GROOVE STUDIO

EVALUATING THE COMPARATIVE DIFFERENCES OF COMPUTER GENERATED
GRAPHIC STYLES IN VIRTUAL REHABILITATION ENVIROMENTS

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Stroke Rehabilitation:

*Can variable computer generated imagery, create an immersive rehabilitative
experience that allows a user to overcome the effects of Post-Stroke Motor
Rehabilitation?*

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2016

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A thesis submitted for a degree of Master of Design
Victoria University of Wellington

Dedication

This thesis is dedicated to my parents, Bridget and Dan-Ellis Kauraka whom was always loving and supportive in my academic and life achievements.

Thank you for believing in me.

Acknowledgements

I would first like to thank my supervisors Kah Chan and Dr. Edgar Rodriguez Ramirez for their guidance and wisdom. I would like to thank my user participant and Dr. Brian Robinson for their hard work in ensuring this research could be undertaken. I would like to thank Nick Wellwoord for his dedication to producing our shared application. Finally I would like to thank my family and friends for their constant love and support, I could not have done this without you.

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ABSTRACT

Upper limb rehabilitation after a stroke is vital when bringing a range of motion and strength back to a patient. Treatment for upper limb rehabilitation has come in many diverse methods over the years including the use of modern technology through the use of mirror visual feedback (MVF) and action observation therapy; this thesis digital applications for stroke rehabilitation and how varying visual styles can impact the patients experience in the upper limb rehabilitation process.

Within the gaming medium the visual style in a game is an aspect of immersion and appeal that is often neglected by the user. The visual style of a game often reflects the tone a game designer has intended to convey while also catering to the target audiences expectations, with realism potentially appealing to a more mature audience while brighter abstract visuals may appeal to a younger demographic. By utilising two different styles of imagery, both realistic and cartoon based visuals, the level of immersion was observed and the user’s reaction to each form of visuals was analysed. The aim of this thesis is to investigate both realistic and stylized visual styles of computer generated imagery, distinguish the advantages and disadvantages for both realism in comparison to cartoon and finally analyse its effectiveness to assist the rehabilitation of upper limb deficiencies. The application being used for this study was made in collaboration with Victoria University Masters student Nicholas Wellwood, providing me the opportunity to focus solely on producing diverse and engaging visual styles to work in unison with a fully developed framework.

CHAPTER 1

Introduction

A stroke is the third largest killer in New Zealand, with close to 2500 people affected every year. Around 10 percent of stroke deaths occur in people under the age of 65. A stroke is a sudden interruption of blood flow to part of the brain, this causes it to stop working with brain cell damage eventually taking place. The consequence of a stroke can be overwhelming and potentially cause long term disability. Within New Zealand alone 9,000 people have a stroke annually with a quarter of all strokes occurring in the working age and potentially even younger. (Stroke Foundation of New Zealand, 2016).

Physical, emotional and cognitive conditions can be heavily effected by stroke and can improve with time and rehabilitation in the post-stroke period. With regards to physical conditions poststroke can include impaired arm function, weakness, numbness and stiffness. This is a common effect of stroke seen in around 70% of stroke cases, and 40% of patients will have a completely non-functioning arm

The restoration of physical, emotional and cognitive function is vital in assisting a person with stroke, allowing them to reach their greatest potential while regaining their independence and quality of life. Through modern improved rehabilitation solutions such as virtual reality; more stroke survivors will be able to live life to their fullest potential. Recently computer gaming has shown promising results and appears to be an effective and interesting way to rehabilitate patients, specifically those with upper limb paresis and spasticity (Saini, Rambli, Sulaiman, Zakaria, & Shukri, 2012). By using computer-based programs that are designed to stimulate real life objects and events, stroke survivors are able to practise everyday activities that they may not be able to practice within the hospital environment context such as driving

Within the gaming medium the visual style in a game is an aspect of immersion and appeal that is often neglected by the user. The visual style of a game often reflects the tone a game designer has intended to convey while also catering to the target audiences expectations, with photorealism potentially appealing to a more mature audience while brighter abstract visuals may appeal to a younger demographic. By utilising two different styles of imagery, both photorealistic and stylized based visuals, the level of immersion was observed and the user's reaction to each form of visuals was analysed.

