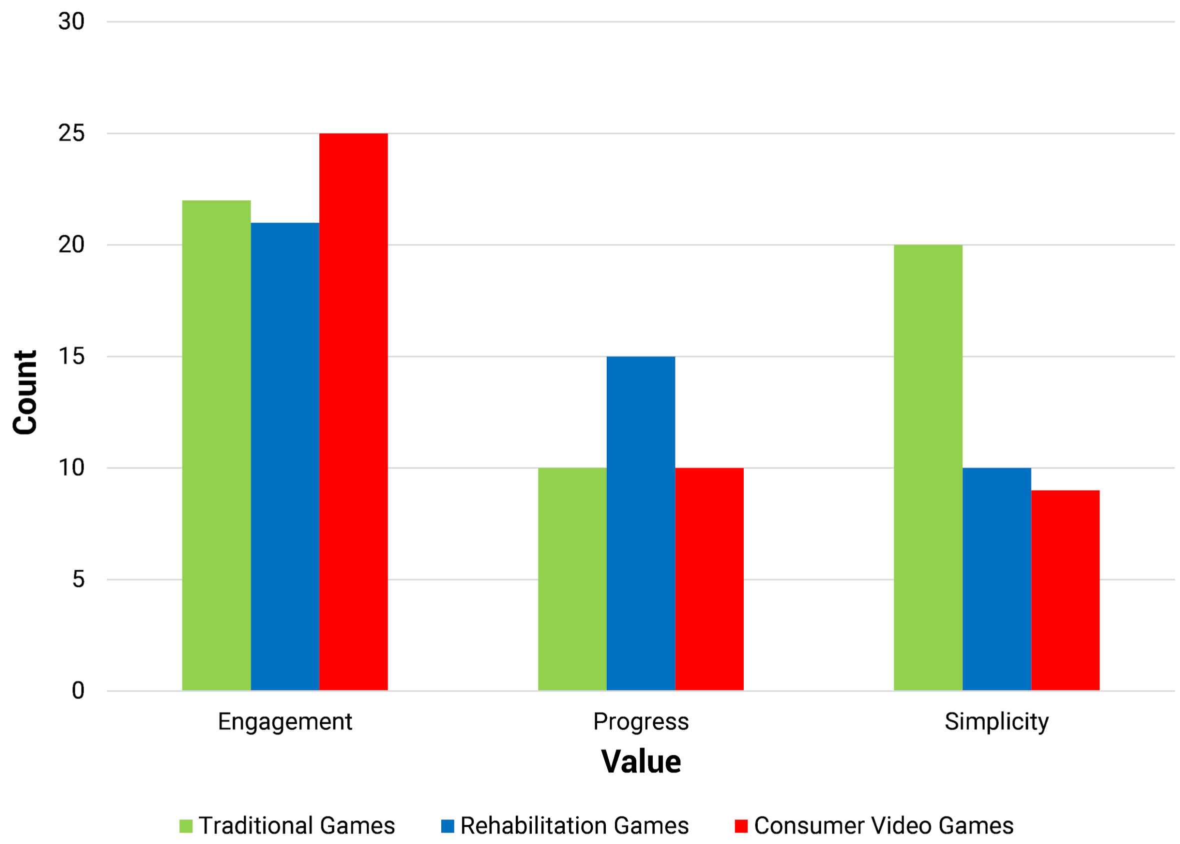

Figure 4.13. Breakdown of game types for each value. The responses for each group were summated to indicate which game types aligned the most with each theme.

Engagement was similar for each game type, which highlighted that all game types aligned with engagement. An in-depth analysis of responses would be required to determine the specific aspects of the games deemed to be engaging. However, the design of the activity was too limited to allow for this. The traditional games were more aligned with simplicity than the other two game types were. Therefore, traditional games were easy to understand for this audience. The Entertainment Software Association (2019) found that gamers aged 55-64 played card games (58% of males & 59% of females), puzzles (35% of males and 45% of females), and virtual board game genres (28% of males and 27% of females). Incorporating elements of traditional games into a game for rehabilitation may make the game more relatable and accessible. The rehabilitation-focused games were the most aligned with progress. Therefore, games designed for rehabilitation may give a perception of progress. Rehabilitation games provide relevant feedback that is translatable into the real world and provide accountability due to the involvement of clinicians. Therefore, the game designed must emphasise the game's rehabilitation value and involve clinicians as much as possible early on as was supported by the user journey activity.

4.7. Design Criteria

Design criteria can assess designs systematically without compromising creative freedom (Rodríguez Ramírez, 2017). The following table outlines the design criteria developed from the constructed themes:

Table 4.1. *Design criteria for an immersive VR game for upper limb stroke rehabilitation*

Theme	Subthemes	Design solutions
Accessibility and Simplicity	● Easy to understand ● Can be played regularly without inducing mental fatigue or cognitive overload ● Provide options to users to tailor and customise their experience	● Tutorialisation of gameplay ● Rely on movements over button inputs ● Customisation options for avatar, e.g. skin tone
Engagement	● Leverage gamification to make repetitive exercise fun ● Games are varied and designed to balance challenge and skill to increase engagement ● Encourage independence and autonomy ● Interactions feel natural and based on real-world interactions	● Design games to maximise repetitions in engaging tasks ● Cater to different play styles and player archetypes through providing choices ● Interactions are grounded in functional tasks
Progress	● Reward successful movements ● Transfer of learned behaviour into the real world ● Adapt difficulty and challenge to the user ● Provide opportunities to play the game independently	● Scoring system to record and incentivise success ● Focus on gross motor movements first ● Adaptive difficulty settings ● Options to play more independently as you progress
Communication and feedback	● Provide clear communication of performance in the game ● Coherency between games, tasks, and goals ● Movement visualisation in the virtual world must match real-world movements.	● Real-time tracking and recording position of both hands ● Games based on functional tasks with clear goals ● Gameplay and user interface guide the user through interactions.
Social connection and wellbeing	● Positive reinforcement ● Involvement of a support network (clinicians, family, and friends) ● Virtual environments that facilitate positive wellbeing	● Clinicians and carers play an active role in initial use ● Validate game mechanics and design with clinicians ● The outdoor setting is relatable and aids wellbeing.

4.8. Limitations

There were several limitations to the design of the workshop. The participants were a highly motivated subset of PwS, which may risk introducing a bias towards more motivated PwS. Also, the small sample size meant the results of the workshop may not be generalisable to the broader population of PwS. During the user journey map, we found that some participants found that it was more helpful to chart out a typical week than just a single day. In the future, this could allow for more flexibility in the activity. The user journey cards were designed to make it easy for participants to chart their journey and ensured that we gained specific data. However, the rigidity of the options may have limited participant's answers. Presenting opportunities for users to provide flexible answers may have produced additional insights. Finally, it would have been useful for all the images in the mood board to be given a like or dislike rating by the participants. Knowing the reasons why some images were either liked or disliked could have informed the game design strategy.

4.9. Conclusion

The workshop provided insights that will guide the design of the game. To maximise the value of the assistive technology, both clinicians and PwS need to be aware of its potential, usability, and its purpose over time. They need to know that it can adapt to the specific needs of the PwS as they progress. There should be a smooth transition from the technology to physical rehabilitation, and this should be communicated clearly to the PwS. The clinician and support people and family members will need to be trained well on the use of the device. Adequate training will allow PwS to manage using the device either independently or with the assistance of a support person at home.

Chapter 5
Design Process

This chapter discusses the design prototypes developed using available VR technologies to form the basis for the final game concept.

5.1. Goals

- Explore technologies that would be feasible to use in the development process
- Explore the usability of the chosen VR platform with a representative PwS
- Develop design concepts based on mirrored movements
- Develop a high-fidelity prototype that incorporates and expands on the design concepts and is guided by our design criteria

5.2. Technology Exploration

Initial development was on the Oculus Rift (Oculus VR, 2016), a VR headset that requires a gaming PC to run the software. A headset called the Oculus Quest (Oculus VR, 2019), which did not require a PC, was released during the project. This standalone system provides positional tracking, stereoscopic three-dimensional imaging, and integrated audio. Four built-in wide-angle cameras spatially track the headset, and two motion controllers capture hand motions and user inputs. Development was moved to the Quest to remove barriers to accessibility because ‘accessibility and simplicity’ and facilitating independent rehabilitation at home were goals of the project.

Hand tracking was explored early on using the Leap Motion (Leap Motion, 2010). This sensor supports hand and finger motions over controllers. However, this technology was abandoned during development as it required a PC to run, and the software development kit did not meet the flexibility needed for the game. The Leap Motion would also require potential users to invest in multiple technologies providing a barrier to accessibility, which the Oculus Quest did not. The controllers provided a more accurately tracked sensor and a more robust toolset for the interaction methods.

5.3. Exploratory Usability Test

An exploratory usability study to assess the usability of the Oculus Quest hardware was conducted with a single PwS. This test occurred concurrent with the design workshop. The male participant had severe left-sided hemiplegia and used a wheelchair for mobility. He had previous experience with conventional MT. This test was conducted at the Auckland University of Technology with a supervising clinician and the participant's support person.

5.3.1. Method

This exploratory session involved a gameplay observation session and two semi-structured interviews pre-test and post-gameplay (see Appendix D). The participant played the tutorial of the Oculus Quest called 'First Steps' for 15 minutes (Oculus, 2019a). This tutorial introduces the player to the controllers and how to interact with objects in the environment (see Figure 2.1). The tutorial was designed to be played with two hands. Therefore, he could not carry out certain bilateral tasks. These tasks were skipped through by the researcher before control of the game was returned to the participant. The controller was positioned in their unaffected right hand while the left controller was in their affected hand resting on their lap. A think-aloud protocol encouraged the participant to narrate their experience as they played the game (Martin & Hanington, 2012, p. 180).

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Figure 5.1. 'First Steps' is the built-in tutorial for the Oculus Quest. These screenshots show the types of interactions completed by the participant in the tutorial. Copyright 2020 by Oculus.

5.3.2. Findings

The preliminary semi-structured interview covered topics including their current rehabilitation, experiences with MT, video games, game-based rehabilitation, and VR. The participant described their recent rehabilitation as *"it's just really a series of exercises. Repetitive exercises."* The participant had previous experience with conventional MT. He described MT as *"quite rudimentary in that [he didn't] think that the people doing it really totally understood how it should work"*. He also stated that *"part of my brain knows that even visually I might think it's moving, but I know it's not"*. VR games using MT will have to provide a convincing visual illusion. The participant had previously tried a range of different game-based therapy tools. He had used an art-based game in

PC VR, as part of art therapy and other computer-based interactive therapy games, which: *"he could see himself doing it more regularly"*. In conclusion, the participant was optimistic about the use of technology as an assistive tool in rehabilitation.

The participant was impressed by the standalone VR technology. When he put on the headset, he exclaimed: *"what a great way to escape the realities of life"*. The participant indicated that he uses smartphones and tablets regularly but saw the promise of this technology to be instantly engaging. Once he saw his virtual hands in the tutorial, he stated that *"my hand is the most unusual white colour. It divorces your mind from the reality of the hand to a certain degree"* (see Figure 2.1). Therefore, providing options to players to choose virtual hands that best match their own will enhance presence.

The participant commented on the controllers and user input. He stated that *"I don't like virtual keyboards. I like the tactility."* Having tactile button inputs may be preferential to hand tracking input alone. The participant enjoyed the haptic vibration feedback of the controllers. Tactile vibration feedback could be used to stimulate the affected hand when the virtual mirrored hand completes a task.

This participant had limited use of their affected hand, which restricted their interactions in the game. Mirrored movements could provide a person who has a severe impairment of their affected hand, a way to play the game while still visualising affected hand movement. The participant found it challenging to grab objects and occasionally dropped an item off the virtual table. In the game, dropped objects would reappear at their previous position, which was an important feature to help the user 'recover from errors' as stated in Nielsen's Usability Heuristics (Nielsen, 1994). Finally, the player at times had trouble with the 'Grip/Grab Trigger' and found that having in-game visualisation of the controller buttons and the hands would be useful.

A follow-up semi-structured interview with the person created an opportunity to discuss topics such as their general thoughts on VR, comparing games to rehabilitation, and the tolerability of VR. The participant said the experience was *"very novel, very interesting … yeah quite addictive possibly"*. When asked about how the tasks performed in this game compared to rehabilitation, he said the game was *"a lot more engaging, a lot more enjoyable than a rehab exercise, which can be a little bit boring … repetitive."* The participant wanted an experience that was "*towards certain goals*". When asked if he would prefer having scores as a measure of progress, he responded *"so it's measurable? That's definitely helpful"*. Therefore, this aligns with having goal-oriented tasks in the game with measurable feedback as an important feature for the VR game.

The participant tolerated the system well. He said *"[he] would need help to adjust the headset to fit"* but overall felt that *"it was not cumbersome at all"*, and he did not feel frustrated when elements in the game weren't working immediately. He did not report any symptoms of motion sickness when asked. On removing the headset, he felt *"it was just like a stark contrast going back to reality. It was quite a contrast"*. A more realistic virtual environment might lessen this contrast and be more relatable. When asked if the game needs an explicit narrative, he said *"it kind of speaks for itself in a way… I don't really need that at all but it would add interest yeah."* Therefore, if the context of the tasks and the virtual environment match, an explicit narrative is not essential.

This session helped highlight the strengths and limitations of the technology. Strengths included the ease of setup and the immersion. Design opportunities for the game included the visual representation of the hands, alignment with rehabilitation goals, and incorporating measurable feedback of performance. This session indicated the tolerability of VR by a person with severe impairment on the affected side. However, this is not generalisable to all PwS. These findings, along with the workshop, helped to inform potential solutions for the design criteria created from the design workshop.

5.4. Design Concepts

VR concepts were developed using research through design (Krogh et al., 2015). Three low fidelity prototypes implementing MT as the central mechanism of interaction were designed in VR using Unity game engine software (Unity Technologies, 2020). The player's unaffected hand movement was tracked. This movement was visualised as a mirrored representation of their unaffected hand movements superimposed onto a virtual representation of their affected hand. Players completed all tasks using their unaffected limb to drive the mirrored virtual limb and maintained their affected limb at rest. The prototypes focused on three movements of the upper limb involving gross motor movements at the shoulder and elbow:

1. Guided Reach-to-grasp (Stationary Objects)
2. Guided Reach-to-target (Moving Objects)
3. Self-guided movements

Reaching is an essential movement in early upper limb rehabilitation due to its importance for daily activities (Collins et al., 2018; McCluskey et al., 2017). MT protocol suggests tailoring the experience to the individual's performance (Rothgangel & Braun, 2013). Therefore, self-guided movements provided an option for users who wanted a self-paced and self-guided experience.

5.4.1. Asset Development

The scope of the design work for the game involved scripting and developing game mechanics and interactions in Unity. Asset creation was out of the scope of the research. Any 3D models were either partially created within the Unity editor, or downloaded royalty-free from the Unity Asset Store, TurboSquid and BlendSwap3D object repositories (see Appendix E). Character animations were created procedurally using Unity tools such as VoxHands and FinalIK while sounds were attribution-free from Youtube Audio Library and edited in Audacity. Textures, graphics, and logos were created using the Adobe suite.

5.4.2. Prototype 1: Pixel Art Puzzles

Pixel Art Puzzles trained reach-to-grasp movements involving the shoulder and elbow. The prototype extended a MT reach-to-grasp task using VR (Rothgangel & Braun, 2013). The game was initially developed using Leap Motion hand tracking. The goal of the game was to match the block positions on the puzzle grid to a template grid. Players picked up blocks and placed them at anchored points on the grid. The player checked progress in-game with a 'check puzzle' button. Messages were displayed if the puzzle was complete or incomplete, coupled with auditory feedback. Upon completion, the player progressed to the next level. The game design allowed for puzzles to get more complex as levels were progressed by incorporating a wider variety of colours and increasing repetitions by requiring more blocks to complete the puzzle.

Figure 5.2. Pixel Art Puzzles. Leap Motion tracked hand movements as the player placed cubes on the puzzle grid (middle); user interface (right).

