Designing an augmented reality video game to assist stroke patients with independent rehabilitation.

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Abstract

Early, intense practice of functional, repetitive rehabilitation interventions has shown positive results towards lower-limb recovery for stroke patients. However, long-term engagement in daily physical activity is necessary to maximise the physical and cognitive benefits of rehabilitation. The mundane, repetitive nature of traditional physiotherapy interventions and other personal, environmental and physical elements create barriers to participation. It is well documented that stroke patients engage in as little as 30% of their rehabilitation therapies. Digital gamified systems have shown positive results towards addressing these barriers of engagement in rehabilitation, but there is a lack of low-cost commercially available systems that are designed and personalised for home use. At the same time, emerging mixed reality technologies offer the ability to seamlessly integrate digital objects into the real world, generating an immersive, unique virtual world that leverages the physicality of the real world for a personalised, engaging experience.

This thesis explored how the design of an augmented reality exergame can facilitate engagement in independent lower-limb stroke rehabilitation. Our system converted prescribed exercises into active gameplay using commercially available augmented reality mobile technology. Such a system introduced an engaging, interactive alternative to existing mundane physiotherapy exercises.

The development of the system was based on a user-centered iterative design process. The involvement of health care professionals and stroke patients throughout each stage of the design and development process helped understand users' needs, requirements and environment to refine the system and ensure its validity as a substitute for traditional rehabilitation interventions.

The final output was an augmented reality exergame that progressively facilitates sit-to-stand exercises by offering immersive interactions with digital exotic wildlife. We hypothesize that the immersive, active nature of a mobile, mixed reality exergame will increase engagement in independent task training for lower-limb rehabilitation.

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CHAPTER 1

Introduction

Stroke is a devastating disease that is usually caused by either a blood clot (ischemic stroke), blocking the flow of blood to portions of the brain, or by a rupture of an artery leading to or within the brain (hemorrhagic stroke). During a stroke, regions of the brain are deprived of oxygen and nutrient carrying blood vessels causing damage to neural pathways in the brain (Alankus, Lazar, May, & Kelleher, 2010, pp. 2113–2114; American Health Association, n.d.). With over 5 million cases worldwide each year (World Health Organization, n.d.), stroke is one of the most common chronic long term conditions. In New Zealand, three-fourths of strokes occur in people aged 65 or older (Stroke Foundation of New Zealand, n.d., para. 2).

Following a stroke, survivors are likely to suffer from sensory, perceptual, cognitive and motor impairments due to damage to neural pathways (Alankus et al., 2010, pp. 2113–2114; Shah, Amirabdollahian, & Basteris, 2014, p. 166). Motor impairments, such as paralysis or weakness of muscles on one side of the body, can cause issues such as: loss of balance, lack of coordination, muscle fatigue, and decrease in fine movement precision. These impairments can make walking difficult or impossible for some stroke survivors (Alankus et al., 2010, p. 2114).

The brain can reorganise and relearn lost function that has been compromised or lost. This relearning process is called neural plasticity (Kleim, 2011, p. 522). Neural plasticity occurs through early, intensive, repetitive practice of task-specific movements, and is suggested to help recover redundant neural pathways resulting in improved cognitive, visual and physical ability (Alankus et al., 2010, p. 2114; Kleim & Jones, 2008). Kleim and Jones (2008) have highlighted ten principles of experience-dependent plasticity that are suggested to being relevant to rehabilitation after brain damage (pp. 227):

1. Use It or Lose It
2. Use It and Improve It
3. Specificity
4. Repetition Matters
5. Intensity Matters
6. Time Matters
7. Salience Matters
8. Age Matters
9. Transference
10. Interference

Organised group exercise classes have been established to support engagement in exercise after stroke. These group exercise sessions help patients reach the level of training intensity needed to elicit neural plasticity changes, maximising functional and cognitive outcomes (Kleim & Jones, 2008; Morris & Williams, 2009, p. 227). However, because of time restrictions, sessions with therapists usually only include a limited range of exercises and repetitions making it difficult for patients to experience significant recovery when engaging in group exercise classes alone (Lang, MacDonald, & Gnip, 2007 as cited in Alankus et al., 2010, p. 2113). To maximise their chances of recovery, stroke patients are encouraged by therapists to continue their exercises at home so they can maximise their chances of recovery through sustained engagement in physical rehabilitation (Alankus et al., 2010, p. 2113; Morris & Williams, 2009, p. 227). Research shows that although patients acknowledge the functional and cognitive benefits gained from sustained engagement in rehabilitation outside of clinical practice, many patients disengage in independent daily physical exercise and return or adopt an inactive lifestyle (Alankus et al., 2010, p. 2113; Morris & Williams, 2009, p. 227; Outermans, Pool, van de Port, Bakers, & Wittink, 2016, p. 2).

As many as 93% of people affected by stroke have ongoing lower-limb mobility limitations after being discharged from inpatient clinical services (Hill, Ellis, Bernhardt, Maggs, & Hull, 1997, p. 178). This lack of locomotive ability makes it difficult for patients to return to their premorbidity roles in society, significantly compromising their health-related quality of life (HRQoL) and their independence within their home and community (Hill et al., 1997; Perry, Garrett, Gronley, & Mulroy, 1995, para. 5; Pound, Gompertz, & Ebrahim, 1998, p. 257; Vincent et al., 2007, para. 7).

It is important for stroke patients to participate in physically engaging activities within their daily lifestyle. Physical activity helps muscles keep active, improve physical function, and regain independence within their home and community (Burke et al., 2009, p. 1086; Morris, 2016, p. 3; World Health Organization, 2002, p. 31). The American Heart Association recommends that stroke survivors should engage in at least 30 minutes of moderately intense physical activity at least four days a week to reduce the chance of a recurrent stroke (Billinger et al., 2014, p. 2540; Sacco et al., 2006, p. 584). As many as 69% of stroke patients fall below this recommended level of physical activity (Shaughnessy, Resnick, & Macko, 2006, pp. 16–17) with approximately 27% of survivors adopting or returning to a sedentary lifestyle (Billinger et al., 2014, p. 16). Embracing personal progression and creating an instance of meaningful play have both been suggested to facilitate engagement in voluntary activities (Burke et al., 2009; De Schutter & Vanden Abeele, 2008; Salen & Zimmerman, 2003). At the same time, video games have proven to be a successful medium for promoting participation in active, rehabilitation related activities (Burke et al., 2009; Flores et al., 2008; Popovic, Kostic, Rodic, & Konstantinovic, 2014).

The World Health Organization (WHO) (2002) have highlighted the need for home healthcare that empowers patients to self-manage their condition (p. 31). Recent evidence suggests that the integration of digital games with rehabilitation interventions can be used to create a unique environment that delivers a high quality, intensive rehabilitative experience that may be suitable for in-home use (Alankus et al., 2010; Bower et al., 2015; Burke et al., 2009, p. 2113; Shah et al., 2014). These systems have been suggested to improve patient engagement, health-related quality of life and cognitive and physical function. Subsequently helping patients progress towards their recovery goals (Alankus et al., 2010; Bower et al., 2015, p. 8; Burke et al., 2009). The following provides a brief overview of the chapters of this thesis.

1.1: Thesis Overview

"How can the design of a video game facilitate engagement in independent lower-limb stroke rehabilitation for older adults?"

This section gives a brief summary of the structure of this thesis.

Chapter 2 (Background: Literature Review, Existing System Analysis, and Precedent Project Analysis) explores existing literature and systems to critically review existing knowledge relevant to the topic. This allowed the researcher to position their research within a body of knowledge.

Chapter 3 (Methods) discusses the researcher's approach to the design process. It discusses the relationship between the aims, objectives and the chosen methods that respond to the objectives.

Chapter 4 (Clinical Observations) provides valuable insight into user behaviour, needs, and the environment that patients are familiar with while they are engaging in physical activity. This explorative observational study enabled the researcher to gather knowledge of existing rehabilitative interventions beyond secondary knowledge by experiencing the exercises first hand.

Chapter 5 (Technology Exploration) explores technologies that could be used to track and promote physical activity. The most promising technology platform would then be incorporated into the design and development of the sequential video game prototype.

Chapter 6 (Design Concepts) discusses the iteratively developed design concepts that refined the design of the sequential video game prototype.

Chapter 7 (Prototype Development) documents the development process of the rehabilitation video game prototype.

Chapter 8 (User Testing) discusses the preliminary usability testing session with neurological physiotherapists and the two user testing sessions with stroke survivors. These testing sessions ran in parallel with the previous chapter. The findings from these testing sessions were turned into actionable design recommendations that refined the development of the video game prototype.

Chapter 9 (Results) presents the results from the design research process and describes the results from the preliminary testing sessions with neurological physiotherapists and user testing sessions with stroke survivors.

Chapter 10 (Discussion) provides a critical evaluation of the video game prototype's ability to facilitate engagement in independent lower-limb rehabilitation. It identifies the strengths, weakness and limitations of the design process while outlining opportunities for further research.

Chapter 11 (Conclusion) brings the research to a close; summarising the findings from the design research process and drawing a conclusion to the research.

CHAPTER 2

Background

This chapter explores existing literature and systems to critically review existing knowledge relevant to the topic. This allowed the researcher to position their research within a body of knowledge. This background research chapter first collects and synthesises research regarding rehabilitation, games, and engagement to distil information from previous research and draw connections between findings that will later inform the design of the researcher's project. The chapter later analyses existing systems and precedent projects based on the findings obtained from the initial section of this chapter. The knowledge gained from the research in this chapter formed the foundation for the design criteria that guided the development of the video game explored in later research.

2.1: Literature Review

The systematic investigation of existing literature regarding engagement, games and rehabilitation identified three fundamental themes that embodied several design elements that were central to developing an engaging rehabilitative experience. These three themes are: designing stroke-survivor-friendly systems, *meaningful play*, and *progression*.

Designing stroke-survivor-friendly systems represents the system's ability to accommodate a broad range of physical and cognitive abilities (Alankus & Kelleher, 2015, p. 258; Ijsselsteijn, Nap, de Kort, & Poels, 2007, pp. 17–19). It aims to provide an experience that is easy for players to understand and coherently learn – enabling the system to be independently used by stroke-survivors.

Meaningful play embodies the system's ability to connect to its players. *Meaningful play* occurs when the successfully communicated benefits of the system are connected to the personal goals that the player has brought to the system. This communication is essential towards creating a mutually trusting relationship with players as they initially engage in the system – this process of engagement is essential towards facilitating sustained engagement (Bright, Kayes, Worrall, & McPherson, 2015, p. 649).

Progression represents the systems to craft an experience in such a way that the player feels a gradual sense of progress towards achieving their rehabilitative goals. Barzilay and Wolf (2013) illustrated "[s]uccess of rehabilitation resides in three key concepts: feedback, repetition and motivation" (p. 182).

2.1.1: Designing Stroke-Survivor-Friendly Systems

"The challenge of system design is to fit into the fabric of everyday life" (Beyer & Holtzblatt, 1998, p. 1).

The most significant barrier facing rehabilitative games is the development of a user-friendly game system for stroke patients. A frequent problem with academic research related rehabilitation game system prototypes, and most commercially available rehabilitative systems, are that they require assistance from researchers or physiotherapists to be used proficiently by stroke patients. Stroke patients should be able to calibrate the system, start games and confidently interact with the systems without cognitive difficulties (Alankus & Kelleher, 2015, p. 258). In other words, the system should embrace normal and expected changes in physical function and cognitive ability associated with ageing (Ijsselsteijn et al., 2007, pp. 17–19) and disabilities (Alankus, Lazar, May, & Kelleher, 2010) by "[accommodating for] a wide range of individual preferences and abilities" (The Center for Universal Design, 1997, pp. 43–44). The following section discusses the most relevant elements from literature discussing how to design engaging digital experiences for people with stroke.

Embracing Age-Related Functional Changes

When designing interactive paradigms for digital systems for the elderly and stroke patients, it is important to embrace and design for normal and expected changes in sensory function, mobility, and cognition associated with ageing (Farage, Miller, Ajayi, & Hutchins, 2012, pp. 3–4; Ijsselsteijn et al., 2007, pp. 1–3). In that sense, the natural decline of sensory-perceptual processes should impose requirements for a customizable interface that would be appropriate for a senior demographic (Ijsselsteijn et al., 2007, pp. 2–3).

Caprani, O'Connor, and Gurrin (2012) have suggested a list of age-related perceptual, psychomotor, cognitive and physical changes that designers and developers should be aware of to design more usable digital systems (pp. 97-98). Similarly, Farage et al., (2012) have established a comprehensive list of visual presentation guidelines developed to accommodate older adults in the design of digital systems (pp. 17-19).

Designing Familiar Experiences

Visual metaphors are used primarily in interface design to describe the use of old, familiar concepts within new introduced interface objects or tools (Norman, 2013, p. 159). Visual metaphors have been suggested to help traditionalists, such as the elderly (Mitzner et al., 2010), feel more comfortable about adapting to new technologies (Norman, 2013, p. 159). Creating a digital experience that is rooted within its physical analogue helps reduce the feeling of anxiety and confusion associated with learning new technologies (Beyer & Holtzblatt, 1998, pp. 7–8) by "easing the transition from the old to the new" (Norman, 2013, p. 159). Apple highlighted the importance of visual metaphors within the design of their mobile, tablet, and desktop computing devices. They suggested that visual metaphors are essential to designing beautiful, engaging experiences that facilitate control and intuitiveness (Apple Inc, 2017).

Lidwell, Holden, and Butler's (2003) book, Universal Principles of Design, is a cross-disciplinary reference of design that provides an extensive selection of concepts that aims to increase the usability of systems for a universal audience. Within this book, they discuss the importance of intuitive mental models that provide effective mapping between controls and their effects (pp. 128- 131). Using common mental models helps users understand the system's interaction models as they can predict the interaction outcome based on other common interaction experiences or mental models (p. 131). Pokémon Go, a location-based augmented reality game, uses a delightful 'swipe up to throw' interaction to entice players to throw Poke Balls to catch Pokémon. This interaction is a common interaction within mobile throwing interaction models, suitable for Pokémon Go's interaction model as it simulates the system's resulting ball throwing motion. For a detailed analysis of Pokémon Go, see page 30.

Designing to Promote Physical Activity

The World Health Organization (WHO) (2002) has illustrated that in current healthcare practice, day-to-day patient behaviour (e.g. sitting to standing from a chair, walking up steps, retrieving mail, and putting out washing) is often overlooked. Despite the fact it influences patients' rehabilitative recovery far more than medical interventions alone (p. 31). Correspondingly, walking has been identified by elderly persons as the most common enjoyable activity (Dallosso et al., 1988, p. 126). Frank, Engelke, and Schmid's 2003 study (as cited by Knöll et al., 2013) emphasised the importance of walking, as it has the potential to be integrated into almost any daily routine. Walking is a highly accessible activity as it requires no additional equipment (p. 183).

Augmented reality, a digital technology that augments digital objects into the user view, allows users to freely interact with the physical world in entirely new ways while providing natural feedback to the user with simulated cues (Milgram, Takemura, Utsumi, & Kishino, 1995, p. 283). Augmented reality could be beneficial within a rehabilitative system because it provides natural intuitive interactions that encourage physical movement.

Social Interaction

Through contextual inquiries and participatory design sessions, De Schutter and Vanden Abeele (2008) highlighted passions in the elderly and developed a variety of game concepts that aimed to provide *meaningful play* for seniors. Findings from this study highlighted that games designed for an elderly audience should facilitate real world interactions, as passions listed from participants emphasised the importance of connecting to others within leisure activities and video games (pp. 3-4).

Ongoing mobility impairments and other personal factors make it difficult for stroke patients to return to their premorbid social roles, compromising their social interactions with their family, friends and community (Vincent et al., 2007, p. 2). In this sense, stroke-survivor-friendly games could help patients recover their quality of life by facilitating social interaction with their family, friends and community (Alankus et al., 2010, p. 2120). Active video games help decrease the feeling of social isolation while motivating players to participate in physical activities (Alankus et al., 2010, p. 2121).

2.1.2: Meaningful Play

"Players bring in a great deal in from the outside world: their expectations, their likes and dislikes, social relationships and so on. In this sense, it is impossible to ignore the fact that games are open, a reflection of who plays them" (Salen & Zimmerman, 2003, p. 96).

Meaningful play is a concept that incorporates the value of play into a design, while making the activity meaningful to the user (Salen & Zimmerman, 2003, pp. 31–37). In their influential book Rules of Play: Game Design Fundamentals, Salen and Zimmerman (2003) emphasise that "*meaningful play* emerges from the interaction between the player and the system, as well as from the context in which the game is played" (p. 33). In other words, meaning is created when the successfully communicated benefits of a system are connected to the user's interests; supporting them in progressing towards their personal goals that they have brought to the system.

The following section discusses the fundamental elements from literature about designing experiences that facilitate *meaningful play*.

Games and Play

Play is a superfluous, voluntary activity that facilitates enjoyment and autonomy (Huizinga, 1980, pp. 7–8). Play situates itself within a "non-serious" make-believe world, often referred to as the magic circle. This space acts as an escape from "ordinary life" or real world problems (Huizinga, 1980, p. 8; Salen & Zimmerman, 2003, pp. 94–99). Play has its own boundaries of space and time, but it can be repeated or re-engaged with at any time (Huizinga, 1980, pp. 9–10). Huizinga (1980) suggests that it is the transformative, pleasurable experiences that take place within the magic circle that make play an activity that holds high amounts of replay value. Specifically illustrating that the need for play is dependent on the need for enjoyment and autonomy that is exhibited during game-play (p. 8). The magic circle is held together by the constitutive acceptance rules that are binding as play demands order (Huizinga, 1980, p. 11; Salen & Zimmerman, 2003, p. 94). Bernard Suits (1978), an influential philosopher, describes this shared acceptance of constitutive rules (game-playing) as the "lusory attitude" (p.40). He argues that fundamental elements of games and play are "the goal, the means of achieving the goal, the rules, and the lusory attitude." (p. 36). Also stating that almost any activity that facilitates these characteristics can be an instance of game-play (p. 35). This notion is similar to that of Csikszentmihalyi's (1990) positive psychology concept of flow theory which illustrates that mundane everyday activities can be transformed into engaging and enjoyable experiences through restructuring activities to provide meaningful, clear goals, established rules and other elements of enjoyment (p. 51).

Enjoyment

An explicit understanding of what stimulates enjoyment and meaning for seniors in their leisure time is needed to effectively design digital experiences for the elderly (Shah, Amirabdollahian, & Basteris, 2014). Based on previous literature in the context of ageing, De Schutter and Brown (2016) identified three forms of enjoyment in later life:

Hedonic enjoyment is formed when the user is engaging in an activity because they find the experience pleasurable (pp. 33-34).

Eudaimonic enjoyment is experienced when the activity provides a meaningful experience that contributes to the user's personal growth (pp. 33-34).

Telic enjoyment is experienced when the game challenges the user's physical or mental functioning, making the user feel joy through improving their current performance (De Schutter & Brown, 2016, pp. 33–34; Gilbert, 2016, pp. 60–68)

Enjoyment is rarely experienced as individual entities as they are very dependant on each other (De Schutter & Brown, 2016, pp. 33–34). These findings are supportive of De Schutter and Vanden Abeele's (2008) research that, through a combination of contextual inquiries and participatory design sessions with seniors, identified three themes that were important towards creating *meaningful play* in elderly life (pp. 3–4):

- Connectedness: Games should include multiplayer options as elderly passions and games were somewhat about being socially connected to their partner, family, friends or community.
- Cultivation: Games should provide the ability to cultivate one's self or others. Games should include an educational aspect.
- Contribution: Games should conceptually try to contribute to society or aim to make the world a better place.

Sweetster and Wyeth (2005) studied enjoyment in video games with the purpose of understanding the underlying engaging qualities of the concept of flow theory (see p. 23 below) and other various heuristic concerns that structure video games. Based on their findings, Sweetser and Wyeth (2005) developed GameFlow, a model that comprises eight characteristics – social interaction, challenge, player skill, concentration, control, clear goals, feedback and immersion (pp. 5-11). GameFlow was validated based on an expert review and has been suggested to be used to "design, evaluate, and understand enjoyment in video games" (p. 1).

Autonomy

Autonomy is a core principle towards facilitating sustained engagement in motor learning and gaming environments (Lohse, Shirzad, Verster, Hodges, & Van der Loos, 2013, p. 172). Proot et al., (as cited in (MacDonald, Kayes, & Bright, 2013) have suggested that a stroke patient's control of their rehabilitative journey is dependent on their level of autonomy (pp. 118-119). Therapists are encouraged to gradually increase patient independence as they progress in their recovery. This allows patients to comfortably take control of their rehabilitative journey (Proot et al., 2000, as cited in MacDonald et al., 2013, pp. 118–119).

Players engagement in games is dependent on their desire for enjoyment and autonomy (Huizinga, 1980, pp. 7–8). In this sense, freedom and choice should be embraced within the design of games (Gilbert, 2016, p. 84; Lohse et al., 2013, p. 172; Salen & Zimmerman, 2003, pp. 61–62). Przybylski, Rigby, and Ryan (2010) state that games that embrace equifinality (when the end goal or state can be reached in many different ways) facilitate autonomous behaviour by giving players a choice in their gameplay decisions (p. 156).

Autonomy gives players the sense of freedom to curiously explore opportunities and make their own choices (Deci & Ryan, 2012; Gilbert, 2016, pp. 84–85). Salen and Zimmerman (2003) propose that the explicit incorporation of meaningful choices and interactivity is critical towards creating instances of *meaningful play* (pp. 61-67). Meaningful choices are created when the result from the player's action is communicated by the system in a discernible way; and the relationship between the player's actions and the system's outcome has significance behind its immediate consequences by being integrated into the larger context of play (pp. 34-35).

2.1.3: Progression

"In anything but a game the gratuitous introduction of unnecessary obstacles to the achievement of an end is regarded as a decidedly irrational thing to do, whereas in games it appears to be an absolutely essential thing to do" (Suits, 1978, p. 39).

Fun arises out of personal *progression*; it is the act of overcoming unnecessary obstacles (solving problems) under set restrictions that makes games fun (Koster, 2005, p. 40; McGonigal, 2011, pp. 20–21). This notion is supportive of Csikszentmihalyi's (1990) positive psychology concept, flow theory, which illustrates that activities like games "are designed to make optimal experiences easier to achieve" (p.72). Csikszentmihalyi (1990) described an optimal experience as the subjective intrinsically motivating state of heightened functioning that requires regulated goals, a direct feedback system, control, and a balance of challenge and skill (p. 72). Similarly, McGonigal (2011) emphasised that when you strip away the mechanics and technology complexities, games are fundamentally comprised of four core traits: "a goal, rules, a feedback system, and voluntary participation" (p. 21).

The following section discusses how an experience can be crafted in such a way that the users feel a sense of *progression* towards achieving his or her rehabilitative goals.

Optimal Challenge

Bernard Suits (1978) defines playing a game as "the voluntary attempt to overcome unnecessary obstacles" (p. 41). This definition describes one fundamental characteristic that makes games fun and rewarding – an optimal challenge. At the start of a game, players usually desire a low degree of difficulty as they correspondingly exhibit a low level of skill because they are acclimating to the environment (Burke et al., 2009, pp. 1088–1089; Lohse et al., 2013, p. 171). In interactive systems such as games, this is usually done through a tutorial that guides the player through the basic elements of the game with task-specific instructions (Lohse et al., 2013, p. 171). Tutorials help give players a sense of confidence and teach them the benefits of the system (Gilbert, 2016, pp. 215–216). v

Flow is a subjective, intrinsically-motivating state of intense concentration that occurs when the user's attention is absorbed due to the preconditions of flow occurring within an activity. To remain in flow experience, the player needs to be working at the very edge of their skill level. Gradually increasing the challenges within the gameplay to match the player's developing skill keeps the player working at the upper edge of their skill level (Csikszentmihalyi, 1990, pp. 49–53; McGonigal, 2011, p. 24); engaged in the activity; and enables a flow experience (see figure 2.1 below; Burke et al., 2009, p. 1088; Csikszentmihalyi, 1990, pp. 49–53).

Figure 2.1 - Concept of Flow (Csikszentmihalyi, 1990, p. 74).

Progression in task-specific rehabilitative exercises can be guided by the manipulation of sensory information, the addition of secondary tasks, the delivery of feedback, and structure of exercises (Signal, 2014, p. 49). Gradually adding challenges or complexities to match the user's ability has been suggested to increase skill transfer (Ahissar & Hichstein, 2000, as cited in Lohse et al., 2013, p. 171). With that in mind, skill transfer is likely to induce neural plasticity changes, maximising outcomes for functional recovery (Kleim & Jones, 2008, p. 227).

Meaningful Goals

Patients want to develop meaningful connections with experiences that help them progress towards their personal goals that they have brought to the platform (Gilbert, 2016, pp. 36–38; MacDonald et al., 2013, p. 120; McGonigal, 2011, p. 21). Providing patients with the ability to set, measure and achieve goals external to the system explicitly articulates the purpose of the system, increasing patient's motivation towards engaging in the system's activities (Gilbert, 2016, pp. 35–38).

Feedback and Achievement

Dynamic, positive feedback has been suggested to increase engagement in voluntary activities (Chou, 2016, p. 91; Csikszentmihalyi, Abuhamdeh, & Nakamura, 2014, p. 55). Feedback increases the user's confidence and motivation by providing a sense of accomplishment when they achieve or progress towards their set goals (Marklund I, Klässbo M & Hedelin B, as cited in MacDonald et al., 2013, p. 120). Feedback is of particular importance in the early phases of rehabilitative games as players have little emotional connection to the activity and are developing competence as they gain confidence by interacting with the system (Ijsselsteijn et al., 2007, para. 11).

2.1.4: Success Criteria

The following success criteria were derived from the findings of the literature review. The success criteria will be used to guide the design and development of the sequential rehabilitation video game prototype.

Designing Stroke-Survivor-Friendly Systems:

- The interactions provide adaptability to suit a range of physical and cognitive needs.
- The visual design of the interface should be clean, readable and consistent.
- The design should be easy to use.
- The design should be safe to use.
- The design should be easy to learn.
- The design should provide a familiar experience.
- The design should promote physical activity.

Meaningful Play:

- The design should clearly communicate the system's benefits.
- The design should support personal growth.
- The design should conceptually contribute to a greater cause.
- The design should support social interactions.
- The video game should support autonomous behaviour.

Progression:

- The design should provide an optimal challenge.
- The design should provide players with the ability to set, measure and achieve clear goals.
- The design should provide dynamic, clear, positive feedback.
- The design should provide a sense of achievement.

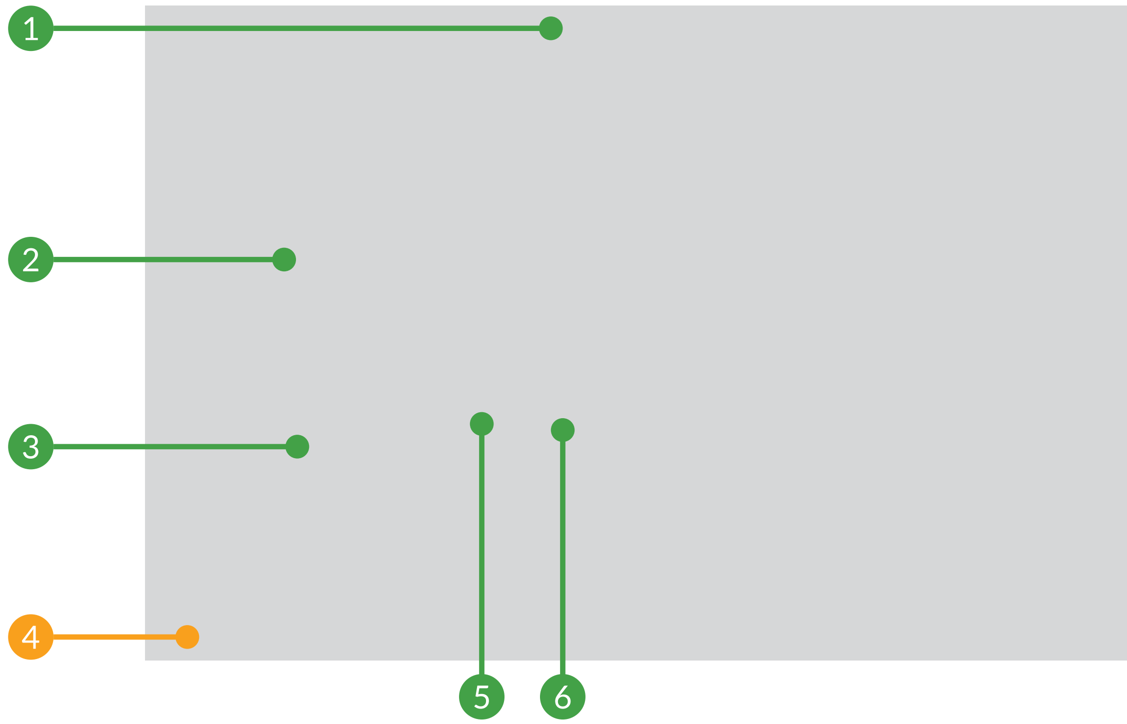
2.2.1: Existing Systems Analysis

Several video game systems have been previously developed to faciliated prescribed rehabiltiation exercsises. This section discusses the work of Brebner, (2016) with *12-12* and *Silverfit* (2015) with SilverFit Newtown. These systems are analysed on their ability to facilitate the key themes of the success criteria: *designing stroke-survivor-friendly systems*, *meaningful play*, and *progression*.

2.2.2: SilverFit Newton

The SilverFit Newton is a virtual therapy system that provides an engaging, dynamic rehabilitative experience in the form of digital, task specific mini games (Rademaker, Linden, & Wiersinga, 2009, p. 119). Players are immersed in the gaming experience as the cognitive and physical challenges within the game are personalised to match the patient's ability and experience (SilverFit, 2015, para. 1). This immersive element alongside the inclusion of clear goals and immediate feedback creates a state of flow – where players are intensely engaged in an enjoyable, meaningful experience (see "2.1.3: *Progression*" on page 22).

The SilverFit Newton enhances its interaction model by incorporating existing mental models developed from traditional exercise experiences resulting in greater ease of use (SilverFit, 2015, para. 1). The ease of the use of SilverFit's system is also increased by developing a natural control-display relationship (also known as mapping; (Lidwell et al., 2003, pp. 128–129). An example of this is the mapping of the pulldown machine to the movement of the digital avatar - illustrated in figure 2.2. In this example the relationship between the physical pulldown bar and the digital avatar is clear enhancing the ease of use of the system (Lidwell et al., 2003, pp. 128–129).



Strengths

1. Natural and Intuitive Mapping
As the user pulls the pulldown machine downwards the avatar moves in an expected downwards direction.