Video games in recent times have evolved beyond simple play with their potential now being realized in multiple fields, such as architecture and education. As they have evolved and their technology has developed so too have the graphical capabilities. With the pursuit of photorealism the visual fidelity of games has greatly improved over time, however this has not stopped the development of more abstract and stylized visuals. The immersive qualities of these visual styles can be debated and was this thesis' intentions to investigate these qualities when each style is utilized in a medical rehabilitation practise

The aim of this thesis was to investigate both the realistic and non-realistic visual styles of computer-based programs and analyse their effectiveness in assisting the rehabilitation process, primarily of upper limb deficiencies. From these results it was hoped that the program designer would be able to create and develop methods of motivating patients and potentially encouraging patients to spend more time undertaking rehabilitation exercises.

Research Question:

Can variable computer generated imagery, create an immersive rehabilitative experience that allows a user to overcome the effects of Post-Stroke Motor Rehabilitation

Aims:

1) To investigate rehabilitative practices through stroke rehabilitation.

Objectives -

- a) To explore existing augmented rehabilitative practices to determine qualities.
- b) To map collected data Identifying qualities and limitations.

2) To design and experiment with different technologies

Objectives -

- a) To identify and test a variety of virtual reality and sensory technologies.
- b) To conduct a series of iterative design experiments utilising existing technologies.
- c) To test usability, engagement, quality and responsiveness.

3) To investigate the level of immersion

Objectives -

- a) To develop a series of photorealistic and stylized 3D models.
- b) To assess how patients react to level of photorealism/stylized visuals.
- c) To investigate the effect of immersion within the application.

CHAPTER 2

Methodology

Due to post-stroke rehabilitation being a condition where every case is unique; designing rehabilitative applications calls for a User-Centered Design approach. UCD can be used to ensure the design of concepts are based around the patients needs, requirements and their engagement during the rehabilitative process (Frascara, 2002). The early stages of the research process will undergo extensive investigation on common post-stroke rehabilitation processes, with a strong focus on modern technological practices for post-stroke rehabilitation. Data generated from the research will therefore create the foundation for Nicholas and myself to refer to while undergoing the development and preparation of early concepts and prototypes. From this foundation early design prototypes will be available for the user to experiment with, initiating the second phase of the research process: usability testing.

This testing will investigate and constitute the level of realism within the application and distinguish preferences of realistic imagery in comparison to non-realistic imagery whilst assessing how the patient reacts. "Testing participants who are representative of the target audience" will be used "to evaluate the degree to which a product meets specific usability criteria" (Rubin, Chisnell, & Spool, 2011 p.21). As we continue to gather more research and feedback from the user we will continue developing prototypes and refining these based on the data gathered. Through a continual series of examination, research and sampling I will be able to design more appropriately according to the needs of the users. The intended end result will be to develop a custom made design suited for rehabilitating patients experiencing varying post-stroke impairments.

Thesis Structure

This thesis will examine different types of rehabilitative design experiments based on people who are suffering from the effects of post-stroke rehabilitation practices. My thesis will provide an insight into variable computer generated imagery, both realistic and non-realistic based, which are aimed at creating a successful rehabilitating experience for post-stroke patients. This will be outlined in the following literature review, methodology and research overview before providing a critical reflection and conclusion.

CHAPTER 3

Literature Review

This literature review summarises the research undertaken within the medical field. It defines accepted terms regarding strokes and establishes general information and practises. It also explores post-stroke rehabilitation practises before highlighting material regarding relevant video game technologies and their potential applications. Concerning realistic and non-realistic visuals this review also details areas that inform my own knowledge regarding the relation between video game visuals and player immersion. It will highlight the development and contrast in these visuals and the potential for immersion through immersive virtual environments.

What is stroke and how does a stroke happen:

A stroke is a brain attack which can happen to anyone at any given time. A stroke is a sudden interruption of blood flow to part of the brain causing it to stop working, (Saini, Rambli, Sulaiman, Zakaria, & Shukri, 2012) with this stoppage eventually damaging brain cells.

The New Zealand Stroke foundation defines a Stroke as sudden damage to the nerve cells in the brain, the following illustrate the different types of stroke:

Ischemic Stroke: Blockage of normal blood supply to the brain, this affects about 83% of New Zealand stroke sufferers. Blockages can occur when the inside walls of the artery thicken up. This makes the opening too narrow, limiting the amount of blood that can pass through. They can also occur due to a blood clot, where some form or object clogs the artery. For example a clot can form in the heart, break off and travel with the blood until it is jammed into a small or narrow artery in the brain. These blockages mean sufficient blood is not getting to the brain cells in that that area. Cells cannot live without oxygen, so within a few minutes after the blood supply is cut off, nerve cells can die and that part of the brain stops working.