The Leap Motion depicted realistic movements that enhanced presence. However, tracking quality and grabbing interactions were unreliable. Therefore, further implementations were developed with the Oculus Quest and controllers. The controllers facilitated more reliable tracking and interactions.

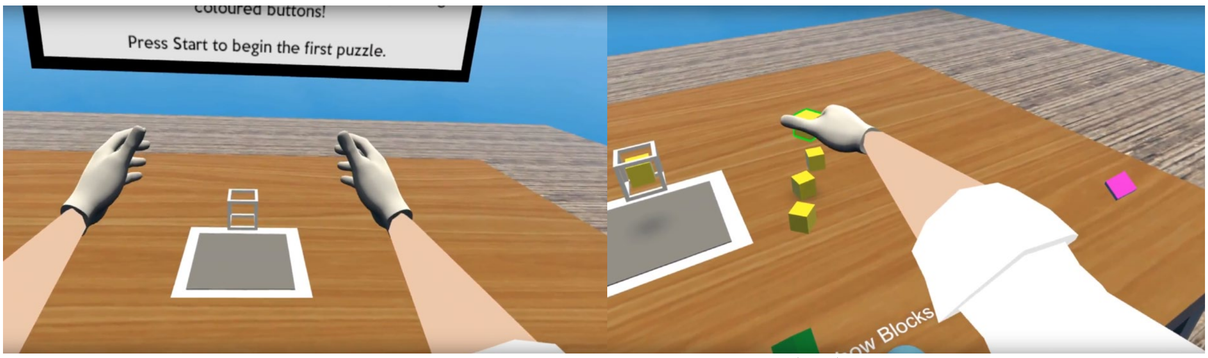

Figure 5.3. Grab mechanics with Oculus controllers. Mirrored hands (left); mirrored left-hand picking and placing a block (right).

5.4.3. Prototype 2: BeatBox

BeatBox was a reach-to-target rhythm-based game that involved gross motor movements at the shoulder, including flexion/extension and abduction/adduction, as well as hand-eye coordination. The player hit moving gold and blue cubes which appeared at one of four heights in time to the music. Cubes were coloured corresponding to the wristband colour on the hand used to hit the cube, the left hand hit gold cubes on the left side, and blue on the right side.

Figure 5.4. BeatBox. Players must swipe blocks with the correct hand (left); blocks are sliced in half (right).

Successful hits sliced cubes in half and increased the score. Multiple successful hits increased the combo meter, while misses reset the combo meter. The placement of cubes guides different movements of the shoulder.

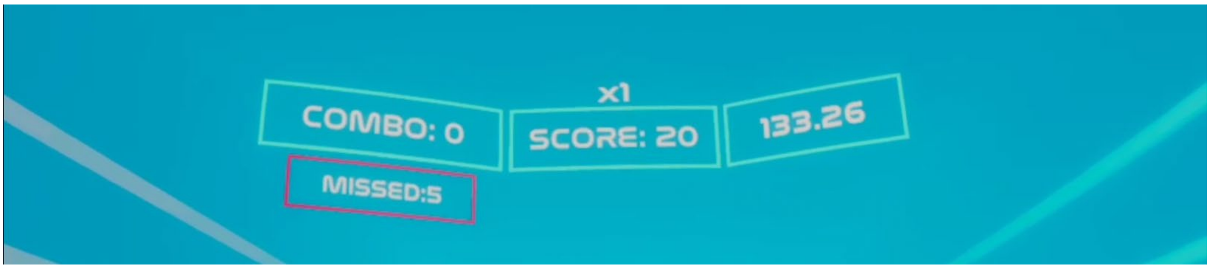

Figure 5.5. Score interface. Highlights cubes hit, cubes hit in a row, cubes missed, and time left.

Behavioural experiments showed pairing visual cues with synchronous auditory cues facilitates attentional engagement (Malcolm et al., 2009). Rhythm games are some of the most popular VR games that pair movement to visual and audio cues. A recent study compared the popular VR rhythm game Beat Saber (Beat Games, 2019) and an archery game, QuiVR (Blueteak, 2018), as exercise alternatives (Kivelä et al., 2019). Beat Saber led to greater increases in heart rate and involved more controller movement compared to QuiVR. However, participants rated Beat Saber as more intense than QuiVR. Therefore, BeatBox aimed to replicate the exercise benefits of Beat Saber, while reducing intensity by slowing the speed, maintaining coloured cubes to specific sides, and minimising visual effects to minimise possible fatigue. The score allowed players to gauge their level of progress and allowed clinicians and carers to document successful repetitions.

5.4.4. Prototype 3: Mirror Draw

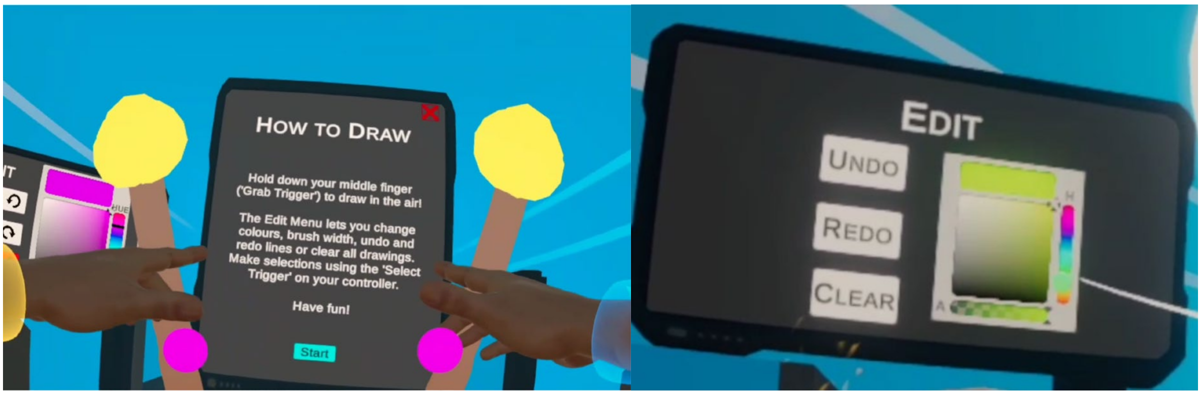

Figure 5.6. Mirror Draw. Symmetrical drawing with hands in different colours (left). Drawing edit menu (right).

Mirror Draw was a self-guided movement drawing game. Players drew with their unaffected hand, and this drawing was mirrored symmetrically and synchronously from the mirrored hand. Players edited drawings and changed colours using an edit menu. Art therapy was chosen as the inspiration for the non-competitive task due to its accessibility for a wide range of people and levels of impairments. Proposed benefits of art therapy include alleviating stress and promoting wellbeing (Reynolds, 2012). This game provided a contrast to competitive games as players could create drawings at a self-guided pace. By drawing on elements of creative exploration from art therapy, it was hoped that this game could help with the wellbeing of players and provide options more suited to non-competitive players.

5.5. Final Game Concept: Mirror VR

The final prototype was developed using the design criteria (see 4.7. Design Criteria) and findings from the design experimentation. The final prototype produced was a simulation game set in an outdoor campground. The outdoor virtual environment was chosen to be relatable to people's lives but also leverage the ability of VR to immerse the user in varied environments. The game consisted of a tutorial and setup level followed by two training mini-games: a competitive reach to target task and a non-competitive drawing game. The games were designed to train gross motor movements at the shoulder and elbow. All tasks were designed to use the unaffected hand driving a mirrored virtual affected hand. This provided accessibility for users with severe impairment of one limb. The game required the player to be seated at a table. The table acted as a point of reference within the virtual environment to minimise motion sickness and ensure safety. The elevation of each hand from the table, in centimetres, was recorded in real-time as a measure of shoulder flexion/extension and abduction/adduction. The three major components are outlined below.

5.5.1. Tutorial and Setup Level

Tutorials teach the game mechanics and controls that are required to play the game successfully. Progression through the tutorial was based on Oculus Quest's built-in tutorial to provide familiarity to the player. The tutorial consisted of setting up the user profile, including gender, affected side, table height, and skin colour. The tutorial allowed the user to familiarise themselves with the user interface (UI) and controller.

Figure 5.7. Mirrored movement visualisation. Third-person view (left) and first-person view (right).

The second part implemented MT, and the player completed a functional reach-and-grasp task using the mirrored hand. Players were tasked to grab a log of wood, chop it with an axe and place the chopped log on the campfire to start the fire. The player's finger movements, when they grasped and released the trigger buttons on the controller, were translated to animations of the virtual fingers. Successful completion of the tutorial presented the player with the opportunity to choose one of two mini-games to play.

Figure 5.8. Tutorial reach-and-grasp task. First-person view and controller instructions (left). The player used the mirrored hand to place the log on the campfire (right).

5.5.2. Competitive Game: Wasp Attack

'Wasp Attack' was a competitive game reach-to-target task. The player hit gold and blue wasps that moved towards the player. This game was based on the BeatBox prototype but used wasps to match the environmental context. Wasps were coloured corresponding to the wristband colour of the hand used to hit the wasp, gold on the left, and blue on the right. In the tutorial level, the player was tasked with hitting 30 wasps before time ran out. If they missed 20 wasps, they restarted the level. The levels of this game progressed to encourage specific shoulder movements through variation of wasp height and placement.

Figure 5.9. Wasp Attack. Wasps appeared at different heights and were hit according to colour.

Figure 5.10. Wasp Attack scoring. Third-person view of VR environment showing unaffected right limb driving a mirrored virtual affected left limb to hit a gold wasp (left). Successful hits are indicated by increased score and visual and sound effects (right).

5.5.3. Non-Competitive Game: Art Camp

Art Camp was a non-competitive game based on art therapy. Players created 3D drawings using the non-affected hand, while their mirrored hand drew symmetrically and synchronously across the sagittal plane. A physical paintbrush in the player's hands changed colours to match the paint colour. Editing controls were placed on a UI resembling a painting palette with extra tools like controlling brush size.

Figure 5.11. Art Camp. Third-person view of VR environment showing the unaffected right limb driving a mirrored virtual affected left limb to draw (left). First-person view showing drawing with paint brushes (right).

5.6. Prototype Development

The following section outlines how the design criteria informed the technical development of the prototypes described above.

5.6.1. Accessibility and simplicity

The tutorial was designed to introduce the fundamental interactions, to set up a user profile, and calibrate table height. Progression through the tutorial taught the player the game mechanics gradually. The player selected their gender, the side affected by stroke, chose skin tone (Figure 5.12), and adjusted table height. Gender and skin tone selection were included to customise the player avatar and enhance presence (see 5.3.2: Exploratory Usability Test). The selection of the side unaffected by stroke enabled the system to determine the roles of each hand.

Figure 5.12. Skin tone selection.

The table provided a fixed reference point in the real world. The player had to set the virtual table height within the game to match their real table. The player must set the table height without removing the headset. The solution was to prompt the player to rest both hands on their real table and hold the indicated buttons on the controller in the unaffected hand. A 3-second timer would countdown to zero, and the virtual table's position on the Y-axis snapped to match the hand position (Figure 5.13).

Figure 5.13. Table height calibration.

The game focused mostly on the movement of the controllers and only required three buttons during gameplay (Figure 5.14):

1. The 'Select Trigger' for menu interactions.
2. The 'Grip Trigger' for grabbing objects or drawing.
3. The 'Thumbstick' for moving objects grabbed at a distance closer and further away.

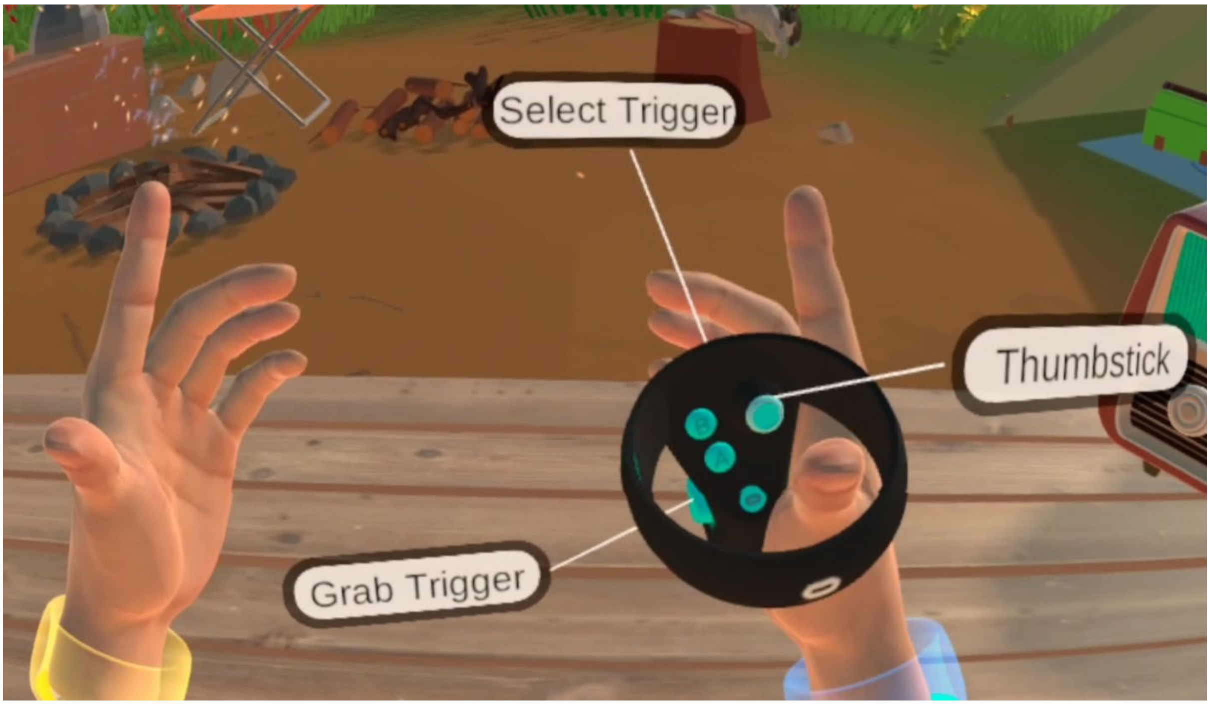

Figure 5.14. Control scheme visualisation.

Limiting the number of inputs simplified the learning process for those inexperienced with game controllers. The controller was visualised in the unaffected hand with tooltips indicating which buttons to press to complete tasks (see 5.3.2: Exploratory Usability Test). Inputs were highlighted as the player progressed to gradually introduce controls and direct attention to the inputs required for the current task.

5.6.2. Communication and feedback

The UI design was a vital consideration for learnability. In VR, it is best practice to use diegetic UI present in the world space (Salomoni et al., 2017). These elements were designed to thematically align with the game to provide context and enhance immersion. The palette and brush were examples of world space UI (Figure 5.15). These objects were visual metaphors for a tool menu and drawing tool used in drawing applications. The palette was used for undoing, redoing, or clearing drawings, and changing brush properties like colour and line width. The brush reflected the player's choices on colour by changing the paint colour on the brush. Brush width was represented by the size of the drawing sphere. These visual metaphors provided feedback on the player's actions.

Figure 5.15. Paint palette diegetic interface.

VR provides a unique challenge because the player always has control over the camera view. Visual cues highlighted objects of importance to guide viewers' attention. Affordances are the properties of an object that signify the actions users can take to interact with it (Norman, 2013). The radio volume button signifies a visual metaphor for the user to control the in-game music (Figure 5.16).

Figure 5.16. Music control via radio diegetic interface.

In 'Wasp Attack', colours were used to distinguish the left and right hands (Figure 5.17). Blue and gold wristbands were a visual aid for the player to hit the correct wasp. Also, when the virtual mirrored affected hand made a successful hit, the controller in the affected hand received vibration sensory feedback (see 5.3.2: Exploratory Usability Test).

Figure 5.17. Coloured wrist bands provide visual cues of which wasp to hit.

It was necessary to have traditional menus in the game to provide instruction during the tutorial, to navigate the various games, and to customise their settings. These spatial menus had fixed positions in the world to maintain best practices for UI in VR at a readable distance (Figure 5.18), which didn't interfere with the environment (Kwon et al., 2017).