2. Repetition Counter
Immediate feedback on player performance.

3. Number of Repetitions Left
Facilitates goal setting & provides motivational performance feedback.

5. Bright Contrast
Strong contrast between background, foreground & user interface elements increases visual clarity (Lidwell et al., 2003, pp. 124-125).

6. User-Friendly Touch Screen Interface
Buttons with large touch interactive zones enhance accessibility by accommodate stroke paitents with fine psychomotor impairments (Alankus et al., 2010, pp. 2113–2114).

Weaknesses

4. Limited Accessability
Game requires specific equipment (e.g. pulldown machine or leg press machine). These requirements create barriers of participation for users (see Stroke & Lower Limb Rehabilitation, p. 17 for more information)

Figure 2.2 - SilverFit Newton

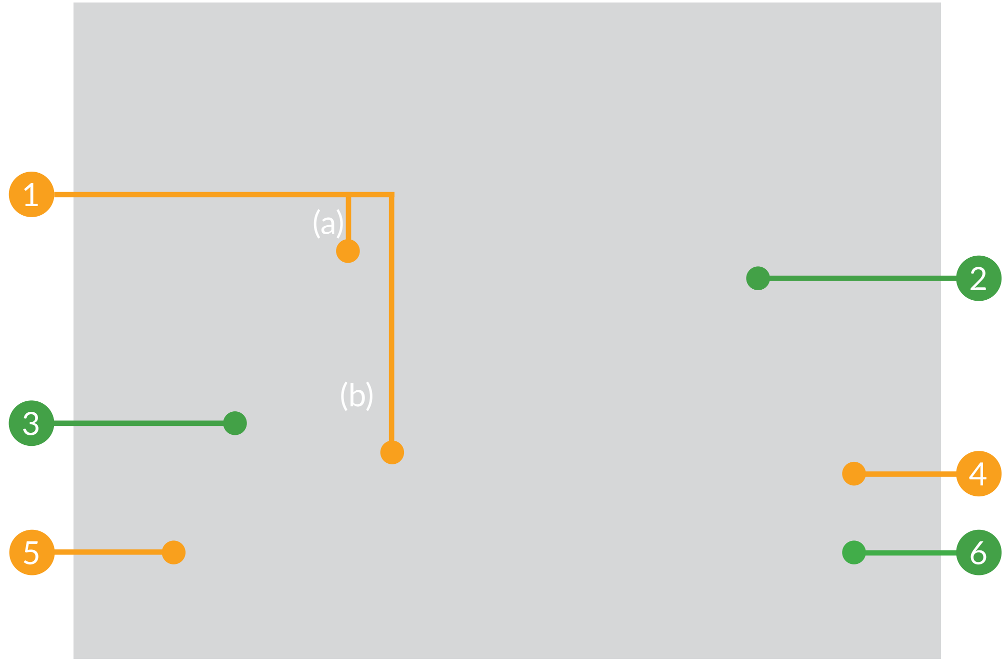
2.2.1: 12-12

Brebner (2016) investigated the use of video games as a rehabilitation tool for people recovering from stroke. The game involved users performing rehabilitative prescribed exercises to interact with a digitalized dominoes video game. The researcher aimed to facilitate engagement through the exploration of three identified themes:

- Adaptability: The system's ability to dynamically adapt its difficulty to match the players growth in ability and the systems ability to adapt its mode of interactivity and interface to accommodate the individuals capabilities (p. 60).
- Connectivity: The system's ability to enable social interaction (pp. 60 – 61).
- Meaningful Interactions: The system's ability to communicate its perceived benefit through gameplay (p. 61).

The researcher argued that adaptability was concluded to being the most important theme of the three as it was emphasised by clinicians, user feedback and was prevalent within engagement specific literature (p. 144).

Brebner (2016) stated that 12-12 met their established criteria with varying degrees of success (p. 146). Adaptability was suggested to be the criteria that was facilitated the most within the final game prototype. The researcher suggested that adaptability was implemented by giving players have precise control over the physical challenge of the game through features like user-defined ending scores and user-defined repetition targets (pp. 143 – 145).



Strengths

Clear Short Term Goals

(2) Targeted triangles highlight the game's short term objectives.

Visual Metaphors

(3) Rich texture reminiscent of games table.

Strong Contrast Buttons

(6) Warm colors recommended for signaling information. Strong contrast with background.

Weaknesses

Lack of Affordance

(1) Interactive user-interface elements (1) share the same graphic style as non-interactive dominoes game elements (2).

Visual Hierarchy Importance.

(4) Unusual placement and size of 'Exit' and 'Help' buttons. Lack of consistency with other systems. Small size of buttons and proximity might be problematic for stroke patients who have fine psycho-motor impairments

(5) Button Design Inconsistency

Inconsistency between button shapes makes it difficult for users to develop mental models of interactable elements (Lidwell et al., 2003, pp. 46-47).

Figure 2.3 - 12-12 Screenshot

2.3: Design Precedents Analysis

The following section critiques two precedent products that are designed to promote physical activity. This section discusses the work of Niantic (2016), with Pokémon Go and Fitbit (n.d) with their Fitbit fitness trackers. These products are analysed on their ability to facilitate *meaningful play* and *progression*.

2.3.1: Pokémon Go

This design precedent analysis focuses on critiquing Pokémon GO's ability to elicit qualities of *meaningful play*.

Pokémon Go, having over 500 Million downloads worldwide, is credited with popularising augmented reality and location-based mobile gaming. Pokémon Go successfully fits "within the fabric of everyday life" (Beyer & Holtzblatt, 1998, p. 1) of its players by restructuring the daily activity of walking to provide a pleasurable gaming experience held together by clear goals, meaningful feedback and accepted rules.

The kinetic nature of augmented reality and location-based technologies stimulates telic enjoyment within Pokémon Go players by physically challenging them to walk to locations to progress through gameplay (Clark & Clark, 2016). Players have the freedom to curiously explore the Pokémon Go Map with the purpose of encountering Pokémon, visiting PokéStops, and challenging other players through gym battles. Mysterious and sometimes delightful rewards are given to players as they overcome physical challenges set upon by them. This element of goal setting and goal achieving creates a sense of pride and meaningful achievement within the user keeping the player engaged in the video as they experience positive emotions (Gilbert, 2016, p. 60)

Players have the freedom to choose what places they want to physically interact with – independently deciding their path in progressing through the game towards the end goal. In this sense Pokémon Go embraces equifinality, driving autonomous behaviour (Przybylski et al., 2010, p. 156). During the onboarding process, players get the option to personalise their character. This empowerment of choice and creativity facilitates autonomous behaviour within the first few minutes of gameplay. This avatar personalization makes the user feel personally connected to their avatar.

The core concept of the gameplay, exploring the 'Map' (see figure 2.4), is a familiar concept to players as it builds off existing knowledge and metaphors drawn from physical and digital maps, e.g.,. Google Maps (Google Inc, 2017). The Map provides players with immediate feedback on their *progression* towards their self-set goal - like walking to a PokéStop. PokéStops are digital places that rely on the physicality of physical landmarks. Players interact with PokéStops by physically walking to their location. PokéStops reward players for their efforts by surprising players with virtual items such as Poké Balls and hatchable eggs. PokéStops also facilitate social interaction by providing a physical space where people can play together and connect over a mutual interest.

PokéStops can reward players with Pokémon eggs which can be hatched in an egg incubator as players walk either 2km, 5km or 10km. Hatching incubated eggs acts as a 'sub-plot' goal to primary tasks like walking to a Gym or PokéStops (Mechelen, 2016), they provide additional motivating towards participating in walking-related activities. However, for the application to track walking distance, the application needs to be open while the player is walking – this could encourage divergent behavior as players exhibit a lack of real-world awareness as they are distracted by their mobile phones while walking. A future development to reduce this convergent behaviour could be to develop the ability to sync fitness tracker data (for example, Fitbit Fitness Tracker) with the Pokémon GO app. This would increase the usability of Egg Incubation tasks as players wouldn't need to consciously remember to have the app open as they exercise.

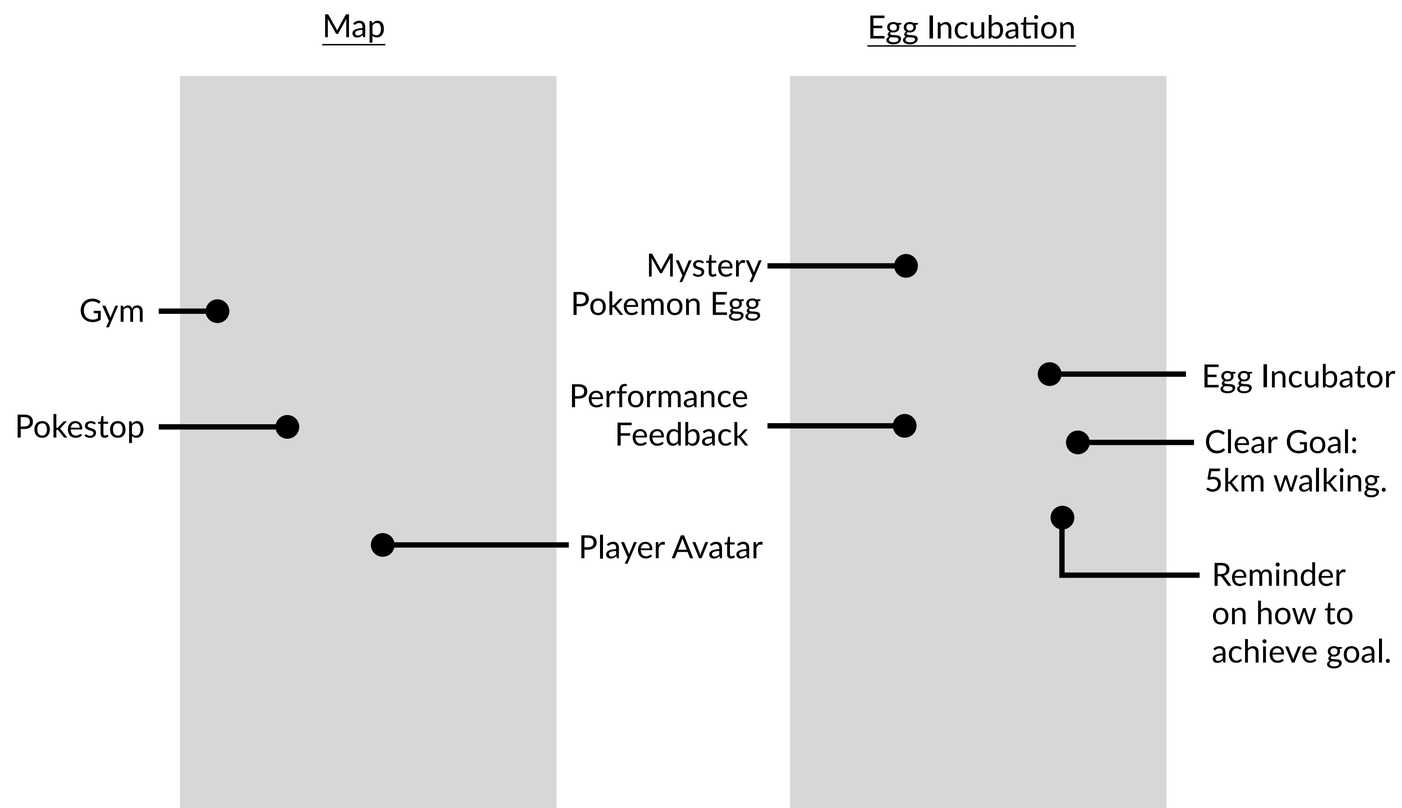


Figure 2.4 - Pokemon Go Screenshots

2.3.2: Fitbit App & Fitbit Tracker

This design precedent analysis focuses on critiquing Fibit's ability to elicit qualities of *progression*.

Fitbit is used to measure physical activity related data such as the number of steps walked, steps climbed and heart rate. Fitbit aims to "design products and experiences that fit seamlessly into your life so you can achieve your health and fitness goals" (Fitbit, n.d., para. 3). Although Fitbit doesn't refer to itself as a game, it does use elements and frameworks associated with games to create a game-like experience (Gilbert, 2016, pp. 30–33). During the onboarding process, users are asked to set personal daily and weekly steps goals. The ability to choose and control their fitness challenges facilitates autonomous behaviour as users independently decide the goals they want to achieve.

Users receive immediate extrinsic feedback on their *progression* towards these personalised goals through Fitbit's mobile application and their fitness tracker. Additionally, Fitbit uses achievement badges and leaderboards to encourage users to achieve and exceed their fitness and health goals. Fitbit provides short-term challenges like daily maximum step badges and long-term challenges like lifetime distance badges. Both types of badges get progressively harder as user ability keeping the user within a optimal experience (Csikszentmihalyi, 1990, p. 51). However, Fitbits badge framework isn't designed for a universal audience (The Center for Universal Design, 1997, pp. 43–44) as they aren't adaptable for people with impairments who progress relatively slower than the average Fitbit user, which would mean that the achievement of badges would be significantly more difficult or unreasonable due to their impairments. A potential improvement to their badge system could be to adapt the badge achievement levels to match the user initial personal goals, or their physical exercise *progression* during their initial stages of engagement. Providing an element of adaptability would make the system more engaging for users with aging or disability related impairments (Alankus et al., 2010).

Figure 2.5 - Fitbit

CHAPTER 3

Methods

This thesis explored how the design of a video game system can facilitate engagement in independent lower-limb rehabilitation. This research was guided by a human-centered design (HCD) framework (Norman, 2013, p. 8). The researcher went through a comprehensive research through design and iterative design process where healthcare professionals and stroke survivors were involved in each phase of the development process.

The involvement of healthcare professionals and stroke survivors throughout each stage of the development process helped understand the user needs, behaviours and activity environments to further refine the design and development of the rehabilitative v ideo game system resulting in a design that is usable and understandable (Norman & Verganti, 2014, p. 88; Shah & Robinson, 2007, p. 132). Additionally, the involvement of healthcare professionals helped to develop the validity of the system as a substitute for traditional rehabilitation interventions.

Throughout the thesis, an exploratory sequential mixed methods approach was applied to address the research objectives (Creswell, 2014, p. 225). The value of a mixed methods approach resides in the possibility of triangulation (Jick, 1979), where aspects of a phenomenon are identified with greater accuracy through the combination of research methods (Jick, 1979, p. 602). A mixed methods approach is also suggested to neutralise the weakness and biases of research methods through the collection of both qualitative and quantitative data (Creswell, 2014, p. 14).

This research project was comprised of two design phases that run in parallel with the research aims and objectives. These two design phases are congruent with the two critical components of the HCD process (ISO, International Organization for Standardization, 2010, as cited by Norman & Verganti, 2014, p. 88):

1. Identifying user needs and “searching for a technology that can better satisfy them” (p. 88).
2. “[Going] through an iterative design process of rapid prototyping and testing, each cycle developing a more refine[d], more complete prototype” (p. 88).

3.2: Aims, Objectives and Applied Methods

The figures below map the aims and objectives to the applied methods.

Aims	Objectives	Methods
First Aim: Define design criteria for the development of a digital lower-limb rehabilitative video game system that engages older adults recovering from a stroke.	Systematically analyse existing game design theory, rehabilitative systems and design precedents to situate the research within a body of knowledge.	**Literature & Precedent Review** (Creswell, 2014, p. 25; Martin & Hanington, 2012, p. 112). Exploring existing literature and systems allowed the researcher to critically review existing knowledge relevant to the topic while additionally positioning the research within a body of knowledge.
	Acquire professional insight on stroke rehabilitation physiotherapy and exercises that will be facilitated through the designed system.	**Fly-on-the-Wall Observation** (Martin & Hanington, 2012, p. 90). Provided valuable insight into user behaviour, needs, and the environment that patients are familiar with while performing rehabilitative exercises.
		Expert Reviews with Clinicians (Kuniavsky, 2003, p. 447). Regular clinical contact provided the researcher with specialist information of stroke and lower-limb rehabilitation while also identifying expected difficulties that the design will need to address.

Table 3.1 - The first aim, the corresponding objectives, and the methods used to achieve the objectives.

Aims	Objectives	Methods
Second Aim (1/2): Design, develop and test a digital game proto-type that engages older adults recovering from a stroke.	Explore emerging technologies that are designed to promote physical activity.	**Research Through Design / Explorative Research** (Martin & Hanington, 2012, p. 146). This approach utilised iterative design, technology exploration and prototyping to gain technical knowledge on potential emerging technologies (Norman & Verganti, 2014, p. 8). This process also helped iterate potential technology driven game concepts in the following objective.
	Iteratively design and develop a final prototype that is guided by the established design criteria (1/2).	**Weighted Matrix Analysis** (Martin & Hanington, 2012, p. 202). A weighted matrix was used to identify and prioritise the most promising explored technologies based on the relevant design criteria (Cagan & Vogel, 2002, p. 117).
		Research Through Design (Martin & Hanington, 2012, p. 146). This approach utilised iterative design, paper prototyping, low-fidelity & high-fidelity prototyping. The development of the game prototype involved specialised tools such as 3D modelling, animation, C# scripting and texturing.

Table 3.2 - The second aim (Part 1), the corresponding objectives, and the methods used to achieve the objectives.

Aims	Objectives	Methods
Second Aim (2/2): Design, develop and test a digital game proto-type that engages older adults recovering from a stroke.	Iteratively design and develop a final prototype that is guided by the established design criteria (2/2).	**Expert Reviews with Clinicians** (Kuniavsky, 2003, p. 447). Regular clinical feedback re-fined the development of game prototype while also vali-dating the system as a substi-tute for traditional interventions.
	Critically evaluate the devel-oped prototype through expert reviews with clinicians and user-testing with stroke survivors. Designs will be iterated and re-fined based on findings.	**User Testing/Evaluative Re-search (Martin & Hanington, 2012, p. 74; Tullis & Albert, 2013, p. 122).** Two high-fidelity prototypes were tested with potential us-ers. Usability tests encouraged participants to 'think-aloud' (Dumas & Redish, 1999, p. 77). User observations were additionally recorded. Following the gameplay ses-sion, participants were asked to fill out a system usability scale (SUS) (Brooke, 1996). This was followed by a retrospective semi-structured interview (Martin & Hanington, 2012, p. 102).
		Data Analysis (Barnum, 2011, p. 239). The self-reported data and observed behaviours were combined and analysed to quickly interpret the data and refine the system based on the findings.

Table 3.3 - The second aim (Part 2), the corresponding objectives, and the methods used to achieve the objectives.

3.2: User Testing Sessions

User testing with healthcare professionals and stroke survivors were fundamental aspects in achieving the second aim: Design, develop and test a digital game prototype that engages older adults recovering from a stroke. User testing allowed the researcher to test and critically reflect on the design decisions that informed the design iterations. Observing potential users interacting with the developed video game helped refine the design of the system and guaranteed that the developed prototype was usable and understandable by its target audience. Due to strict ethical restrictions from the Health and Disabilities Ethics Committee and under the guidance of neurological physiotherapists, the researcher was required to test the prototypes with clinicians before the prototypes could be tested with stroke survivors. Therefore, the researcher conducted usability testing sessions with clinicians before testing prototypes with stroke survivors.

3.2.1: Description of Testing Sessions

Following is a brief description of each testing session and the methods used in each session:

Session 01 – Initial Expert Review by Clinicians: Provided feedback on our initial ideas and direction. Clinicians highlighted the importance of adaptability within a rehabilitative system.

Session 02 - Second Expert Review by Clinicians: Provided feedback on technology exploration prototype and game concepts. Provided guidance on exercises that the system could facilitate.

Session 03 – Preliminary Usability Testing with Experts (Clinicians): Ensured that the system was ready for usability testing with stroke survivors.

Session 04 - Usability Testing with Stroke Patients: This session focused on both the usability of the system and the intuitiveness of core interaction models that promoted physical activity. Feedback and data from this session were evaluated, and changes were made to refine the design of the system.

Session 05 - User Testing with Stroke Patients: This session focused on both: the usability of the system and the full established design criteria. Feedback and data from this session were evaluated, and changes were made to refine the design of the system.

3.2.2: User Testing Protocol

Usability tests were conducted to observe participants' experiences while they were interacting with the game prototypes. They provided valuable information that helped refine the design of the video game system. Usability tests followed the Concurrent Think-aloud Protocol technique (Dumas & Redish, 1999, p. 77). Participants were asked to verbalise what they are thinking as they are playing the video game prototype, this helped the researcher understand each participant's experience while they were playing the game (Tullis & Albert, 2013, p. 81). User observations were also recorded to capture behaviours that may not have been articulated by the participant.

Following the gameplay session, participants were asked to fill out a System Usability Scale (SUS) (Brooke, 1996). SUS helped identify the perceived usability of the game prototype (Tullis & Albert, 2013, p. 137). SUS is a simple usability scale that consists of a ten-item questionnaire. SUS has been suggested to yield more consistent ratings compared to other self-reported metrics even with low sample sizes - making it appropriate for this study (Tullis & Albert, 2013, p. 145). Sequentially, participants were also asked to participate in a retrospective interview to provide additional insight into behaviour, usability issues, and the perceived benefit of the system (Mogey, 1999). The qualitative interview additionally provided deeper insight into the responses from the quantitative questionnaire (Creswell, 2014, p. 224).

The second user testing session included a likert scale questionnaire (Martin & Hanington, 2012, p. 140) that, alongside the SUS questionnaire, quantitively measured the system's ability to fulfil the established design criteria.

3.2.3: Participant Inclusion Criteria

Developing inclusion and exclusion criteria helped find the most suitable patients to participate in our clinical trials. The inclusion criteria gave the researcher a set of standards to screen potential participants. The exclusion criteria helped the researcher ensure that participants could safely interact with the developed game prototype. The recruitment of participants was done with the support of the Stroke Foundation of New Zealand and Auckland University of Technology.

Following are the inclusion and exclusion criteria used for this study:

Inclusion Criteria

- Over the age of 18.
- Had experienced a stroke which impairs walking.
- Able to walk without standby assistance.

Exclusion Criteria

- Significant cognitive deficit in the opinion of the screening physiotherapist.
- Unable to comprehend one step verbal commands.
- Unable to give informed consent.
- Medically unsuitable in the opinion of physiotherapists, general practitioners or medical specialists.
- Experience excessive joint pain.

CHAPTER 4

Clinical Observations

Early within the exploration and conceptualisation phases, the researcher visited a neurological physiotherapy clinic alongside two physiotherapists who facilitated the observational session. The group physiotherapy session was situated within a private neurological rehabilitation clinic This clinic offered a more intensive form of therapy through a high-paced group circuit class. Ten patients were observed in this class. The classes lasted for one hour and occurred either once or twice a week. The purpose of this observational study was first to analyse the ability of group exercise class members to facilitate engagement and secondly to provide an opportunity to experience exercises that could be promoted within the developed system.

4.1: Methods.

This exploratory observational study responded to the first aim's second objective: acquire professional insight on stroke rehabilitation physiotherapy and exercises that will be facilitated through the designed system. As the research aims were to gather information on participant behaviour, the researcher conducted a fly-on-the-wall observation (Martin & Hanington, 2012, p. 90). Unlike other types of observations, fly-on-the-wall observations distance the researcher from the participants to minimise the potential bias and behaviour influences that may be apparent if the researcher interacted with participants (p. 90).

4.2: Observations

The group class consisted of twelve exercises stationed around the clinic. Each station focused on improving either walking, balance, flexibility or fitness (Neurological Physiotherapist, personal communication, January 19, 2017). Patients spent three to five minutes at each station and moved on to the next circuit station as the timer went off. One physiotherapist and one physiotherapy student supervised the ten-person exercise class. The facilitating physiotherapist explained that the maximum sized class they have run involved 14 patients. The observed phenomena were critically analysed based on the themes established by the background chapter: Designing for People with Disabilities, *Meaningful Play* and *Progression* (see 25).

The structuring of these observations helped the researcher define and reflect on the strengths and weaknesses of the observed phenomena in relation to the scope of the research.

4.2.1: Stroke-Survivor-Friendly Systems

Patients were accustomed to working comfortably at their own pace as each exercise station had its own implicitly defined space. The activities within the group exercise session were designed to replicate daily real-world interactions to make the skills acquired transferable to real-world situations (Neurological Physiotherapist, personal communication, January 19, 2017). This element of skill transferability supports Kleim & Jones's (2008) principles of neural plasticity (see Chapter 1: Introduction, p. 10).

There was a lack of digital technology within the clinical environment – this could potentially be because, as discussed in chapter 2 (p. 17), existing rehabilitation systems are not stroke-survivor-friendly. Most research prototypes and commercially available systems require the assistance of a researcher or physiotherapist to be operated by stroke survivors. The facilitating physiotherapist explained that they are open to the use of digital technology and have trialled the use of a commercially available upper-limb rehabilitative exergame system, but patients found it difficult to learn and consequently difficult to use. The therapist explained that the system required a significant amount of digital interactions that were difficult for a frail population – this made it physically difficult for patients to operate the system (Neurological Physiotherapist, personal communication, January 19, 2017).

The following section discusses observed phenomena that were relevant to creating instances of *meaningful play* in voluntary activities.

4.2.2: Meaningful Play

Instructional posters were positioned at each exercise to help participants orientate the exercise environment and as a method of cueing. Cueing supported patients in visualising their specific exercise goal by explicitly communicating the benefit of the activity to their rehabilitative goals (Neurological Physiotherapist, personal communication, January 19, 2017). This implied concept of 'imagining the movement and then applying the movement' additionally enabled patients the ability to set and achieve goals (Neurological Physiotherapist, personal communication, January 19, 2017). However, these structured goals lacked the incorporation of meaningful choices within their design. Meaningful choices are critical to the design of autonomous experiences and coherently, instances of *meaningful play* (see Chapter 2: Background, p. 19). The incorporation of a digital interactive system could improve the quality of *meaningful play* through giving players open-ended choices towards achieving set goals (Gilbert, 2016, p. 84; Salen & Zimmerman, 2003, pp. 61–62). Allowing patients to set, measure, and achieve goals embraces personal *progression*. The following section discusses observed phenomena that were relevant to facilitating *progression*.

4.2.3: Progression

Progression was the most prominent theme exhibited within this observational study. The classes and most of the individual exercises were designed in such a way that the physical challenge of each activity could be personalised to match the patient's functional ability and individual needs. As patients progressed, physiotherapists added more challenges within the activity to keep the patients working at an elevated level of physical intensity. The facilitating physiotherapist explained that sensory information and biomechanical challenges were manipulated to match the patients developing skill level with the purpose of maintaining a high degree of exercise intensity and to retain their focus on the activity (Neurological Physiotherapist, personal communication, January 19, 2017). High exercise intensity is a precondition of neural plasticity: changes which have been suggested to help patients recover lost physical and cognitive function (see Chapter 1: Introduction, p. 13). The manipulation of sensory and biomechanical information observed within this session ensured that the exercise's challenges matched the patient's developing skill level keeping the patient engaged in the activity as they experienced the concept of flow (see Chapter 2: Background, p. 22). If the challenges are too low, patients won't be working at the very edge of their skill level and will enter a state of boredom.

Some participants exhibited a feeling of boredom while participating in restrictive activities such as walking on a treadmill or riding an exercise bike. This negative experience of boredom was observed through behaviours like fidgeting and looking around the room at others. These restricted activities lacked a gradually increasing challenge to match each participant's developing skill level. This optimal match would restructure the experience to provide a state of flow – keeping the player engaged in the activity. Patients showed higher engagement levels in activities that embraced personal *progression* through the design of the activity. However, several participants required regular augmented feedback from physiotherapists to remain focused on the exercise activity. At times, this regular feedback was not available as physiotherapists were engaging with other participants. Consequently, some patients showed a lack of concentration on the task because they lacked regular augmented feedback and instant gratification that would provide patients with a sense of *progression*. The incorporation of an interactive video game within the rehabilitative process could aid the feedback and achievement gratification provided by physiotherapists. As discussed in Chapter 2: Background (see p. 22), the interactivity and explicit feedback provided by digital systems would help patients measure their progress towards their set goals, making the patient feel a sense of *progression* in their recovery. Sequentially, improving patient engagement in rehabilitative activities.

4.3: Chapter Conclusion

This clinical observational session gave insight into how a digital rehabilitation system could fit into the everyday lives of older adults recovering from a stroke. It provided the researcher with an in-depth understanding of the environment and exercises that patients might be familiar or comfortable with. As discussed in Chapter 3: Background (see page 17 above), providing familiar elements within the design of a digital system helps traditionalists (such as the elderly) feel more comfortable during their initial engagement with innovative technologies. In this sense, using an exercise that patients might be familiar with as the core interaction within the design of the developed digital game could help ease the transition from their current exercise methods to the proposed intervention incorporated within the researcher's developed rehabilitative system.

CHAPTER 5

Technology Exploration

This chapter presents the design technology experiments that were carried out for this thesis. The intention of this explorative research was to explore technologies that could be used to track and promote physical activity. Technologies that were explored in this section were selected because of their ability to promote movement within the nature of interacting with the system. During this explorative process, the following criteria were used to identify and prioritize the most promising technologies:

1. Safety;
2. Adaptability;
3. Movement tracking accuracy;
4. Ability to facilitate natural interactions; and
5. Accessibility.

Seven technologies were explored within this process. The three most promising technologies: IMU Sensors; marker augmented reality; and tango augmented reality, were analysed within the body of this thesis.

5.1: Wearable Sensors

The researcher wanted to explore the capabilities of a wearable inertial measurement unit (IMU), as a method for tracking user's foot movement. The researcher intended to use the IMU sensor as a controller for the digital game. The IMU sensor was wirelessly connected to a mobile device using Bluetooth Low Energy (BLE). Using BLE allowed the IMU sensor to communicate with the mobile device with significantly lower power consumption compared to classic Bluetooth connections (Google, n.d.). The experimental mobile application automatically connected to the BLE IMU sensor on start-up, enhancing the usability of the system. The researcher aimed to track the movement of the user's foot through a gesture recognition system that could learn specific movements, like sidesteps and walking forwards and backwards – which would then be used as a core interaction within the game.

Unfortunately, during the development of the explorative prototype there were filtering issues that limited the IMU's capacity to communicate with the mobile device. The data received from the IMU wasn't filtered accurately enough to seamlessly track the natural movement of players.

Figure 5.1 below shows the developed system which tracked two different movements: step count and toe raises. The IMU sensor worked well at a slow speed. However, at a natural, faster speed the sensor overcalculated the rotation initially and then recalculated itself after several seconds to correct its rotational position (known as drift correction). This overcalculation and delayed correction of the sensor's rotation made it difficult to track the user's natural movement accurately. The lack of movement tracking accuracy could make it difficult for the sensor to be used within a rehabilitative context as users desire instant, accurate feedback on their performance (see Chapter 3 Background, p. 24 above).

Figure 5.1 - IMU Sensor: Toe Raise Position.