Haemorrhagic Stroke: Blood bursting into the brain from a blood vessel, this affects the other 17% of New Zealand stroke sufferers. Blood bursts through the walls of an artery and leaks into the brain itself (intracerebral haemorrhage) or onto the surface of the brain (subarachnoid haemorrhage). This can happen because a person was born with a defective artery, or because disease has caused the artery walls to become thin and brittle. The blood is forced into the brain tissue and, because there is little space around the brain in the skull cavity, the build-up of blood presses on the part of the brain where the bleeding occurs, damaging the nerve cells so that parts of the brain cannot function.

Transient Ischemic Attack (TIA): is a “mini-stroke,” caused by a temporary blood clot and is typically identified by the retreat of common stroke symptoms several hours post stroke (National Heart Lung and Blood Institute, 2016).

These different types of strokes described cause similar damage to the nerve cells in the brain. Some nerve cells (neurons) are too severely damaged to recover and these eventually die. However other cells can sometimes repair themselves. When brain cells die during stroke, abilities controlled by that area of the brain such as memory and muscle control are lost. Some neurons may be only partially damaged, usually by the brain swelling that takes place after a stroke. When the swelling goes down, these nerve cells recover and start working again, although at a slower rate than previously, however noticeable improvement can occur within weeks. How badly a person is affected by their stroke depends significantly on where the stroke occurs in the brain and how much of the brain is damaged.

Though there is no given evidence of a total cure for post-stroke patients, meaning that the patient will not be able to re-establish themselves into what and how they were prior to said stroke, there is a process where patients are able to re-teach other neurones to make new pathways through extensive rehabilitation. This review also highlights the concepts of photorealism, stylized visuals and visual immersion, noting instances where these fields have been previously explored while allowing me to establish definitions of these concepts to work from for the purpose of my own thesis.

What is Post-stroke rehabilitation:

Many post-stroke sufferers experience physical, emotional and cognitive conditions. Patients encounter difficulty in moving, thinking and sensing, this causes problematic experiences for patients as they are unable to undergo everyday activities such as writing, walking and driving. This is when rehabilitation becomes vital for all patients, rehabilitation is defined as the process in which various forms of therapy are used to regain strength and functionality of injured or effected parts of the body (Saini, Rambli, Sulaiman, Zakaria, & Shukri, 2012). This is undertaken so that they are able to return to their previous lives and regain their independence.

New Zealand stroke foundation defines rehabilitation, beyond physical therapy, as:

- Identifying what you want to do
- Finding ways to move forward with your personal goals
- Continually looking for options that will help you progress
- Finding solutions to problems

Common rehabilitation therapy does include:

- Physiotherapy - which is aimed at assessing and treating physical problems through physical methods such as massage, movement and balance
- Occupational therapy - which is the use of particular activities as an aid to rehabilitate from physical and mental illness
- Language therapy – which assesses and treat patients with verbal communication and difficulties with speech
- Alternative therapy – These include homeopathic remedies, massage, relaxation techniques etc.

Rehabilitation success heavily depends on the motivations, courage and perseverance of the post-stroke patient. There is a large amount of success in various forms of rehabilitation therapy however the intention of this thesis is to shed light on technology and computer generated imagery as a means of effective motor rehabilitation experience for the post-stroke patient. Recovery after a stroke is directly influenced by the patient's level of synaptogenesis (the formation of synapses between neurons in the nervous system), which has a direct correlation to frequency and intensity of exercises performed (O'Dell, Lin & Harrison, 2009).

Modern technology for post-stroke rehabilitation:

Recently modern technological systems have taken place to successfully implement post-stroke rehabilitation and have proven to aid in stimulating motivation and improve the effectiveness of rehabilitation. Growing scientific evidence has suggested that video games may help improve physical therapy outcomes by better engaging the user thereby increasing motivation. This will encourage longer gaming sessions, thereby encouraging repetition which will establish the brain pathways allowing for better recovery of the patient. Rand et al found that by replacing conventional therapy environments with video games they were able to monitor an increase in patient motivation (2012). This lead to an improvement in the patient's use of their affected upper extremities.

The following theories were used to establish the foundation of my research and enabled me to develop an improved application for creating a successful rehabilitating experience for post-stroke patients.