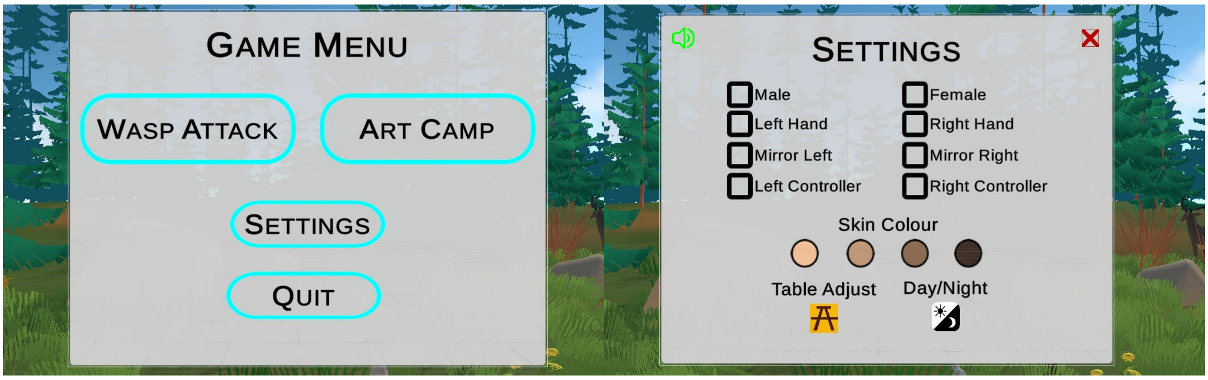

Figure 5.18. Fixed spatial UI. Game Menu for navigation (left) and settings menu (right)

All menu navigation was done using the unaffected hand. A popular selection method in VR is casting a ray from controllers to simplify pointing and selecting (Pietroszek, 2018). A ray was cast out of the end of the controller with a target reticle at the end of the ray to make UI selections (Figure 5.19).

Figure 5.19. UI selection with ray.

Arrows directed attention to interactable objects to guide players through the intended interactions as players progressed. Eventually, players could grab distant objects using the laser to bring them into their near space (Figure 5.20). Dropped objects due to player error would reappear at their original position to help error recovery (see 5.3.2: Exploratory Usability Test).

Figure 5.20. Visual cues. Direct attention to interactable objects (left). Distant grab mechanic to place a log on the fire (right).

Figure 5.21. Scoring feedback. Real-time feedback (left). Summary provides level performance (right).

For 'Wasp Attack', the scoring feedback was updated in real-time and displayed in a fixed spatial UI above the player (Kwon et al., 2017). The player was provided with their level of achievement as indicated by the number of wasps hit and missed (Figure 5.21). The player also had real-time elevation feedback on their virtual wrists. This feedback indicated their range of movement. This was recorded as both distance elevated from the table, and the elevation in degrees, which is a clinical measure of flexion of the shoulder (McCluskey et al., 2017).

The scoreboard summarised the score and elevation performance. On level completion, the scoreboard was a self-assessment tool to help players set and achieve goals. Monitoring the range of movement could be useful for clinicians. This data could be documented to provide clinicians and PwS with data to motivate further engagement.

5.6.3. Engagement

A variety of game design features were used to actively engage the player. The game environment was chosen to support a narrative of outdoor exploration (Mutz & Müller, 2016). As the player built out their campsite and interacted with different objects during the tutorial, they became immersed in the environment as they learnt the controls in the tutorial. Players were provided with a choice of training mini-games to cater to different playstyles (Lohse et al., 2013; Scharkow et al., 2015). 'Wasp Attack' was designed to cater to aspects of competition discussed during the workshop as well as providing a game where performance could be monitored and quantified. 'Art Camp' was designed to cater for non-competitive players. Players had the freedom to be creative and explore the different options on the palette to learn the interface without time-pressure or score.

The sound design in VR is a key element to facilitate immersion in the virtual environment. Spatial audio and ambient diegetic sounds enhanced presence (Çamci, 2019). These included bird sounds and the fire crackling. Interactable items provided auditory feedback, for example, when logs were chopped or when wasps were successfully swatted. Interaction with the menus provided non-diegetic auditory cues when menu buttons were pressed to indicate successful interactions (Çamci, 2019). There were different sounds for selection versus closing a menu. Successful hits in 'Wasp Attack' had sound and visual effects, and victory sounds were played when the level was completed successfully. The challenge was to have enough sound to enhance immersion, while not distracting the player from the tasks. The music and sounds were intended to create a calm tone reflecting the outdoor environment to reduce any tension felt by the player while learning the game.

5.6.4. Progress

The progression of movements during the tutorial helped to ease the players into the game mechanics. Each mechanic was broken down into single steps so that users could gain familiarity with the controls one at a time. For example, menu navigation was presented first, followed by avatar customisation, then finally the reach-and-grasp task. Tasks were broken down into the simplest steps to acclimate the player gradually.

Levels were a method of monitoring player progression and grading the difficulty of exercises. In level 1 of 'Wasp Attack', blue and gold wasps appear symmetrically at one of four different heights. Therefore, if the unaffected hand hit a wasp, the affected hand was at the correct height to hit the correct wasp due to symmetry (Figure 5.22). However, in level 2, gold and blue wasps appear one at a time (Figure 5.22). Therefore, the player had to shift attention between the affected and unaffected side, adding an extra challenge. Subsequent levels continued to change one factor providing extra layers of challenge.

Figure 5.22. Progression in difficulty from Level 1 to 2. Level 1 shows the symmetrical placement of wasps (left), while level 2 requires shifting visual attention between hands (right).

Elevation feedback provided a measure to grade movement. Movement of the unaffected and affected arms was tracked in the background, and this information was presented at the end of the level. Unintended purposeful movements of the affected arm could be used to quantify the motor improvement in future iterations.

5.6.5. Social Connection and wellbeing

There is scope for social elements in the games. 'Wasp Attack' could incorporate an online leaderboard to provide a competitive aspect for players who are motivated by this. In 'Art Camp' it is possible to save and share screenshots of their art using the headset's built-in social features. These elements may foster creativity and self-expression. The game needs to provide a variety of experiences that connect players to ensure sustained engagement.

The virtual outdoor environment aimed to provide an environment conducive to positive wellbeing and presented an escape from the home and clinic. Studies have shown that outdoor adventures can assist with subjective well-being, perceived self-efficacy, mindfulness, and perceived stress (Mutz & Müller, 2016). The strength of VR to immerse the user in an outdoor setting may draw on some of these benefits to facilitate wellbeing.

5.7. Conclusion

The design process allowed for experimentation in the VR medium. Mirrored movements were used as a central interaction method to guide early concepts. The design criteria helped to inform the game design strategy to develop the initial testable prototype for evaluation by clinicians.

Chapter 6
Expert Review

Expert review was conducted to gain an independent expert opinion on the feasibility of the game and potential user experience issues (Privitera, 2019). Clinicians provide expertise and perspectives for a variety of PwS before in-depth testing with PwS.

6.1. Goals

- Conduct expert review of designs with clinicians
- Analyse feedback against design criteria
- Outline design changes to the prototype

6.2. Methods

Individual expert reviews were conducted with four physiotherapists and two occupational therapists. The design researcher played the VR game and streamed live gameplay via video conferencing in a first-person view and third-person view (Figure 6.1) using mixed reality software (LIV Inc, 2019). A think-aloud protocol encouraged experts to articulate feedback during gameplay (Martin & Hanington, 2012, p. 180). Semi-structured interviews were conducted following the gameplay (see Appendix F). Feedback from clinicians generated design recommendations for the game. A System Usability Scale (SUS) and Intrinsic Motivation Inventory (IMI) were conducted offline post-test (John, 1996; Popović et al., 2014).

Figure 6.1. Mixed reality setup. Clinicians viewed gameplay in third-person (main view) or first-person (bottom left). The head camera (bottom right) provided an unobstructed view of arm movements.

6.3. Clinician Feedback

Feedback from the expert review sessions was audio-recorded to allow the analysis of findings. The following highlights the discussion points against the design criteria:

6.3.1. Accessibility and simplicity

Overall, clinicians could follow the setup process. However, they suggested to continue to simplify the instructions to be more accessible and directive:

> "*It's nothing more frustrating than starting to play something and not getting it in the beginning and you give up because you just can't follow the instructions*" (Clinician 3).

Most clinicians felt that *"these fantastic and innovative technologies are going to be more suited to people with stroke, maybe the next generation of stroke survivors"* (Clinician 1) who are more technologically inclined:

> *"I work with an older population over 65. They're quite easily put off things if they're deemed too difficult. I think some of my patients would be more receptive to it."* (Clinician 6)

Alternatively, one clinician said:

> *"I've got a client in his mid-seventies who uses similar things and loves it and he wasn't a gamer as a teenager … it engages him and drives him to do more therapy and more repetitions"* (Clinician 5)

Therefore, testing with the target audience is needed to make conclusions on the appeal of the game to PwS. One clinician pointed out, *"even though the majority of people that have a stroke are over 65 you still have a quarter under 65 who will be gamers and I think that would appeal to them as well."* (Clinician 2). Therefore, there is scope for the game to appeal to a younger audience more familiar with games.

The use of MT to make the game accessible to a wide variety of motor impairments before incorporating their affected arm was met positively:

> *"The way you have set it up if you can't use your affected side … opens it up for a lot of people. There are other VR systems where the person has to use the affected arm and they can't and therefore what is the point?"* (Clinician 2)

> *"This is good because even if they can't move that arm it's bringing in movements and looking, and it's bringing in a lot of other aspects of functioning and looking at the body as a whole"* (Clinician 3)

> *"I could see [the game] being used at all levels actually in terms of upper-level rehabilitation … We would use mirror therapy for someone who has got no activity … You could use [the game] with someone who's got some active movement and some limited function to improve their range of motion and their function and drive them to use their arm."* (Clinician 5)

This implementation of MT provided more flexibility than the limited movements in conventional MT:

> *"I like the idea that it's more reaching and moving of the arm and so you can get more mirror therapy for the arm rather than just putting the hand in the box and you're limited to movements really just at the lower part of the arm."* (Clinician 5)

The visual illusion could also be enhanced by having a full arm visualised. A clinician commented that *"being able to see the whole arm might be more conducive to what a mirror session in real life would be – because that's part of the illusion, to see your arm."* (Clinician 2). Two clinicians liked the customisation options for skin tone, for example, *"you have thought of a lot of important things like being able to change skin colour and being able to customize the hands"* (Clinician 2). Having a representative hand is key to achieving the mirror illusion.

Clinicians commented on the suitability within the stroke population. "*It will be for select people and that is fine. Because it is something you can work on independently with or without therapist input*" (Clinician 1). Three clinicians expressed explicit concerns about accessibility for those with visual neglect or cognitive impairments:

> *"The limitations would be around people who have related visual problems or are cognitively unable to manage or fatigue, or maybe those that have got more vestibular problems who have got a lot of dizziness"* (Clinician 5)

Design changes include simplifying instructions and applying full-body tracking to increase immersion.

6.3.2. Communication and feedback

Recording performance through scoring and tracking limb position was valuable:

> *"The score itself and range of movement being displayed does give that reward to the patients to see the result and then be able to compare it for future use. I like to see that improvement quantified."* (Clinician 6)

The clinicians felt limb elevation was useful information to show progress. However, this should be reported at the end of the level so as not to overwhelm people during gameplay when they are focused on the score:

> *"Right at the very end of the game when it's finished, you could have that information, "okay my goodness elevation, that's the best I did" … but not ... too much all at once because when you play the game all you want to know is how many wasps I hit"* (Clinician 3)

Two clinicians also liked the provision of haptic vibration feedback to the affected hand in the 'Wasp Attack' game:

> *"A good thing to add on, to get that kind of sensory vibration feedback."* (Clinician 5)

The main suggestion was to reorganise how end-of-level feedback was reported to the user.

6.3.3. Engagement

The clinicians felt that VR could be empowering and self-motivating in a home setting. A clinician stated, *"what we really need to strive for is independent self-rehab and that is where we are heading"* (Clinician 1). Clinicians appreciated the value of VR to provide enjoyment compared to exercise repetitions:

> *"It is a hell of a lot more interesting than sitting in front of a table and picking up a glass or cup. ...This is really interesting and fun and challenging"* (Clinician 1)

> *"Some can find exercising very boring … we say "okay, you're gonna do a hundred reps of the arm movement today" and they just can't be self-motivated. Whereas if they sat down and put this on ... They just kind of get immersed in it. Before you know it they've done 15 minutes of arm training!"* (Clinician 5)

The clinicians wanted more repetition of tasks during the tutorial:

> *"It would be helpful to make sure you repeat the same movement a couple of times"* (Clinician 3)

The clinicians appreciated the outdoor campsite setting and felt that the environment would be relatable and engaging for their clients. For example, clinician 4 said *"it's really nice that it's not indoors. I like that … everybody can relate to something outdoors ... I think it's a really lovely theme."* However, they unanimously felt the environment was too complex in its current state. A clinician commented that: *"stroke is quite fatiguing. It is* *fatiguing; sometimes, lots of stimulus can increase that fatigue"* (Clinician 2). The feedback was that simplifying the environmental complexity would enhance the immersion and facilitate attention to the tasks:

> *"You could have gotten away with probably 30% less of all that potentially … just having all those trees and a few things around is still visually rich."* (Clinician 4)

> *"Making it nice and simple in terms of the environment and … not requiring too much … divided attention between things." (*Clinician 6)

Clinicians also wanted an option to remove the environment in the drawing game to make drawings easier to see. Overall, including more repetitions of certain tasks and simplifying the environment were key suggestions to facilitate engagement.

6.3.4. Progress

The tasks have scope to provide the progress of patient performance. A clinician stated, *"I think you have the capacity to really progress that and really make both of those tasks varied and challenging"* (Clinician 1). Having levels for the tasks was a motivating element:

> *"People love that and go to the next level to the next level, and so they strive for that"* (Clinician 1)

> *"Change one variable at a time as you go up a level and you could get to the point where they are getting really good"* (Clinician 2)

> *"Having other layers or other levels that they could explore"* (Clinician 4)

A clinician felt that both mini-games provided scope to grade the level of challenge and difficulty. For 'Wasp Attack' they said *"I really like the idea of progression. I think ultimately you want the wasps to come from … all over the screen. This whole hand-eye visual coordination. They're having to work pretty hard to work out which direction they need to elevate and abduct. The speed could be adjusted too."* (Clinician 1). Whereas, for 'Art Camp' *"they have this potential to explore. By going through these various grades of difficulty by changing the colour, by changing this, by changing that"* (Clinician 1). The art therapy game was appreciated for its contrast to other tasks and their ability to stimulate creativity. *"I loved the creating. I thought that was really neat. The contrast between the wasp and the free drawing"* (Clinician 1)

Clinicians suggested additional important movements such as reach-to-grasp and midline movements:

> *"I'll often start with reaching forward tasks… they could be reaching for a hot drink and bringing it to their mouth... so you're getting combinations of movements"* (Clinician 5)

> *"Reaching to grab or grasp something is a really key initial task."* (Clinician 6).

It was suggested that including functional tasks related to activities of daily living could be relatable and suited in the context of the camp setting:

> *"Something for eating … you're turning things over to pour the kettle but you need something so that you're actually bringing your hands to your face."* (Clinician 3)

> *"Whether it's to make a campfire and pour yourself a cup of tea or make a sandwich."* (Clinician 4)

Goal attainment through meaningful feedback was viewed as a key driver for replayability:

> *"What will bring them back is goal attainment and feedback … if they see any changes or feel their affected upper limb feels different or moves differently"* (Clinician 1)

> *"They're driven by personal best … high scores where they can visually see that and then being obviously driven by their affected arm."* (Clinician 4)

> *"If there are smaller goals they're able to achieve that sort of spurs them on to want to continue."* (Clinician 6)

Highlighting near successes is important for those more severely impaired or less confident:

> *"A sense of fun, a sense of maybe near success but not quite a success so that they want to get back and try again."* (Clinician 4)

Design changes include graded difficulty and adding activities of daily living, for example, food preparation, and movements that require bringing hands to the midline.