5.2: Marker Based Augmented Reality

The researcher aimed to explore the use of Marker Based Augmented Reality (AR), also known as natural feature tracking (NFT) AR, as a base technology for a rehabilitative system. Marker based augmented reality uses real-time video tracking capabilities to calculate the orientation and position of physical markers relative to their surroundings (Kudan Computer Vision, n.d.). This computer vision technology allows mobile devices to facilitate natural feedback by seamlessly blending digital objects and information with the user's environment, allowing users to freely interact with the physical world in entirely new ways (see figure 5.2).

The researcher used Kudan AR's software development kit (SDK; Kudan Computer Vision, n.d.), with Unity's game engine (Unity Technologies, n.d.) to develop a prototype mobile application that facilitated stepping rehabilitative exercises using marker based augmented reality technologies. The stepping exercise was inspired by the observational study discussed in Chapter 4.

The movement tracking of the developed system was accurate, however the tracking was dependant on the marker always being within view of the phone's video camera. Once the marker left the camera's viewport, tracking was lost. This meant that the mobile phone would always need to be looking at the marker for the tracking to be proficient. This dependency could cause usability issues for a frail population as they frequently exhibit upper limb muscle weakness and fine motor impairments which would make this physical interaction difficult. It would also limit the user's control of the system as the movement of the phone would be limited. In the proposed circumstances, where the digital object is blended with the physical step, safety could be an issue as the phone and digital object are covering their view of the physical step which may increase a user's chances of falling as their vision of the physical obstacle (step) is blocked. In addition, making the user look down consistently could cause divergent behaviour in posture control from a physiotherapy perspective as one of the focuses for physiotherapists while doing task training exercises it to get patients to look up while walking (Physiotherapist, personal communication, January 19, 2017).

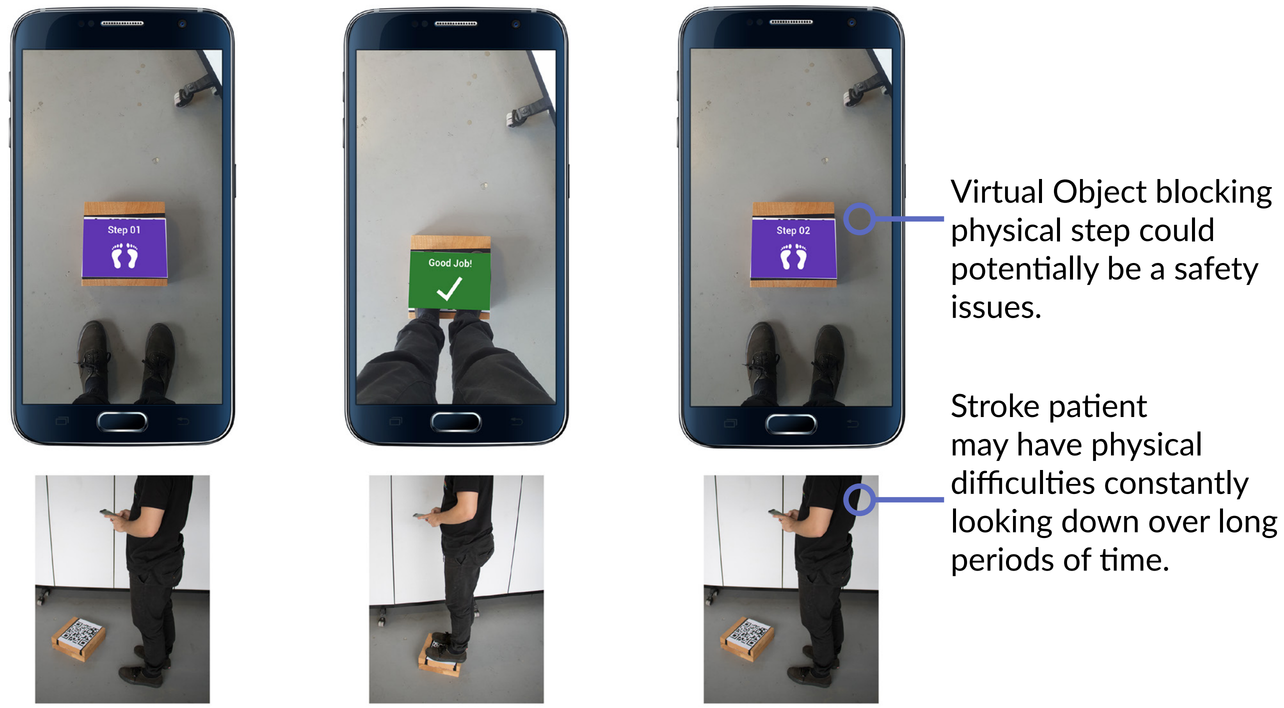


Figure 5.2 - Natural Feature Tracking Augmented Reality.

5.3: Tango Augmented Reality

Tango is a revolutionary, innovative augmented reality, computing platform, developed by Google (2014). Tango enables mobile devices to understand their position and orientation relative to their environment by combining visual and inertial data (Google Inc, 2016b) without the use of external signals such as GPS or tracking markers (Lenovo, n.d.).

Tango's ability to develop physical relationships with the user's environment is possible through the integration of three core technologies: Motion Tracking; Depth Perception; and Area Learning. The researcher explored the capabilities of these three core technologies individually to understand the benefits and limitations of each technology for a rehabilitative system. This explorative research identified that Tango's AR platform is best suited to indoor environments and has issues tracking non-reflective surfaces such as black flooring or dark leathered furniture (see Appendix A).

This explorative research is discussed further in Appendix A. Sequentially, the researcher developed an explorative prototype that helped identify and contextualise the potential of Tango as a base technology for a rehabilitative system.

The researcher developed a prototype that involves user's doing sit-to-stand exercises to feed a virtual pet. When the user sat down, they picked up food. When they stood up, the food was automatically thrown to the dog. Tango-enabled mobile devices aren't restricted by physical tracking markers as Tango gives devices the ability to understand its position in space. This tracking freedom gives users control over where they aimed the device. The tracking of the virtual object was natural and accurate providing an immersive experience that required little cognitive memory to interpret.

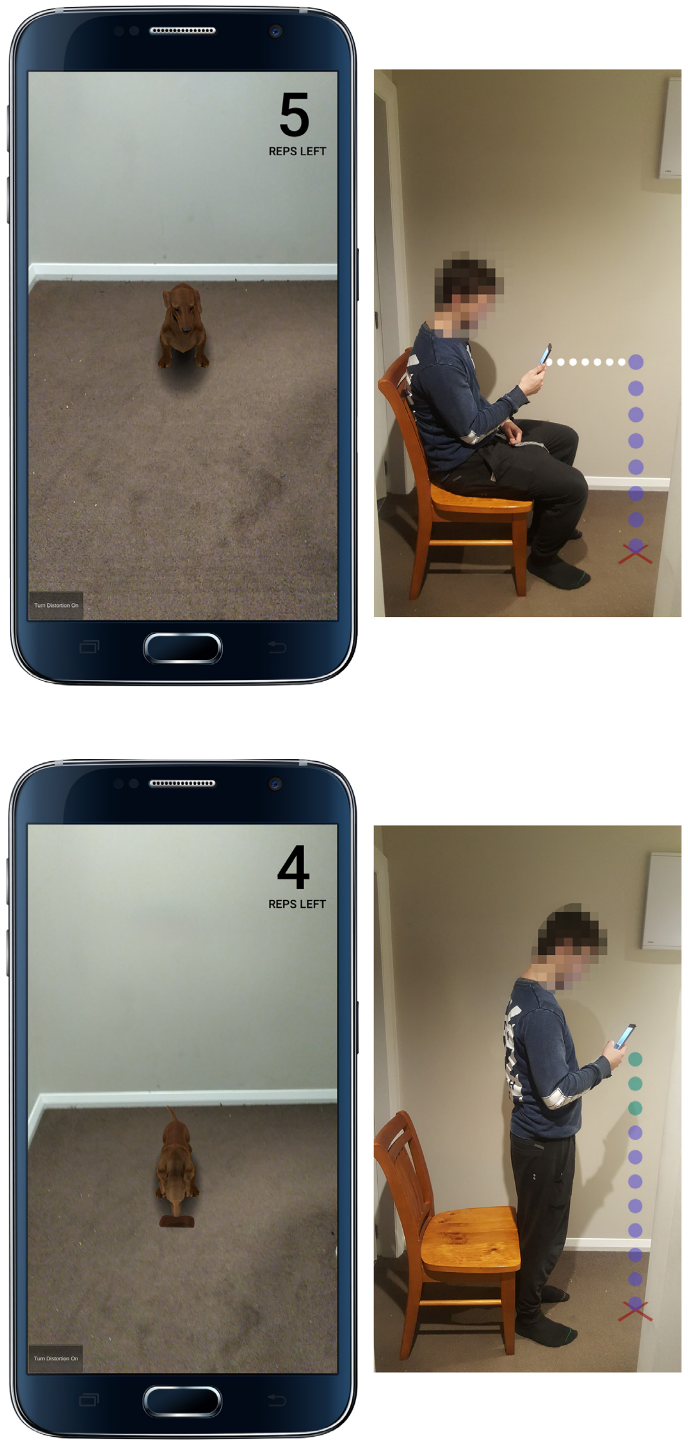


Figure 5.3 - Tango Augmented Reality Exploration.

5.4: Discussion

A weighted matrix (Cagan & Vogel, 2002, pp. 117–118; Martin & Hanington, 2012, pp. 202–203) was used to prioritise the most promising explored technologies based on the relevant design criteria. Tango's augmented reality technology was identified to potentially provide the most promising opportunities in a rehabilitative context (see table 5.1). Virtual reality, although being the second most promising technology, lacked an element of safety within a rehabilitative context. This was because the experience of current virtual reality systems would be incongruent with the physical exercise tasks as users lose sensory-perceptual information due to being fully immersed in a virtual world – lacking vision of their physical body. The extensive manipulation exhibited within virtual reality systems could be cognitively difficult for a frail population that have balance-related difficulties. The IMU sensor's lack of movement tracking could create usability issues for an audience that demands natural, immediate feedback.

Tango's ability to provide an immersive, physically engaging experience while using natural, accurately tracked movements as a core interaction model highlighted an innovative opportunity for this emerging technology within the context of rehabilitative exergames. Tango's accurate motion tracking capabilities enable natural, intuitive interactions. Interactions that could potentially be based off existing mental models developed from other experiences (Lidwell, Holden, & Butler, 2003, p. 130), such as moving from a sit to stand position. Capturing an intuitive interaction model results in greater ease of use (see Chapter 2: Designing Familiar Experiences, p. 17; Lidwell et al., 2003).

Tango's ability to scan environments and its understanding of its position in 3D space relative to its surroundings provides an opportunity for precise location-based gameplay. Location-based gameplay could facilitate salience by giving context to the patients in game tasks. In other words, the gameplay tasks would be relevant to the environment in which the game is played. For example, sit-to-stand exercise in the lounge, or stepping over virtual obstacles in the hallway. Contextualising the exercise tasks makes the benefits and relevance of the user's actions more obvious (Kleim & Jones, 2008, pp. 231–232). Building on this, AR could proficiently specify the task to the context as what the patient feels, sees and smells while immersed in an AR experience is congruent with the rehabilitative task (Neurological Physiotherapist, personal communication, January 31, 2017). Only the visual and auditory senses are delightfully manipulated to provide simulated cues (Milgram, Takemura, Utsumi, & Kishino, 1995, p. 283).

This chapter explored design technologies that had the capabilities to promote physical activity through the nature of interacting with the system. Tango's augmented reality platform was identified as providing the most technological opportunities within a rehabilitation context. The following chapter discusses the iterative game concept process and presents the final game concept that utilised the technological capabilities provide by Tango's augmented reality platform to enhance the rehabilitative experience.

TECHNOLOGIES EXPLORED → / ↓ DESIGN CRTIERIA	WEIGHT	IMU Bluetooth Sensors	Marker Augmented Reality	Tango Augmented Reality	Video Pass-through Mixed Reality	Location-based GPS Technology	Markerless Augmented Reality	Desktop Virtual Reality
Safety	3	3	1	3	1	1	2	1
Adaptability	3	2	2	3	1	1	2	3
Movement tracking accuracy	2	1	2	3	1	1	1	3
Natural Interactions	2	2	1	2	3	3	2	3
Accessibility	1	1	3	2	2	2	3	1
Total		24	18	30	16	17	21	25

Table 5.1 - Weighted Matrix Analysis of Technologies Explored.

CHAPTER 6

Design Concepts

This chapter presents the three strongest iteratively designed game concepts that helped develop and refine the final game concept that is sequentially discussed in this chapter. The ideas articulated within these concepts were built off the knowledge explored in the previous chapters. In Chapter 5, Google Tango's augmented reality platform was identified as having the strongest technological opportunities towards better satisfying user's needs in the design of a stroke-survivor-friendly system. Therefore, the discussed concepts were fundamentally designed to utilise the technological capabilities provided by Tango's augmented reality platform.

The game concepts were developed through an iterative research through design process (Martin & Hanington, 2012, p. 146) that consisted of sketching, paper prototyping and an expert review with clinicians (Kuniavsky, 2003, p. 447).

6.1: Hoops

Hoops is a physics-based 3D basketball video game that is shaped by the space it's played in. Players score points by throwing the virtual basketball into the virtual hoops that are placed on the walls of the players' physical surroundings. Players throw basketballs at the hoops by aiming the device at a hoop and performing a repetition of a sit-to-stand exercise. The further the player scores a hoop from, the more points they gain. However, longer shots demand more accurate throws. Players are given multiple hoop choices that accommodate for a range of skill levels. More challenging hoops are worth more points. Players gain point multipliers as they consecutively score hoops. Players receive performance feedback following their gameplay session that shows the number of hoops they scored and the furthest distance they scored from. The position of the hoop relative to the player would be gradually more challenging as to match the player's increasing skill level.

Meaningful play was the most successfully explored success criteria theme applied within this concept. This concept's interaction model was built from existing sports knowledge to help establish a clear mapping between the player's physical movements and the digital game's response while also highlighting the benefits of the system to the player.

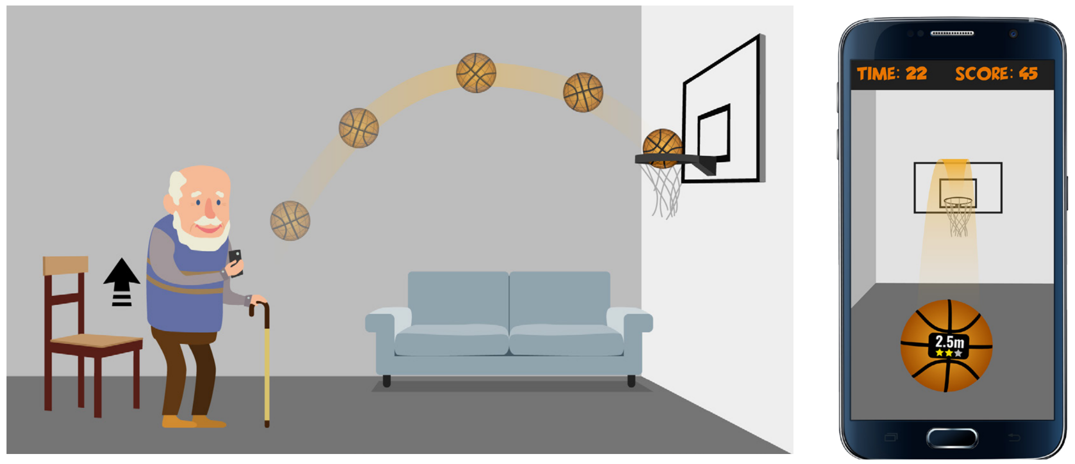


Figure 6.1 - Hoops.

6.2: Wildlife Safari

Wildlife Safari is a location-based augmented reality educational game that involves players searching for exotic animals by exploring the real world. As players walk in the real world, they drop berries within the game map (see figure 6.2). These dropped berries attract wild animals that follow the trail of berries to the player's location. If an animal successfully follows the trail of berries back to the player's location, the player has a chance of taming the exotic animal. Players tame animals by carefully sneaking over to the animal and physically interacting with the animal to develop a trusting relationship. When sneaking over to the wild animal, steps with low amplitudes will frighten and cumulatively cause the animal to become scared and run away (see figure 6.4). Approaching steps with high amplitudes (see figure 6.3) will keep the animal calm, allowing the player to interact with the animal once they are near it. This sneaking movement was conceptually intended to resemble a similar movement to stepping over obstacles - an observed exercise during the researcher's clinical observational session (see Chapter 4: Clinical Observations, p. 44). Wildlife Researcher was intended as an experience that would seamlessly integrate into daily life by providing a rich gameplay experience that explicitly set and measured progress towards goals external to the system. Through engaging in walking activities players were praised with rich augmented feedback and immersive augmented interactions with digital exotic animals.

Phase one - Distributing Berries

Phase Two - Observing Animals

Figure 6.2 - Wildlife Researcher.

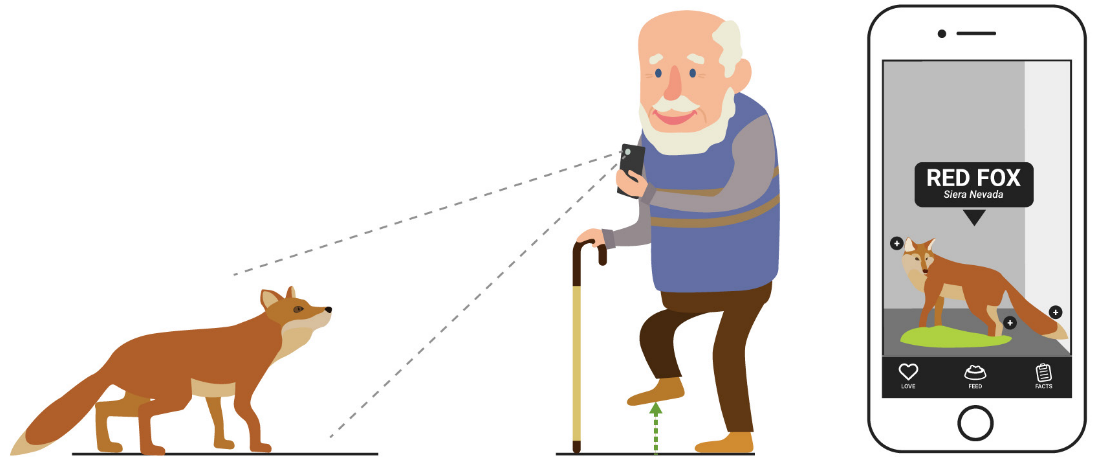


Figure 6.3 - Wildlife Researcher: Phase two – good step amplitude.

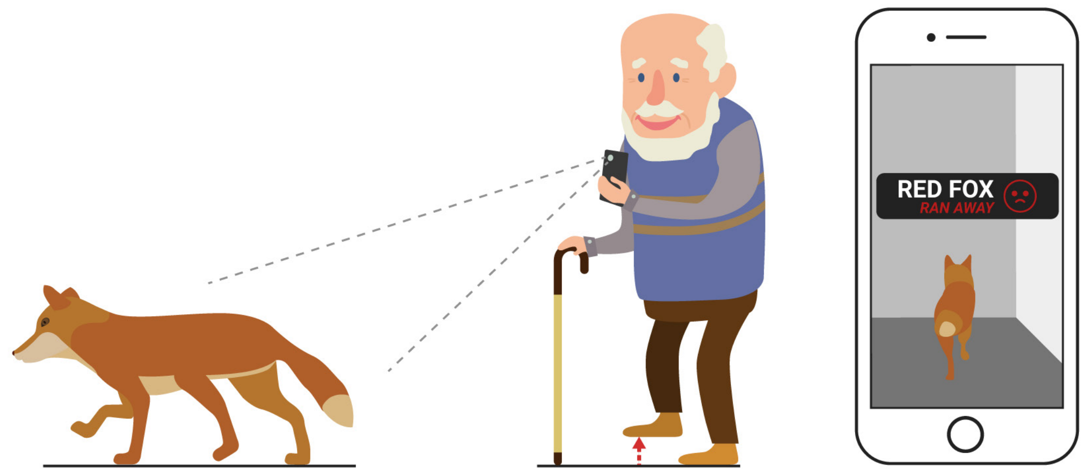


Figure 6.4 - Wildlife Researcher: Phase two – bad step amplitude.

6.3: New Zealand Fauna Through Time

New Zealand Fauna Through Time (NZFTT) is an augmented reality location-based game where players discover virtual historical spaces as they physically navigate the real world. These virtual spaces take players on an immersive, virtual journey that visually narrates the historical significance of the physical environment that they are surrounded by. Similarly to Wildlife Researcher, players explore the real world to find locations within the game's digital map that mark historically significant spaces. Once the player entered a marked historical space, an augmented environment is generated to match the physical space. For instance, Figure 6.5 shows a historical space that educates players about the extinct New Zealand Moa bird. Players can engage within augmented fauna and their surrounds beyond the screen by getting up close to virtual objects and walking around the virtual space. Collectable items are hidden within each location to provide an incentive for players to actively explore and engage in the augmented experience.

Figure 6.5 - New Zealand Fauna Through Time Concepts.

6.4: Concepts Review

The developed concepts explored and highlighted several promising gameplay mechanics that may help develop an engaging rehabilitative gaming experience. This section summarises the most critical components of each concept that helped refine the final game concept.

Players with impaired cognitive and functional skills may have difficulties gaining competence and progressing while playing Wildlife Researcher because it involves two complex game-play phases (see Figure 6.2). In contrast, Hoops explored the incorporation of a simple feedback loop (pick up a ball -> throw the ball at the hoop > achievement-feedback) alongside intuitive motion mapping (sit-to-stand exercises being mapped to interacting with the ball). The logical mapping of the player's movement to the system in-game response has been suggested to improve the usability of digital systems (Lidwell, Holden, & Butler, 2003, pp. 128–131) and elicit instances of meaningful play (Salen & Zimmerman, 2003, p. 34). Although Hoops showed promise in its interactions, this concept lacked the educational aspects embraced within the design of NZFTT which have been suggested towards creating instances of meaningful play. The cultivation of knowledge within the video game design has been proposed to be an important aspect towards creating instances of meaningful play in elderly life.

Although rather speculative and subtle, Hoops' use of the physical environment to define the positions of the target hoops empowers the game with a contextual awareness of the player's physical surroundings – uniquely positioning the hoops within the space the game is played in. Similarly, NZFTT generates a virtual environment that matches the defined physical play space. However, this space is defined by the system rather than the player – limiting the player's control over their game experience. Allowing the player to define their play-space could give players control over their gameplay experience – making the experience feel personalised and unique while embracing autonomous behaviour (see Chapter 2: Background, p. 21).

Hoops has a very simple gameplay-model where success is almost immediate. It facilitated simple, meaningful goals that enabled instant achievement gratification which resonated within the throwing and scoring of basketballs. Hoops incorporated a simple yet adaptive challenge framework of which the difficulty of short-term goals (scoring hoops) was matched to the player's skill level through player-relative hoop placement. As the player's skill developed, the target hoops would be placed in challenging positions within the player's environment. Similarly, as players progress in NZFTT, the items hidden within the augmented environment would be placed in harder-to-reach positions.

The iteratively developed concepts were presented to clinicians to provide feedback on both the game concept's potential application within a rehabilitative setting and the exercises incorporated into the designs. The following section discusses the results from this expert review session.

6.4.1: Expert Review

The developed concepts were presented to physiotherapists along with the Tango technological exploration demo (see Chapter 5: Technology Exploration). Feedback from clinicians primarily focused on the accessibility of the proposed exercises and the game concepts application within a rehabilitative setting. The Tango technology demo helped give context to the developed game concepts.

Regarding the concepts that explored walking exercises, a reviewing Neurological Physiotherapist mentioned that:

> If you have to look down to engage with the game [while walking], you automatically have a problem because you don't want to walk around with your head down and you shouldn't because you have got to predict what's coming towards you.

This comment suggested that the core interactions of walking within the two concepts: Wildlife Researcher and NZ Fauna Through Time could be problematic as they may encourage this described divergent behaviour. In contrast, the sit-to-stand mechanics within Hoops were praised by the reviewing physiotherapists:

> I could see [the game paired with Tango AR technology] being effective for sitting, sit-to-stand, and stationary standing exercises . . . Anyone could use it for sitting and sit-to-stand exercises.

Additionally, physiotherapists also highlighted the importance of simplicity within Hoops:

> [this kind of AR system] would be used more with people who require games with lower levels of difficulty.

They explained that the game concepts Wildlife Researcher and NZFTT were too complex and needed to be simplified for use by people who had suffered a stroke. Based on the feedback received from the expert review with clinicians, the following final design concept was established.

6.5: Final Game Concept - NZ Fauna AR

The final game concept was a refined version of NZFTT that borrowed promising aspects from the concept Hoops. Although Hoops as a concept showed the most promise as a paper concept, it lacked the depth of gameplay provided by NZFTT that is necessary for sustained engagement. The education aspects and immersive interactivity of NZFTT were hypothesised to provide an experience that facilitated instances of Meaningful Play – of which Hoops lacked in its conceptual design.

An expert review by physiotherapists identified several severe safety issues within the development of a walking based handheld AR rehabilitative experience. In contrast, they highlighted the accessibility of a game that facilitated sit-to-stand exercises. Therefore, the mechanics within *NZ Fauna AR*'s design were refined to facilitate sit-to-stand rehabilitative exercises.

NZ Fauna AR enabled the player to define the play space. This self-declaration allowed the experience to be personalised to the player's environment through giving the game spatial awareness of its surroundings.

NZ Fauna AR's progression elements were heavily influenced by Hoops' conceptual, spatially-aware hoops placement framework.

Discussed below is the final game concept, *NZ Fauna AR*.

6.5.1: Game Overview

NZ Fauna AR is a hand held augmented reality rehabilitative experience that lets players transform everyday spaces into unique virtual forest environments, enabling players to freely interact with virtual New Zealand fauna in the real world through the lens of a mobile phone.

The first iteration of the game focused on interacting with a digital kiwi called Fizzy. Fizzy is a unique, curious kiwi who is always energetically looking for berries to eat. Players can feed Fizzy berries through performing sit-to-stand rehabilitative exercises. Sitting down picks up berries from the virtual bucket placed on the player's floor. Standing up throws berries into the virtual forest for Fizzy to chase and eat. Players receive points for throwing berries.

Players can obtain extra points if they throw the berries into the target zones that are randomly placed within the augmented environment. *NZ Fauna AR* features challenging and immersive physics-based gameplay that is uniquely structured by the player's physical surroundings delivering a personalised, immersive experience.

6.5.2: Gameplay Breakdown

Designing a Stroke-Survivor-Friendly System

NZ Fauna AR incorporated a simple interaction mapping that was hypothesised to increase the usability of the system. The game concept's interaction model was deliberately reminiscent of traditional target-based sport interaction models, such as basketball or bowls. In these sports, players pick up a ball, throw the ball and then look for feedback on their performance. *NZ Fauna AR* built off these existing interaction models to provide a familiar experience for players - allowing players to predict the system's outcome to their interactions throughout their gameplay experience. As illustrated by Lidwell et al., (2003) "when the imagined and real outcomes [of a system's response to the user's action] correspond, a mental model is accurate and complete" (p. 130).

The researcher aimed to incorporate as little digital interaction as possible within the core interactions of the conceptual design of the game to accommodate players with fine motor impairments who may find accurate digital interactions difficult to perform.

Meaningful Play

Theoretically, this concept incorporates two interests that are suggested to elicit instances of meaningful play in elderly life (see chapter 2: Background (page page 19)). These passions are self-cultivation (learning about New Zealand Fauna) and helping others (in this instance: helping a digital kiwi).

Progression

Players gained points by throwing virtual fruit into circle targets through doing sit-to-stand exercises. As gameplay progressed, the target circles were placed in harder to reach places within the player's environment. Players were presented with multiple target circles that respectively had different point values based on their adapted difficulty - harder targets were worth more points.

Each level consists of eight throws. At the end of each level, players received a postgame performance report which enables players to retrospectively reflect on their performance and independently set goals for their subsequent gameplay session.

Players are award a one to three-star rating based on the number of points they attained. With one-star being attained for simply finishing the level; two-stars for completing the level and attaining a good score; three-starts for completing the level and attaining a difficult-to-obtain score.

CHAPTER 7

Prototype Development

Having iteratively established a game concept in Chapter 6, this section documents further work undertaken to fulfil the second research aim: design, develop and test a digital game prototype that engages older adults recovering from a stroke. Based on the knowledge established in Chapter3: Background, this chapter discusses the development of *NZ Fauna AR*, a video game prototype that explores the incorporation of an augmented reality exergame into the rehabilitative process. The considerations and methods applied to fulfil the second research objectives of this aim are discussed below.

Objective 2: Iteratively design and develop a final prototype that is guided by the established design criteria.

A. Research Through Design (Martin & Hanington, 2012, p. 146):

This approach utilised an iterative design process that incorporated sketching; low-fidelity, and high-fidelity prototyping; as well as specialist technical knowledge that included 3D modelling, animation, texturing, character rigging, programming, visual effects development and photography. The specialist tools and software utilised within this design phase are described in Appendix C [Specialised Tools and Software].

B. Expert Reviews with Clinicians (Kuniavsky, 2003, p. 447):

Regular clinical feedback refined the development of game prototype while additionally validating the system as a substitute for traditional rehabilitation interventions

7.1: Success Criteria

Designing Stroke-Survivor-Friendly Systems

- The interactions provide adaptability to suit a range of physical and cognitive needs.
- The visual design of the interface should be clean, readable and consistent.
- The design should be easy to use.
- The design should be safe to use.
- The design should be easy to learn.
- The design should provide a familiar experience.
- The design should promote physical activity

Meaningful Play

- The design should clearly communicate the system's benefits.
- The design should support personal growth.
- The design should conceptually contribute to a greater cause.
- The design should support social interactions.
- The video game should support autonomous behaviour.

Progression

- The design should provide an optimal challenge.
- The design should provide players with the ability to set, measure and achieve clear goals.
- The design should provide dynamic, clear, positive feedback.
- The design should provide a sense of achievement.

7.2: Design Process

The design process in this chapter explored 3D modelling, animation, texturing, character rigging and programming. These processes incorporated an iterative design approach that utilised the knowledge acquired from background research and explorative research.

The following sections are structured as short design documents that each focus on the development of a fundamental aspect of the video game prototype. These sections contextualise and communicate the design actions and decisions taken during the iterative development of the video game prototype. These three aspects are discussed below:

- Procedural generation pipeline development;
- Art direction development;
- User-interface development.