Mirror Therapy

Mirror therapy is used to improve a patient's motor function after stroke. During therapy a mirror is placed over the effected arm and uses the reflection of the unaffected arm moving in the mirror. This technique creates the illusion that the impaired arm is now fully functional (Thieme, Mehrholz, Pohl, Behrens, & Dohle, 2013). Over time "mirror training and movement imagery have been demonstrated to be effective in treating several clinical conditions, such as phantom limb pain, stroke-induced hemiparesis, and complex regional pain syndrome" (Trojan et al, 2013, p.634). Outcomes have shown that mirror therapy was effective in improving ones short and middle-term motor functions. This method is one of the more successful forms of therapy often employed due to its simplicity, low cost and practicality.

However mirror therapy was "followed by a gradual decrease in function as the patients became bored with the movements and began resisting therapy" (Paik et al, 2014, p.7).

Action observation therapy

Action observation therapy is a form of therapy founded upon the observation, imitation and performance of actions. This form of therapy is founded upon mirror neuron theory where neurons are triggered under two conditions, when an action is performed and when an action is observed by a second party (Zhu et al., 2015). It focuses on the benefits of combining action observation with the repetitive practice of functional tasks (Park et al, 2014).With this considered there is a strong potential for action observation therapy in rehabilitation. With the ability to recover motor function and capability through observation one suffering from the effects of a stroke can potentially still benefit from this form of therapy (Garrison, Aziz-Zadeh, Wong, Liew, & Winstein, 2013).

Sensory Devices

Sensory devices, with regards to this thesis, are forms of hardware that are able to track body movement and composition, allowing for raw data to be streamed from the device to the developer or designer. The Microsoft Kinect V2 uses this type of technology to track a user's body movement and create visual representations of this gathered data (Saini, Rambli, Sulaiman, Zakaria, & Shukri, 2012). These devices have often been used in the services of entertainment but have since transitioned into other fields, with more practical applications. The Kinect with its low cost, accessibility and small form factor make it an ideal candidate for clinical practise and in home use (Saini, Rambli, Sulaiman, Zakaria, & Shukri, 2012). However the Kinect is not without its downfalls. The Kinect is unable to track fine movements such as joint and shoulder

rotations accurately, as it estimates these movements for smoother performance (Webster & Celik, 2014). Also, when regarding the Kinect in terms of clinical use and rehabilitation, its inability to measure fine movement accurately can hinder its ability to assist with those whose disabilities are more severe (Webster & Celik, 2014).

Defining photorealism and non-realism in video games:

The pursuit of photorealism has been a constant in the medium of video games. As technology continues to develop game developers and designers have often strived for photorealistic representations rendered in real time, to create visuals indistinguishable from that of real life. "Photorealism aims to create a visually sound representation of the world, reducing the pictorially difference between real and virtual images" (Shin & Human Interface Technology Laboratory New Zealand, 2008, p. 3). However hardware has often been unable to fully recreate these aesthetics in real-time as it was a task left for offline rendering algorithms (Fumarola & Poelman, 2011). The pursuit of photorealism has often proven to be incredibly inefficient and difficult. These limitations forced developers to find alternative methods to create games that are both aesthetically pleasing (Haller, Hanl, & Diephuis, 2004) and functional. Stylized visuals, defined as non-realism creating an abstract version of both the real and virtual through stylization (Chen, Turk, & MacIntyre, 2012), and aesthetics initially came about because of the technical limitations of their hardware, forcing developers to compromise and find a middle ground between fluid gameplay and pleasing visuals. However as technology has progressed these limitations no longer necessarily apply, leading to a divide in video game aesthetics, as developers pursue both photorealistic and non-realistic visuals.

Photorealism

Photorealism heavily relies on a hardware's technical resources, as the ability to render high quality textures with large numbers of polygons comes at a heavy computational cost. In photorealism the "virtual objects should be expressive, clear and look aesthetically perfect" (Haller, Hanl, & Diephuis, 2004, p. 2). These costs coupled with the rendering and baking of real time lighting maps has meant that the production of photorealistic imagery, rendered in real time, has only truly come of age in the past twenty years (Kyprianidis, Collomosse, Wang, & Isenberg, 2013). Though pursuits in the early to mid-nineties saw real time 3D polygons attempt to achieve or imitate forms of realistic imagery, the technical limitations of the time lead to low resolution textures with low polygon models. These early attempts lead to a distinctly blocky visual style, seen in games such as "Metal Gear Solid" (Konami, 1998) and "WWF Smackdown!" (THQ, 2000) for the Sony PlayStation, with jagged lines common due to the lack of anti-aliasing. However over time technical improvements and innovations have arguably led to an increase in the amount of games striving for photorealism, with the visual fidelity and detail of these steadily being improved over time. Modern games such as "Uncharted 4: A Thiefs End" (Naughty Dog, 2016) and "Crysis 3" (Crytek, 2013) have each set a high standard for visual fidelity in video games however the pursuit of photorealism will continue as hardware continues to develop.