6.3.5. Social connection and wellbeing

The clinicians admitted "*there needs to be a bit of generational and systemic change. Then people will be more open to [VR]*" (Clinician 2), but appreciated that adjunctive tools like VR could be a great home program for self-directed rehabilitation providing autonomy:

> *"They are actually in charge of it themselves. Once set up … you could let them loose, and they can work away themselves and set their own targets and goals and ... get the engaging instant feedback."* (Clinician 1)

A key finding from the design workshop was the importance of clinicians as motivators of rehabilitation. For clinicians to be onboard, the technology must be simple to learn, setup, and use:

> *"The trickiest bit is to get the therapist – how much training should you give them?"* (Clinician 2)

> *"As a profession, we're a lot more open-minded than we used to be, but it needs to be... around education, demonstration, and being able to loan these bits of equipment so people can have a play and a feel and then see the benefits"* (Clinician 5)

> *"If the clinician has confidence and is able to explain and teach how to use the technology"* (Clinician 6)

However, they appreciated that the game would not be used in isolation:

> *"If someone is unmotivated by a game, that's not the game's fault. I think the therapist has to figure what will work for that person"* (Clinician 2)

One clinician suggested having multiple players, for example, a family member could play along on an external device to facilitate intergenerational play:

> *"This social aspect of having people ... helping you and working alongside you with your rehab is super important ... if there would be a way of having a couple of 2 player games … you could download an app and match into a game with someone … you would get things like grandparents who could play with the grandkids, and that would be an amazing way of connecting."* (Clinician 2)

The intergenerational play was cited as a motivating factor for the elderly during the design workshop.

6.4. Outcome Measures

6.4.1. System Usability Scale

The System Usability Scale (SUS) recorded clinicians' perceptions of the game's potential usability. The SUS is a 10-point measure of usability covering usefulness, ease of use, consistency, learnability, and confidence (John, 1996). Scores ranged from 48 to 83, with a mean of 67 and a median of 66.

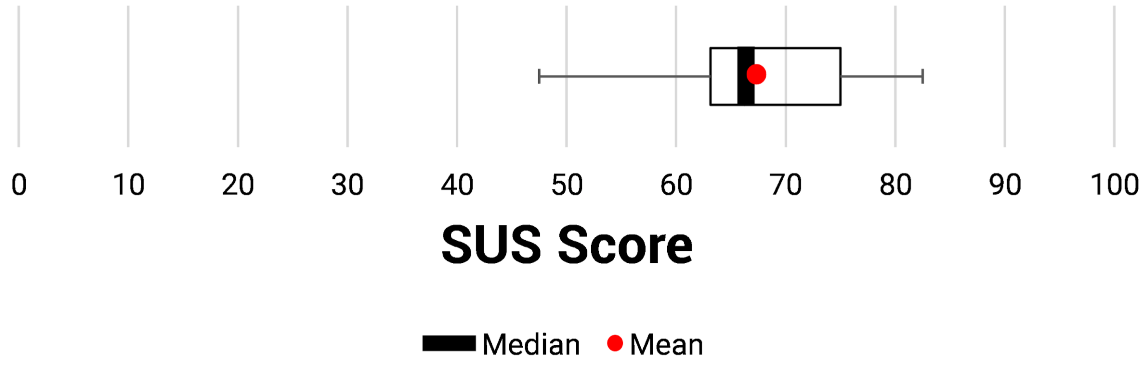

Figure 6.2. Box-and-whiskers plot of SUS scores highlighting the spread and averages for all participants (n = 6).

Scores above 68 on this scale are classified as above average usability or greater usability than 50% of products measured using the SUS (Sauro, 2011). Once iterations are implemented to accommodate their recommendations, it is anticipated that a retest may lead to an increase in SUS score.

6.4.2. Intrinsic Motivation Inventory

A modified Intrinsic Motivation Inventory (IMI), with 26 items out of the total 45, was completed by clinicians (Popović et al., 2014). The IMI has been used in studies looking at intrinsic motivation and self-regulation in serious games for stroke rehabilitation (Burke et al., 2009; Mihelj et al., 2012; Popović et al., 2014). The IMI measures domains of interest/enjoyment, value/usefulness, effort/importance, perceived competence, perceived choice, and pressure/tension. The IMI was used for measuring perceived motivational aspects of the game as seen by the clinicians.

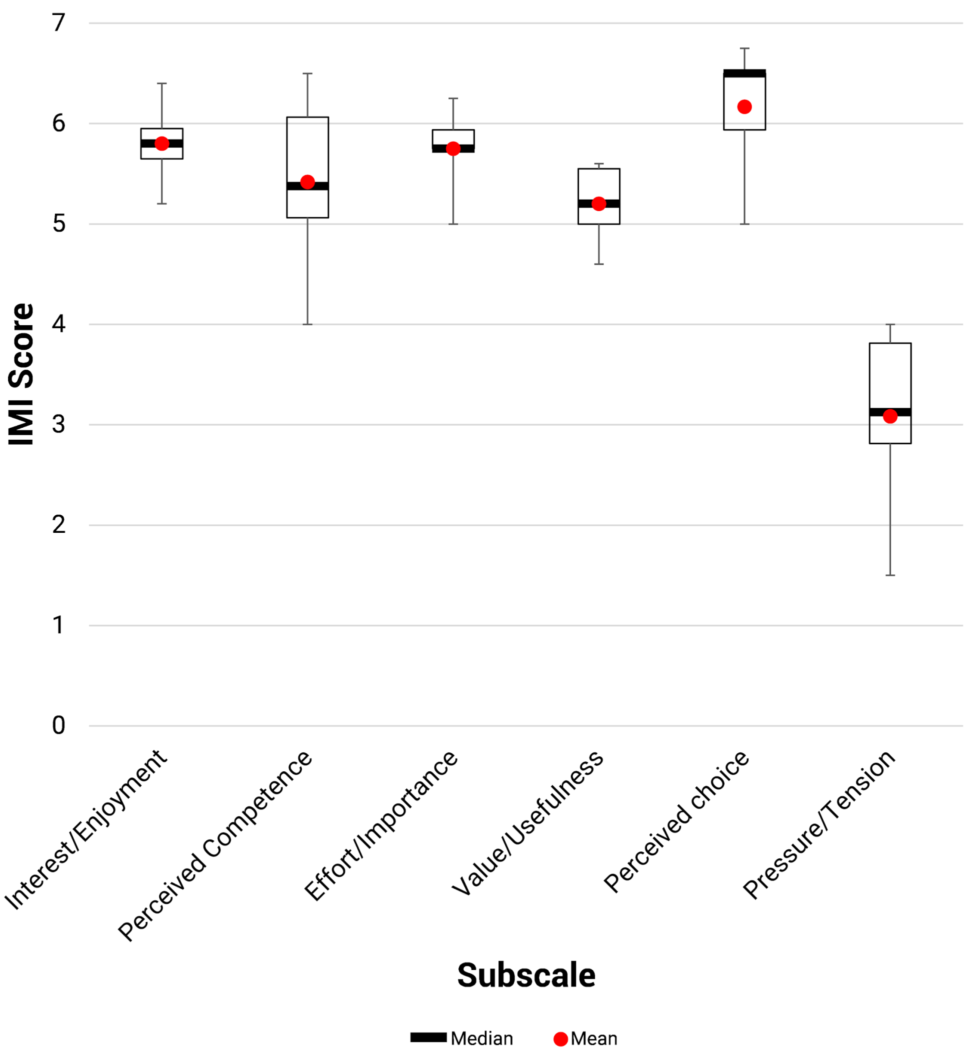

Figure 6.3. Box-and-whiskers plot of IMI subscales. Scores range from 1 = not at all true to 7 = very true.

The results showed that overall, there was a favourable response on all subscales. The quartile distribution is presented in Figure 6.3. The interquartile range (IQR) provides the variability of the data that is resistant to outliers. The highest average scores were obtained on the subscales interest/enjoyment (median = 5.8, mean = 5.8, IQR = 0.3), effort/importance (median = 5.8, mean = 5.8, IQR = 0.2), and perceived choice (median = 6.2, mean = 6.5, IQR = 0.6). Medium to high average scores were obtained for perceived competence (median = 5.4, mean = 5.4, IQR = 1) and value/usefulness (median = 5.2, mean = 5.2, IQR = 1). Finally, pressure/tension was medium to low with a wide degree of variability (median = 3.1, mean = 3.1, IQR = 1). The IMI and SUS were intended to be used with the clinicians and PwS after they played the game themselves. Therefore, these results must be taken with caution. They provide an indication that clinicians viewed the early prototype favourably in terms of usability and potential to capture elements of intrinsic motivation.

6.5. Design Changes

The expert review session identified several areas that the clinicians identified could use further improvement. The following table outlines the issues, potential solutions, and the priority for design changes:

Table 6.1: Design changes

Issue	Design Solution	Priority
Full Body Avatar	● Use inverse kinematics to have full-body representation ● Visualisation of shoulder and elbow will enhance the illusion	High
Progression of Tasks	● Reorder progression of tasks from simplest to most complex ● Modify reach-to-grasp activity to be more relevant ● Add activity of daily living, e.g. food preparation, requiring midline movement	High
More Practice and Repetitions	● Provide practice task for mirrored movements before grab task ● Options to set repetitions	High
Environmental complexity	● Simplify the scene ● Remove distracting elements ● Option to enable/disable environment in the drawing game	High
Level Feedback	● Remove real-time elevation feedback from the wrist to reduce distraction ● Highlight performance more clearly on the scoreboard	High
Adaptive Difficulty	● Use the number of hits and misses to modify the difficulty in real-time	High
Social Features	● Options for sharing results and drawings	High
Additional Environments	● Extra environments and locations	Low
Multiple Players	● Multiplayer games	Low

Changes with high priority were made to the game and are highlighted in the following chapter.

Chapter 7
Design Output

The following chapter of screenshots of the final design output highlights the design changes following the expert review. An extended gameplay video is available online at:

https://vimeo.com/senailenistonkahsai/mirrorvr/

7.1. Full Body Avatar

Figure 7.1. Full body avatars. Male (left) and female (right) avatars were implemented to enhance mirror illusion and presence compared to just having hands.

Figure 7.2. Clothes customisation. Change shirt and pants colour (left); Changes reflected in real-time.

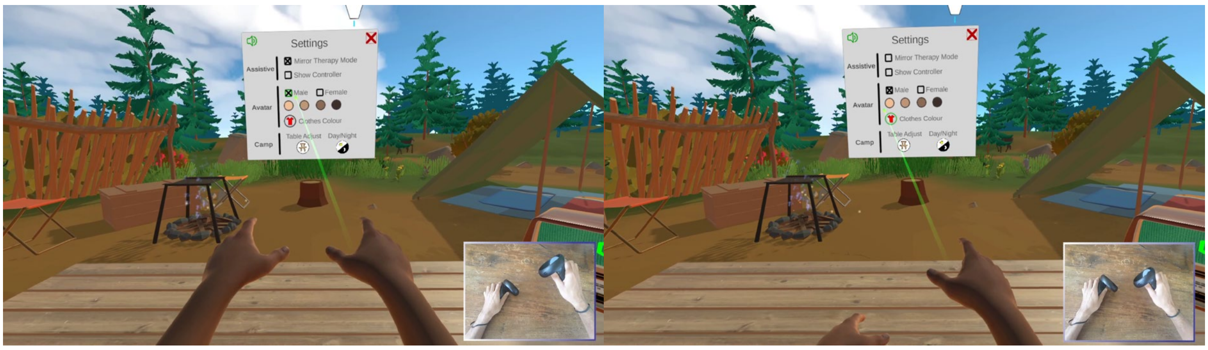

Figure 7.3. Mirror therapy mode. Right hand movement mirrored onto left. (left). Mirrored movement turned off (right).

7.2. Progression of Tasks

Figure 7.4. Difficulty levels. Colour-coded difficulty levels: easy, medium, hard (left); reaching-and-grasping activities, which clinicians felt were too complex for the tutorial, were made into their own tasks: Picnic and Campfire (right).

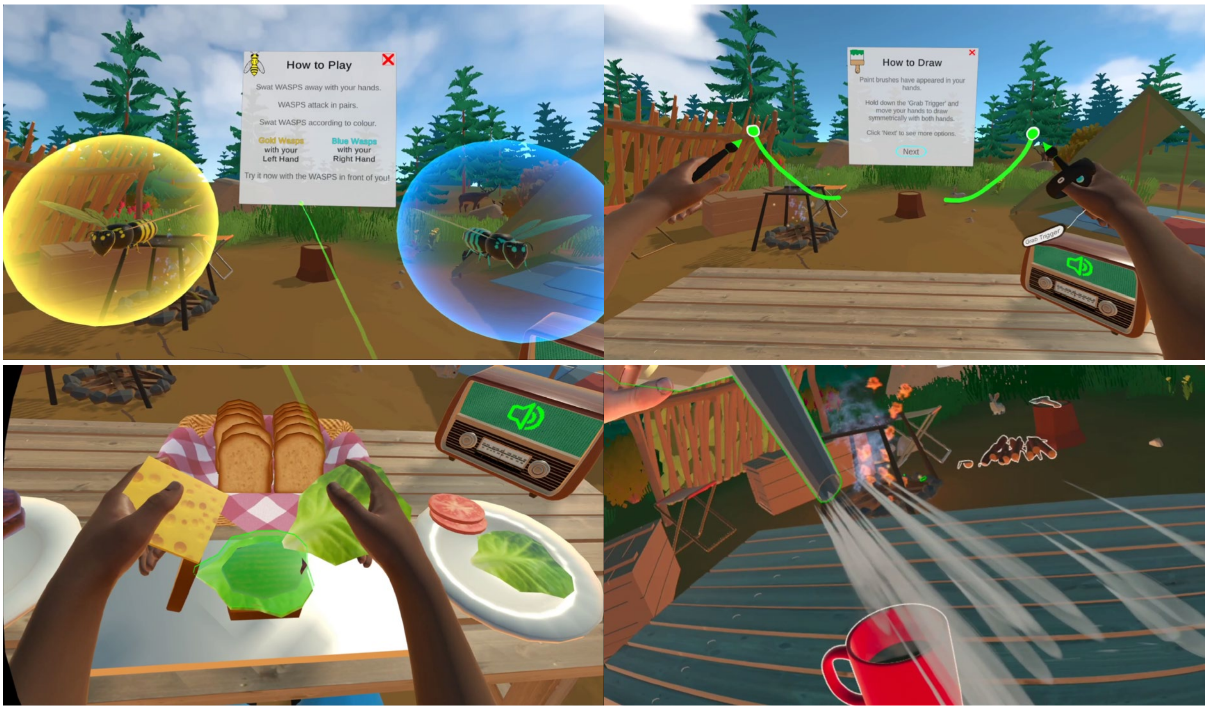

Figure 7.5. Mini-games. Each task had a tutorial with clear goals outlined explicitly to the player. Wasp Attack for shoulder and elbow movement (top left). Art Camp for unguided self-paced movement (top right). Picnic for reach-to-grasp and midline movements (bottom left). Campfire for more advanced reach-to-grasp movements including pouring a kettle into a cup (bottom right).

7.3. More Practice and Repetitions

Figure 7.6. Mirrored movement practice. Players moved the mirrored hand to floating targets (left); Successful hit provides feedback (right).

Figure 7.7. Goal setting. Setting the number of repetitions in 'Wasp Attack'.

7.4. Environmental Complexity

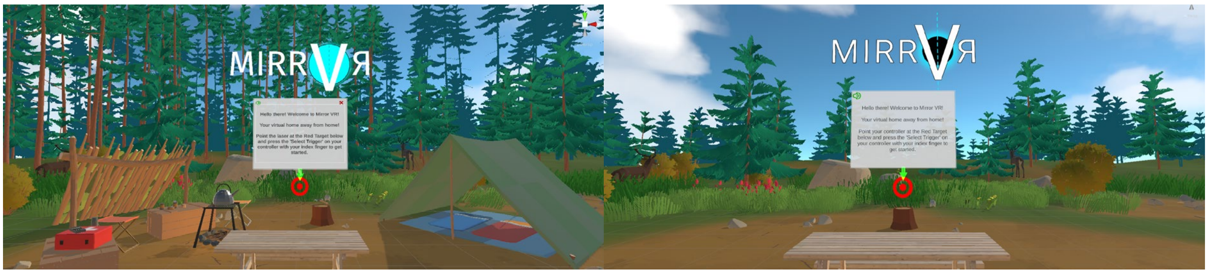

Figure 7.8. Simplified initial environment. The original environment was too busy (left); the updated environment removed environmental complexity without removing richness (right). The campsite was revealed as players progressed.