7.2.1: Procedural Generation Pipeline

The researcher utilised Tango's spatial understanding capabilities (see Chapter 5, p. 56) to iteratively develop a procedural generation pipeline that handled the creation of the virtual entities. This procedural generation pipeline enabled the game to generate a personalised experience that adapted to the physical space that the player resided in. The incorporation of this spatial understanding together with the developed procedural generation techniques enhanced the accessibility of the system by allowing it to be played seamlessly within any indoor environment of arbitrary size.

Procedural generation techniques are advantageous to AR experiences because they provide an opportunity to facilitate Meaningful Play and Progression. Procedural generation enhances an AR experience by coherently generating an endless amount of unique content that is structured by the configuration of the player's physical environment - supporting meaningful choices and adding additional replay value (Przybylski, Rigby, & Ryan, 2010, p. 156) and autonomous behaviour (see Chapter 2 , p. 21).

The procedural generation pipeline allowed for the in-game challenges to be dynamically set. This procedural aspect enhanced the adaptability of the system's progression framework by enabling the game's challenges to be dynamically adjusted to match the player's developing skill level - providing

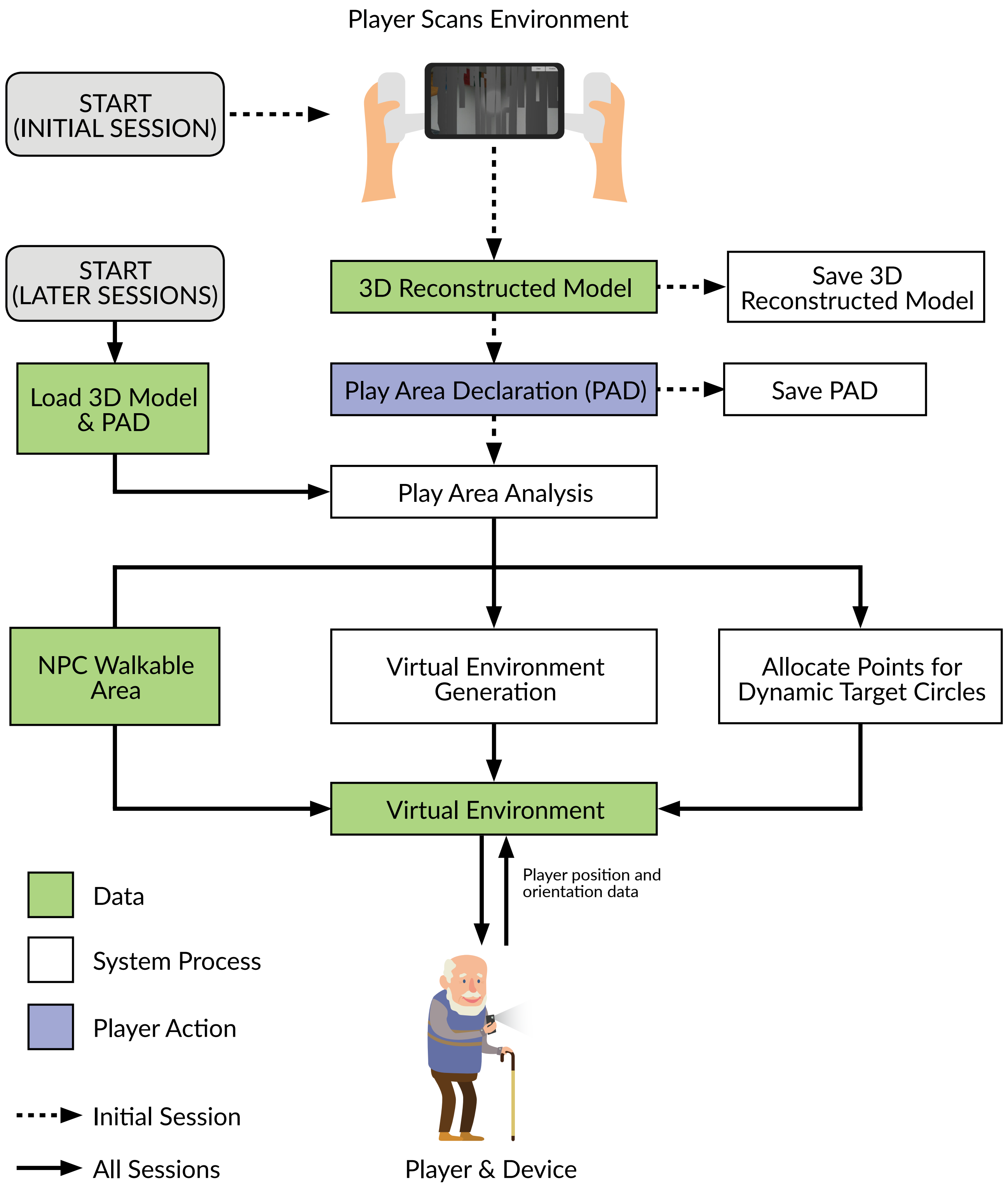


Figure 7.1: Procedural Generation Pipeline. Figure inspired from Sra, Garrido-Jurado, Schmandt, & Maes, 2016, p. 193.

an optimal challenge in the gameplay experience (see chapter 2: *Background*, p. 23). This design aspect is discussed in further detail in Section 7.2.1.4.

The following subsections discuss the development of the fundamental aspects of the procedural generation pipeline (see figure 7.1).

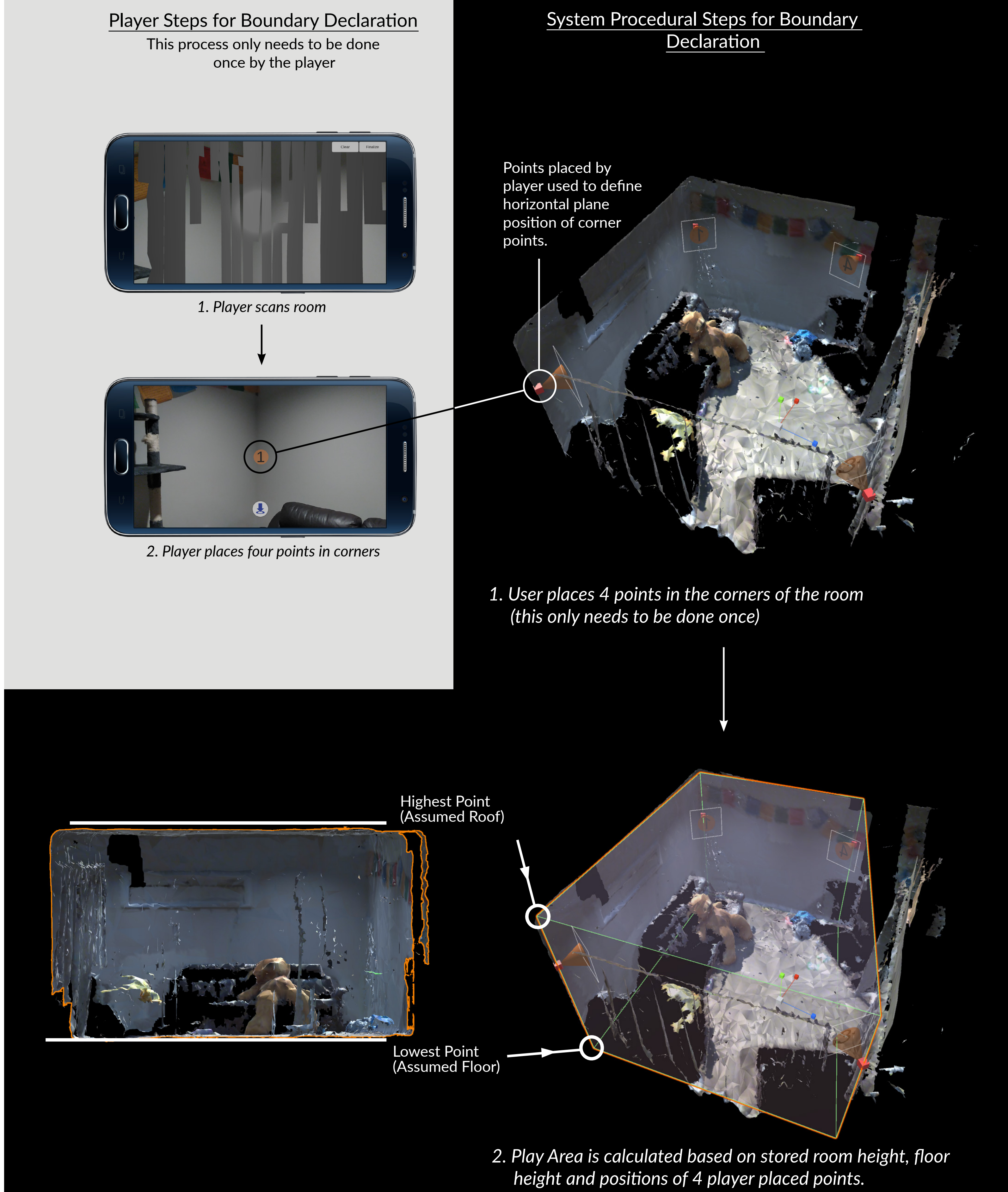
7.2.1.1: Defining the Play Boundaries

Huizinga (1980) illustrates that all play travels and has its value within the play boundaries that are established before play takes place (p. 10). This materialised declaration creates a distinct boundary between this non-serious, make-believe world and ordinary life (see Chapter 2: Background, p. 19). Within more traditional video games, the boundaries of play are usually defined by the game creator through the creation of a predetermined virtual world. In contrast, the researcher aimed to develop a gaming experience that would adapt to the physical boundaries of the real world that the player resided in. This innovative design aspect conflicted with traditional design practices, however this design feature was necessary for the game to be played within any indoor space and be built from physical affordances that mimicked real-world interactions (for instance, bouncing berries off walls and furniture). These desired qualities developed the need for the play space to be materially defined either by the player or automatically by a procedural algorithm. Allowing the player to define the play space seemed like a logical decision as it provides a human-level of verification in the declaration of the play space – giving the player control over their play experience.

Tango-enabled devices have the ability to scan and store environment information as a 3D point-cloud data through the use of its onboard depth sensing and motion tracking hardware. This stored data can be interpreted to give the device an understanding of its position and orientation in 3D space. It can also be saved to the device and re-learnt at the next play session - this functionally is defined as Area Learning (see Chapter 5).

The researcher converted the stored data, provided by Tango's Area Learning functionality, to a digital mesh of the physical space surrounding the player (in this thesis the digital mesh is referred to as an area mesh). This area mesh provided a very efficient user flow for declaring the play boundaries within an augmented reality experience (see figure 7.2 opposite).

Opposite: Figure 7.2 - Play Area Declaration Framework.



7.2.1.2: Area Mesh Analysis

The last section discussed the process of play area declaration that was an input for the Area Mesh Analysis discussed in this section. The Area Mesh Analysis script is a set of procedural rules that systematically analyse the scanned area to identify the planar surfaces (floor, walls, and the ceiling) of the player's surroundings and that are used further within the procedural pipeline (see figure 7.3 opposite).

This innovative framework was used as a foundation for other procedural tools: such as the procedural environment generator (see page 80); and the progressive target zones (see page 82). This algorithm gave other developed procedural tools an understanding of the objects within the designated play area. This environmental understanding is fundamental towards developing an augmented experience that leverages the physicality of the real world (Sra et al., 2016).

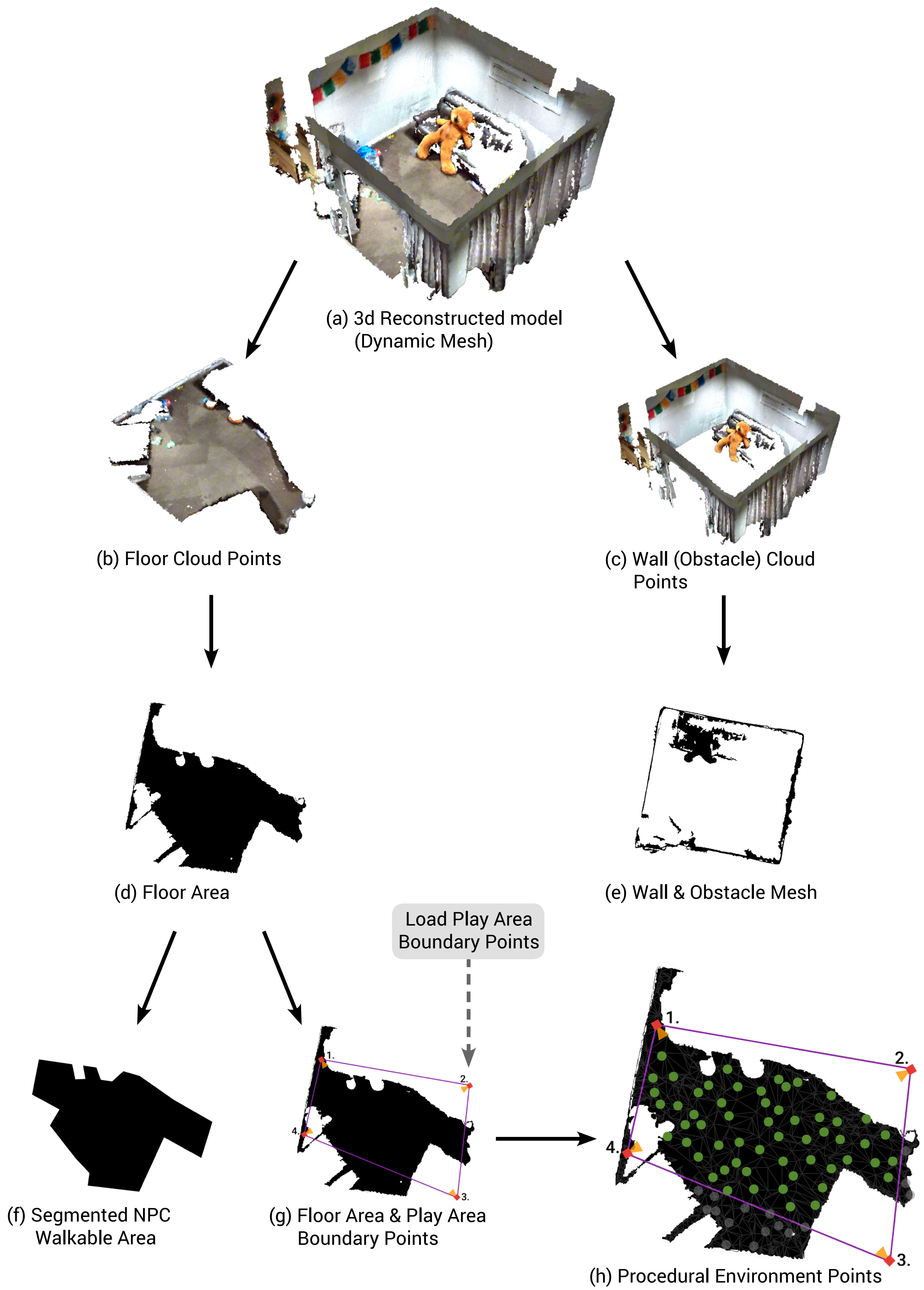


Figure 7.3 - Area mesh analysis process. Key: (a) area scanned by user. (b-c) Floor and wall/obstacle point cloud. (d-e) Top down view of floor and walls/obstacles. (f) segmented walkable area for virtual kiwi. (g-h) Use of floor point cloud data for procedural environment.

7.2.1.3: Virtual Environment Generation

Procedural generation is a method of systematically processing data to automatically generate unique environments. In this case, the use of procedural generation tools offers an opportunity to create unique, dynamic virtual environments that are structured by the player's scanned physical surroundings.

The researcher developed a set of flexible procedural rules that systematically designed and generated a unique game environment for each play session. These rules were inspired by forest ecosystems and the natural patterns and relationships between woodland flora. In order to conceptually understand and mimic these phenomena, the researcher explored and photographed natural forest ecosystems in the Wellington region (see Appendix B). This exploration helped the researcher define the procedural rules of the virtual ecosystem (see Table 7.1 below).

The flexibility of the parameters within the procedural ecosystem generation rules allowed for several types of forest densities to be generated. It must be noted however that increasing the forest density could influence the cognitive difficulty during gameplay as thicker forest vegetation could be more challenging to navigate (see figure 7.4 opposite).

Parameter	Low Difficulty	Moderate Difficulty	High Difficulty
Min/Max Distance Between Trees	4-8 Metres	3-6 Metres	2-4 Metres
Min/Max Distance Between Shrubs	3-5 Metres	2-4 Metres	1-3 Metres
Min/Max Distance Between Forest Floor Plants	2-3 Metres	1-3 Metres	0.5-2 Metres

Table 7.1 - Example of Ecosystem Procedural Rules.

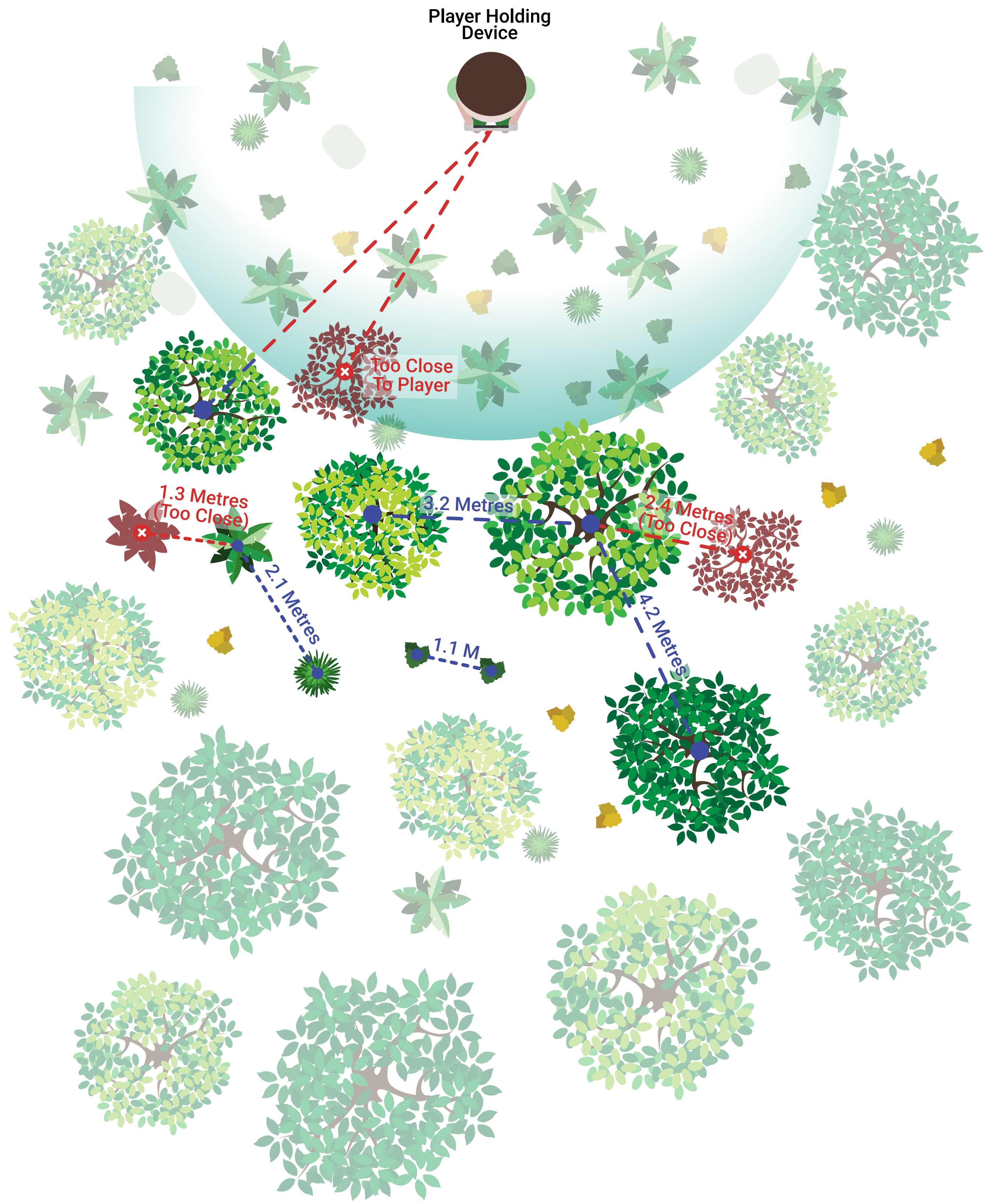


Figure 7.4 - Forest Ecosystem Procedural Rules Example.

7.2.1.4: Dynamic Target Circles

Players gain extra points by throwing berries into target circles that are randomly placed within the player's surroundings (see figure 7.5). Every time the player successfully throws a berry into one of the target circles, a new target circle is placed in the within the physical environment (see figure 7.7). The target circles can appear on floor and wall planar surfaces that are inputted from the Area Mesh Analysis script discussed earlier within this chapter.

As gameplay progresses and players become more skilled, the target circles are moved further away from the player's midline axis (see figure 7.6). Placing the target circles further away from the player's midline axis makes the movement more challenging as players must rotate their body further to throw berries to these wider positioned targets.

The researcher developed a set of procedural rules that allocated the floor and wall cloud points, generated from the Area Mesh Analysis Algorithm (see figure 7.3), into target zone areas that were used to define the set positions of the target circles (see figure 7.6).

Figure 7.5 - Target Circle Example.

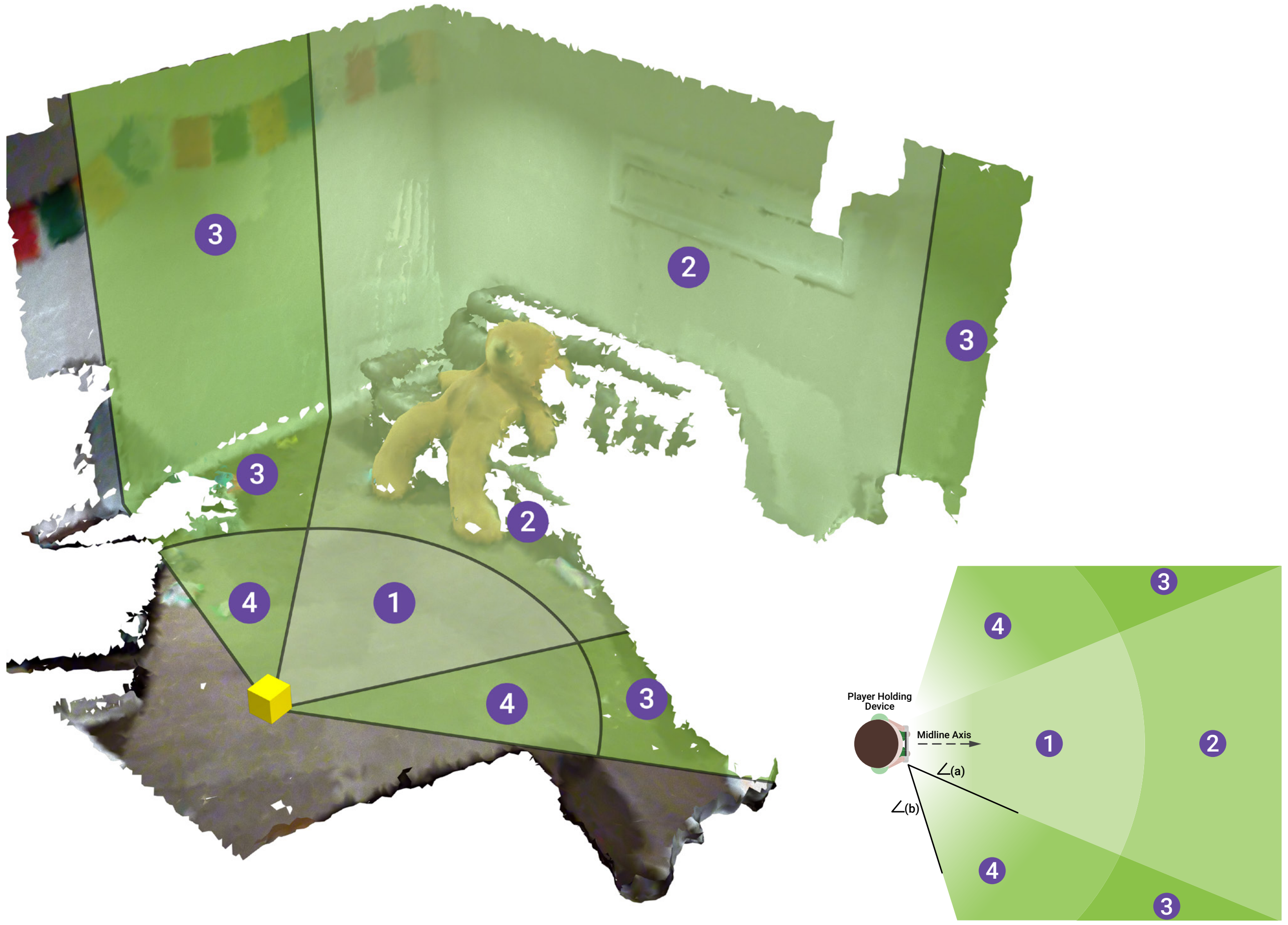


Figure 7.6 - Target Zone Areas Example. The target circle is randomly positioned from its allocated zone (1-4). The higher the number, the more challenging the target zones are. The angles between the midline axis and (a - b) are adaptive to the player's skill level and can be changed dynamically during gameplay.

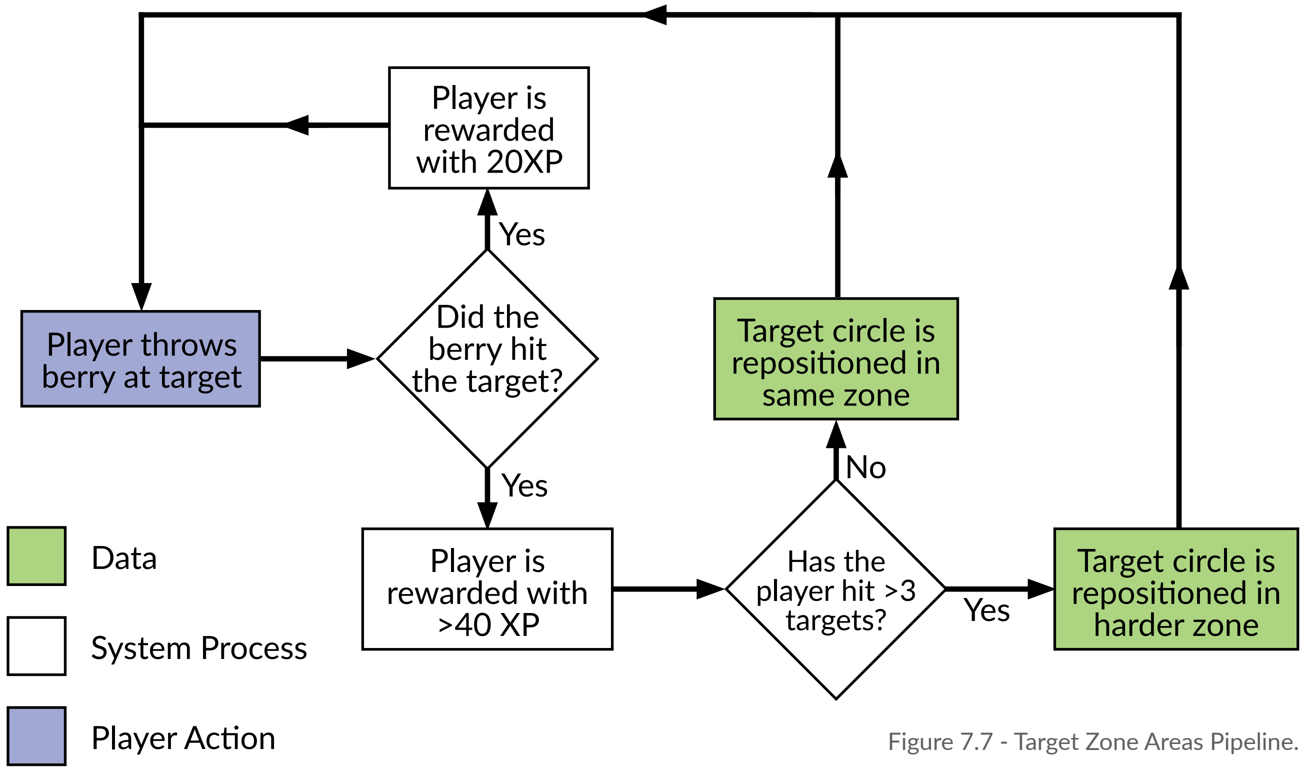


Figure 7.7 - Target Zone Areas Pipeline.

7.3.2: Art Direction

The following section discusses the art direction decisions taking by the researcher. The game's art direction was primarily driven by the narrative that grounded the location that the video game was set in.

Environment Development

The environment art style aimed to reflect New Zealand native flora with the intention of developing an environment that visually educated the player about the rowi kiwi's natural environment. To achieve this desired aesthetic, the researcher developed 3D models and textures that were reminiscent of New Zealand native flora. This involved photographing and scanning native New Zealand leaves, branches and trees to develop a library of vegetation textures and reference images that were used alongside the developed corresponding 3D assets (see figure 7.8: Developed native forest textures below).

Figure 7.8 - Developed native forest textures. Textures were used for developed assets to provide an experience reminiscent of New Zealand flora. All photographs and textures were taken or created by the author at the Wellington Botanical Gardens.

7.2.2.3: Cavernous Spaces/Expandable Trees.

A more creative pursuit that aimed to embrace exploration and curiosity in the narrative experience was the creation of cavernous spaces. Cavernous spaces are enclosed spaces that give an illusion of vast depth. In this case, cavernous spaces are created by tall trees that extended through the player's physical ceiling. For a tree to consistently pass through the player's physical ceiling, the tree trunk's height had to be adaptive to the height of the upper limit of the play space. As illustrated in figure 7.8 if the roof of the play space exceeds the default height of the expandable tree then the middle section of the tree is cloned and reused to expand the tree's height to ensure it passed through the roof.

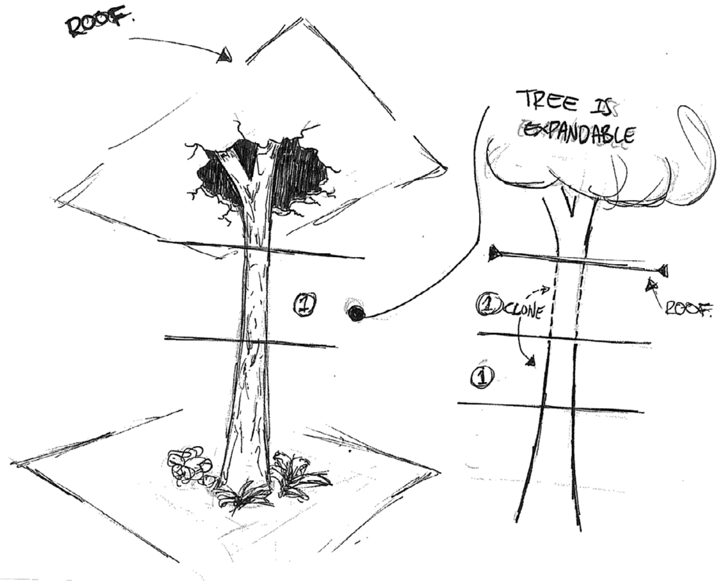


Figure 7.8 - Cavernous spaces. Expandable trees adapt to the height of the physical roof of the space they are enclosed within.