Stylize non-realism

In contrast, while the pursuit of photorealism has often pushed the limits of hardware, stylized visuals have often worked both within a systems limitations and hand in hand with the game designer's intentions. For example "The Legend of Zelda: The Wind Waker" (Nintendo, 2002), released in 2002 for the GameCube, divided fans with its use of cel-shading and bold colours.

However its use of stylized visuals established a more complete world, adding to the experience and allowing for more stylistic license within the game. “Non-photorealistic pictures can be more effective at conveying information” and “be more expressive and more beautiful” (Haller, Hanl, & Diephuis, 2004, p. 2). An example being the way wind is depicted. In the Wind Waker (2002), wind was shown through stylistic, cartoon like streaks of air. With wind being a key feature of the game it was necessary that it could be easily shown. Miyamoto (2002) stated that realistic graphics often contain the unrealistic depiction of certain elements, such as bumping into walls, simply because if these “are not expressed properly, they seem out of place” (as cited in IGN Staff, 2002).

Visual Immersion:

Game immersion can be described as the sense of being so absorbed in a game that one excludes all else outside of the game world (Jennett et al., 2008). What it is that creates this sense of immersion is something that cannot be easily defined. It can be considered a combination of various elements such as, a positive gaming experience, the visual appeal, the games performance and the users overall enjoyment with “high appeal for a game” leading “to high immersion” (Christou, 2014, p. 99). This concept of immersion has been defined by Charlene Jennett as cognitive absorption, or CA, a state of deep involvement with software. CA shares clear links to immersion with a focus on temporal disassociation and awareness of surroundings indicating high engagement (Jennett et al., 2008), however it is stated that immersion is more concerned with the psychological experience, potentially arguing that immersion within a video game is more relevant to feeling and emotion. Georgios Christous (2014) states that immersion creates a state of enjoyment drawing players into the game environment while highlighting that the visual aspects are only one element that determines a games immersive qualities.

The literature covered in this review helps establish and define key concepts and terminology that build a foundation from which I can begin my own work. It does not discuss all that has been covered in each field however it gives an overview of what has been researched. Highlighting the key concepts of my thesis which are variable graphical styles, namely photorealism and stylized visuals, and the concepts of immersions.

CHAPTER 4

Precedent Analysis

The following chapter will highlight games of contrasting graphical styles relevant to the intentions of the thesis. It will highlight the techniques and methods used to achieve each graphical style and the reasoning behind their choice of said graphical style. The games of Uncharted 4: A Thief's End (Naughty Dog, 2016) and Crysis 3 (Crytek, 2013) will be used as examples of photorealistic graphics while Overwatch (Blizzard, 2016) and The Legend of Zelda: The Wind Waker (Nintendo, 2002) will highlight stylized graphics. The chapter will also highlight the developers design choices and the relation between those choices and the developed visuals of each game. This chapter will also discuss the concept of immersion with regards to each game where possible and see if any noticeable data of information can be obtained. The observation of each of these games will inform my design process and influence how I construct and develop my own distinct visual styles. These styles will then be achieved and made functional through digital 3-D modelling, animation and texturing. It is these influences that will determine what visuals reach the post-stroke rehab application.

Uncharted 4

Beginning with Uncharted 4: A Thiefs End (Naughty Dog) their technical team intended to push the boundaries from early stages of development. Rob Ruppel (2016), an art director from Naughty Dog, stated that their goal from the beginning of the series was to achieve visuals of high complexity and believability (as cited in Playstation, 2016). However for the sake of gameplay they noticed visual elements had to be sacrificed in order to achieve smoother gameplay and performance. Through the development of new hardware, in this instance the ps4, Naughty Dog were able to use higher resolution textures with these having a major impact on the visual fidelity of Uncharted 4.

Figure 4.1 Screenshot from Uncharted: A Thief's End (Naughty Dog, 2016).