Figure 7.9. Enable/disable forest environment. Using the palette to disable the environment (left); provided to see drawings more clearly (right).

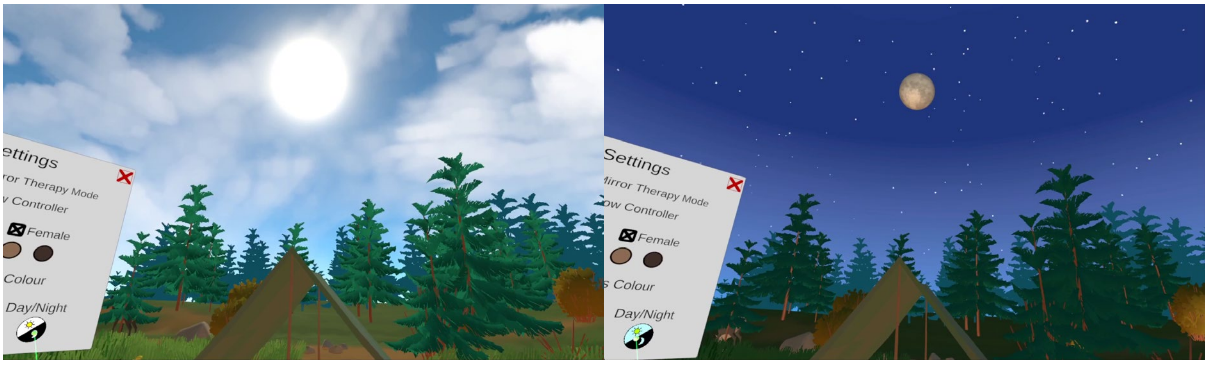

Figure 7.10. Day/night customisation.

7.5. Adaptive Difficulty

Figure 7.11. Adaptive difficulty. Wasp speed increased by one factor when a player hits ten wasps in a row (left); missing a wasp resets the wasp speed to 1x (right).

7.6. Level Feedback

Figure 7.12. Level feedback. Star system provided understandable feedback (left); poor performance leads to encouragement to replay the level (right).

7.7. Social Features

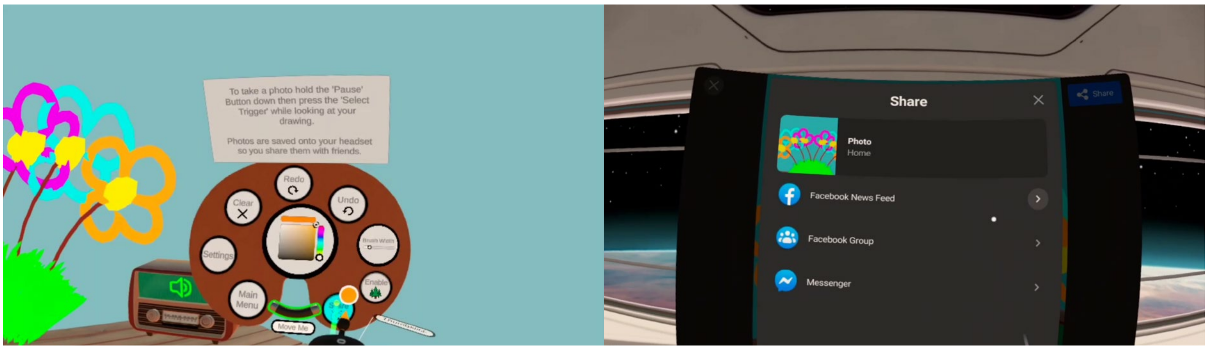

Figure 7.13. Social features. Added ability to take screenshots (left) and share drawings (right)

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Chapter 8

Discussion

An immersive VR game based on MT was developed using iterative research through design, and according to design criteria, constructed following a design workshop with PwS and stroke rehabilitation experts. Experts validated the designs, and their feedback was evaluated against the design criteria.

The literature review discussed two key themes to support the use of VR in upper limb rehabilitation post-stroke: immersion and presence, and gamification of rehabilitation. These themes were used to create a game design strategy for a VR game to support upper limb stroke rehabilitation. Translating movement onto realistic representations of the hand facilitates embodiment and enhances the mirror illusion (Schüler, 2014; Slater & Sanchez-Vives, 2016). The VR headset provided the immersion, while the game used a variety of features such as tracking limb position, avatar customisation, virtual environments, and simulation of realistic interactions to achieve presence. Movement of an unaffected hand was captured and mirrored onto a virtual hand representing the affected hand. The clinicians felt the VR application of MT overcame the spatial limitations of conventional MT, allowing for a greater variety of possible movements.

The game used elements of gamification to enhance engagement in rehabilitation (Lohse et al., 2013). Visual and auditory feedback was given on score, movement performance, and successful interactions in the game. The games had clearly identifiable goals, broken down into a variety of engaging tasks. Challenge was implemented through grading each mini-game as well as using features such as adaptive difficulty during gameplay.

People with stroke and clinicians were included as much as was feasible to inform the design process. The design criteria were used throughout the process to evaluate the designs at different stages. The following evaluation discusses how the criteria were met to varying degrees of success.

8.1. Design Criteria Evaluation

8.1.1. Accessibility and simplicity

Accessibility and simplicity referred to how the game was designed to cater to a range of impairments and technological experience. Video games and rehabilitation games have become more widely accepted in older populations (Anderson, 2016). However, VR is a new medium of interactivity, which meant players had to be guided gradually through the experience. The tutorial and profile setup were designed to teach the player the controls and mechanics gradually through direct and simple instruction. The clinicians felt that the use of MT would help open up the accessibility of the game to a wide audience initially, as they can use their unaffected arm to learn how to use the game, while still receiving visual feedback of their affected arm.

8.1.2. Communication and feedback

Communication and feedback related to communicating how player actions result in success through feedback. People wanted relevant and timely feedback to help players learn how to play the game and to highlight success. The game provided performance feedback through scores and feedback on successful engagement in interactions such as setting table height or customising the character. Meaningful feedback that aligns with therapeutic goals may lead to greater acceptance of the game and motivate people to engage with the game and therefore, rehabilitation (MacDonald et al., 2013, p. 120). Clinicians will be more likely to support the game providing timely feedback on their client's progress.

8.1.3. Engagement

The VR game was designed to facilitate engagement through enjoyable and challenging tasks as well as immersion in the environment. The environment and games turned repetitive exercise movements into engaging and fun activities in a virtual environment that avoided the boredom occasionally felt by some PwS when using home programs (Kenah et al., 2018; Miller et al., 2017). The campground setting used relatable tasks such as food preparation or drawing and extended PwS into a fantastical and relatable environment. Clinicians felt that the tasks were more enjoyable and varied than traditional exercises and that for some less-motivated PwS the immersion afforded by VR may help them increase their therapeutic dose.

8.1.4. Progress

Progress related to how success in short-term game goals could lead to long term progressions. The variety of games and levels to progress through, provided replayability to promote sustained engagement (Lohse et al., 2013). Players can choose to set the level of difficulty according to their level of skill and increase difficulty accordingly as they progress. Adjusting the challenge acted as a motivator to set new goals to reach. Future iterations of the game will require investigation into how achievement of short-term goals is aligned to progression towards individual rehabilitative goals.

8.1.5. Social connection and wellbeing

Social connection is cooperation and competition with others, while wellbeing refers to feelings of positivity. There is potential for social interactions in the current prototype to be better supported, while the concept of wellbeing was catered to by having positive encouragement in the performance feedback, fostering play, and through the outdoor environment. The design workshop highlighted that competition with others was a motivating element for some PwS. The current game implemented high scores and there is potential for future iterations to have leaderboards where players around the world could compete. The game attempted to foster social interactions outside the game between PwS and clinicians or support people, as these are the people involved with initial training and setup of the device. Future iterations could include features to support sharing performance analytics with clinicians or via social media or by introducing multiplayer options to foster social connections (Lohse et al., 2013).

8.2. Limitations

Due to the limited sample size and the nature of the remote testing, these results should be interpreted with caution. More informed conclusions about usability will be achieved when the game is tested with PwS. However, due to unforeseen circumstances around COVID-19, this was not possible. The usability of the device with a severely impaired PwS pre-COVID provided anecdotal evidence that VR could be tolerated. However, the small sample size of participants may not produce generalisable results to the wider population of PwS. An expert review was a valuable method to validate the game under the circumstances. This method also highlighted that the level of therapist training and interaction within the VR game requires further investigation. MT was chosen to accommodate PwS with severe limb impairment; this may be inaccessible to PwS with non-motor symptoms of stroke and further research into the accessibility of these games for PwS with visual neglect, cognitive impairments, and fatigue are required.

8.3. Future Directions

The expert review highlighted the importance of testing the prototype with PwS formally. A recent pilot study showed that an immersive VR intervention based on MT, similar to the one in this thesis, was well tolerated by PwS in the chronic stage in terms of usability and symptoms of motion sickness as quantified by the Motion Sickness Susceptibility Questionnaire (Weber et al., 2019). Therefore, there is scope for the VR game to be tolerated by PwS. There was confidence expressed in the expert review that immersive VR therapy could be coupled with conventional rehabilitation to increase therapy dose at home. Further research is required to investigate whether immersive VR can provide efficacy in terms of functional outcomes, similar to the use of conventional MT as an adjunct to improve motor outcomes (Laver et al., 2017).

The impact of VR on affective constructs such as immersion, motivation, and engagement need to be clearly measured and defined in future studies. Rorhbach et al. (2019) found that, although motivation, engagement, and immersion were commonly cited as key strengths of using VR for stroke rehabilitation, the measurement of these constructs and how they link to functional outcomes was lacking in a majority of studies. For example, motivation was cited in 123 of 155 studies yet only measured in 42 of them. Systematic measurement of these constructs is required to validate their theoretical importance. In future clinical studies, it would be valuable to conduct an analysis of how these constructs are facilitated by VR and their relationship to functional outcomes.

In the game, although the affected arm is resting on the table, the position of the affected arm in the background is always tracked. Weber et al. (2019) observed unintended movement of the affected arm to match the mirrored virtual representation, even when subjects were asked to maintain their affected arm at rest. These unintended movements were quantified and could be used in future iterations to grade the range of movement of their affected limb to encourage more movement of the affected limb over MT and provide more relevant timely feedback, as the PwS progresses.

Hand-tracking without the use of controllers may lead to increased accessibility for those inexperienced with game controllers. Leap Motion hand tracking was experimented with initially. However, it did not afford flexibility and relied on the use of a computer. During the development pipeline, the Oculus Quest received a hand-tracking software update using computer vision without additional hardware needed (Oculus, 2019b). A recent study comparing interaction types on the Oculus Quest reported that the using controllers, where both hands and controllers were visualised, was the most preferred for grabbing interactions, while hand-tracking without controllers was most usable for typing tasks (Voigt-Antons et al., 2020). Therefore, hand-tracking input could be an interaction modality option for future VR games to improve the accessibility for those less familiar with game controllers. Since hand-tracking is built-in to the headset, there is no additional cost beyond the headset.

This research found that all the clinicians saw value in using immersive VR-based MT to encourage engagement with rehabilitation. Research has found that clinicians do not widely use technology in stroke rehabilitation (Langan et al., 2018). VR games could act as an assistive tool for therapists, which could be used to engage, educate, and empower PwS in monitoring their progress and setting goals over the long-term at home. Tracking player analytics will allow PwS and their clinicians to monitor progress, potentially enhancing the patient-clinician relationship (MacDonald et al., 2013, p. 114). Providing additional detailed analytics that could be viewed on the web or a smart device application may facilitate sustained engagement and contribute to setting long-term goals.

Chapter 9
Conclusion

This research found that there is potential for immersive VR to facilitate engagement in upper limb rehabilitation as an adjunct to conventional physical therapy. A game was designed to engage PwS in sustained upper limb rehabilitation, make repetitive exercises more enjoyable and to track, quantify, and record movement performance. VR game systems have become more accessible and affordable to a wider audience In addition to the gamification of exercise, the 3D environments in VR are more immersive than traditional video games using 2D interfaces, which can facilitate engagement and presence in the virtual environment.

The research used a human-centred design approach. The design thinking workshop led to the construction of design criteria for the VR game: accessibility and simplicity, communication and feedback, engagement, progress, and social and wellbeing. These criteria ensured that the needs and goals of both PwS and clinicians were represented in the development of the VR game. The final design output, Mirror VR, extended the visual illusion used in MT, opened up the accessibility of the game to PwS with severe upper limb motor impairments, and provided a variety of challenging activities for different playstyles and skill levels. Clinicians felt that the VR games could potentially increase the perceived value of engaging with their therapy through clear feedback, self-empowerment to track progress, alignment with rehabilitative goals, enjoyment, and fostering social connections with other players or with their clinicians. Therefore, the research demonstrated that consumer VR products, in combination with specific therapeutic games, are suitable for rehabilitation and that VR games could provide an engaging home-based self-management tool in the future.

The human-centred design and multidisciplinary approach to developing the game has contributed towards the health and design disciplines by exploring how VR rehabilitation was received by clinicians. The expert reviews found that clinicians saw potential for this technology to empower PwS at home with their rehabilitation as long as there was adequate training on the technology for clinicians, PwS, and support people, and that the game is clearly aligned with therapeutic goals and meaningful movements. People will be more likely to engage with these games when there is clear feedback on how the short-term game goals align with their therapy goals. Future investigation into the tolerability and usability of the VR game will be required through usability testing by PwS, including those with non-motor symptoms such as visual neglect, cognitive impairment, and fatigue. Qualitative analysis of user testing and quantitative analysis of validated outcome measures of engagement, motivation, and immersion should be conducted to evaluate how the game facilitates motivation and engagement in rehabilitation. In conclusion, VR games could provide an immersive and novel self-management tool for PwS to positively engage with their rehabilitation.

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List of Figures

Appendices

Appendix A: HDEC Out of Scope Letter

Health and Disability Ethics Committees

Health and Disability Ethics Committees
Ministry of Health
133 Molesworth Street
PO Box 5013
Wellington
6011
0800 4 ETHICS
hdecs@moh.govt.nz

3 September 2019

Mr Senai Leniston-Kahsai
Victoria University of Wellington
lenistsena@myvuw.ac.nz

Dear Mr Leniston-Kahsai,

Study title:	The design of a virtual reality application for upper limb rehabilitation post-stroke

Thank you for emailing HDEC a completed scope of review form on 02 September 2019. The Secretariat has assessed the information provided in your form and supporting documents against the Standard Operating Procedures.

Your study will not require submission to HDEC as, on the basis of the information you have submitted, it does not appear to be within the scope of HDEC review. This scope is described in section three of the Standard Operating Procedures for Health and Disability Ethics Committees.

This is a feasibility intervention study on a post-stroke rehabilitation virtual reality application. As identified, this device is classified as a low-risk (class I) medical device by Australia's Therapeutic Goods Administration, and your study therefore does not require HDEC review. Despite this exclusion, it has been noted that your study will involve a participant group which, being comprised of stroke survivors, could be considered 'potentially vulnerable', and the appropriate NEAC guidance on informed consent must be followed (see the *Ethical Guidelines for Observational/Intervention Studies*).

If you consider that our advice on your project being out of scope is incorrect please contact us as soon as possible giving reasons for this.

This letter does not constitute ethical approval or endorsement for the activity described in your application, but may be used as evidence that HDEC review is not required for it.

Please note, your locality may have additional ethical review policies, and you must contact your institutional ethics committee before you begin.

Please don't hesitate to contact us for further information.