7.2.2.4: Main Character Development

The main character, Fizzy, is a unique, curious kiwi who is always energetically looking for berries to eat. The process of developing the non-playable character (NPC) Fizzy consisted of two phases. The first phase was the development of Fizzy's visual characteristics. The second phase was the development of Fizzy's behavioural characteristics (artificial-intelligence (AI)).

The process in developing Fizzy's visual characteristics involved: concept sketching, digital concept art, box modelling, model refinement, model skinning (binding the model to a custom skeleton), character rigging (custom armature that enables the skinned model to be accurately animated), keyframe animation, UV Mapping, and texturing. Fizzy's visual design style was intended to reflect his vibrant, clumsy and cute narrative driven personality.

The process in developing Fizzy's behavioural characteristics involved the development of an animation controller (manages and transitions between the NPC's various animation states); AI Navigation (allows the NPC to intelligently move around the physical environment); and AI Movement Controller (handles the NPC's physical movement and pathfinding – needed to chase berries; See Video_01 attached).

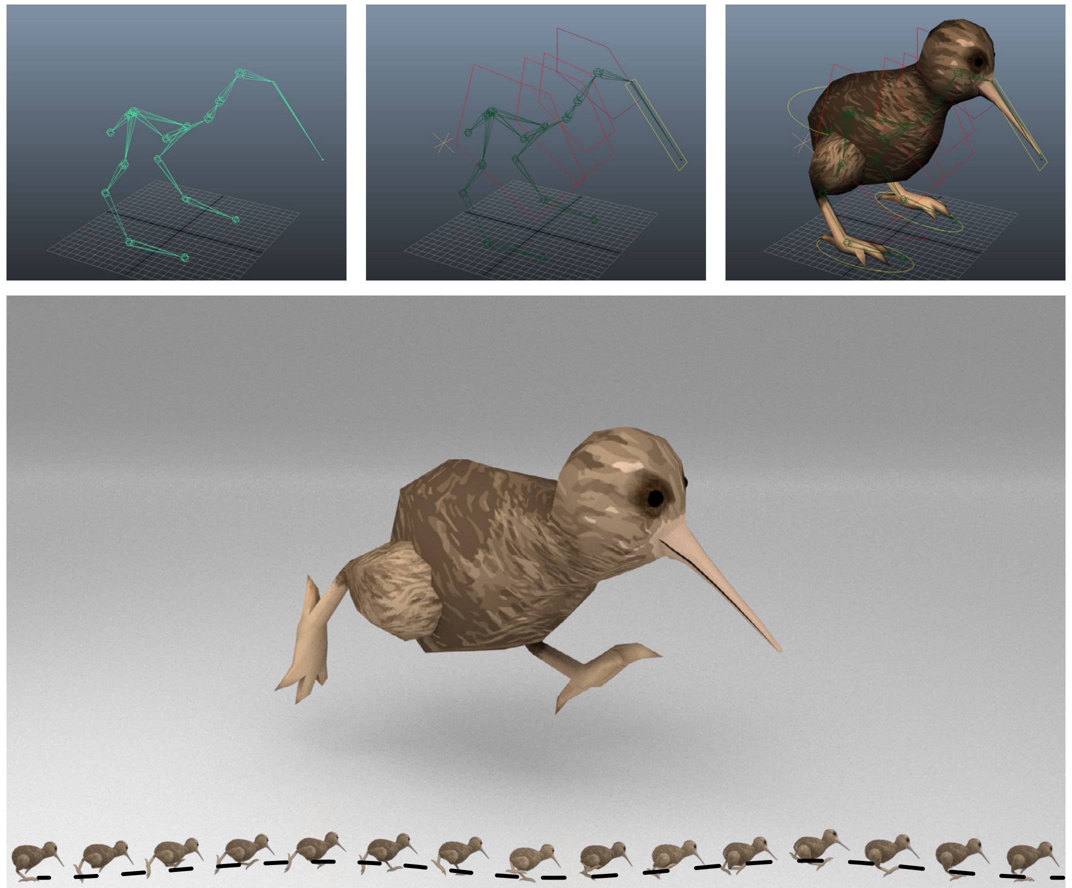


Figure 7.9 - Fizzy's Run Cycle.

7.2.3: User-Interface Development

The roles of play and user-interfaces (UIs) within video games are fundamentally contradictory; nevertheless together they form an engaging experience that encapsulates the player within a virtual world driven by gameplay and storytelling (Adams & Rollings, 2010, p. 201). Games provide a gradually increasing unnecessary challenge, while in contrast, UIs fundamentally aim to reduce all unnecessary challenges. These conflicting goals created a fundamental paradox within the conceptual design of a video game's desired user experience (Suits, 1978, p. 39). This notion reveals the complexities and importance of incorporating a UI design in video games.

A video game's interface mediates between the player and the video game's internal systems by translating the player's interactions into the game's responses in the virtual world. This relationship between the player and system is structured by the game's interaction model (Adams & Rollings, 2010, pp. 200–201) and is critical towards creating instances of meaningful play (see Chapter 2: Background, p. 19).

The video game's interface ability to provide augmented feedback on the player's performance is critical in creating an experience in which the player feels a sense of progression towards their rehabilitative goals. Players need this dynamic feedback to understand the in-game consequences to their physical actions in order to progress through gameplay (see Chapter 2: Background, p. 22).

The following sections discuss the development of the video game prototype's UIs. These sections are structured based on the design spaces that the interfaces reside within: screen-space UIs, world-space UIs and world-space visual cues.

7.2.3.1: Screen-Space User Interface

Screen-space UIs convey information that wouldn't make sense being in the game world but is required for players to engage in the game successfully. Screen-space elements reside within a non-spatial design space that overlays the game's viewport.

This design space was visually organised to match the ergonomic design of the game controller (developed by co-researcher RuiFeng Yeo). From a game experience perspective, the game controller was beneficial because it ensured that players wouldn't accidentally block the sensors located on the back of the phone while they are holding the device (see figure 7.10). These sensors were essential for Tango's augmented reality technologies to function successfully.

Interactive elements, such as buttons, were positioned on the left and right of the screen-space to make the game more ergonomically accessible (see figure 7.11). Positioning the interactive elements on the edges of the screen ensured that players could naturally interact with the interface elements while holding the game controller. Feedback elements, for instance the level performance interface, were positioned at the top and bottom of the screen. The positioning of the feedback elements ensured that the centre of the screen was left clear so players weren't unintentionally distracted by the interface when they were immersed within the game (see figure 7.11).

The following subsections discuss the development of the two types of screen-space interfaces: interactive interfaces and feedback interfaces.

Figure 7.10 - Game Controller and Sensors.

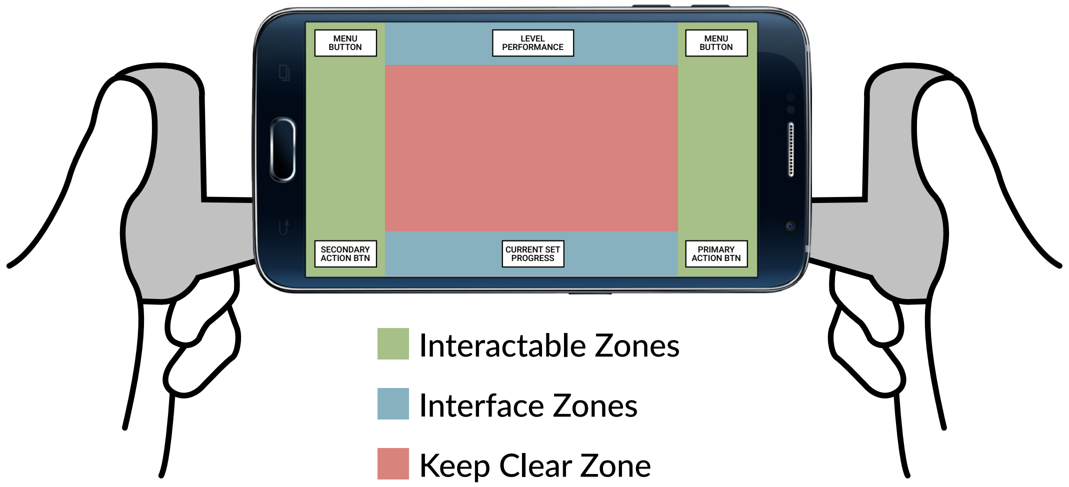


Figure 7.11- Visual Organisati of Screen Elements.

Figure 7.12 - Game Controller in use.

Interactive Elements

All interactive screen-space elements shared a similar aesthetic style. Embracing consistency between interactive elements has been suggested to improve the learnability and usability of a system (Lidwell, Holden, & Butler, 2003, p. 46). Consistency enables users to competently transfer knowledge obtained from other experiences into new contexts, making the learning process more comfortable and familiar (p. 46; see Chapter 2: Background), p. 17)

All the interactive elements in the developed prototype are aesthetically consistent in terms of their colour, shape and size. This aesthetic consistency embraces the usability principle 'recognition over recall' (Lidwell et al., 2003, p. 164) as users recognise that the interface element is interactive based on its aesthetic similarities with other known interactive elements.

The interactive areas of the interactive elements were substantially larger than their corresponding graphics (see figure 7.13 opposite). These increased interaction areas enhanced the usability of the system by accommodating stroke survivors who had fine motor skill difficulties that may make it difficult to perform accurate touch interactions.

Figure 7.13 - Interactive Interface Elements.

Feedback Elements

Feedback elements shared a clean, sharp design aesthetic that was distinctively different to the design of the interactive elements. This visual organisation was intended to help players intuitively navigate and interact with the game's interface.

The feedback elements were non-diegetic (Fagerholt & Lorentzon, 2009, p. 51), residing outside of the game world and presented in an overlay manner. The visual treatment of these interfaces were influenced by the game's art direction and design heuristics that accommodated people with disabilities (Farage, Miller, Ajayi, & Hutchins, 2012, p. 15).

The exercise progress feedback bar (see figure 7.14 opposite) provided players with feedback on their physical progress within the game's level. The blueberry icons within this interface enhanced the game's interaction model by providing performance feedback on the player's physical progress in their exercise repetitions – gamified through the notion of throwing berries to the virtual kiwi.

The Level Performance Interface (see figure 7.14) enabled players to set, measure and achieve their end-game goals. This interface embraces performance-contingent rewards by providing ongoing feedback on a player's level performance while rewarding them granting them level stars as they progress – providing a feeling of pride for their achievements (see chapter 2: Background p. 24).

Figure 7.14 - Feedback Interface Elements.

7.2.3.2: World Space User Interfaces

The world-space interface developed in *NZ Fauna AR* primarily comprised of diegetic UI elements. Diegetic UI elements exist within the spatial and fictional world (Fagerholt & Lorentzon, 2009, p. 52). They enhance the narrative experience through presenting themselves as entities that would be viewed by the game character rather than the game player (which would be the case for screen-space UI elements).

The following subsections discuss the development of the two most significant world-space interfaces: The Clipboard UI and the Help Book.

Clipboard UI

The clipboard diegetic UI was a visual metaphor used for aspects relating to player calibration and post-gameplay level performance. The two circumstances that the clipboard UI is used for, player calibration and level-performance, closely aligned with the clipboards physical analogue usage - taking down field notes (akin to calibration) and showing results (akin to level performance). These visual metaphors were intended to help players understand the purpose of these specific phases of gameplay through building off player's knowledge of the use of the element's physical analogue. These visual metaphors additionally provided an element of familiarity within the design of the interface - making the experience more comforting (see Chapter: *Background* 2, p. 17).

Help Book

The design of the in-game help book aimed to provide a familiar experience to players by using a visual metaphor that reflected the traditional analogue of instruction manuals. As discussed in Chapter 2: *Background* (see p.17), creating a digital experience that is rooted within its physical analogue helps reduce the feeling of anxiety and confusion associated with learning new technologies (Beyer & Holtzblatt, 1998, pp. 7–8).

Figure 7.15 - Clipboard Diegetic User Interface.

Figure 7.16 - Player Help Book.

7.2.3.3: Visual Cues

Stroke survivors commonly have cognitive impairments that may limit their ability to remember information (see Chapter 2: Background, p. 17). Visual cues were used to help players recall, rather than remember, what they should do to progress through gameplay. Remembering information is significantly harder than recalling information. Providing contextualised information (a visual cue) that is associated with the desired action helps players retrieve information from their memory - reducing the unnecessary cognitive pressure existent if players are required to remember information necessary for gameplay progression (Lidwell et al., 2003, p. 164).

The following discusses two visual cues that helped players learn the basic gameplay mechanics and intuitively progress through gameplay: hold-able berries and the trail renderer.

Hold-able Blueberry

As players sat down, a blueberry swiftly moved from the virtual bucket (next to the player's seat) to a point in front of the player's field of vision. The blueberry sat in front of the player's field of vision to mimic the idea of the player holding the blueberry. This acted as a visual cue intended to help player's recall the next action within this interaction which was to stand and throw the fruit.

Trail Renderer

The trail renderer helped stroke survivors with vision impairments who may find it difficult to track the motion of their thrown berry. This design feature emphasised the feeling of motion given to the thrown berry - acting as an instant visual reward for players as they completed their sit-to-stand exercise repetition.

The trail renderer gives visual clarity to the berry, highlighting the path of the thrown fruit. It allowed players to trace the motion of the thrown berry, focusing their attention on where the berry has landed. This design feature allowed players to measure their performance (whether they managed to throw the berry within the target zone) and additionally receive achievement feedback as the digital kiwi chased and ate the berry.

Figure 7.17 - Blueberry Visual Cue.

Figure 7.18 - Trail Renderer.

CHAPTER 8

User Testing

This chapter discusses the testing of the developed video game prototype, NZ Fauna AR. This design chapter responds to the second research aim: design, develop and test a digital game prototype that engages older adults recovering from a stroke. The research within this chapter was conducted parallel with the research discussed in the previous chapter which focused on the development of the video game prototype – responding to the second objective of the second aim. This chapter explores the third objective of the second aim. This objective and the relevant methods applied to achieve this objective are discussed below.

Objective 3: I will critically evaluate the developed prototype through expert reviews and user-testing with stroke survivors.

A. User Testing/Evaluative Research (Martin & Hanington, 2012, p. 74; Tullis & Albert, 2013, p. 122).

Two high-fidelity prototypes were tested with potential users during the development process. Testing sessions were facilitated by neurological physiotherapist to control potential biases that might arise if conducted by the researcher. Usability tests encouraged participants to 'think-aloud' (Dumas & Redish, 1999, p. 77). User observations were documented through photographs, audio recordings, and video recordings. Following the gameplay session, participants were asked to fill out a system usability scale (SUS) (Brooke, 1996). This was followed by a retrospective semi-structured interview (Martin & Hanington, 2012, p. 102). User testing with stroke survivors helped refine the design of the system while also providing context specific insight that could not have been obtained through secondary research.

B. Data Analysis (Barnum, 2011, p. 239).

The self-reported data and observed behaviours were combined and analysed to quickly interpret the data and refine the system based on the findings.

The following sections discuss the testing of the video game prototype, the findings from these testing sessions and the changes that responded to the identified problems that further refined the design of the video game prototype.

8.1: Methods

The usability testing session was conducted within a clinical environment. The session was moderated by a neurological physiotherapist to avoid biasing participant articulated experiences that were expressed as they were interacting with the game prototypes (Barnum, 2011, p. 162). During the testing session, the researcher took notes, non-identifying photos, videos, and audio-recordings to further analyse and evaluate the findings from the testing session.

The following sections describe the recruitment process, the participants and details of the individual sessions.

8.1.1: Recruitment

Participants were contacted, screened and recruited by clinicians. Inclusion and exclusion criteria were used to find the most suitable participants for participation in this usability trial. Potentially participants were screened based on the following criteria:

Inclusion Criteria

- Over the age of 18.
- Had experienced a stroke which impairs walking.
- Able to walk without standby assistance.

Exclusion Criteria

- Significant cognitive deficit in the opinion of the screening physiotherapist.
- Unable to comprehend one step verbal commands.
- Unable to give informed consent.
- Medically unsuitable in the opinion of physiotherapists, general practitioners or medical specialists.
- Experience excessive joint pain.

The inclusion criteria listed participant attributes that were essential to their selection in taking part in the study. The inclusion criteria were very broad as the system was intended to be used independently by an audience that has a wide range of associated cognitive and physical impairments. The exclusion criteria helped the researcher ensure that participants could safely and independently interact with the developed game prototype without clinical supervision and articulate their thoughts as they were engaging with the prototype. This recruitment process resulted in several participants who generously donated their time to participate in the user testing sessions.

8.1.2: Participants

Five participants were recruited for the initial usability testing session. These participants provided the study with a user base that represented an audience with a wide range of cognitive and physiological abilities. The following provides a brief overview of those who participated in the usability trial. Participants were given aliases to conceal their identities.

"Andrew" (2 Sessions)

Andrew is in his early seventies. He had a moderate stroke two years ago and now suffers from left side hemiparesis, spasticity, gross and fine motor impairments and moderate cognitive impairments. Andrew engages in regular physical activity both with a personal trainer and independently within in his own home. Andrew is highly motivated towards his recovery and shows significant improvements in the balance and strength of his lower-limb muscles, and can now walk short distances without the use of a walking stick. Andrew had recovered a significant amount of gross motor function after stroke but still struggles with fine motor movements. Andrew had had little experience with computers and no experience with video games at the commencement of the trial.

"Brenda" (1 Session)

Brenda is in her late sixties. She had a hemorrhagic stroke twenty-two years ago. She had paralysis on the right side of her body, apraxia, aphasia, short-term memory damage, contractures of her right hand and loss of mobility – leaving her confined to a wheelchair. Ten years after her stroke, Brenda's mobility progressed enough to allow her to discontinue her use of a wheelchair and instead wear an ankle-foot orthosis (AFO) that helped control the position and motion of her ankle. Brenda had difficulties holding the two-handed game controller as her right hand was severely paralysed. Brenda had had experience with computers but little experience with video games at the commencement of the trial.

"Caroline" (2 Sessions)

Caroline is in her late sixties. She had a stroke seven years ago and suffered from left side hemiparesis, spasticity, gross and fine motor impairments, and moderate cognitive impairments. Caroline had recovered most of her gross and fine motor movements allowing her to walk independently without the use of a walking aid. However, Caroline still has mild contractions in her right hand and suffers from moderate cognitive impairments. Additionally, Caroline has had surgery on her right knee to reduce aging-related pains. Caroline articulated her high motivation towards her recovery as she explained that her motto was: "everything is rehab and rehab is everything". Caroline had had moderate experience with technology and had been playing brain-training games on her iPad to help improve her memory and thinking skills. Caroline emphasised the importance of performance feedback and progression within the brain-training games that she plays.

"Debbie" (1 Session)

Debbie is in her early eighties. She had a stroke nine years ago and suffered from minor left side hemiparesis, gross and fine motor impairments, short-term memory loss, and mild cognitive problems. Debbie had noticeable balance and coordination issues while additionally explaining that she uses a scooter for distances further than one kilometre. Debbie had not had any experience with technology nor video games at the commencement of the trial and explained that she additionally does not enjoy video games.

"Edward" (1 Session)

Edward is in his late forties. Edward had a stroke twelve years ago and suffered from left side hemiparesis, loss of proprioception, and vision impairments. At the beginning of his recovery, Edward was completely bed-ridden, but over time he recovered significant lost functionality. The strength in his leg muscles has improved significantly as he can walk independently over long distances without the use of a walking aid. However, he mentioned that as he gets tired, he occasionally experiences minor drop foot. Edward currently experiences contractions in his left hand and muscle stiffness in his left elbow. Edward had had moderate experience with digital technology but little experience with video games.

8.1.3: Testing Protocol

This section discusses the two testing sessions conducted with stroke survivors for the developed video game prototype. Each testing session lasted approximately one hour and involved a usability test followed by a questionnaire and a semi-structured interview. The gameplay session involved participants playing through the game's tutorial and then playing the first level of the game.

The system's ability to fulfil the second and third theme within the success criteria, Meaningful Play and Progression, is dependent on the system's ability to be used independently by stroke patients. In other words, the player cannot experience elements of meaningful play and progression if the system is not inherently usable by its audience. Therefore the testing and refinement of the usability of the system is necessary before the system's ability to fulfil the full criteria is explored.

As the system introduced an innovative rehabilitative experience that incorporated several design assumptions before being put in the hands of users, usability testing was essential to the refinement of requirements for a stroke-friendly system. As illustrated by Norman (2013), "If everything worked perfectly, little is learned. Learning occurs when there are difficulties" (p. 229). In this case, observing users interacting with the prototype helped the researcher understand what the system was failing to achieve at that point in the research process.

The first prototype was tested within the initial stages of development. The first testing session focused on the interactivity and usability of the system - aligning itself with the first theme of the success criteria, Designing Stroke-Survivor-Friendly Systems (see Chapter 2: Background, p. 25).

A more refined prototype was tested in the second testing session. This testing session helped to validate the design decision that responded to the usability problems identified during the initial testing session. Additionally, this session aimed to test the refined prototype's ability to fulfil the full success criteria.

Think-aloud Protocol was used during the gameplay testing session, which encouraged participants to articulate what they were thinking, feeling or doing as they progressed through the game. Having users 'think aloud' helped identify aspects of the system that delight, frustrate and confuse users. These findings were then turned into actionable design recommendations that refined the game prototype.

The following sections provide a summary of the findings of each prototype that helped refine the development of the rehabilitative system.

8.2: Initial Usability Testing Session

Five stroke survivors participated in the initial usability testing trial. The prototype gameplay sessions lasted between ten to fifteen minutes while the session lasted approximately one hour. This session involved a usability test followed by a SUS questionnaire (Brooke, 1996) and a semi-structured interview. The testing session was facilitated by a physiotherapist to control potential biases that might arise if conducted by the researcher.

Given the use of cutting-edge technology within the prototype paired with an audience that is associated with traditional media usage, little was about how players would respond to the innovative developed system. This initial testing session gave valuable insight into how players interacted with and responded to the device and video game prototype.

The system's ability to fulfil the established requirements within the theme 'Designing Stroke-Friendly-Systems' was measured through both a post-gameplay SUS questionnaire (Brooke, 1996), and through analysed articulated thoughts exhibited by participants as they were interacting with the game prototype (Tullis & Albert, 2013, pp. 121–158).

8.2.1: User Feedback

All participants could engage with the video game prototype without difficulty. All five participants successfully finished the tutorial and the first level of the game. However, all five participants stated confusion or showed a lack of understanding of the short-term goals within the game. This user testing session identified several significant problems that limited the usability of the game prototype:

- The tutorial did not teach all the mechanics that were necessary for players to become compe-tent in interacting with the system independently.
- Lack of visual feedback cues that would remind players of short-term goals.
- Lack of visual feedback that would show players where the berries has been thrown.
- Buttons did not accommodate for those with fine motor impairments.

The following sections discuss these usability findings in further detail.

8.2.1.1: Tutorial/Instructions

All five participants found that the tutorial did not explain the main mechanics and short-term goals of the game clearly enough for them to intuitively interact with the system. Because of this, some participants failed to understand the benefits of the video game in a rehabilitative context during their gameplay session. Brenda and Debbie described specific instructions that would be useful towards understanding how to achieve the goals within the game. For example, Brenda said she would like an instruction that said:

> "When you aim the controller, you aim it to where the fruit is going to land." - Brenda

She explained that she found it difficult to make this connection as this aspect of the game was not explained to her during the tutorial. Additionally, Caroline had difficulties understanding the fundamental sit-to-stand goals of the game. Following completion of the tutorial, Caroline had to be told three times by the facilitating physiotherapists what she needed to do at each stage of the game before she understood the core interactions within the game. Caroline explained that the initial instructions were not clear enough for her to make the connection between the physical standing interaction and digital throwing of the fruit:

> "Oh right, I get it now, great. You stand up to throw the food, yes. I didn't get that from the initial instructions. I don't think the instructions up front iare clear enough to give me that idea of this is what I want to do." - Caroline

It was observed that Debbie had difficulties understanding that the controller could be used to explore the virtual environment to throw berries to specific places within the room for Fizzy to chase. Again, this could potentially be linked to the tutorial's ineffectiveness in explaining the game's core mechanics.

8.2.1.2: In-game Feedback

Andrew, Brenda and Caroline had issues tracking the motion of the fruit once it had been thrown – this occurred after the player moved from a sitting to a standing position which resulted in the fruit being thrown to the target point. Andrew and Brenda experienced negative emotions of frustration and confusion as they had not seen the kiwi eat the thrown berry:

> "I didn't see the berry. . . Did he get the berry? . . I missed that one" – Andrew.

> "Oh, where did [the berry] go? I don't know what I did there." – Brenda.

If players missed the kiwi eating the fruit, they would lose the visual reward that acknowledged their physical engagement. Visually seeing the kiwi eat the fruit acted as a form of achievement gratification that aimed to elicit feelings of pride within players as they performed the exercise repetitions.

8.2.1.3: Interactions.

All five participants could perform the core interactions within the game (sit-to-stand). However, no participants reached a level of intuition where they could subconsciously interact with the system without having to recall which interaction was required to progress to another level. All five participants had difficulties understanding the short-term goals within the game. More specifically, when to sit down (to pick up berries) and when to stand up (to throw the picked-up berries at the target).

8.2.1.4: Interface

Four participants could sufficiently interact with the interface with ease. Although, it was observed that Andrew had minor problems pressing the interactive zones of the buttons as he had fine motor impairments that made accurate touch interactions difficult. Brenda could not perform the touch interactions as she could only interact with the device using her left hand, which was the one holding the device.

8.2.2: Design Changes

This initial user testing session explored the usability of the developed system identifying several design flaws and usability problems that negatively affected players' experiences while interacting with the developed system. Based on the identified issues, the following design changes were made to the developed system:

Parameter	Low Difficulty	Severity
More in-depth tutorials that focus on individually introducing four key interactions: 1. Introduce controller movement (looking around the room). 2. Introduce sit-to-stand interaction to pick up and throw fruit. 3. Introduce target reticle. 4. Introduce target zones.	Lack of depth to the tutorial made it difficult for all participants to learn the fundamental interac-tions within the game. Conse-quently, players were confused about the core aspects of the game.	High.
Add visual and audio cues that help players recognise when they should sit down to pick up fruit and stand to throw fruit. • When the player sits down, a blueberry is held by the player within the virtual world. • After the player stands up and the kiwi has eaten the thrown fruit, the player is prompted to sit down to pick up more fruit to throw to the kiwi.	Players found it difficult to know when to sit, and when to stand as they were recalling what they needed to do rather being provided with a simulated cue that would help them recognise the next short-term goal. “Recognition memory is much easier to develop than recall memory” (Lidwell, Holden, & Butler, 2003, p. 164).	High.
A trial renderer was added to the thrown blueberry which highlighted the flight path of the berry as it was traveling through the air (see Chapter 7, p. 96). This assistive feature complemented the player’s vision by helping them trace the motion of the berry to find the position where the thrown berry landed – allowing the player to see the fruit being eaten by the virtual kiwi.	Three players found it difficult to trace the flight path of the fruit, making it difficult for them to see where the fruit had landed.	Moderate.
Full screen ‘touch to continue’ buttons were added where appropriate while the non-full-screen button interaction zones were increased to accommodate those with fine mo-tor impairments.	One participant had difficulties interacting with the digital buttons because they lacked the fine mo-tor control that was required within the design of the interac-tive UI elements.	Moderate.

Table 8.1 - Design Changes Following Initial Testing Session.

8.3: Final User Testing Session

Another more refined prototype was tested in the second testing session. The second session aimed to test the refined prototype’s ability to fulfil the full established success criteria (p. 25). The prototype’s ability to meet this criteria was measured through a post-gameplay SUS questionnaire (Brooke, 1996); likert scale questionnaire (Martin & Hanington, 2012, p. 140); semi-structured interview (Martin & Hanington, 2012, p. 102); and through participant articulated comments observed while participants were interacting with the prototype (Tullis & Albert, 2013, pp. 121–158). For a more elaborate discussion on why these methods were selected see Chapter 3: Methods (p. 41).

This testing session involved two stroke-survivors, Andrew and Caroline. Both participants participated in the initial usability trial, so they both had experience with the video game prototype. However, their memory of the system was rather reserved as the initial testing session occurred a month prior.

8.3.1: User Feedback

Both participants felt that the design of the system had improved significantly from the initial game prototype:

> “Oh my goodness, what an improvement, this is fantastic. This is amazing honestly.” – Caroline.

Additionally, they both showed a higher level of competence and expressed less frustration while progressing through the refined tutorial. Caroline explained, during her post-gameplay interview, that this prototype’s tutorial felt more purposeful than the previous prototype’s tutorial:

The instructions [tutorials] were such an improvement on what it was before. It is much clearer also because there’s an aim to instructions. It’s not just to stand and throw the berries. I mean this time I got actually that I had to pick up the berry to throw it. I kind of missed that last time. - Caroline

Although Andrew felt that the tutorial was well paced, he experienced significant difficulties in understanding the short-term goals within the first level of the game. With this in mind, Andrew also illustrated that the implemented visual cues had not provided enough feedback for him to progress through gameplay intuitively:

> "I'd like to be told to look for the target." - Andrew

> "I need to be told to stand up; I need to be told to aim at the target." - Andrew

The held blueberry visual cue that appeared once the player sat down was intended to help players recall the action of looking for the target and sequentially standing up (see chapter 7: Prototype Development, p. 96). In contrast, Caroline found the blueberry visual cue sufficient enough for her to intuitively recall the short-term goals of the game:

> "Hey this is so much fun, I'm not even thinking about sitting and standing." - Caroline

It was identified that Caroline was having difficulties completing the challenges within the second half of the first level - despite her competence during the tutorial. It was observed that she did not learn a key element within the game's interaction model that helped overcome more difficult challenges. For players to throw fruit at hard to reach targets they must first focus the UI reticle on the desired target circle before they move to a standing position and maintain their focus as they are changing positions. Neither Andrew nor Caroline were focusing on the target as they moved to a standing position – making it difficult to throw the berries into the target circle.

Andrew found the first level following the tutorial too challenging, missing six of the eight targets and only scoring 20 points. As the video game only incorporated performance-congruent feedback (where players are rewarded for good performance), Andrew did not get the sense of achievement or gratification that he should experience for engaging in the activity – which would help motivate Andrew to overcome the game's challenges. This lack of positive feedback resulted in Andrew expressing feelings of frustration as he could not overcome the in-game challenges that would reward him with the sense of achievement or gratification that he needed to remain motivated.

The second prototype did not reward players with points for their physical engagement in the activity (doing sit-to-stand exercises), it only rewarded players for their successful achievement in overcoming the game's challenges (successfully throwing berries into the target zone). After several unsuccessful throws resulting in Andrew getting zero points with each throw, he acknowledged his need for engagement-congruent feedback (where players are rewarded for engagement):

> "Have I been missing the target? . . . . I'd like some reward [for performing the exercise at least]." - Andrew

This identified that another layer of rewards was necessary to acknowledge players' physical engagement. Building on this, performance-congruent feedback (successfully overcoming the game's challenges) could also be used to provide additional rewards for personal gameplay progression.

8.3.2: Design Changes

The second testing session explored the refined prototype's ability to fulfil the full success criteria. It identified several design flaws that negatively affected the player's experience while engaging with the developed system – correspondingly limiting the prototype's ability to meet the established success criteria (p. 25). Based on the problem identified during the testing session, the following design changes were made to the developed system.

Parameter	Low Difficulty	Severity
Restructure Points System Players obtain points for throwing blueberries – this acts as an engagement-congruent reward that is given to players as they complete a repetition of a sit-to-stand exercise. Players can gain additional points by throwing the berries into the target circles – this acts as a performance-congruent reward that builds on top of the engagement-congruent rewards – the researcher wants the player to feel good about their performance regardless of whether they get the fruit within the target circle or not.	At times players lack a sense of achievement for their physical engagement as the initial prototype only incorporated performance-congruent rewards.	High.
Target Circle Focus Feedback The target circle provides visual feedback when the player fo-cuses the UI reticle on the tar-get circle. This design change provides players with visual feedback on their ability to focus on the tar-get while they are moving from a sitting to a standing position (as the circle would turn back to its original colour if the player lost focus).	Players need a form of feedback to encourage them to concentrate on the circle as they move to a standing position. Additionally, they need dynamic feedback (through the circle changing its colours) to measure their performance of their focusing ability.	Moderate.

CHAPTER 9

Results

Chapter 7 discussed the development of NZ Fauna AR – a rehabilitative video game prototype that explored the incorporation of an augmented reality exergame into the rehabilitative process. The previous chapter discussed the testing of the developed video game prototype with stroke survivors and the changes made to the developed system based on the findings of these testing sessions. First, this chapter discusses the result of the design research process, an augmented reality rehabilitative video game called NZ Fauna AR. Second, this chapter discusses the findings from the preliminary session with physiotherapists and the user testing sessions with stroke survivors.

9.1: Final Design: NZ Fauna AR

The final output of the design research process was a handheld augmented reality rehabilitative video game called NZ Fauna AR. NZ Fauna AR was an educational location-based game that converted prescribed sit-to-stand exercises into active gameplay. NZ Fauna AR utilized Google Tango's augmented reality platform to provide an immersive experience that was structured by the configuration of the player's physical surroundings. The use of procedural generation techniques enabled the video game to be played seamlessly within any indoor space of arbitrary size – giving the player control over their play space.

9.1.1: Interactions

The game's core interaction model built off one of the most frequently performed physical tasks, standing up from a sitting position (Pollock, Gray, Culham, Durward, & Langhorne, 2014, p. 5). Players stood up from a seated position to throw berries to the virtual kiwi, Fizzy. Players sat down to pick up more berries from the virtual bucket that was placed on the player's physical floor. The game was designed to incorporate minimal touch interactions – this was driven by the interaction model which was comprised of natural physical movements. Interactive interface elements (for instance, buttons) and feedback interface elements (for example, the level performance bar) had their own distinctive design language to identify themselves from one another.

9.1.2: Tutorial

The game's tutorial introduced the four main mechanics of the game that were fundamental towards overcoming the challenges within the first level. The first phase of the tutorial taught players to interact and explore the virtual world with the game control. It showed players that the controller could be used to interact with augmented objects in the real world.

The second phase of the tutorial taught players how to pick up and throw fruit to the kiwi through doing sit-to-stand exercises. It showed players the facilitated exercises within the game while explaining how these exercises linked to the in-game goals and their corresponding visual cues.

The third phase of the tutorial taught players how to throw the berries in a specific direction. It showed players that the target reticle could be used to throw berries to specific spots within the room for the kiwi to chase. This knowledge was necessary for players to overcome the challenges within the fourth phase of the tutorial and additionally the following levels within the game. This tutorial additionally introduced the points-based reward and the points that players receive as they throw a berry to the kiwi.

The fourth phase of the tutorial taught players about the target circles that players can throw berries into to gain additional points. To throw berries into the positioned targets players must utilise the skills they obtained in the previous phases of the tutorial. This phase introduced players to the challenges that they must overcome during the first level.

9.1.3: Level One

To overcome the set challenges within the game's levels players must utilise the skills they learnt during the tutorial. In this level, players are given eight berries to throw into the positioned targets that are randomly placed in the player's physical surroundings. As players successfully throw berries into the placed target circles, the circles are placed in increasingly difficult positions – making the challenge more difficult for the player. After players complete all their throws they are presented with a post-game report that displays their final points and corresponding star-rating.

The following images depict the final prototype of NZ Fauna AR the researcher developed for this research.

Figure 9.1 - Main menu.

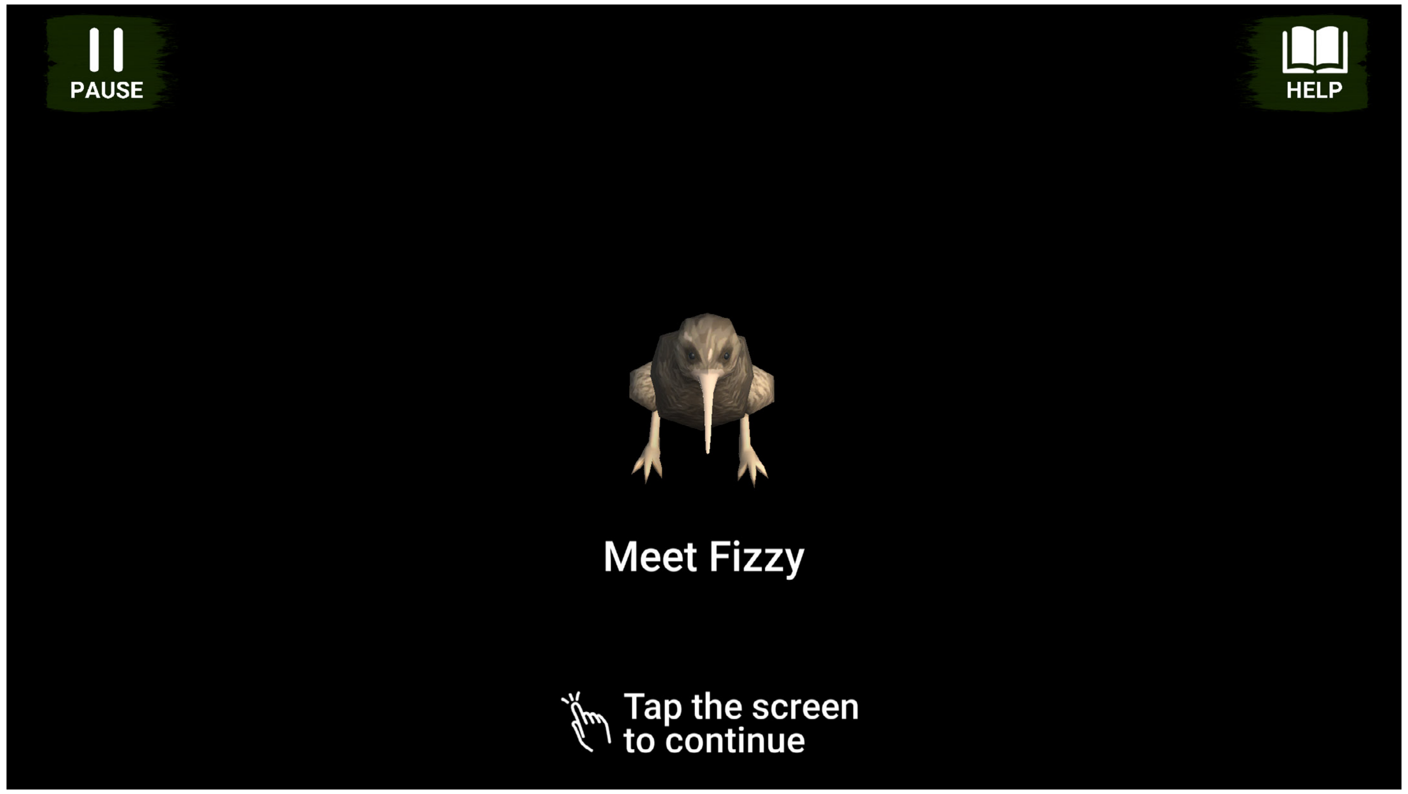


Figure 9.2 - Tutorial: Introducing main character.

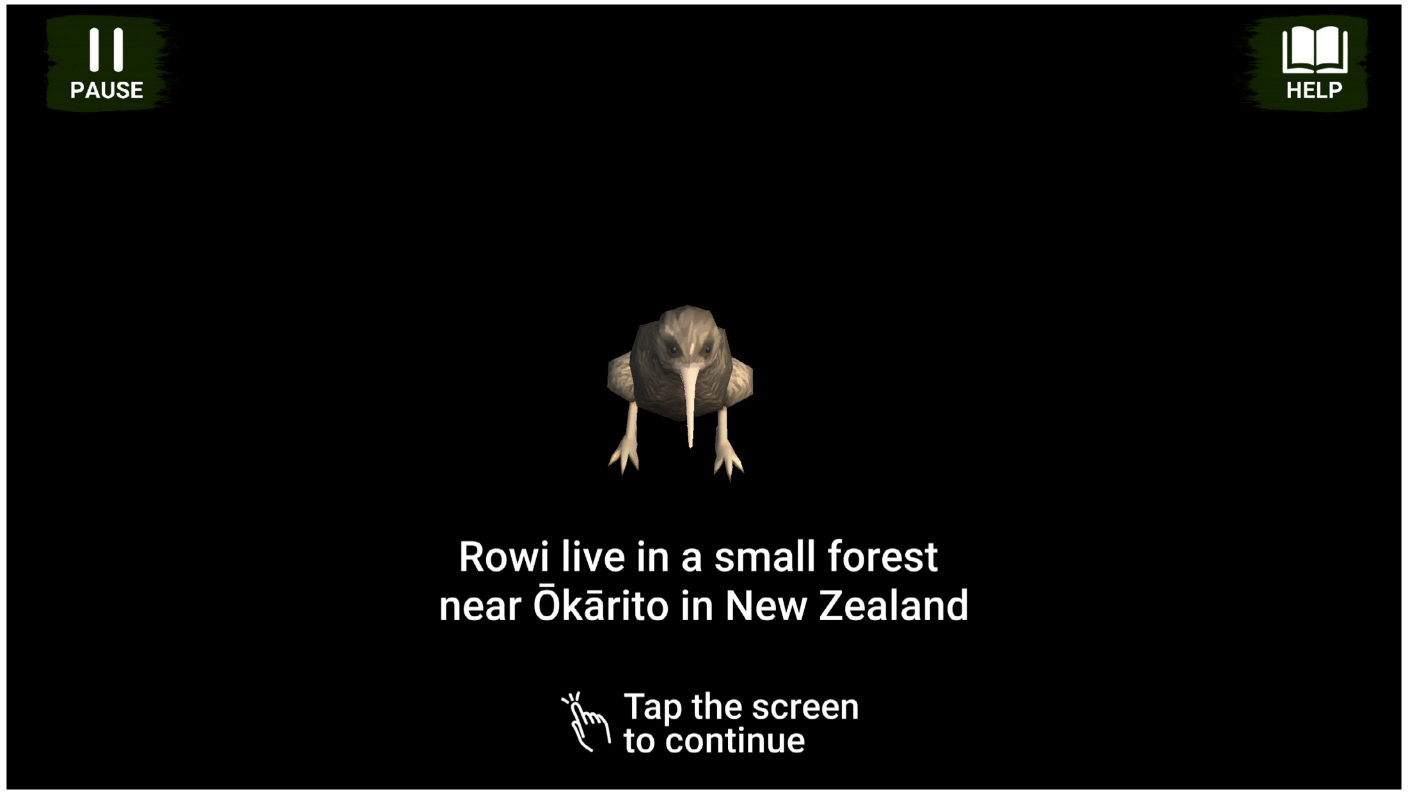


Figure 9.3 - Tutorial: Self-cultivation through facts about kiwi.

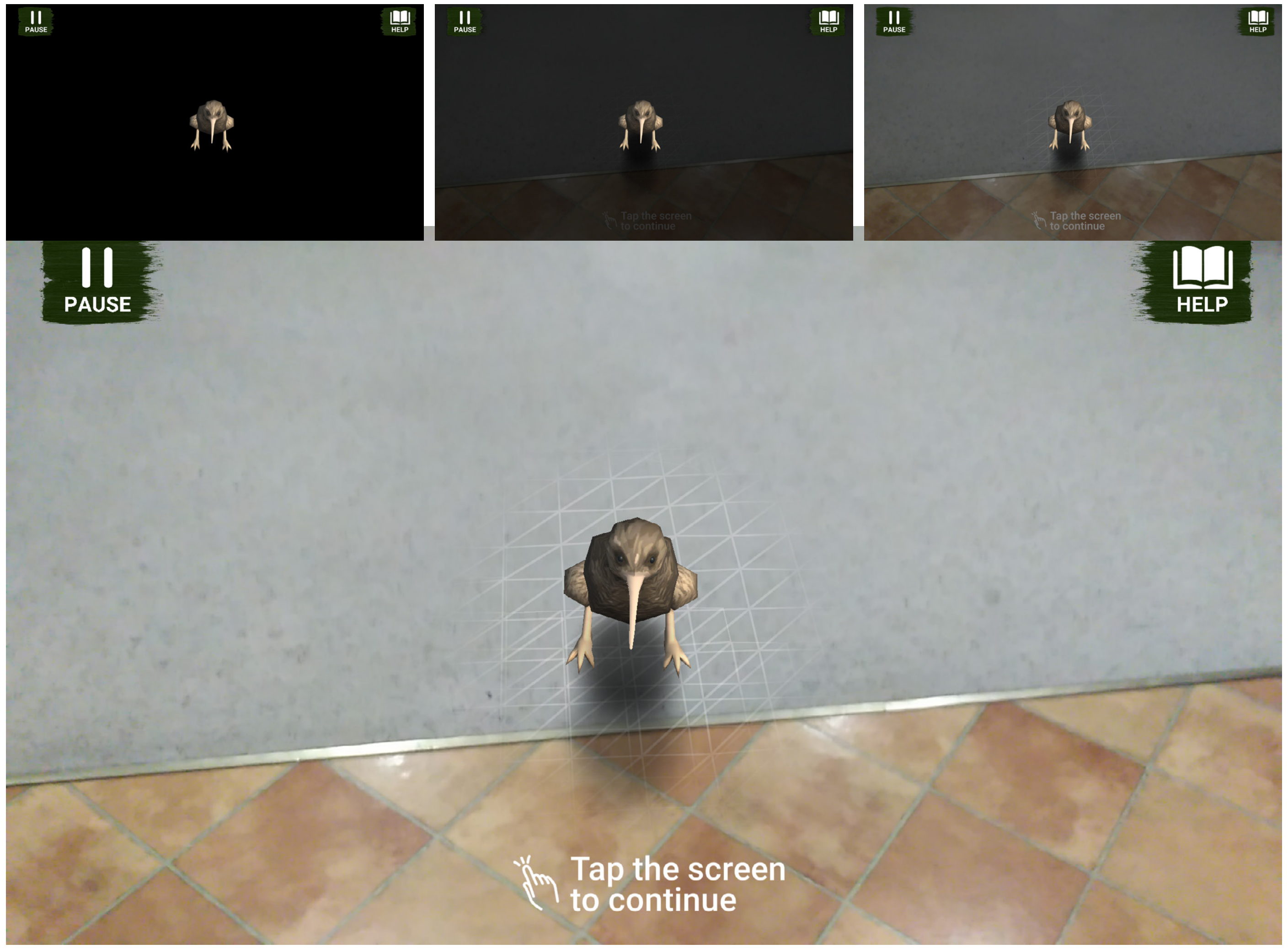


Figure 9.4 - Transition to augmented world

Figure 9.5 - Tutorial: Teaching controller movement.

Figure 9.6 - Tutorial: Communication of games benefits.

Figure 9.7 - Tutorial: Sit-to-stand calibration

Figure 9.8 - Tutorial: Sit-to-stand calibration

Figure 9.9 - Tutorial: Teaching sit-to-stand interaction.

Figure 9.10 - Tutorial: Introducing the target reticle.

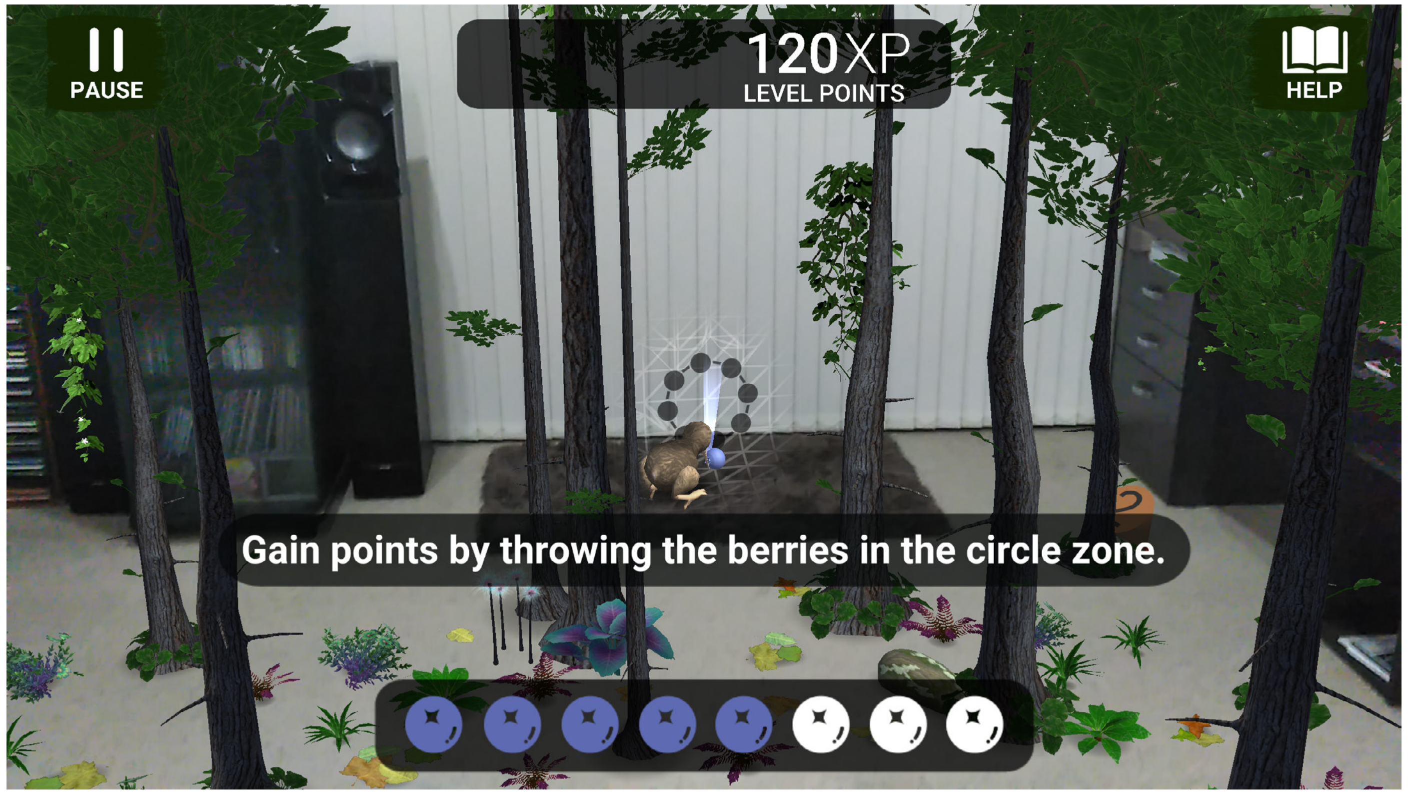


Figure 9.11 - Long distance throw.

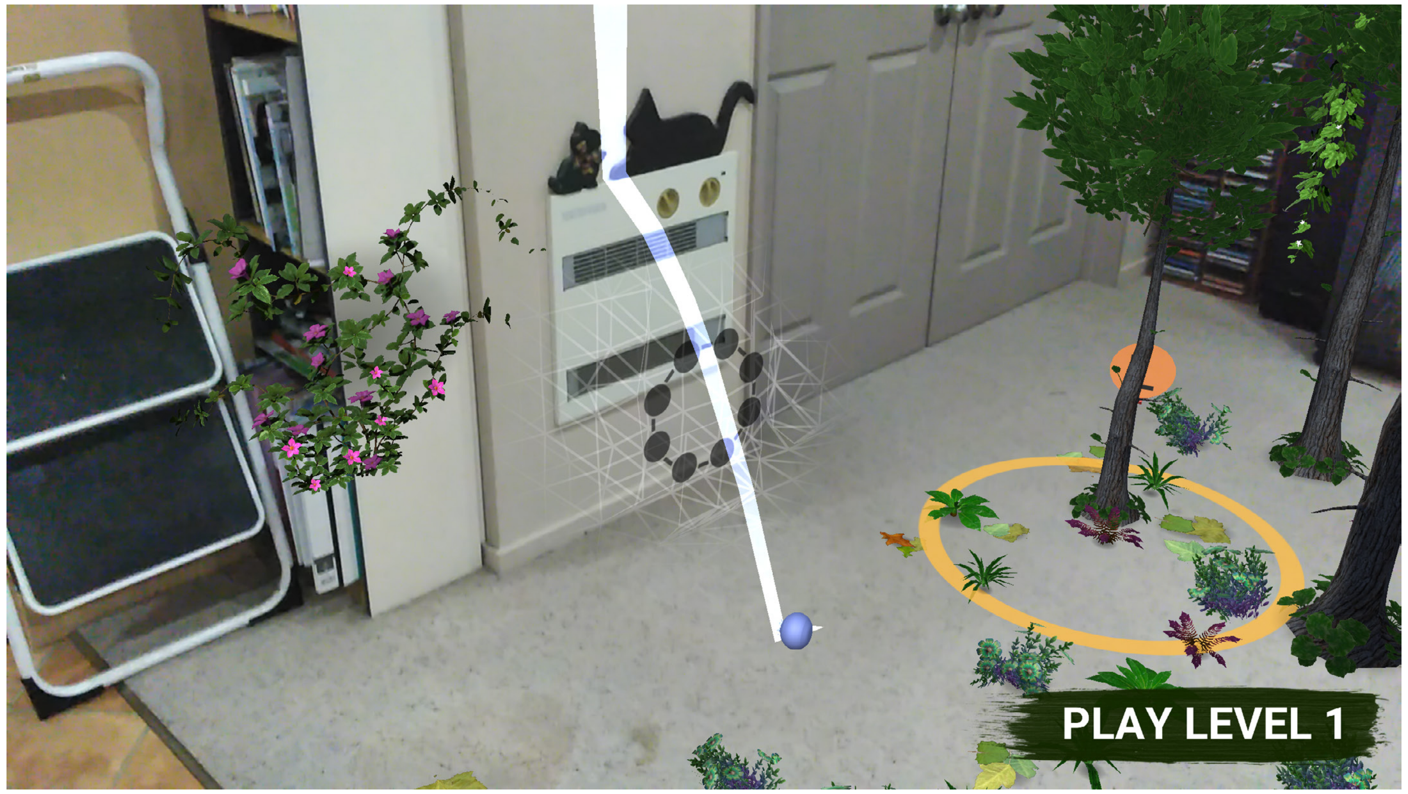


Figure 9.12 - Bouncing Berries off walls.

Figure 9.13 - Tutorial: Aiming for target circle.

Figure 9.14 - Successfully hitting target circle.

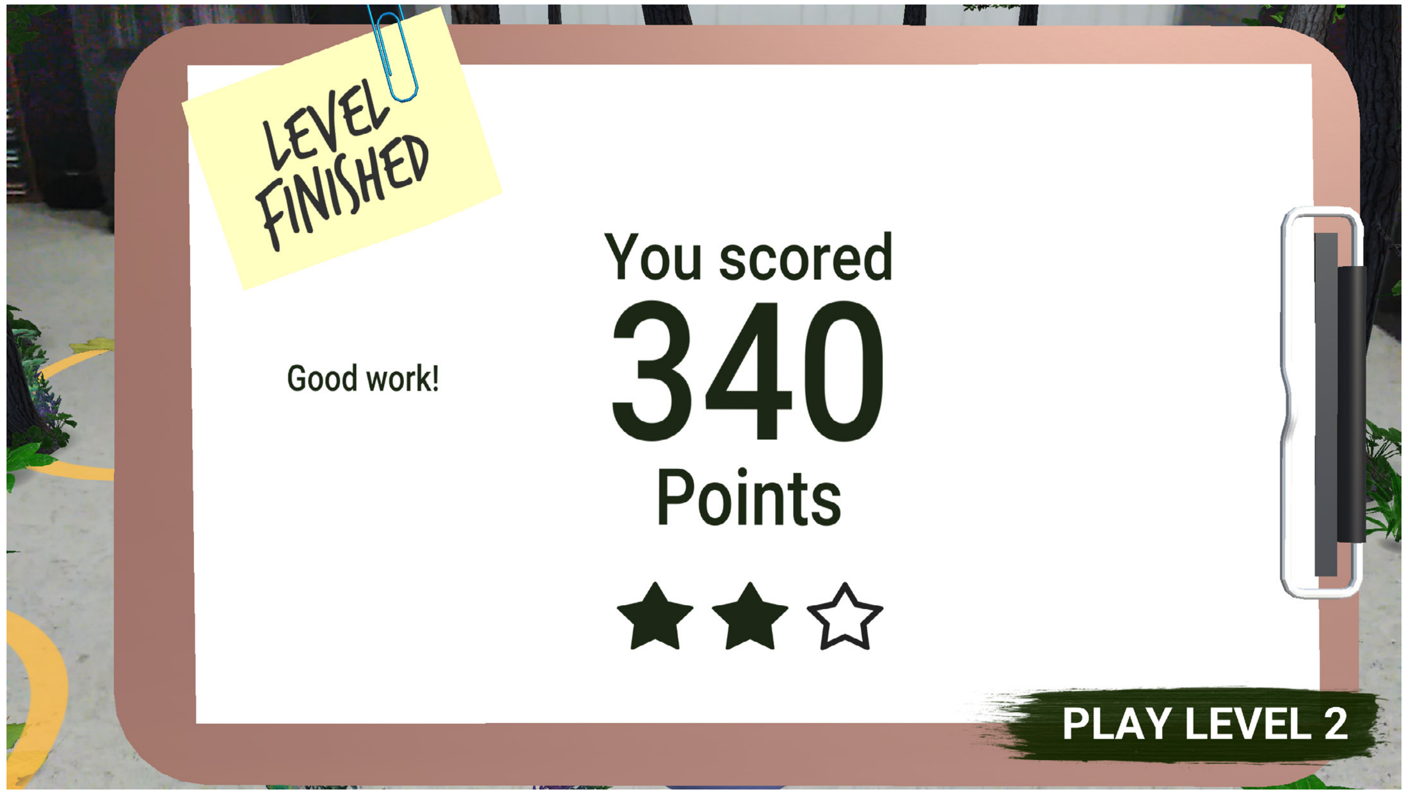


Figure 9.15 - End of level performance.

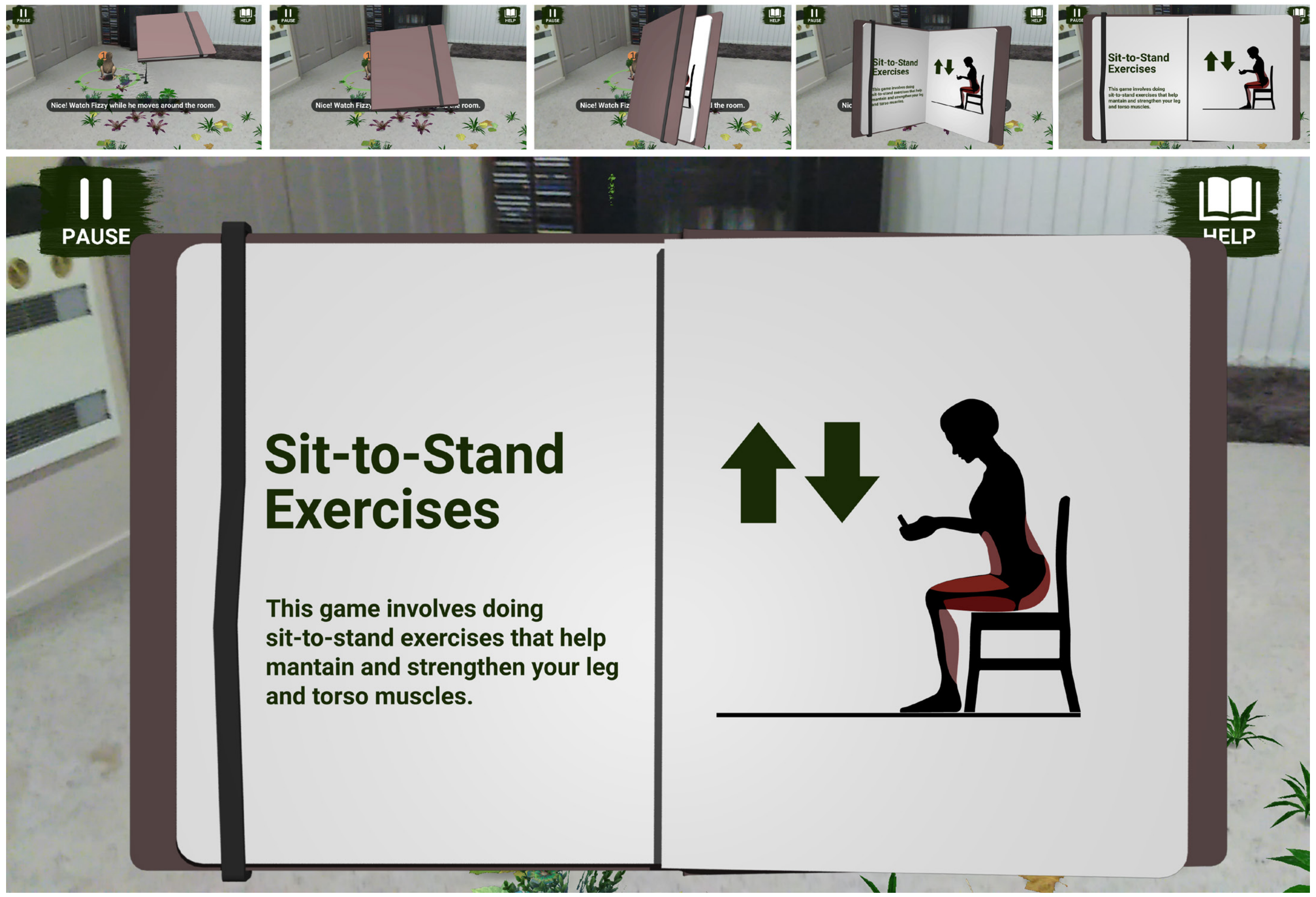


Figure 9.16 - Help Book.