Yours sincerely,

Mark Joyce
Advisor
Health and Disability Ethics Committees
hdecs@moh.govt.nz

Out of Scope – HDEC email submission

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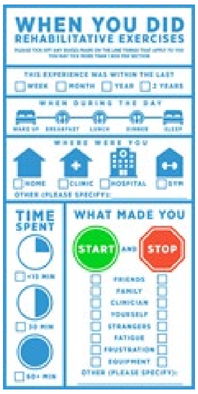
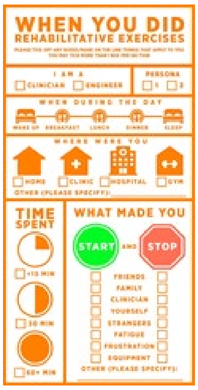
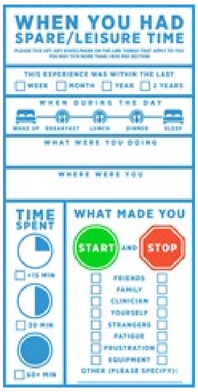
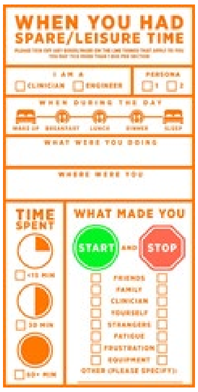
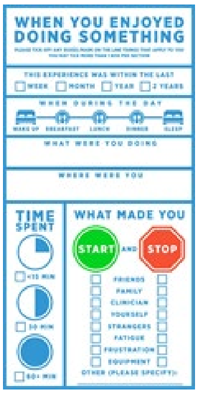
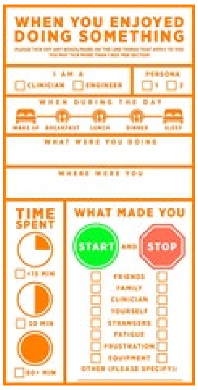
Appendix B: User Journey Map Cards

Table B.1. Pre-prepared cards for the user journey map

Question	People with Stroke (PwS)	Clinicians and Engineers (Experts)
When you did rehabilitative exercise?		
When you had spare/leisure time?		
When you enjoyed doing something?		

Appendix C: Modified User Personas

Figure C.1. User personas used by experts for the user journey map. Personas were modified from Pyae et al., 2013.

Appendix D: Exploratory Usability Test Questions

Preliminary Interview (20 minutes)

1. When did you experience your first major stroke?
2. What type of stroke did you have? Ischaemic or haemorrhagic?
3. How has the stroke affected you? Do you have left or right sided hemiparesis?
4. What form of rehabilitation have you had following the stroke?
5. What was the extent of this rehabilitation in terms of length and intensity?
6. Have you regained any motor function?
7. Can you comment on the difficulty of the rehabilitation?
8. Are you still undertaking any form of stroke rehabilitation?
9. Have you ever had action observation therapy and/or mirror therapy as part of your rehabilitation?
   a. If yes how have you felt it has benefited your rehabilitation? If not, have you heard of action observation therapy and/or mirror therapy?
   b. Can you tell me about what aspects of action observation therapy and/or mirror therapy worked for you? Do you have any suggestions on how it could be improved?
10. What medical devices do you use to assist with therapy at home or in the clinic?
11. What is your experience with technology as part of your everyday life, for example smartphones, computers, the internet and tablets?
12. What types of games do you enjoy playing? (*Board games, puzzles, etc.*) Why?
13. What experience do you have with video games or digital games?
    a. What are your thoughts on using video games to assist rehabilitation?
14. Have you ever heard of virtual reality or have you ever had a virtual reality experience?
    a. What would you expect out of virtual reality? What kind of virtual experiences would interest you? (*Travel/tourism, fantasy, storytelling/narrative driven experiences, puzzles, real life simulations e.g. gardening or sport?*
15. Would you be interested in using a VR application to support stroke rehabilitation?
16. Do you have any additional thoughts or comments you would like to add?

Post-Test Interview (20 min)

1. What was your overall impression of this experience?
2. What are your thoughts on virtual reality now that you have experienced it?
3. Do you have any suggestions about changing this application in order to make it more useful and more interesting for you?
   a. Would you add something?
   b. Would you remove something?
4. What are your thoughts about including specific content to the game, for example, playing a certain sport or completing a puzzle?
   a. Do you have any suggestions?
5. What did you think of the interactions used during the game?
   a. Did you find interactions with the environment natural or unnatural?
   b. Did you find the gestures you used felt natural or unnatural?
   c. Did your interactions with objects in the virtual world match your expectations?
6. How natural did the movement feel in the game?
7. What do you think about adding reward/punishment effects to the game (e.g., a certain number of lives, more audio or visual effects)?
8. How immersed did you feel in this virtual environment?
   a. What aspects of the game made you feel more immersed or less immersed in the experience?
9. Would you want to play this game again?
10. How did this specific game compare to rehabilitation exercises?
    a. Was it more or less difficult?
    b. Was it more or less interesting?
11. Did you feel dizzy or uncomfortable (symptoms of motion sickness) playing the game?
12. Do you have any additional thoughts or comments you would like to add?

Appendix E: Hardware, Software and Assets

Hardware

Oculus Quest: Standalone VR headset including Touch game controllers.
Leap Motion: Hand-tracking sensor.
Kinect V2: Depth sensing camera for mixed reality and remote user testing.
Elgato Green Screen: Collapsible chroma key panel for background removal in mixed reality.

Software

Unity: All-purpose game engine allowing flexibility, ease of use, reliability, and integration with VR technologies.
Adobe Photoshop/Illustrator: To create and modify logos, textures and icons.
Audacity: Open source audio editing software.
Open Broadcasting Software: Open source software for screen recording and streaming.
LIV: Content creation tool for VR that simplifies and enhances mixed reality capture.
Zoom: Video and audio conferencing platform.

Table E.1: Assets used for game development

Repository (License)	Asset (Creator)
Unity (Asset Store EULA)	Custom Timer (Sage Miller)
	Deucalion's Humans (FG3D)
	Final IK (ROOTMOTION)
	Flexible Colour Picker (Ward Dehairs)
	Flying Insects (GTox Models)
	FREE Casual Food Pack (Lumo-Art 3D)
	FREE Skybox Extended Shader (BOXOPHOBIC)
	Fresh Bread (Megan Alcock)
	Leap Motion Realistic Hands (Fifthview)
	Low Poly Animated Animals (polyperfect)
	Lowpoly Nature and Camping (Izen)
	Low Poly Survival Essentials (Broken Vector)
	Oculus Integration (Oculus)
	The Illustrated Nature (Artkovski)
	Vintage Style Radio (PolyLabs)
Turbo Squid (Royalty-Free)	artist palette (MP Design)
	3D Coffee Mug Low Poly model (rco_design)
	Low Poly Picnic Table (caliberbeats)
	Paint Brush 3D (EDplus)
BlendSwap (CC-BY License)	3D Hand Model (SuperDasil)
Github (MIT License)	OpenSaberVR: Open source clone of game logic for BeatSaber (https://github.com/dhcdht/OpenSaberVR)
	VoxHands: Humanoid finger controller animator (https://github.com/hiroki-o/VoxHands)
	VRDraw: VR drawing tool (https://github.com/dilmerv/VRDraw)
	VRGrabber: Distance grabbing (https://github.com/hecomi/VrGrabber)
	VRTK: Toolkit for rapidly building VR experiences (https://github.com/ExtendRealityLtd/VRTK
Youtube Audio Library (Attribution-Free)	Game music and sound effects

Appendix F: Expert Review Interview Questions

Post-Test Discussion (20 min)

General Impressions

1. What was your overall impression of this experience?
2. What are your thoughts on virtual reality now that you have seen it?
3. How would you improve or modify this application in order to make it more useful, relevant and interesting for stroke survivors?
    a. What would you add?
    b. What would you remove?
4. What are your thoughts about including specific exercises or content to the game? Do you have any suggestions? Joints, planes of movement, progressions?
5. What did you think of the interactions used during the game?
    a. Did you find interactions with the environment natural or unnatural?
    b. Did you find the gestures felt natural or unnatural?
    c. Did the interactions with objects in the virtual world match your expectations?
6. How natural did the movement seem in the game?
7. What do you think about adding rewards or extra challenges to the game (e.g., a certain number of lives, more audio or visual effects)?
8. How immersive was the virtual environment?
    a. What aspects of the game seemed more immersive or less immersive?

Feasibility for Stroke Survivors

9. What type of stroke survivors would benefit most from this?
10. In your experience do you believe these types of games would engage your typical patients or clients?
11. In your experience how difficult do you find the movements required in the game for a typical stroke survivor?
12.
    a. Reflecting on a stroke survivor who is highly motivated in their rehabilitation, what aspects of the game would appeal to them and what wouldn't?
    b. Reflecting on a stroke survivor who is severely disabled, what aspects of the game would appeal to them and what wouldn't?
    c. Reflecting on a stroke survivor who is less motivated in their rehabilitation, what aspects of the game would appeal to them and what wouldn't?
    d. Reflecting on a stroke survivor who is highly functioning, what aspects of the game would appeal to them and what wouldn't?
13. What aspects of the game that were included might make a stroke survivor want to play this game again? Can you think of anything that could be included to motivate stroke survivors to repeat the game or hold their attention?
14. How comfortable or competent do you think your patients or clients would be with using technology like this?
15. How did this specific game compare to rehabilitation exercises that you complete with your patients and/or clients?
    a. Did it seem more or less difficult?
    b. Did it seem more or less interesting?
16. Do you have any additional thoughts or comments you would like to add?

Appendix G: Expert Review Questionnaires (SUS & IMI)

Participant ID:______________
Date:___/___/___

THE POST-TESTING SYSTEM USABILITY SCALE (SUS) OF A VR APPLICATION

For each of the following statements, please mark one box that best describes you reaction to the **application** you tested today:

	Strongly disagree 1	2	3	4	Strongly agree 5
1. I think that I would like to use this **application** frequently.					
2. I found the **application** unnecessarily complex.					
3. I thought the **application** was easy to use.					
4. I think that I would need the support of a technician to be able to use this system.					
5. I found the various parts of this **application** were well integrated.					
6. I thought there was too much inconsistency in this **application**.					
7. I would imagine that most people would learn to use this **application** very quickly.					
8. I found the **application** very awkward to use					
9. I felt very confident using the **application**					
10. I needed to learn a lot of things before I could get going with this **application**.					

Participant ID: Click or tap here to enter text.
Date: Click or tap to enter a date.

THE POST-EXPERIMENTAL INTRINSIC MOTIVATION INVENTORY

For each of the following statements, please indicate how true it is for you, using the following scale:

		Not true at all			Some what true			Very true
	Question	**1**	**2**	**3**	**4**	**5**	**6**	**7**
1	I would enjoy doing this activity very much.	☐	☐	☐	☐	☐	☐	☐
2	I think I would be pretty good at this activity.	☐	☐	☐	☐	☐	☐	☐
3	I would put a lot of effort into this.	☐	☐	☐	☐	☐	☐	☐
4	I would not feel nervous at all while doing this.	☐	☐	☐	☐	☐	☐	☐
5	I would think this was a boring activity.	☐	☐	☐	☐	☐	☐	☐
6	I would believe this activity could be of some value to me.	☐	☐	☐	☐	☐	☐	☐

1

7	After playing the game for a while, I would feel pretty competent.	☐	☐	☐	☐	☐	☐	☐
8	I would believe I had some choice about doing this activity.	☐	☐	☐	☐	☐	☐	☐
9	I would not try very hard to do well at this activity.	☐	☐	☐	☐	☐	☐	☐
10	I think that doing this activity could be useful for recovery of hand/arm movements.	☐	☐	☐	☐	☐	☐	☐
11	This activity would not hold my attention at all.	☐	☐	☐	☐	☐	☐	☐
12	I would feel very tense while playing the game.	☐	☐	☐	☐	☐	☐	☐
13	I would feel like it was not my own choice to use this game.	☐	☐	☐	☐	☐	☐	☐
14	I would think this activity was quite enjoyable.	☐	☐	☐	☐	☐	☐	☐

2

15	I would be willing to do this again because it has some value to me.	☐	☐	☐	☐	☐	☐	☐
16	I would be satisfied with my performance at this task.	☐	☐	☐	☐	☐	☐	☐
17	I think this is important to do because it could help me grasp desired objects more easily.	☐	☐	☐	☐	☐	☐	☐
18	It is important for me to do well at this task.	☐	☐	☐	☐	☐	☐	☐
19	I did this activity because I had no choice.	☐	☐	☐	☐	☐	☐	☐
20	I would be anxious while playing the game.	☐	☐	☐	☐	☐	☐	☐
21	While I was watching the game, I was thinking about how much I would enjoy it.	☐	☐	☐	☐	☐	☐	☐
22	I would do this activity because I wanted to.	☐	☐	☐	☐	☐	☐	☐

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23	This was an activity that I could not do very well.	☐	☐	☐	☐	☐	☐	☐
24	I would not put much energy into this.	☐	☐	☐	☐	☐	☐	☐
25	I would feel pressured while doing these.	☐	☐	☐	☐	☐	☐	☐
26	I think using this application could help me to recover faster.	☐	☐	☐	☐	☐	☐	☐

N.B. The following was not shown to participants:

The six subscales included the following questions:
Interest/enjoyment: 1, 5, 11, 14, 21
Perceived competence: 2, 7, 16, 23
Effort/Importance: 3, 9, 18, 24
Value/Usefulness: 6, 10, 15, 17, 26
Perceived choice: 8, 13, 19, 22
Pressure and tension: 4, 12, 20, 25.

Scoring information for the IMI.

To score this instrument, you must first reverse score the items for questions 4, 5, 9, 11, 13, 19, 23 and 24. To do that, subtract the item response from 8, and use the resulting number as the item score. Then, calculate subscale scores by averaging across all of the items on that subscale. The subscale scores are then used in the analyses of relevant questions.

A 26 item variant of the IMI modified from Popović, M. D., Kostić, M. D., Rodić, S. Z., & Konstantinović, L. M. (2014). Feedback-mediated upper extremities exercise: increasing patient motivation in poststroke rehabilitation. *BioMed research international*, *2014*, 520374. doi:10.1155/2014/520374

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Appendix H: Ethics for Workshop

The design of medical devices and games for upper limb rehabilitation post-stroke

INFORMATION SHEET FOR PARTICIPANTS FOR FOCUS GROUPS

You are invited to take part in a study of the **usability of medical devices and games for stroke rehabilitation**. Please read this information before deciding whether or not to take part. If needed, one of the researchers can read this document to you. If you decide to participate, thank you. If you do want to take part now, but change your mind later, you can pull out of the study at any time. If you decide not to participate, thank you for considering this request.

This Participant Information Sheet will help you decide if you'd like to take part. It sets out why we are doing the study, what your participation would involve, what the benefits and risks to you might be, and what would happen after the study ends. We will go through this information with you and answer any questions you may have. You do not have to decide today whether or not you will participate in this study. Before you decide you may want to talk about the study with other people, such as family, whānau, friends, or healthcare providers. Feel free to do this.

If you agree to take part in this study, you will be asked to sign a Consent Form on the last page of this document. You will be given a copy of both the Participant Information Sheet and the Consent Form to keep.

This document is 8 pages long, including the Consent Form. Please make sure you have read and understood all the pages.

Who are we?

Our names are Senai Leniston-Kahsai and Tiger Guo. We are Masters students in the Masters of Design Innovation programme at Victoria University of Wellington. This research project is to work towards our individual theses projects.

What is the aim of the project?

The aim of the study is to test the **usability of robotic medical devices and video games for stroke rehabilitation** that we are developing to be used by people who are recovering from stroke.

This study is only a **usability** study for a potential additional tool for stroke rehabilitation therapy to complement conventional physical rehabilitation that people with stroke may receive. The devices or games would not replace any other therapy you may be receiving.

Our aim for this focus group is to come up with a set of design requirements for new devices, games or apps to be used for stroke rehabilitation.

The device will be designed and game will be developed by students as a requirement for a Masters degree. This research is funded by the School of Design at Victoria University of Wellington.

Any other questions you have can be answered by Dr. Edgar Rodriguez (463 6245)

This research has been approved by the Victoria University of Wellington Human Ethics Committee [Ref #0000027728].

How can you help?