9.2: Preliminary Testing

Due to strict ethical restrictions from the Health and Disabilities Ethics Committee and under the guidance of neurological physiotherapists, the researcher was required to test the prototypes with clinicians before the prototypes could be tested with stroke survivors. Therefore, the researcher conducted usability testing sessions with clinicians before testing prototypes with stroke survivors.

Being early in the development process, the low-fidelity prototype primarily focused on developing the procedural generation pipeline as this was the foundation for the developed system. In this sense, the low-fidelity prototype presented itself as more of an 'interactive experience' rather than a video game as it lacked the core elements necessary for a play experience: rules, goals and the means of achieving the goals.

All three physiotherapists praised the prototypes ability to facilitate and encourage physical activity through its core mechanics. One physiotherapist went on to highlight that "this is what we need to get people to enjoy therapy" (Neurological Physiotherapist, personal communication, March 22, 2017). They explained that they could see it being effective for sitting, sit-to-stand, and stationary standing exercises. Furthermore, they suggested that "anyone could use it for sit-to-stand exercises" (Neurological Physiotherapist, personal communication, January 31, 2017). One physiotherapist highlighted the games potential to add more layers as players progressed and therefore required more challenging exercises:

> "The game has potential to add more layers, which is great" (Neurological Physiotherapist, personal communication, January 31, 2017).

The participating physiotherapists concluded that although they could provide feedback on the design of the system in terms of its application within a rehabilitative context, they could not exactly describe how stroke survivors would respond to the developed system nor how they would interact with the developed system:

> "We can tell you all this stuff, but once you put it in the hands of a stroke patient, it might be a whole other story."

The participating physiotherapists suggested that we test the developed system with stroke survivors at the earliest opportunity to provide early insight into how potential users might respond to the developed system.

The following section discusses the results of the user testing sessions with stroke survivors.

9.3: User Testing Sessions

Two testing sessions were conducted with stroke survivors throughout the prototype's development process. Observing potential users interacting with the developed video game helped refine the design of the system by identifying potential design flaws that could limit the usability and interactivity of the developed system. These findings were then turned into actionable design recommendations that refined the development of the game prototype. Additionally, these testing sessions provided insight into how potential users may respond to the developed augmented reality rehabilitation system.

Five stroke survivors participated in the initial testing session. This initial session provided insight into how potential users may respond to the developed video game system. As shown in figure 9.17, during the initial testing session 59% of participants articulated positive responses (e.g., This is pretty good.) – with 30% of the responses being strongly positive (e.g., This is amazing!). 13% of participants responses were suggestions for improvement – which helped refine the usability of the system. 10% of participant responses were negative – 3% of which were strongly negative (e.g., "This is terrible!").

The two stroke survivors that participated in the final testing session expressed different experiences as they interacted with the final video game prototype (see figure 9.17. Caroline was highly engaged in the video game. She passionately expressed feelings of delight and pride when she comfortably progressed through the levels of the video game. 91% of Caroline's articulated thoughts were positive - with 78% of her responses being strongly positive (see figure 9.17). She expressed no negative emotions throughout the final user testing session. In contrast, Andrew had difficulties understanding the short-term goals within the final prototype. This limited his engagement and overall experience with the video game prototype as he could not progress through the game independently without help from the facilitating physiotherapist.

The final prototype received a final SUS score of 74. As demonstrated by Sauro (2011), a raw SUS score of 74 provides a percentile rank of 70% (p.55). A 70 percentile rank suggests that the developed prototype is considered more usable than 70% of products tested by the SUS scale (p.55). The final SUS score had increased by 7% since the first testing session. However, three more participants were involved in the initial testing session which meant the results of this initial testing session would have provided a more accurate SUS score compared to the final testing session that only involved two participants.

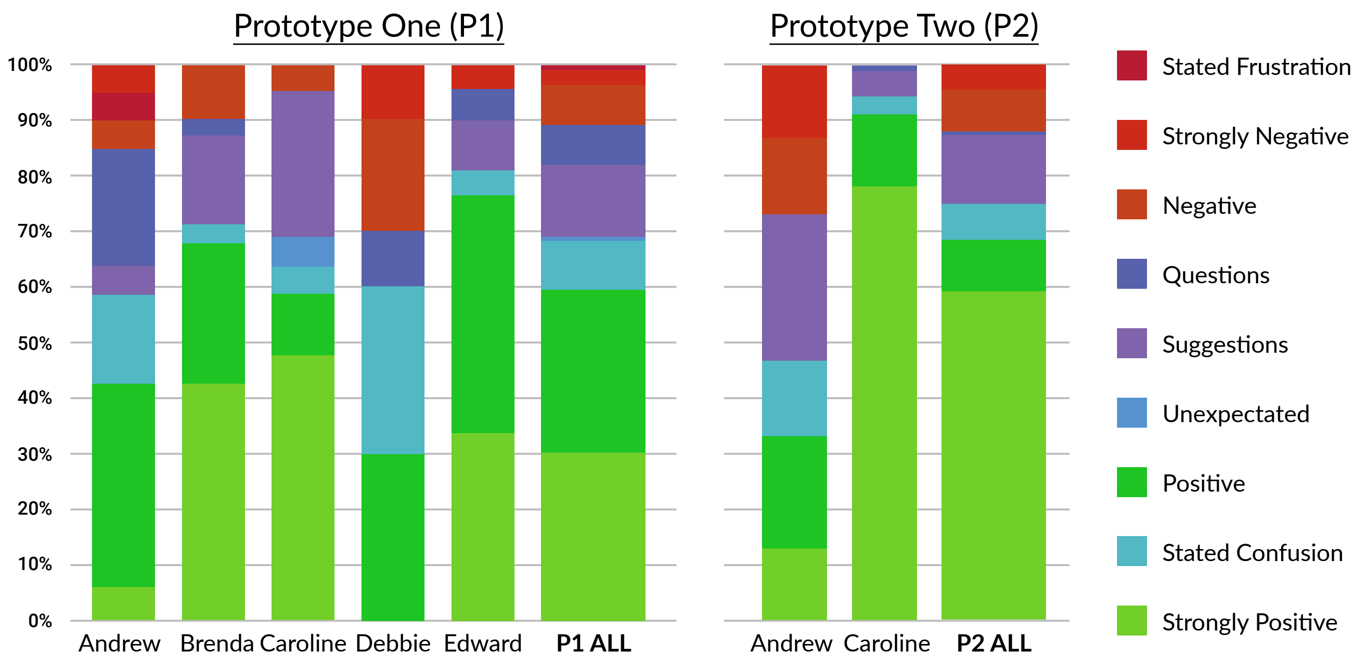


Figure 9.17 - Percentage of positive, neutral, and negative comments from participants across both testing

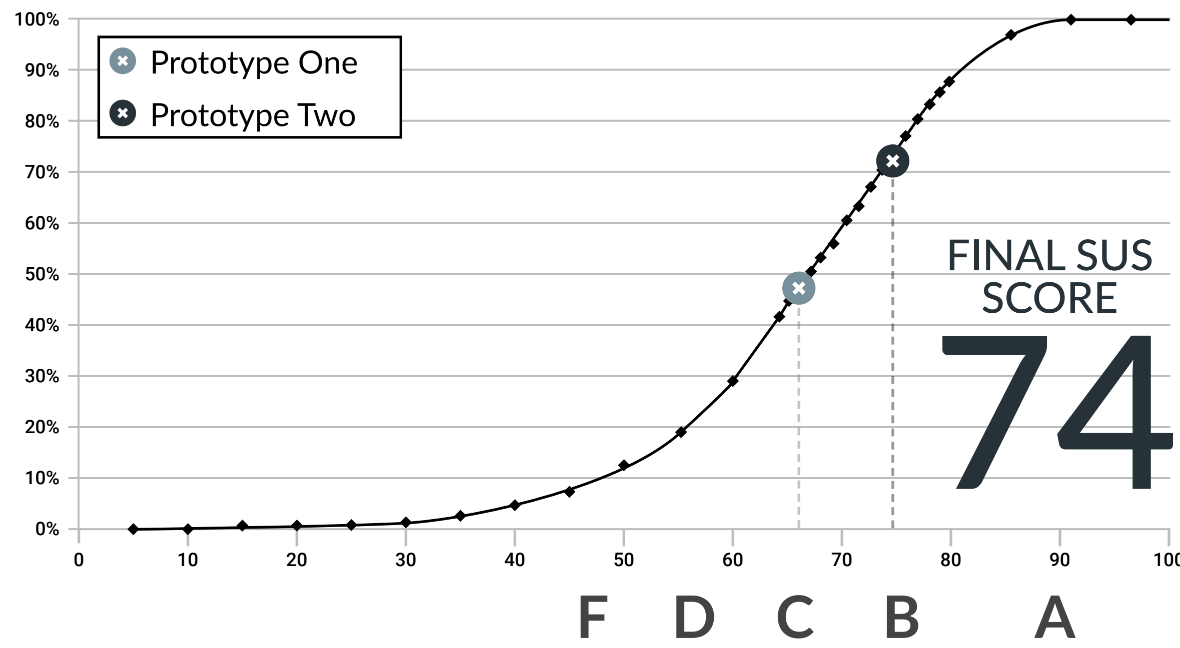


Figure 9.19 - System Usability Scale (SUS) Score. The developed prototype is considered more usable than 70% of products tested by the SUS scale (Sauro, 2011, p. 55).

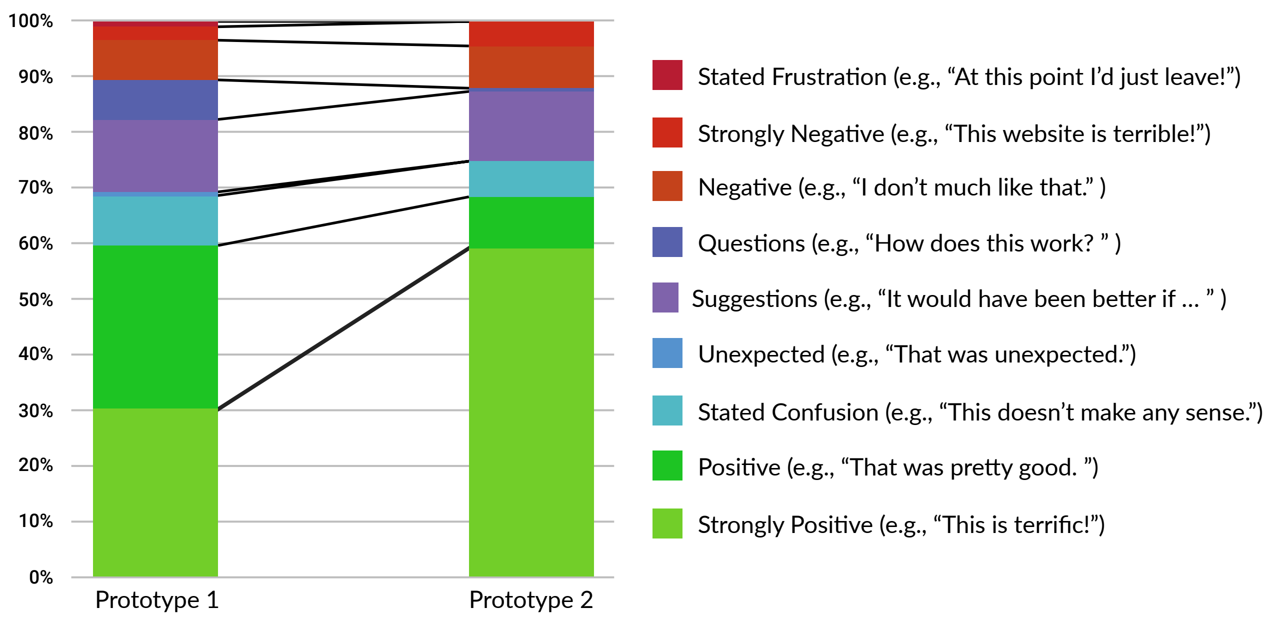


Figure 9.18 - Change in comments between prototypes testing sessions.

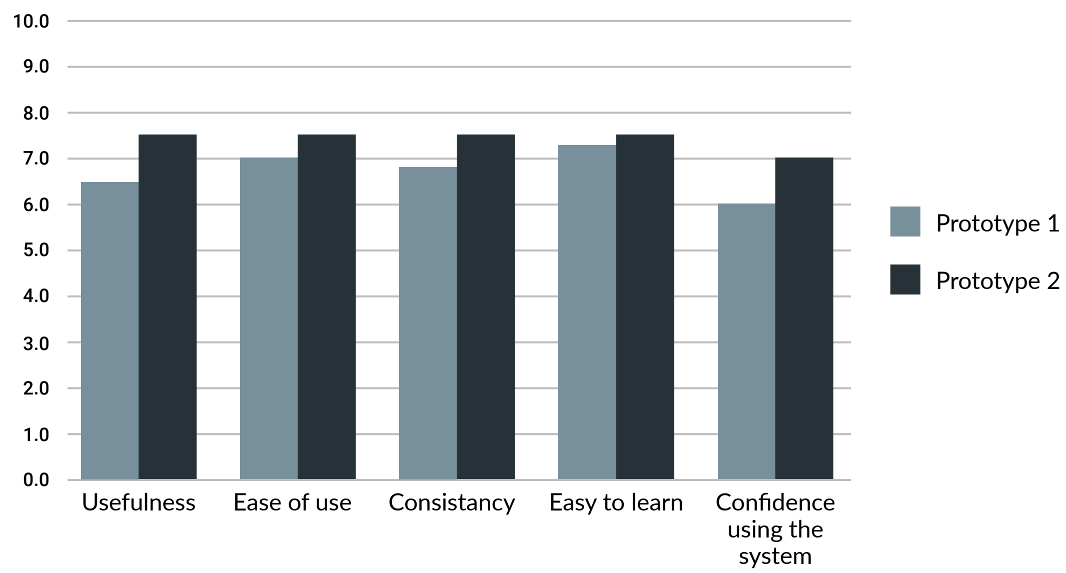


Figure 9.20 - System Usability - derived from SUS questionnaire.

9.3.1: Designing Stroke-Survivor-Friendly Systems

All five participants could sufficiently perform the facilitated sit-to-stand exercises while playing the video game. All five participants could independently calibrate the system to their individual sitting and standing heights. Both Andrew and Caroline acknowledged the implemented design changes that responded to the findings from the initial testing session. Caroline was delighted by the improvements to the system as she praised the refined tutorial design:

> "Oh my goodness, what an improvement, this is fantastic. This is amazing honestly." – Caroline.

> "It was so much fun. It was a huge, huge change and a big improvement." – Caroline.

Caroline explained, during her post-gameplay interview, that the final prototype's tutorial felt more purposeful and intuitive than the previous prototype's tutorial:

> "The instructions [tutorials] were such an improvement on what they were before. It is much clearer also because there's an aim to the instructions." – Caroline.

She then explained that the tutorial proficiently helped her learn the game's interaction model. The final prototype tutorial additionally introduced the more refined narrative that explained that the game's main goals are to sit down to pick up food from the bucket on the ground and to stand up to throw the food to the hungry Kiwi:

> "It's not just to stand and throw the berries. I mean this time I got actually that I had to sit down to pick up the berry to throw it. I kind of missed that last time." – Caroline.

Caroline commented on the implemented 'grid pattern' which was intended to show players the digital space that had been scanned. She described this feature as being helpful because it assisted her in navigating the digital space:

> "There was some kind of grid pattern that showed me where I was going as well. So that was also helpful yeah, to see that." – Caroline.

All participants found the user interface and buttons readable. Caroline, Debbie and Edward found the digital buttons easy to identify and interact

with. There were no complaints about the visual style of the game's interface.

Although Andrew acknowledged that the video game has significantly improved, he had significant difficulties understanding the short-term goals within the game. More specifically, he had difficulties understanding when he should sit within the game and when he should stand. Andrew verbally stated confusion and lack of understanding several times throughout the final testing session. 10% of his comments stated confusion or lack of understanding. His lack of understanding then lead to experiences of frustration and other negative emotions - observed through Andrew's behaviour and articulated thoughts as he could not progress through the game because he could not understand the game's short-term goals. Andrew explained that he felt that the game's goals weren't clear enough for him – despite the implemented visual cues that were intended to help players recall the short-term goals (see Chapter: 7: Prototype Development, p.96):

> "How do I know to sit down?. . . . Well, I don't know what to do. I need a reminder to sit down." – Andrew.

> "There's not enough feedback to tell me what to do next. I need to be told to stand up; I need to be told to aim at the target. And I would like to be told this every time." – Andrew.

9.3.2: Meaningful Play

Four of the five participants demonstrated the importance of a system's identified benefits being connected to the participants' personal goals that they bring to the experience of use. Andrew explained how these communicated benefits affected his thoughts on the system:

> "For a start, it didn't hold my attention. It wasn't until the game told me [during the tutorial] about the standing up and sitting down, and the outcome was exercising those muscles. That made sense. After I knew that it held my attention a lot more. I then thought it was a good concept." – Caroline.

Throughout both his user testing sessions, Andrew regularly repeated comments that suggested his high motivation towards his rehabilitative recovery. While playing the video game, Andrew mentioned that the repetitions of sit-to-stand exercises are "going to be for [him]."

All five participants showed a positive experience towards interacting with the virtual kiwi. Caroline explicitly demonstrated that she had developed personal connection with the kiwi expressed through positively appraising comments directed at the kiwi:

> "[As the kiwi is eating the thrown fruit] Good Boy! . . . . We are making a whole Garden of Eden here." - Caroline.

During the post-gameplay interview, Caroline explained that rehabilitation is about finding the ambition within yourself to sustain motivation to engage in physical activity regularly. In other words, everything in rehabilitation is focused on the patient:

> "Everything in rehab is about you, you know and it is about you having to find the strength inside of yourself to do something for yourself." – Caroline.

She then went on to highlight that interacting with and throwing food to the virtual kiwi took the focus off her for once, as she was helping the kiwi and this relationship to her was important:

"Feeding the Kiwi is outside of yourself, it's like actually you're helping someone else, you know, helping a little bird to eat. So even though it is virtual, that is still something that takes the focus off me and that's important." – Caroline.

This phenomenon was reminiscent of De Schutter and Vanden Abeele (2008) findings that suggested that experiences that are intended to create instances of Meaningful Play for the elderly should conceptually contribute to society or aim to make the world a better place (see Chapter 2: Background, p. 73).

Additionally, Caroline demonstrated the importance of play and its ability to embrace the 'lighter moments':

> "If my daily rehab had something like that that was fun and kind of brought attention to something outside of myself, like I'm feeding this kiwi and I'm playing a game scoring points and I'm getting recognition for it in a sense. That is so valuable. Carers don't know how to bring that element to your life because everyone's in the same place of loss and grief the whole time; there's nothing that comes in that brings this kind of thing, you know, the lighter moment; and for rehab especially." – Caroline.

Andrew, Brenda, Caroline and Edward showed curiosity towards exploring the physical environment and interacting with the real world. Edward inquisitively explored the room looking for various places within the room to throw fruit for the kiwi to chase. Edward expressed positive emotions of delight as he was visually rewarded for his physical engagement through the kiwi's interaction with the physical environment:

> "Can [the kiwi] climb chairs? . . . Wow, he can, that's cool." – Edward.

Debbie had a contrasting opinion on the video game prototype relative to other participants. Debbie illustrated that the game concept and game format did not appeal to her. However, Debbie did explain that she did not enjoy video games in general and she would rather just do the exercises on their own without the facilitating video game. Furthermore, Debbie explained that she does not enjoy technologies that expand beyond her physiological needs:

> "The only technology I want is when I put my power on the light comes on." – Debbie.

However, Debbie did state that she regularly participated in social bingo nights at a local community hall. She explained that despite her dislike for video games, she enjoyed playing bingo because of the game's cognitive benefits:

"I like to do bingo because I tell myself that putting the numbers down fast is good for my brain." – Debbie.

Interestingly, when asked if she played other traditional games that incorporated cognitive challenges, for instance, sudoku or crosswords, she promptly stated that she does not play them as she does not like them. However, Debbie did state that she would play a 'numbers based' rehabilitative video game but would not want to play it by herself in her own home. When asked, Debbie explained that she would not play a bingo-themed rehabilitative video game because she already plays social bingo twice a week at the local community hall.

9.3.3: Progression

Andrew, Brenda, Caroline and Edward thought the system would be beneficial within a home environment. Brenda highlighted the benefit of the system within a rehabilitative context, explaining that the system offered dynamic feedback on their progress which gives players a sense of pride:

"Anything that gives you feedback about your improvement can just give you a sense of achievement - no matter how small your improvement is and that is important." – Brenda.

Similarly, Caroline explained that traditional exercise classes lack the immediate sense of achievement that she needs to stay motivated. Furthermore, she stated that the system could enhance the rehabilitative experience by giving players an immediate feeling of achievement through its explicit interactivity and instant feedback:

"The exercise classes are dreadfully boring as you can't see the immediate effect of what you are doing, even though they are so challenging. Something like this where you can actually sit by your bed and do it on your own and feel a sense of achievement as your success is almost immediate. . . . I could see there being a lot of opportunity in rehab for something like this where your success is almost immediate." – Caroline.

Caroline demonstrated her ability to set, measure and achieve goals facilitated by the video game prototype's point-based rewards system.

> "220, oh perfect. 240 brilliant! I love this. I want to get 300 points. . . . 300 woohoo! Oh my goodness, what an improvement, this is fantastic. . . . I will do sit-to-stand three times a day, four times a week." – Caroline.

Caroline praised the gradually increasing difficulty of the positioned target circles. She explained that it encouraged her to do movements that she would not regularly do but knew would be of benefit to her recovery (In this instance, the target circle was positioned in zone 4 of the target zones – see figure 7.6, p. 82):

> "You know what struck me was that one of the last circle that was like right here [points to the floor on her right], I kind of had to move like this [rotates her upper body to the right as she keeps her feet on the floor], which is not a movement I often do, so I quite like being able to do that." – Caroline.

Caroline explained that while playing the video game she was motivated to perform the challenging movement as she wanted to overcome the game's challenges to get the additional points:

> "In rehab right at the very beginning that was one of the things that we had to do, to try and shift out of our midriff and it is so hard to do, because I couldn't even find my midriff area; but with this I automatically did the exercise because the circle was here [on her right side] and it was the only way I was going to get to it. I wasn't going to turn around in my chair." – Caroline.

CHAPTER 9

Discussion

Findings from the user testing sessions suggested that the developed augmented reality video game, NZ Fauna AR, could facilitate sit-to-stand exercises in an unsupervised environment. Facilitating prescribed rehabilitation exercises through the medium of a video game allows patients to receive immediate, dynamic feedback on their progress - stimulating emotions of pride and delight in players as they see the immediate outcomes of their engagement.

Participants could independently interact with the final prototype. However, the concluding testing sessions identified that some players might have difficulties understanding the game's short-term goals due to a lack of clear, appropriate feedback. This usability issue could make it difficult for some players to progress through gameplay intuitively. Interestingly, Caroline had no difficulties understanding the short-term goals enabling her to progress through gameplay proficiently.

68% of participants' comments during the final testing session were positive, with 86% of these comments being highly positive (see figure 9.17), suggesting that the broad demographics' attitude towards the rehabilitation game prototype were highly positive. Participant questions that identified indecipherable elements of the tested prototypes were reduced by 7% in the concluding testing session, representing 1% of the overall comments in this testing session. In tandem with the positive results from the SUS questionnaire (see figure 9.19), this suggests that the developed system was perceived as being easy to use.

10.1: Evaluation Through Criteria

This section discusses the researcher's evaluation of the final prototype's ability to facilitate the three themes of the success criteria: Designing Stroke-Survivor-Friendly Systems, Meaningful Play, and Progression.

10.1.1: Designing Stroke-Survivor-Friendly Systems

Designing Stroke-Survivor-Friendly Systems represents the system's ability to accommodate a broad range of physical and cognitive abilities. It aims to provide an experience that is easy for players to understand and coherently learn – enabling the system to be independently used by stroke-survivors. Designing Stroke-Survivor-Friendly Systems was thought to be the most significant theme as the other two themes, Meaningful Play and Progression are dependent on the system's ability to be independently used by players. The following analyses the final prototype's ability to be Stroke-Survivor-Friendly by evaluating the system's design against the success criteria of this theme:

- The design should be easy to use.
- The design should be safe to use.
- The design should be easy to learn.
- The design should provide a familiar experience.
- The design should promote physical activity.

Ease of Learning

Players found that the tutorial was sufficient in teaching the core mechanics of the video game. Players praised the purposeful instructions that allowed them to perform the interactions without any negative consequences. NZ Fauna AR's tutorial elegantly introduced players to the game's core mechanics through purposeful interactive tutorials that each focused on one of the core mechanics that were essential towards reaching competence in interacting with the system. These tutorials were objective-based - where players got to test the mechanics without any negative consequences and were rewarded for their engagement. This enabled players to familiarise themselves with the system and understand the rules and constraints of the game world before being faced with the game's gradually developing challenges. The developed system aimed to minimise digital touch screen interactions and instead focused on natural interactions that promoted physical engagement.

Ease of Use

The logical, clear mapping of the player's interactions to the game's corresponding effect formed an intuitive interaction model that built off one of the most frequently performed physical tasks, standing up from a seated position (Pollock, Gray, Culham, Durward, & Langhorne, 2014, p. 5). Physiotherapists illustrated that "anyone could use the [video game] for sit-to-stand exercises" (Neurological Physiotherapist, personal communication, January 31, 2017), indicating that incorporating this exercise could accommodate a broad range of physical capabilities. When players stood up from a seated position, a virtual blueberry was thrown in the game world - mimicking the motion of the player as they moved to a standing position. When players sat down, they picked up a virtual berry from an augmented bucket that was resting on the floor next to the player's seat. Initial tests with stroke survivors suggested that the logical mapping between the player's interactions and the game's corresponding actions resulted in greater ease of use. This finding is supportive of one of Lidwell et al.'s, (2003) design principles, Mapping, which states that "good mapping between controls and their effects results in greater ease of use." (p. 128).

Familiarity

The virtual environment aimed to provide a familiar experience by reflecting the aesthetic of New Zealand native forests. Although the design aesthetic of the environment was not acknowledged repeatedly by participants, no negative comments were received about the aesthetic of the virtual environment, indicating that the environment design did not embody any cognitive pressures in its representation. The feelings elicited by the environment were briefly express by one participant as she described the environment as a 'Garden of Eden'. Although the environment aesthetic was primarily structured by the game's narrative (NZ Fauna), the environment additionally aimed to reflect an environment that players would be familiar with – New Zealand native forest.

Ability To Promote Physical Activity

NZ Fauna AR demonstrates its ability to promote physical activity through empowering players to freely interact with the video game entities beyond the screen and utilising the player's physical environment to define the play space within which the virtual world exists. One participant demonstrated that she was immersed in the play experience as she commented on how she had forgotten that she was engaging in a rehabilitative activity while playing the video game: "It actually felt like I was playing a game because I was. I wasn't thinking about how it was rehab." This finding is supportive of Huizinga's (1980) concept of play where he describes play as a make-believe space, known as the magic circle, that acts as an escape from ordinary life or real world problems (p.9-10; also see Chapter 2: Background, p. 20). In this case, the player is immersed in the game, forgetting that she is engaging in a rehabilitative activity that is an activity of ordinary life. The following section describes how the developed prototype facilitates elements of meaningful play

10.1.2: Meaningful Play

Meaningful Play emerges when the successfully communicated benefits of the system are connected to the personal goals that the player has brought to the system. During the game's tutorial, players are being introduced to the system. They are gathering a first impression of the system and deciding whether or not they will continue to develop a connection with the system or device – this concept of a gradual developing relationship is described as the process of engagement (Bright, Kayes, Worrall, & McPherson, 2015). The following analyses the final prototype's ability to create instances of Meaningful Play by evaluating its design against the success criteria of this theme:

- The design should clearly communicate the system's benefits.
- The design should support personal growth.
- The design should conceptually contribute to a greater cause.
- The design should support social interactions.
- The video game should support autonomous behaviour.

Communication of Benefits

NZ Fauna AR communicated its rehabilitative benefits through the second phase of the tutorial which explains how the sit-to-stand exercises facilitated in the game help maintain and strengthen leg and torso muscles (see figure 9.17]). Explaining how the facilitated exercises could benefit patients' rehabilitative recovery earlier within the onboarding process helped develop a trusting connection between the player and the system (Gilbert, 2016, p. 215). Participants involved in the user testing sessions emphasised the importance of the system benefits connecting to their personal rehabilitative goals. Interestingly, Andrew explained that "the more benefit [they] see the device to [their] recovery, the more [they're] going to use it" - this illustrates the importance of perceived usefulness of the process of rehabilitation technology acceptance by stroke survivors. This finding is supportive of preceding literature which discusses patient technology acceptance (Karsh, 2006, p. 991; Wang & Sun, 2016, p. 61).

Furthermore, participants demonstrated the successful communication of NZ Fauna AR rehabilitative benefits through their articulated thoughts and through the quantitative post-gameplay system usability questionnaire – where the final prototype was rated 7.5/10 for its usefulness (see figure 9.20). Andrew explained that once he had learnt the benefits of the system, he found the activity more purposeful and engaging. Andrew's comments in tandem with the results from the system usability questionnaire demonstrate the system's ability to facilitate elements of meaningful play.

NZ Fauna AR additionally aimed to create instances of meaningful play by embracing the three themes that were emphasised through elderly passions: personal growth, contribution, and social interaction (De Schutter & Vanden Abeele, 2008, p. 3).

Self-Cultivation

Personal growth and contribution were the two most explored themes within the final prototype. NZ Fauna AR's narrative embodies both personal growth and contribution to a greater cause. As players progress through gameplay, they are educated about New Zealand's native wildlife. The initial chapter of the game focuses on a Kiwi called Fizzy. As the game commences, players are introduced to Fizzy while a text overlay which gives context to the endangered bird through explaining species-specific information. This storyline shapes the game play experience by explaining the bird's vulnerability - adding purpose to the game's following objectives which are to help the kiwi by feeding him berries.

Contribution

Conceptually, feeding the birds berries aims to fulfil the theme of contribution. During the initial testing session, Caroline passionately illustrated that taking the focus off her is important and that her being the caregiver (instead of the care receiver) and coherently helping someone else (the kiwi) was delightful and made the experience meaningful to her. As discovered during the initial user testing session, players visually seeing the kiwi chase and eat the berries was an important feedback element that was necessary for players to feel that they were helping others. This feedback element acted as a form of achievement-gratification eliciting feelings of pride and achievement.

Social Interaction

Social Interaction was the least explored of the three themes that had been suggested to create instances of meaningful play in elderly life. Due to network and scope limitations, multiplayer functionality was not explored. However, the researcher hypothesised that the broad narrative that structures the gameplay and the technology capabilities of Tango would allow for multiplayer functionality to be implemented without any negative disturbance to a player's experience. Debbie emphasised her need for social interaction in play experiences. She explained that she enjoyed playing social bingo for its cognitive benefit, but did not enjoy other number-based games, for instance sudoku and crosswords, that are primarily single player games. This suggests that Debbie engages in bingo not just for its cognitive benefits but also for its social benefits.

10.1.3: Progression

Progression represents NZ Fauna AR's ability to craft an experience in such a way that the player feels a gradual sense of progress towards achieving their rehabilitative goals. NZ Fauna AR challenges players with immersive physics-based gameplay that is attuned to the player's physical environment. The following analyses the final prototype's ability to facilitate Progression by evaluating its design against the success criteria of this theme:

- The design should provide an optimal challenge.
- The design should provide players with the ability to set, measure and achieve clear goals.
- The design should provide dynamic, clear, positive feedback.
- The design should provide a sense of achievement.

Clear, Dynamic Feedback

Players receive positive engagement-congruent feedback as they finish a repetition of the facilitated sit-to-stand exercises. This form of achievement gratification acknowledges the player's physical participation in the rehabilitative activity through audio and visual feedback that highlighted that the player is gaining experience points for throwing berries to the kiwi through doing exercise repetitions. These exercise points contribute towards the player's overall level score. This form of feedback was implemented following the second testing session so remained untested. However, the researcher has hypothesised that this engagement-congruent feedback would increase motivation as behaviours observed in the second testing sessions suggested that the game lacked achievement-feedback that responded to the player's physical engagement.

The game's ability to communicate its short-term gameplay goals (which enable progression) is dependent on the game's ability to provide clear feedback to the player. Visual cues are used in NZ Fauna AR to communicate to the player where they are within the game and what they need to do next to progress through gameplay. The effectiveness of the implemented visual cues is ambiguous as both stroke patients who participated in the final testing session expressed divergent experiences while progressing through the game's first level (see figure 9.17). Caroline reached a level of proficiently of which she could intuitively interact with the system without having to think about the controls of the system. This allowed her to develop a sense of meaning to her actions and begin setting her own goals (Gilbert, 2016, p. 85).

In contrast, Andrew felt that the game lacked the feedback necessary for him to intuitively progress through gameplay. He explained that he felt that the goals of the game were not clear enough for him to progress without help from the facilitating physiotherapist.

Due to the two extremes in overall experiences related to the quality of feedback, it is suggested that the current prototype should undergo further testing with a larger sample size to gather a more reliable response to the effectiveness of the prototype's visual cues and short-term goals.

Optimal Challenge

Players obtain additional points by throwing the berries into the target circles that are positioned on planar surfaces in the player's physical environment. Players need to throw berries into these targets to gain a higher star-rating for the finished level – which reflects the player's performance. At the end of each level, players receive a post-gameplay performance report that allows them to reflect on their performance – creating a sense of achievement and pride in players. Players were given a one to three-star rating based on the number of points they had earned.

Meaningful Goals

Fundamentally, the points-based reward system enables players to set, measure and achieve personal goals. This was demonstrated through Caroline's comments, during the second testing session, as she set her goal of reaching 300 points; was able measured her progress through performance feedback and expressed her feelings of pride and delight as she reached her goal of 300:

"220, oh perfect. 240 brilliant! I love this. I want to get 300 points. . . . 300 woohoo! Oh my goodness, what an improvement, this is fantastic. . . . I will do sit-to-stand three times a day, four times a week."

Caroline comment that she would "do sit-to-stand three times a day, four times a week [if she was playing the game]", demonstrates the game's ability to facilitate meaningful goals as she has brought an external non-game goal into her play experience. This highlights the system's ability to build a connection with the players personal goals that they have brought to the system. Although the points system seems to work as a meaningful goal, further research could investigate how to relate the game world goals to their rehabilitation, without making the rehabilitation aspect too present during the gameplay experience.

Sense of Achievement

Caroline felt that the gradually increasing challenges matched her developing skill level. She demonstrated that the positions of target circles in the latter part of the game challenged her physically as they required her to perform movements that she would not normally do in day to day life. She explained that the video game motivated her towards performing these difficult movements as she wanted to overcome the game's challenges to be rewarded with points. This suggests that the game's reward system provides enough feedback for players to feel a sense of achievement – encouraging them to overcome the game's physically engaging challenges.

10.2: Research Limitations

As with previous, similar studies (Flores et al., 2008, p. 383; Nap, Kort, & IJsselsteijn, 2009, p. 260), the findings from the research process are subjective, so they cannot be applied to the broader audience of stroke survivors in general or the elderly. The small sample size of participants involved with the testing of the developed prototypes may not have been a representation of the broad demographic of stroke patients. While the findings are not generalisable, they offer a situational representativeness relevant to the specific context and participants that were involved in the project. Further research should involve more participants to increase the validity of the studies.

All the participants that were involved in the user testing sessions exhibited an elevated level of self-motivation as they chose to give up their time and participate in the testing sessions. These participants had already taken the first step to recovery which others may not have taken.

10.3: Further Work

The following discusses what could be explored further within the current prototype, NZ Fauna AR:

- **Improve feedback's ability to communicate clear goals.** Improving the quality and appropriateness of the in-game feedback would help some participants that had difficulties understanding the games short-term goals.
- **Testing of prototype in a home setting.** As the developed prototypes were both tested within a clini-cal environment, the novelty of the virtual world being structured by the player's personal environ-ment remained untested. Testing the prototype within participants' homes may reveal the benefits of the environment adapting to the physical space in which it is being played.
- **Player Analytics.** Sustained engagement could be improved by implementing meaningful player ana-lytics – this would enable players to set, measure and achieve long-term rehabilitation goals.
- **Incorporation of other exercises.** The video game has the potential to facilitate other rehabilitation exercises through location-based gameplay. For instance, players could progress to stepping exercises that are played within the hallway of the player's house once they have become too skilful to be limited to sit-to-stand exercises. This concept is discussed in more detail in the section below.
- **Implementation of multiplayer options.**
- **Testing of play area declaration process.** Due to time constraints, the process of defining the play boundaries was not tested by par-ticipants. This play area declaration process was only undertaken once per play space. Therefore, the researcher decided not to focus on this aspect of the system as the researcher's focus was primarily on the core experience. Additionally, this initial set up process exhibited several technically complex usability problems that were apparent due to the innovative nature of the technology that was being used to enable the experience.

Figure 10.1 - Future Work: Interface Development – End of Level Analytics. This provides a comprehensive picture of the player's progress within the level. This style of analytics could also be used to display long-term player performance progress. Showing the speed of the throws could foster meaningful goals through encouraging players to set goals related to the speed of their throws (sit-to-stand speed).

10.3.1: NZ Fauna Video Game Series

NZ Fauna AR's concept fundamentally aims to educate players about native New Zealand fauna. Through physically interacting with digital entities, players learn about the animal's characteristics, behaviours and physical environment. This thesis focused on what would come to be the first chapter of the video game franchise, where players interacted with a kiwi called Fizzy. The broad theme that structures the player's experience (New Zealand native animals) enables the potential for the game's narrative to be extended beyond Fizzy the kiwi, and feature other New Zealand fauna (such as, yellow-eyed penguins or tuataras) while still maintaining the theme of New Zealand fauna that brings purpose to the gameplay experience.

Extending the game's narrative to accommodate subsequent chapters would help foster a broader scale of Progression. This would enable sustained, long-term engagement as the video game prototype would facilitate prescribed exercises that are more physically difficult than sit-to-stand. Furthermore, during the preliminary testing session, a neurological physiotherapist highlighted the video game's progressive potential in a rehabilitative context: "The game has the potential to add more layers, which is great" (Neurological Physiotherapist, personal communication, January 31, 2017).

The following provides a summary of the proposed game chapters and the exercises that would be facilitated in each game chapter allowing for a gradual increasing in physical challenge:

1. **Fizzy the Kiwi.** This game chapter would focus on stationary rehabilitative exercises, for instance sit-to-stand exercises. This video game chapter was developed within this thesis.
2. **Biggie the Tuatara.** This chapter would focus on stepping exercises, for instance stepping over ob-stacles.
3. **Penny the Yellow-Eyed Penguin.** This chapter would focus on walking exercises.

10.4: Final Evaluation

"How can the design of a mixed reality exergame facilitate engagement in independent lower-limb stroke rehabilitation for older adults?"

For a patient to be engaged in their rehabilitation, they must express a deliberate effort and commitment towards their recovery goals demonstrated through active, energetic participation in their rehabilitative activities (Lequerica & Kortte, 2000, as cited in MacDonald, Kayes, & Bright, 2013, p. 112). The criteria used to evaluate NZ Fauna AR were established through the systematic review of preceding knowledge regarding engagement, games and rehabilitation. The results from the testing sessions demonstration that NZ Fauna AR meets these criteria with varying degrees of success.

Designing Stroke-Survivor-Friendly Systems was the criteria theme that NZ Fauna AR fulfilled the most as the video game's interaction model was built off physical movement – promoting physical activity in the nature of interacting with the game. Meaningful Play was partially fulfilled as the game communicated its rehabilitative benefits clearly and facilitated personal growth as well as contribution. The game's ability to enable meaningful play may have been restricted by its lack of social interaction elements. Future research should investigate the implementation of multiplayer options to improve the game's ability to facilitate instances of meaningful play. Progression was the least fulfilled criteria theme as the game prototype lacked the feedback necessary for participants to understand the video game's short-term goals – impairing some player's ability to progress through the video game independently.

Upon reflection of the results of the user testing with stroke patients, it was realised that a key determinant of the success of the system's ability to meet all three themes of the success criteria was the implementation of clear, dynamic, and appropriate feedback. Facilitating prescribed rehabilitation exercises through the medium of a video game allows patients to receive immediate, dynamic feedback on their progress – stimulating emotions of pride and delight within players as they see the immediate outcomes of their engagement. The use of appropriate clear feedback helped players understand the core mechanics in competently interacting with the system while helping them learn the key benefits of the systems towards their personal recovery. Additionally, clear feedback helped players recall the short-term goals that they must achieve – allowing them to progress through gameplay, giving them a sense of achievement.

CHAPTER 11

Conclusion

This thesis sought to explore how the design of a video game can facilitate engagement in independent lower-limb rehabilitation for older adults. The monotonous nature of traditional physiotherapy interventions and other personal, environmental and physical elements make it difficult for stroke survivors to remain motivated in their rehabilitative recovery. Digital gamified systems have shown positive results towards addressing these barriers of engagement in rehabilitation (Burke et al., 2009; Flores et al., 2008; Popovic, Kostic, Rodic, & Konstantinovic, 2014). However, there is a lack of portable systems that are designed to be used in a home setting. At the same time, emerging augmented reality mobile technologies have shown potential towards increasing engagement in physical activity while offering a personalised experience.

This research aimed to make rehabilitative exercises more engaging by exploring the incorporation of an exergame into the rehabilitative process. The developed system converted prescribed exercises into active gameplay using commercially available augmented reality mobile technology. Such a system introduced an engaging, interactive alternative to existing mundane physiotherapy exercises. The investigation of emerging technologies revealed an opportunity to utilise Google Tango's augmented reality capabilities to develop an intuitive interaction model that facilitated sit-to-stand exercises to overcome the game's purposeful physical challenges. The appropriate intuitive mapping of the player's physical interactions (sit-to-stand) to the video games corresponding actions enabled players to interact with the system proficiently.

In this thesis, the researcher tried to shift the focus from clinical-based rehabilitative systems, that required the help of researchers or clinicians to be operated by stroke survivors, to home-based rehabilitative systems that empowered patients to self-manage their conditions. This has led to the development of NZ Fauna AR, an augmented reality video game that facilitated engagement in independent lower-limb rehabilitation. NZ Fauna AR has contributed towards the greater field of rehabilitation systems research by exploring how emerging augmented reality technologies could enhance stroke survivors rehabilitative experience by better satisfying their holistic needs.

Patient's holistic needs were represented by design criteria that informed the design and development of the rehabilitative system. The proposed design criteria were derived from background research on games, engagement and rehabilitation. The fundamental themes of this criteria were designing stroke-survivor-friendly systems, meaningful play, and progression. The researcher proposed that facilitating these themes in a rehabilitation exergame would help engage stroke survivors in their rehabilitative recovery.

The research process was guided by a human-centered design (HCD) framework (Norman, 2013, p. 8). The involvement of healthcare professionals and stroke survivors throughout each stage of the research process helped further refine the development of the rehabilitative video game system resulting in a design that is usable and understandable.

User testing with stroke patients identified that players could not experience progression or meaningful play if they could not independently operate the developed system. This highlighted the dependency of meaningful play and progression on the system's ability to accommodate stroke patients' broad range of physical and cognitive impairments. Coherently, this accommodation of skills and preferences was embodied within the first theme, designing stroke-friendly-systems, determining this theme to being the most vital element in the success criteria.

The natural progression for the video game would be to improve its ability to communicate the short-term goals elicited through clear, dynamic feedback. The concluding testing session identified that some participants felt that the visual feedback cues within the game (see Chapter 7: Prototype Development, p. 96) were too abstract in their ability to communicate the game's short-term goals. This made it difficult for some participants to progress through gameplay proficiently. However, other participants felt that the visual cues were sufficient at allowing them to progress through gameplay intuitively. Because of these two divergent experiences expressed within a small sample size of participants, it is suggested that further research should involve more participants to gather insight into the quality of the current prototype's feedback elements.

NZ Fauna AR was responded to very positively by participants who expressed emotions of enjoyment and enthusiasm while interacting with the developed prototypes. While the results are not generalisable, they do provide insight into the acceptance and benefit that an augmented reality rehabilitation video game could provide within the daily lives of people recovering from a stroke.

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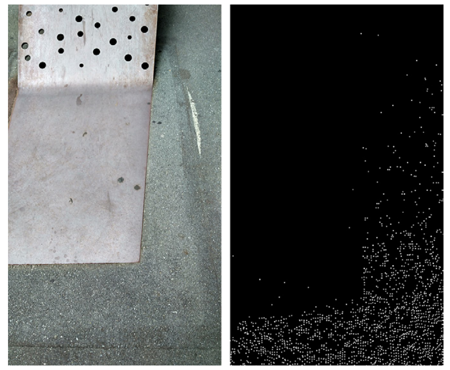
Figure List

Appendix A: Depth Perception Testing

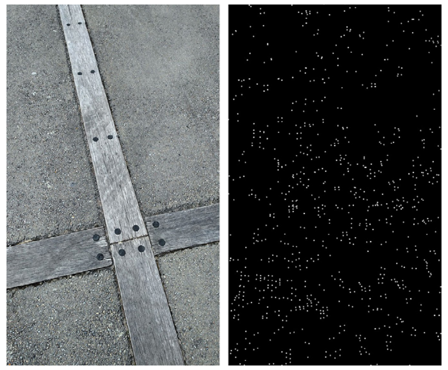
(a)

(b)

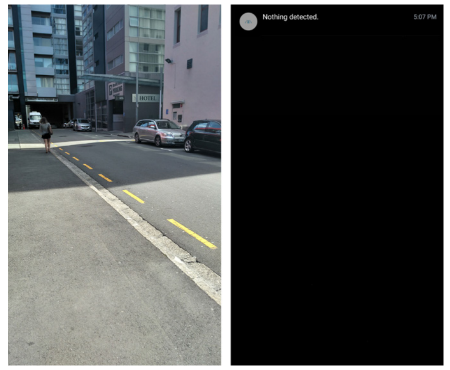


(c)

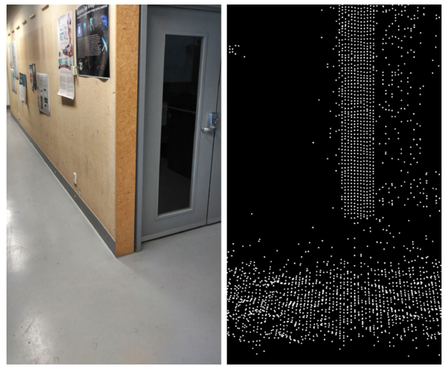
(d)



(e)

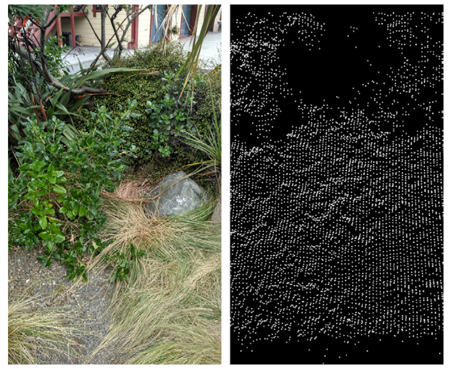


(f)



(g)

(h)



(i)

Appendix B: Photographs taken of native forest ecosystems at the Wellington Botanical Gardens

Appendix C: Specialised Tools and Software

The following section discusses the specialised tools and software that were used to develop to video game prototype.

Adobe Photoshop

Photoshop was used for the development of foliage textures. Textures of leaves, stems, and flowers were scanned into and corrected in Photoshop to use as foliage textures within the developed prototype.

Larger sized textures, for instance tree bark, were photographed and turned into flat textures in Photoshop to use alongside 3D assets within the developed prototype.

Autodesk Maya

Maya was primarily used for 3D Modelling of foliage, rocks, plants, trees and props such as the help-book UI, clipboard UI and the fruit bucket. Keyframe animation techniques were also used to animate interactive props such as the clipboard UI and help-book UI.

Maya was used for developing the main character asset, Fizzy the Kiwi. This development process included 3D modelling, weight painting, character rigging and keyframe animation.

Unity3D Game Engine

Unity3D was the chosen game engine because of its all-purpose engine flexibility, reliability and advanced graphics capabilities. Google Tango's software development kit also supports Unity3D integration. Unity3D's effort-saving Asset Library and strong developer community was crucial towards the development of the video game prototype. Unity3D being a cross-platform game engine provides the opportunity for the developed prototype to be extended to other platforms such as Microsoft's HoloLens and Apples ARKit.

C Sharp Programming Language

With the researcher having prior experience in developing with the C Sharp Language, and because of the strong developer community associated with it, C Sharp was chosen as the software language to be used in Unity3D to develop the game prototype.

Adobe After Effects

After Effects was used to create sprite sheets for 2D Animations such as the help screen animations.

Adobe Illustrator

Illustrator was used to design and develop the user interfaces within the game.

Appendix D: Ethics/Forms

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Participant Information Sheet

Study title:	**A Game for Physiotherapeutic Rehabilitation for Stroke Survivors**		
Locality:	**Wellington**	Ethics committee ref.:	**16/CEN/15**
Lead investigator:	**Brian Robinson**	Contact phone number:	**(04) 463 6155**

You are invited to take part in a study a digital game system on the recovery process from stroke. Whether or not you take part is your choice. If you don't want to take part, you don't have to give a reason, and it won't affect the care you receive. If you do want to take part now, but change your mind later, you can pull out of the study at any time.

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 the 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 6 pages long, including the Consent Form. Please make sure you have read and understood all the pages.

WHAT IS THE PURPOSE OF THE STUDY?

This study is to develop computer controllers and computer games that can be used by people who are recovering from stroke. This is for rehabilitation that they can carry out by themselves at home.
We are wanting to know how you find using the computer, the controller and the game. Our aim is that these will be easy to use and understand as well as challenging and rewarding for you. It is also important that the movements made when using the games will help with stroke rehabilitation.
These devices and games are 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. Brian Robinson (463 6155)
This research has been approved by the Health and Disability Ethics Committee.

WHAT WILL MY PARTICIPATION IN THE STUDY INVOLVE?

We asked you to take part in this research because you have had a stroke that affects your walking but you can walk without someone, beside you, helping you.
The research study will take place at AUT Akoranga North Shore, Physiotherapy Department.
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 computer, a computer controller and a game
You will be asked to use the computer and the control device to play a computer game.
You can play this game for as long as you like and can tell us when you want to stop.
We will take a video and photographs of you using this computer controller and 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. 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.
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. We will do this by blurring parts of the images and videos.
We will ask you for your thoughts on using the computer control and game. 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 using the game or device. We realize that this can be tiring for you so we ask you can tell that 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.

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 the day, every day.
This study is to support people who have had a stroke to provide stroke rehabilitation therapy in their home. This can be by themselves or with the help of carer support or family members.
We are wanting to find out whether this device or game may be useful in stroke rehabilitation. This research is finding out whether you can use it and what you think of it.
This does not replace any other therapy you may be receiving. We are not using the device and game as part of your therapy at this stage. We want to find out whether this might be usable as a therapeutic device.
While you are using the computer and playing the game you will be sitting in a chair. We will want you to stay sitting. We may also ask you to carefully walk while using one of our devices. We will make sure there are no hazards around that may make you trip.

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 travel to you.

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.

WHAT ARE MY RIGHTS?

You are volunteering to take part. You do not have to take part in this study and you can withdraw at anytime.
We can show you the video recording and photographs of you we have collected. We can also give you a copy of what we have recorded you saying to us about using the computer device and game.
It is unlikely that participating will affect your health but if it does, we will contact you immediately.
We will not identify you in any of the students work or presentations of the work.

WHAT HAPPENS AFTER THE STUDY OR IF I CHANGE MY MIND?

After you have taken part and change your mind about being involved, please contact the researcher (the design student) or the lead investigators (Brian Robinson, in the first instance, or Edgar Rodriguez) 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.
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 books or journals.

WHO DO I CONTACT FOR MORE INFORMATION OR IF I HAVE CONCERNS?

If you have any questions, concerns or complaints about the study at any stage, you can contact:

Dr Brian Robinson, Senior Lecturer, Graduate School of Nursing, Midwifery & Health, Victoria University of Wellington.
Work phone: (04) 934 9321
brian.robinson@vuw.ac.nz

24 Hour contact numbers:
Dr Robinson: 029 776 9321
If you cannot contact Dr Robinson, please contact
Associate Professor Edgar Rodriguez: 027 563 6544

If you have other questions, concerns or complaints and wish to contact a Māori support person, you can contact:
Katherine Reweti- Russell, Research Advisory Group – Māori, CCDHB
Work phone: (04) 806 2524

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.

You can also contact the health and disability ethics committee (HDEC) that approved this study on:

Phone: 0800 4 ETHICS
Email: hdecs@moh.govt.nz

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Consent Form

If you need an INTERPRETER, please tell us.
If you are unable to provide interpreters for the study, please clearly state this in the Participant Information Sheet

Please tick to indicate you consent to the following

I have read, or have had read to me in my first language, and I understand the Participant Information Sheet.	Yes ☐	
I have been given sufficient time to consider whether or not to participate in this study.	Yes ☐	
I have had the opportunity to use a legal representative, whanau/ family support or a friend to help me ask questions and understand the study.	Yes ☐	
I am satisfied with the answers I have been given regarding the study and I have a copy of this consent form and information sheet.	Yes ☐	
I understand that taking part in this study is voluntary (my choice) and that I may withdraw from the study at any time without this affecting my medical care.	Yes ☐	
I consent to the research staff collecting and processing my information, including information about my health.	Yes ☐	
I understand that my participation in this study is confidential and that no material, which could identify me personally, will be used in any reports on this study.	Yes ☐	
I consent to the research staff taking pictures or video recordings of me and I understand that if used in presentations, these will be altered so that I or my involvement cannot be identified.	Yes ☐	
I understand the compensation provisions in case of injury during the study.	Yes ☐	
I know who to contact if I have any questions about the study in general.	Yes ☐	
I understand my responsibilities as a study participant.	Yes ☐	
I wish to receive a summary of the results from the study.	Yes ☐	No ☐

Declaration by participant:
I hereby consent to take part in this study.

Participant's name:

Signature: Date:

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.

Researcher's name: RuiFeng Yeo, Regan Petrie, Amy Buell

Signature: Date:

Health and Disability Ethics Committees

Health and Disability Ethics Committees
Ministry of Health
Freyberg Building
20 Aitken Street
PO Box 5013
Wellington
6011

0800 4 ETHICS
hdecs@moh.govt.nz

21 April 2016

Dr Brian Robinson
Graduate School of Nursing, Midwifery & Health
PO Box 7625
Newtown 6242

Dear Dr Robinson

Re:	**Ethics ref:**	**16/CEN/5**
	Study title:	Developing Interactive Devices and Games for Physical Therapies in Stroke Recovery

I am pleased to advise that this application has been ***approved*** by the Central Health and Disability Ethics Committee. This decision was made through the HDEC-Full Review pathway.

Conditions of HDEC approval

HDEC approval for this study is subject to the following conditions being met prior to the commencement of the study in New Zealand. It is your responsibility, and that of the study's sponsor, to ensure that these conditions are met. No further review by the Central Health and Disability Ethics Committee is required.

Standard conditions:

1. Before the study commences at *any* locality in New Zealand, all relevant regulatory approvals must be obtained.

2. Before the study commences at *any* locality in New Zealand, it must be registered in a clinical trials registry. This should be a WHO-approved (such as the Australia New Zealand Clinical Trials Registry, www.anzctr.org.au). However https://clinicaltrials.gov/ is acceptable provided registration occurs prior to the study commencing at *any* locality in New Zealand.

3. Before the study commences at *a given* locality in New Zealand, it must be authorised by that locality in Online Forms. Locality authorisation confirms that the locality is suitable for the safe and effective conduct of the study, and that local research governance issues have been addressed.

Non-standard conditions:

- The Participant Information Sheet (PIS) was not tracked, making it difficult to check. Please ensure future submissions are supported with tracked versions of documents.

- The section in the PIS headed, "What are the possible benefits and risks of this study" still does not include benefits and risks to participants therefore this section's title should be changed.

Non-standard conditions must be completed before commencing your study. Non-standard conditions do not need to be submitted to or reviewed by HDEC before commencing your study.

If you would like an acknowledgement of completion of your non-standard conditions letter you may submit a post approval form amendment. Please clearly identify in the amendment that the changes relate to non-standard conditions and ensure that supporting documents (if requested) are tracked/highlighted with changes.

For information on non-standard conditions please see section 128 and 129 of the Standard Operating Procedures at http://ethics.health.govt.nz/home.

After HDEC review

Please refer to the *Standard Operating Procedures for Health and Disability Ethics Committees* (available on www.ethics.health.govt.nz) for HDEC requirements relating to amendments and other post-approval processes.

Your **next progress report** is due by **20 April 2017**.

Participant access to ACC

The Central Health and Disability Ethics Committee is satisfied that your study is not a clinical trial that is to be conducted principally for the benefit of the manufacturer or distributor of the medicine or item being trialled. Participants injured as a result of treatment received as part of your study may therefore be eligible for publicly-funded compensation through the Accident Compensation Corporation (ACC).

Please don't hesitate to contact the HDEC secretariat for further information. We wish you all the best for your study.

Yours sincerely,

Mrs Helen Walker
Chairperson
Central Health and Disability Ethics Committee

Encl: appendix A: documents submitted
appendix B: statement of compliance and list of members

Appendix A
Documents submitted

Document	*Version*	*Date*
Covering Letter: New Covering Letter indicating to responses and changes made	1	05 April 2016
CV for CI: CI CV	1	11 December 2015
Evidence of scientific review: Peer Review	1	11 December 2015
Protocol: Updated Protocol for Research	2	04 April 2016
Survey/questionnaire: Demographic questions and examples of questions for semi-structured interviews and recruitment information	1	11 December 2015
PIS/CF: Example of Participant Information Sheet and Consent Form	1	05 April 2016
Application		
Response to Request for Further Information		06 April 2016

Appendix B
Statement of compliance and list of members

Statement of compliance

The Central Health and Disability Ethics Committee:

- is constituted in accordance with its Terms of Reference
- operates in accordance with the *Standard Operating Procedures for Health and Disability Ethics Committees*, and with the principles of international good clinical practice (GCP)
- is approved by the Health Research Council of New Zealand's Ethics Committee for the purposes of section 25(1)(c) of the Health Research Council Act 1990
- is registered (number 00008712) with the US Department of Health and Human Services' Office for Human Research Protection (OHRP).

List of members

Name	*Category*	*Appointed*	*Term Expires*
Mrs Helen Walker	Lay (consumer/community perspectives)	01/07/2015	01/07/2018
Dr Angela Ballantyne	Lay (ethical/moral reasoning)	30/07/2015	30/07/2018
Dr Melissa Cragg	Non-lay (observational studies)	30/07/2015	30/07/2018
Dr Peter Gallagher	Non-lay (health/disability service provision)	30/07/2015	30/07/2018
Mrs Sandy Gill	Lay (consumer/community perspectives)	30/07/2015	30/07/2018
Dr Patries Herst	Non-lay (intervention studies)	27/10/2015	27/10/2018
Dr Dean Quinn	Non-lay (intervention studies)	27/10/2015	27/10/2018
Dr Cordelia Thomas	Lay (ethical/moral reasoning)	19/05/2014	19/05/2017

Unless members resign, vacate or are removed from their office, every member of HDEC shall continue in office until their successor comes into office (HDEC Terms of Reference)

http://www.ethics.health.govt.nz

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Designing a System for 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 Regan Petrie and I am a Masters student in the School of Design at Victoria University of Wellington. This research project is work towards my thesis.

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 I will interview you in your office, a meeting room in the School of Design's campus or in a public place, such as a café. I 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. 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. I will not name you in any reports, and I will not include any information that would identify you. Only my supervisors and I will read the notes or transcript of the interview. The interview transcripts, summaries and any recordings will be kept securely and destroyed *3* years after the research ends.

What will the project produce?

The information from my research will be used in my Masters thesis. You will not be identified in my report. I may also use the results of my research for conference presentations, and academic reports. I 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:**
Name: Regan Petrie	Name: Dr Edgar Rodriguez
University email address:	Role: Programme Director Industrial Design
Petrierega@myvuw.ac.nz	School: School of Design
	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: Associate Professor Susan Corbett. Email susan.corbett@vuw.ac.nz or telephone +64-4-463 5480.

TE WHARE WĀNANGA O TE ŪPOKO O TE IKA A MĀUI
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Designing a System for Stroke Rehabilitation

CONSENT TO INTERVIEW

Researcher: *Regan Petrie, 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 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 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: ______________________