We asked you to take part in this research because you have had a stroke and may have limited use of one of your arms. We will invite you to be part of a focus group with other people with stroke, clinicians (physiotherapists, occupational therapist, etc), engineers and designers. If you agree to take part you will be part of a focus group at AUT Health and Rehabilitation Research Institute. We will ask some questions about you such as how old you are, your ethnic background, how long ago you had the stroke and how the stroke affects you now.

We will then ask you questions about what it is like for you to do rehabilitation at home and we will discuss responses with the group. We want to reassure you that there are no wrong answers and hearing about your actual experience will be very valuable for us. We are interested in knowing whether you carry out physiotherapy exercises at home or not, what you find motivating and what kind of barriers you encounter.

Your participation in the focus group will take 1.5 hours each day over 2 days (2 hours overall). We will audio record the focus group and take photographs with your permission and write it up later.

The information shared during the focus group is confidential. That means after the focus group, you may not communicate to anyone, including family members and close friends, any details about the identities or contributions of the other participants of the focus group.

Your participation requires your concentration remembering your experience and discussing with the group. You can withdraw from the focus group at any time before the focus group begins.
You can also withdraw while the focus group is in progress. However, it will not be possible to withdraw the information you have provided up to that point as it will be part of a discussion with other participants.
You may be invited to take part again if you would like to help us test the designs we develop.

What are the possible benefits and risks of this study?

We know that people who have had stroke cannot access stroke rehabilitation therapy regularly. They have to travel to clinics or hospital. We also know that rehabilitation is more effective when it is carried out for several hours throughout day, every day.

This study is a usability study for a potential additional tool for stroke rehabilitation therapy to complement conventional physical rehabilitation that people with stroke may receive.

Participation in this focus group, or testing the devices we develop if you wish to continue to participate, would not replace any other therapy you may be receiving.

While you are in the focus group you will be sitting in a chair.

What will happen to the information you give?

This research is confidential[1*]. This means that the researchers named below will be aware of your identity but the research data will be combined and your identity will not be revealed in any reports, presentations, or public documentation. However, you should be aware that in small projects your identity might be obvious to others in your community.

Only my supervisors , the transcriber (who will be required to sign a confidentiality agreement) and I will read the notes or transcript of the focus

[1*] Confidentiality will be preserved except where you disclose something that causes me to be concerned about a risk of harm to yourself and/or others.

group. The focus group transcripts, summaries and any recordings will be kept securely and destroyed on 15/10/2024.

Stroke rehabilitation physiotherapists and designers will review these recordings. We will keep the audio and photographs securely in the University. Your involvement in the study will only be known by the researchers. All photographs and audio will be taken using cameras and recorders belonging to the School of Design. The images and audio will be taken off these devices and immediately after this session and then kept secure in the University computer system.

If we do use photographs of you for presenting our research we will not show any part of you, such as your face, that can tell other people that you have taken part. We will do this by blurring parts of the images. We will record what you say. If you tell us something useful that we quote, we will not use your name with what you say.

What will the project produce?

The information from my research will be used in my Masters and for developing the final product.

We can present the findings of this study at stroke clubs within a year of conducting the study.

We can also send you a summary of the student's thesis describing the outcome of the study.

We may also present this study with other similar studies we are conducting at conferences or in academic publications.

Who pays for the study?

This study is funded by Victoria University of Wellington and the School of Design through medical technology research grants from the Centre of Research Excellence of Medical Technologies.

You will not incur any costs by taking part and we will reimburse your travel costs, travel to you or give you taxi chits.

What if something goes wrong?

If you were injured in this study, which is unlikely, you would be eligible for compensation from ACC just as you would be if you were injured in an accident at work or at home. You will have to lodge a claim with ACC, which may take some time to assess. If your claim is accepted, you will receive funding to assist in your recovery.

If you accept this invitation, what are your rights as a research participant?

You do not have to accept this invitation if you don't want to. If you do decide to participate, you have the right to:

- choose not to answer any question;
- ask for the recorder to be turned off at any time during the focus group;
- withdraw from the focus group while it is taking part however it will not be possible to withdraw the information you have provided up to that point;
- ask any questions about the study at any time;
- read over and comment on a written summary of the focus group;
- be able to read any reports of this research by emailing the researcher to request a copy.

If you have any questions or problems, who can you contact?
If you have any questions, either now or in the future, please feel free to contact either:

Students:

Name: Senai Leniston-Kahsai

University email address: lenistsena@myvuw.ac.nz

Name: Tiger Guo

University email address:

guochon@myvuw.ac.nz

Supervisors:

Primary

Name: Edgar Rodriguez

Role: Associate Professor

School: School of Design

Phone: (04) 934 9321 (Work),

027 563 6544 (24 Hour Emergency)

edgar.rodriguez@vuw.ac.nz

Secondary

Name: Dr Brian Robinson

Role: Senior Lecturer

School: School of Nursing, Midwifery and Health Practice

Phone: (04) 934 9321 (Work),

029 776 9321 (24 Hour Emergency)

edgar.rodriguez@vuw.ac.nz

Human Ethics Committee information

If you have any concerns about the ethical conduct of the research you may contact the Victoria University HEC Convenor: Dr Judith Loveridge. Email hec@vuw.ac.nz or telephone +64-4-463 6028.

If you want to talk to someone who isn't involved with the study, you can contact an independent health and disability advocate on:

Phone: 0800 555 050
Fax: 0800 2 SUPPORT (0800 2787 7678)
Email: advocacy@hdc.org.nz

For Maori health support please contact your health provider and they will refer you to the representative Maori health support group.

The design of medical devices and games for upper limb rehabilitation post-stroke

CONSENT TO PARTICIPATE IN FOCUS GROUP

This consent form will be held for a minimum of five years.

Researchers: Senai Leniston-Kahsai, School of Design, Victoria University of Wellington.
Tiger Guo, School of Design, Victoria University of Wellington.
Associate Professor Edgar Rodriguez, Programme Director of Interaction Design Programme, School of Design, Victoria University of Wellington.

- I have read the Information Sheet and the project has been explained to me. My questions have been answered to my satisfaction. I understand that I can ask further questions at any time.
- I agree to take part in a video recorded focus group.

I understand that:

- I acknowledge that I am agreeing to keep the information shared during the focus group confidential. I am aware that after the focus group, I must not communicate to anyone, including family members and close friends, any details about the identities or contributions of the other participants of the focus group.
- I can withdraw from the focus group while it is in progress however it will not be possible to withdraw the information I have provided up to that point as it will be part of a discussion with other participants
- The identifiable information I have provided will be destroyed on 15/10/2020.
- I understand that the findings may be used for a Masters, academic publications, presented to conferences and/or developing the product.

- I understand that the observation notes and recordings will be kept confidential to the researcher, the supervisors and the transcriber.
- My name will not be used in reports and utmost care will be taken not to disclose any information that would identify me.
- I would like to receive a copy of the final report and have added my email address below. Yes ☐ No ☐

Declaration by participant:

Signature of participant: ______________________________

Name of participant: ______________________________

Date: ____________

Contact details: ______________________________

Declaration by member of research team:

I have given a verbal explanation of the research project to the participant, and have answered the participant's questions about it.

I believe that the participant understands the study and has given informed consent to participate.

Signature of researcher: ______________________________

Name of researcher: ______________________________

Date: ____________

Appendix I: Ethics For VR Hardware Individual User Test

The design of an immersive virtual reality application for upper limb rehabilitation post-stroke

INFORMATION SHEET FOR PARTICIPANTS FOR INDIVIDUAL USER TESTS

You are invited to take part in a study of the usability of an immersive virtual reality game, based on current neurorehabilitation techniques, intended for potential use in stroke rehabilitation. Please read this information before deciding whether or not to take part. If needed, one of the researchers can read this document to you. If you decide to participate, thank you. If you do want to take part now, but change your mind later, you can pull out of the study at any time. If you decide not to participate, thank you for considering this request.

This Participant Information Sheet will help you decide if you'd like to take part. It sets out why we are doing the study, what your participation would involve, what the benefits and risks to you might be, and what would happen after the study ends. We will go through this information with you and answer any questions you may have. You do not have to decide today whether or not you will participate in this study. Before you decide you may want to talk about the study with other people, such as family, whānau, friends, or healthcare providers. Feel free to do this.

If you agree to take part in this study, you will be asked to sign a Consent Form on the last page of this document. You will be given a copy of both the Participant Information Sheet and the Consent Form to keep.

This document is 9 pages long, including the Consent Form. Please make sure you have read and understood all the pages.

Who am I?

My name is Senai Leniston-Kahsai and I am a Masters student in the Masters of Design Innovation at Victoria University of Wellington. This research project is to work towards my thesis.

What is the aim of the project?

1

The aim of this study is to test the **usability** of an immersive virtual reality-based computer game that we have developed to be used by people who are recovering from stroke. Virtual reality involves wearing a headset that covers your eyes and displays an artificial environment to each of your eyes through screens/lenses within the headset. Since you can't see the real environment that you are in (for instance your lounge), the virtual reality experience is said to be "immersive" as the goal is that you feel immersed in the artificial environment. This game uses virtual reality to place you in a virtual environment where you are able to carry out fun tasks based on stroke rehabilitation exercises. You will be using your own physical hands and motion video game controllers to interact with the virtual environment.

This study is only a **usability** study for a potential additional tool for stroke rehabilitation therapy to complement conventional physical rehabilitation that people with stroke may receive.

We are only wanting to find out whether this game may be useful in stroke rehabilitation. This research is finding out whether you can use it and what you think of it. We are not testing this game for efficacy in stroke rehabilitation.

This game does not replace any other therapy you may be receiving.

We are wanting to know how you find playing the virtual reality game. Our aim is that the game will be easy to use and understand as well as challenging, engaging and rewarding for you.

This game is developed by a student as a requirement for a Masters degree. This research is funded by the School of Design at Victoria University of Wellington.

Any other questions you have can be answered by Dr. Edgar Rodriguez (463 6245).

This research has been approved by the Victoria University of Wellington Human Ethics Committee [Ref #0000027728].

How can you help?

You have been invited to participate in this research because you have had a stroke in the past 12 months and may have limited use of one of your arms.

The research study will take place at AUT Health and Rehabilitation Research Institute or your home.

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If the research study takes place in your home, two research students as well as a clinician will come. They will bring mobile telephones with them so that they can contact their research supervisors.

We will ask some questions about you such as how old you are, your ethnic background, how long ago you had the stroke and how the stroke affects you now.

We will show you a virtual reality-based computer game.

You will be asked to wear a virtual reality headset and use gesturing with your hands and a game controller captured by an external camera device to play the virtual reality computer game.

You can play this game for two 15 minute sessions with a break in between (~40-45 minutes including break) and can tell us when you want to stop at any time. We will check in and pause each session at the 15 minute mark and will give you a rest and a chance to get a refreshment.

We will take a video, photographs and screen capture of you playing the game. This is to make sure that using the controls and the game in ways that will be useful for stroke recovery and not cause harm.

After you have played the game we will ask you for your thoughts on playing the game in an interview. We will record what you say. If you tell us something useful that we quote, we will not use your name with what you say.

Your participation requires your concentration while playing the game. We realize that this can be tiring for you so we ask that you inform us if you are wanting to rest or to stop the session. You may be invited to take part again if you would like to help us test changes.

The research session will take approximately 1.5 hours. We will allow 30-45 minutes for user testing (with breaks) and 30 min for post-testing interviews and questionnaires. You can stop the user testing at any time, without giving a reason. We ask that you inform us if this is the case and you can stop the game by removing the headset yourself or asking one of the researchers to assist you. You can withdraw from the study by contacting me at any time before 07/06/2020. If you withdraw, the information you provided will be destroyed or returned to you.

What are the possible benefits and risks of this study?

We know that people who have had stroke cannot access stroke rehabilitation therapy regularly. They have to travel to clinics or hospital. We also know that

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rehabilitation is more effective when it is carried out for several hours throughout day, every day.

While you are playing the game you will be sitting in a chair. We will want you to stay sitting. This experience has been specifically designed to minimise motion sickness and other adverse effects of VR. Possible adverse effects of VR and video games include dizziness, motion sickness, flashing lights and epilepsy/seizure risk. It is possible that you may experience temporary symptoms of motion sickness due to the virtual reality, including headache, dizziness and nausea. Therefore, we ask that you inform us if this is the case and you can stop the game by removing the headset yourself or asking one of the researchers to assist you.

What will happen to the information you give?

This research is confidential. This means that the researchers named below will be aware of your identity but the research data will be combined and your identity will not be revealed in any reports, presentations, or public documentation.

Only my supervisors, the transcriber (who will be required to sign a confidentiality agreement) and I will access the notes, recording and/or transcript of the interview and user test. The material I collect will be kept securely and destroyed on 15/10/2024.

After you have taken part and change your mind about being involved, please contact the lead investigator (the design student) or supervisors and any data, information and images associated with your participation will be destroyed.

We will securely store the information and data you have provided for five (5) years and it will then be destroyed on 15/10/2024.

Stroke rehabilitation physiotherapists will review these recordings. We will keep the video and photographs securely in the University. Because other researchers will be interested in our research we may show the photographs or a video of you. Your involvement in the study will only be known by the researchers. All photographs and videos will be taken using cameras belonging to the School of Design. The images and videos will be taken off these cameras and immediately after this session and then kept secure in the University computer system.

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If we do use photographs or videos of you for presenting our research we will not show any part of you, such as your face, that can tell other people that you have taken part. If we take pictures in your home, we will also make sure that we do not show anything that identifies your house or that you took part. We will do this by blurring parts of the images and videos.

What will the project produce?

The information from my research will be used in my Masters and for developing the final product.

We can present the findings of this study at stroke clubs within a year of conducting the study.

We can also send you a summary of the student's thesis describing the outcome of the study.

We may also present this study with other similar studies we are conducting at conferences or in academic publications.

Who pays for the study?

This study is funded by Victoria University of Wellington and the School of Design through medical technology research grants from the Centre of Research Excellence of Medical Technologies.

You will not incur any costs by taking part and we will reimburse your travel costs, travel to you or give you taxi chits.

What if something goes wrong?

If you were injured in this study, which is unlikely, you would be eligible for compensation from ACC just as you would be if you were injured in an accident at work or at home. You will have to lodge a claim with ACC, which may take some time to assess. If your claim is accepted, you will receive funding to assist in your recovery.

If you accept this invitation, what are your rights as a research participant?

You are volunteering to take part. You do not have to accept this invitation if you don't want to. If you do decide to participate, you have the right to:

- choose not to answer any question;

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- stop the interview and/or test at any time;
- ask for the recorder to be turned off at any time during the interview or test;
- withdraw from the study before 07/06/2020;
- ask any questions about the study at any time;
- receive a copy of your recording (photos and video recording);
- receive a copy of your interview transcript;
- be able to read the final report of this research by providing your contact details or emailing the researcher to request a copy.

If you have any questions or problems, who can you contact?

If you have any questions, either now or in the future, please feel free to contact either:

Student:

Name: Senai Leniston-Kahsai

University email address: lenistsena@myvuw.ac.nz

Supervisors:

Primary

Name: Edgar Rodriguez

Role: Associate Professor

School: School of Design

Phone: (04) 934 9321 (Work),

027 563 6544 (24 Hour Emergency)

edgar.rodriguez@vuw.ac.nz

Secondary

Name: Dr Brian Robinson

Role: Senior Lecturer

School: School of Nursing, Midwifery and Health Practice

Phone: (04) 934 9321 (Work),

029 776 9321 (24 Hour Emergency)

edgar.rodriguez@vuw.ac.nz

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Human Ethics Committee information

If you have any concerns about the ethical conduct of the research you may contact the Victoria University HEC Convenor: Dr Judith Loveridge. Email hec@vuw.ac.nz or telephone +64-4-463 6028.

If you want to talk to someone who isn't involved with the study, you can contact an independent health and disability advocate on:

Phone: 0800 555 050

Fax: 0800 2 SUPPORT (0800 2787 7678)

Email: advocacy@hdc.org.nz

For Maori health support please contact your health provider and they will refer you to the representative Maori health support group.

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The design of an immersive virtual reality application for upper limb rehabilitation post-stroke

CONSENT TO PARTICIPATE IN USER TESTING

This consent form will be held for a minimum of five years.

Researcher: Senai Leniston-Kahsai, School of Design, Victoria University of Wellington.
Associate Professor Edgar Rodriguez, Programme Director of Interaction Design Programme, School of Design, Victoria University of Wellington.

- I have read, or have had read to me in my first language, the Participant Information Sheet and the project has been explained to me. My questions have been answered to my satisfaction. I understand that I can ask further questions at any time.
- I agree to take part in this video and audio recorded user test and an audio recorded interview.

I understand that:

- I may withdraw from this study at any point before 07/06/2020, and any information that I have provided will be returned to me or destroyed.
- The identifiable information I have provided will be destroyed on 15/10/2024.
- Any information I provide will be included in a final report but the observation notes and recordings will be kept confidential to the researcher and the supervisor and the transcriber.
- I understand that the findings will be used for a Masters, academic publications, presented to conferences and/or developing the product.
- My name will not be used in reports and utmost care will be taken not to disclose any information that would identify me.

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- I would like a copy of the recording of my test and interview: Yes ☐ No ☐
- I would like a copy of the transcript of my interview: Yes ☐ No ☐
- I would like to receive a copy of the final report and have added my email address below. Yes ☐ No ☐

Declaration by participant:

Signature of participant: ______________________________

Name of participant: ______________________________

Date: ______________

Contact details: ______________________________

Declaration by member of research team:

I have given a verbal explanation of the research project to the participant, and have answered the participant's questions about it.

I believe that the participant understands the study and has given informed consent to participate.

Signature of researcher: ______________________________

Name of researcher: ______________________________

Date: ______________

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Appendix J: Ethics for Expert Review and Interview

TE WHARE WĀNANGA O TE ŪPOKO O TE IKA A MĀUI
VICTORIA
UNIVERSITY OF WELLINGTON

Designing a game/device for upper limb Stroke Rehabilitation

INFORMATION SHEET FOR PARTICIPANTS

Thank you for your interest in this project. Please read this information before deciding whether or not to take part. If you decide to participate, thank you. If you decide not to take part, thank you for considering my request.

Who am I?

My name is *Edgar Rodriguez* and I am an Associate Professor in the School of Design at Victoria University of Wellington. This research project is work towards my research and my postgraduate students' theses.

What is the aim of the project?

This project aims to design a system of physical devices and videogames that help stroke patients carry out their physical rehabilitation. This research has been approved by the Victoria University of Wellington Human Ethics Committee *[23011]*.

How can you help?

If you agree to take part we will interview you in your office, a classroom, a meeting room in a university or in a public place, such as a café; or through the Zoom videoconference system. We will ask you questions about stroke rehabilitation. I will audio record the interview and write it up later. We will construct a set of criteria and designs that facilitate stroke rehabilitation based on the findings from the research.

In a second interview, we will seek your feedback about the new designs. Depending on the stage of the project, we may post a prototype of our designs to you to evaluate or show it to you through sharing our Zoom screen. Each interview will take 60 minutes. You can stop the interviews at any time, without giving a reason. You can withdraw from the study up to four weeks after the first interview. After this time, we will use the information you provide to design new objects. You can also withdraw your information for the second interview up to four weeks after it occurs. If you withdraw, the information you provided will be destroyed or returned to you.

What will happen to the information you give?

This research is confidential. We will not name you in any reports, and we will not include any information that would identify you. Only the people named in this information sheet will read the notes or transcript of the interview. A professional transcriber will listen to the recordings and sign a confidentiality form. The transcripts, summaries and any recordings will be kept securely and destroyed *5* years after the research ends.

1

What will the project produce?

The information from our research will be used in the students' theses. You will not be identified in our reports. We may also use the results of our research for conference presentations, and academic reports. We will take care not to identify you in any presentation or report.

If you accept this invitation, what are your rights as a research participant?

You do not have to accept this invitation if you don't want to. If you do decide to participate, you have the right to:

- choose not to answer any question;
- ask for the recorder to be turned off at any time during the interview;
- withdraw from the study up until four weeks after your interview;
- ask any questions about the study at any time;
- receive a copy of your interview recording (if it is recorded);
- read over and comment on a written summary of your interview;
- agree on another name for me to use rather than your real name;
- be able to read any reports of this research by emailing the researcher to request a copy.

If you have any questions or problems, who can you contact?

If you have any questions, either now or in the future, please feel free to contact either:

Student:	**Supervisor:**
Senai Leniston-Kahsai lenistsena@myvuw.ac.nz	Name: Dr Edgar Rodriguez Role: Associate Professor Industrial Design School: School of Design
Chongsheng Guo (Tiger) tiger.guo@vuw.ac.nz	Phone: 04 5636544 edgar.rodriguez@vuw.ac.nz

Human Ethics Committee information

If you have any concerns about the ethical conduct of the research, you may contact the Victoria University HEC Convener: Dr Judith Loveridge. Email judith.loveridge@vuw.ac.nz or telephone +64-4-4636028.

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TE WHARE WĀNANGA O TE ŪPOKO O TE IKA A MĀUI
VICTORIA
UNIVERSITY OF WELLINGTON

Designing a System for Stroke Rehabilitation

CONSENT TO INTERVIEW

Researcher: *Dr Edgar Rodriguez, School of Design, Victoria University of Wellington.*

In order to consent to the research, you can:

- *Print this sheet, scan it and email it back to us; or,*
- *Sign this sheet electronically and send it back to us; or,*
- *Email us back stating: I agree to participate in the research project VUW HEC 23011.*

- I have read the Information Sheet and the project has been explained to me. My questions have been answered to my satisfaction. I understand that I can ask further questions at any time.
- I agree to take part in an audio recorded interview.

I understand that:

- I may withdraw from this study up to *four weeks* after the first interview or up to four weeks after the second interview reviewing the designs, and any information that I have provided will be returned to me or destroyed.
- The information I have provided will be destroyed *5* years after the research is finished.
- Any information I provide will be kept confidential to the researcher and the supervisor. I understand that the results will be used for a *Masters/PhD* report and a summary of the results may be used in academic reports and/or presented at conferences.
- My name will not be used in reports, nor will any information that would identify me.
- I would like a summary of my interview: Yes ☐ No ☐
- I would like to receive a copy of the final report and have added my email address below. Yes ☐ No ☐

Signature of participant: ______________________

Name of participant: ______________________

Date: ____________

Contact details: ______________________

Appendix K: Image Copyright Approval

Figure 2.1 Permission

Senai Leniston-Kahsai
lenistsena@myvuw.ac.nz

21/08/2020

Dear Bernard Francois,

My name is Senai Leniston-Kahsai. I am a master's student at Victoria University of Wellington and am writing a research portfolio on *"the design of a fully immersive virtual reality application for upper limb rehabilitation post-stroke using mirror therapy"* for my master's degree. A print copy of this research portfolio will be deposited in my University's Library, and a digital copy will also be made available online via the University's digital repository. This is a not-for-profit research repository for scholarly work that is intended to make research undertaken in the university available to as wide an audience as possible.

I am writing to request permission for the following image, for which I believe you hold the copyright, to be included in my research portfolio:

The Shapes and Rhythm prototype. Players move their left hand to the rhythm of the music to match hand gestures represented in the virtual environment, while their right-hand remains still. Reproduced from "Mirror Therapy, Reinvented: PreviewLabs at De Krook" by H. Geeroms with photo by H. Demeulemeester, 2017, Retrieved September 4, 2019 from http://previewlabs.com/mirror-therapy-previewlabs/. Copyright 2019 by PreviewLabs. Reproduced with permission.

If you agree, the image is to be referenced and accompanied by the following text

> However, in fully immersive VR-based mirror therapy using head-mounted displays (HMDs) and sensors for hand tracking, for example, the Shapes and Rhythm prototype (Figure 2.1) and Rewellio (Figure 2.2), the patient can freely rotate their head and move their virtual limbs (Geeroms, 2017; Rewellio GmbH, 2018). Therefore, HMDs afford immersion to be increased beyond the conventional mirror box through creation of virtual environments and representations of the body, which are not constrained in the physical world, extending the types of exercises and movements that are possible.

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If you agree, I should be grateful if you would sign the form below and return a copy to me. Additionally, if possible, could you also send a high-resolution copy of the image, that would be appreciated. If you do not agree, or if you do not hold the copyright in this work, would you please notify me. I can be reached most quickly by email at lenistsena@myvuw.ac.nz.

Thank you for your assistance. I look forward to hearing from you.

Yours sincerely,

Senai Leniston-Kahsai

I Bernard Francois agree to grant you a non-exclusive license for an indefinite period of time to include the above materials, for which I am the copyright owner, in the print and digital copies of your thesis.

Signed ______________

Date September 3rd, 2020

Figure 2.2 Permission

Senai Leniston-Kahsai
lenistsena@myvuw.ac.nz

21/08/2020

Dear Rewellio,

My name is Senai Leniston-Kahsai. I am a master's student at Victoria University of Wellington and am writing a research portfolio on *"the design of a fully immersive virtual reality application for upper limb rehabilitation post-stroke using mirror therapy"* for my master's degree. A print copy of this research portfolio will be deposited in my University's Library, and a digital copy will also be made available online via the University's digital repository. This is a not-for-profit research repository for scholarly work that is intended to make research undertaken in the university available to as wide an audience as possible.

I am writing to request permission for the following image, for which I believe you hold the copyright, to be included in my research portfolio:

Rewellio's VR stroke therapy software. In addition to mirroring the non-paretic movement, an electromyography biofeedback monitor on the paretic arm detects small movements and visualises them onto the virtual representation of the affected hand. Reproduced from "Virtual Reality (VR) and rewellio's innovative stroke therapy software" by Rewellio GmbH, 2019, Retrieved June 1, 2019 from https://www.youtube.com/watch?v=y3tWWlVG0zA. Copyright 2019 by Rewellio GmbH. Reproduced with permission.

If you agree, the image is to be referenced and accompanied by the following text

> However, in fully immersive VR-based mirror therapy using head-mounted displays (HMDs) and sensors for hand tracking, for example, the Shapes and Rhythm prototype (Figure 2.1) and Rewellio (Figure 2.2), the patient can freely rotate their head and move their virtual limbs (Geeroms, 2017; Rewellio GmbH, 2018). Therefore, HMDs afford immersion to be increased beyond the conventional mirror box through creation of virtual environments and representations of the body, which are not constrained in the physical world, extending the types of exercises and movements that are possible.
>
> The Rewellio (Figure 2.2) and Rehabilitation Gaming System (Figure 2.4) collect data from each therapy session to help guide and optimise the patient's future therapy sessions to enhance recovery (da Silva Cameirão et al., 2011; Rewellio GmbH, 2018).

I am seeking from you a non-exclusive licence for an indefinite period to include these materials in the print and electronic copy of my research portfolio. The materials will be fully and correctly referenced to you.

If you agree, I should be grateful if you would sign the form below and return a copy to me. Additionally, if possible, could you also send a high-resolution copy of the image, that would be appreciated. If you do not agree, or if you do not hold the copyright in this work, would you please notify me. I can be reached most quickly by email at lenistsena@myvuw.ac.nz.

Thank you for your assistance. I look forward to hearing from you.

Yours sincerely,

[redacted]

Senai Leniston-Kahsai

I TEUFL GEORG agree to grant you a non-exclusive license for an indefinite period of time to include the above materials, for which I am the copyright owner, in the print and digital copies of your thesis.

Signed ______________ Rewellio GmbH, Georg Teufl, MSc, Geschäftsführung, Technoparkstraße, A - 4820 Bad Ischl

Date 24.8.20

Figure 2.3 Permission

RE: idre20:Computerised mirror therapy with Augmented Reflection Technology for early stroke rehabilitation: clinical feasibility and integration as an adjunct therapy Inbox × lenistsena@myvuw.ac.nz ×

Academic UK Non Rightslink <permissionrequest@tandf.co.uk> Wed, Jan 8, 12:51 AM
to Senai

Dear Senai Leniston-Kahsai,

Material requested: Figure 1. Augmented reflection technology system showing the mirror functionality for a person with an impairment on the left side: the unimpaired right hand is mirrored to the left side of the screen: 'Simon Hoermann, Luara Ferreira dos Santos, Nadine Morkisch, Katrin Jettkowski, Moran Sillis, Hemakumar Devan, Parimala S. Kanagasabai, Henning Schmidt, Jörg Krüger, Christian Dohle, Holger Regenbrecht, Leigh Hale & Nicholas J. Cutfield (2017) Computerised mirror therapy with Augmented Reflection Technology for early stroke rehabilitation: clinical feasibility and integration as an adjunct therapy, Disability and Rehabilitation, 39:15, 1503-1514, DOI: 10.1080/09638288.2017.1291765'.

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Figure 2.4 Permission

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Gmail **Senai Moses <senai.m.lk@gmail.com>**

Re: [SPAM] Eodyne "Obtaining permission to use a work in my thesis"
3 messages

anna mura <anna3.mura@gmail.com> Sat, Jan 4, 2020 at 2:32 AM
Reply-To: amura@ibecbarcelona.eu
To: lenistsena@myvuw.ac.nz
Cc: Eodyne MGT List <mgt@eodyne.com>

Dear Senai,

thank you for your interest in our work
May I ask you in which context in your thesis you are going to use the description and image of our product?

Are you a scientist? Is there any other publication authored by you that we can have a look?

best, Anna

On Fri, Jan 3, 2020 at 12:19 PM Pedro Omedas <pedro.omedas@eodyne.com> wrote:

---------- Forwarded message ---------
From: **Senai Leniston-Kahsai** <pomedas.eodyne@gmail.com>
Date: Fri, Jan 3, 2020 at 2:41 AM
Subject: [SPAM] Eodyne "Obtaining permission to use a work in my thesis"
To: <contacto@eodyne.com>

From: Senai Leniston-Kahsai <lenistsena@myvuw.ac.nz>
Subject: Obtaining permission to use a work in my thesis

Telephone:

Message Body:
Dear Eodyne,

I am a research student in the School of Design at Victoria University of Wellington. I am writing up my research in a thesis entitled 'The design of an immersive virtual reality application for upper limb rehabilitation post-stroke'.

I am seeking permission to utilise the following copyright material in my thesis for the purposes of examination and subsequent deposit in Victoria's publicly available digital repository, ResearchArchive:

- The following showing the Augmented reflection technology system obtained from Eodyne. (2019). How it works. Retrieved September 4, 2019, from Eodyne website: https://www.eodyne.com/wp-content/uploads/2018/05/RGS-how-it-works-EN-e1526579798961.jpeg

I wish to use this image as part of my literature and precedent review.

If you are happy to grant permission, I can send a letter for you to sign and return a copy to me. You may also add specific instructions regarding the attribution statement that I will include in my thesis, and any additional terms and conditions that you require.

If you wish to discuss the matter further, please contact me at lenistsena@myvuw.ac.nz.

Thank you for your consideration of this request.

Yours sincerely

Senai Leniston-Kahsai

--
This e-mail was sent from a contact form on Eodyne (http://beta.eodyne.com)

Senai Moses <senai.m.lk@gmail.com> Sat, Jan 25, 2020 at 8:54 AM
To: amura@ibecbarcelona.eu

Hi Anna,

I would only be referring to your work as part of my literature review. Your work is one of my design precedents of a successful virtual rehabilitation tool. I also talk about your novel approach to adapting challenge and difficulty in the RGS.

I do not have any published research yet but I have funding to publish the findings of this research project once I finish my Masters thesis.

Kind regards,

Senai
[Quoted text hidden]

anna mura <anna3.mura@gmail.com> Sat, Jan 25, 2020 at 10:55 AM
To: "amura@ibecbarcelona.eu" <amura@ibecbarcelona.eu>, "lenistsena@myvuw.ac.nz" <lenistsena@myvuw.ac.nz>
Cc: Eodyne MGT List <mgt@eodyne.com>

Hi Senai,

You can use to our images but please
add: from @SPECS-lab https://specs-lab.com/

Thx Anna

Sent from my iPhone

On 3 Jan 2020, at 14:32, anna mura <anna3.mura@gmail.com> wrote:

[Quoted text hidden]

1 of 2 21/08/2020, 11:27 am2 of 2 21/08/2020, 11:27 am