Crysis 3

Powered by the CryEngine 3, Crytek, the creators and developers of the Crysis franchise, have always pursued to push hardware limitation and strived to achieve a photorealistic graphical quality. An example of this would be Crysis 3 (2013) for the PC. For Crysis 3 to run at its intended visual quality a higher requirement in computer hardware was required. The Crytek CEO, Cevat Yerli (2012), has been quoted as saying that Crysis 3 would “melt down PC’s” (as cited in Parrish, 2012). Setting a benchmark in graphical performance, the engine pursues rendering of high quality graphics in real-time with the use of various techniques such as volumetric fog shadows, dynamic caustics, and physical based rendering materials (PBR). Each of these processes and techniques contribute to enrich the experience of the user through high quality visual imagery combined with quality gameplay performance using real-world physics.

Figure 4.2 Screenshot from Crysis 3 (Crytek, 2013).

Overwatch

Created by Blizzard, Overwatch (2016) is a recently released game that showcases the use of stylized graphics. The game is a multiplayer first person shooter featuring the use of a diverse range of characters, with each having their own unique abilities and classes within the game game. Aesthetically Overwatch features a vibrant and bold visual style. With exaggerated body types for each character and facial features showcasing a strong Japanese anime or manga style influence. Assistant game director Aaron Keller (2016) stated their intentions were to create a world that was colourful as they wanted the game to feel “hopeful and inspirational” (as cited in Orland, 2016). In attempting to create to create a bright world the developers went against the photorealistic style and trends of the time and “purposefully strayed away from something grim” (2016). Though the game was against creating grim photorealistic imagery it incorporates similar techniques to its photorealistic counterparts to achieve its visual aesthetic though employs them to a different effect.

Figure 4.3 Screenshot from Overwatch (Blizzard, 2016).

Zelda

Nintendos The Legend of Zelda: The Wind Waker was released in 2002 for the Nintendo Gamecube before being re-released in HD for the Wii U in 2013. This game featured an art style that strongly utilized a technique known as cel-shading. This technique is often employed to create a comic book or carton like aesthetic as it creates shading that appears flat, often built out of a single colour, as opposed to the more realistic shading that creates a gradual change in tone. Takuhiro Dohta (2013) stated that “with The Legend of Zelda: The Wind Waker HD, I think we were able to express a good feeling that doesn't come across by simply portraying a photorealistic sea or sky” (as cited in Iwata Asks, 2013). This art style divided many upon its reveal as the early Gamecube Zelda demos had indicated that the series would be continuing to take a more mature or photorealistic approach to its visuals. The Wind Wakers use of both simple and bold textures crossed with cel-shading created a unique aesthetic that was both bright and colourful while being engaging and immersive. The reason for the shift towards this style was due to the games development team feeling that their current progress was not satisfactory, with Eiji Aonuma, the original Wind Wakers Director, stating the game as a whole was not coming together as it should (2013). The team then developed this new style based on concepts, began developing this aesthetic and steadily progress towards a final output.

Figure 4.4 Screenshot from The Legend of Zelda: The Wind Waker (Nintendo, 2002).

CHAPTER 5

Design Process

Utilising what I have stated above I will use this new information to support the output of the research.

Target Audience

The application was constructed according to the needs of the target audience or intended demographic. Game design is often concerned with demographic variables such as age, gender (Schell, 2014) and the limitations of the user when creating an end product. These design principles were employed in our own design process to produce a product more suited to our users. While the effects of upper limb stroke often vary between stroke sufferers this research was utilized to provide a solution for stroke survivors, those who had suffered left or right side hemi paresis resulting in a restricted range of motion.

Concept Design (User Flow/Goals)

While catering to the needs of the intended user was the primary focus of this project the application required -

implementations that could still fulfil the aims of my own research questions. These implementations were planned from the outset to ensure they were always considered and properly implemented in the design of the application. The application needed to be an engaging experience for the end user while also incorporating traditional physiotherapy movements to support the rehabilitation component of the research.

Collaboration

The physical output of this research was developed in collaboration with fellow masters student Nicholas Wellwood. Nicholas Wellwood contributed the backend framework of the application, specifically developing the gameplay mechanics, game logic and reporting systems. My development focus was on the front end of the application, designing the aesthetic components of the game which included both the photorealistic and stylized 3D models, animations of dance and exercises level design and the user interface.

Technology and Software 3d Modelling Tools

The following software and tools were what I used primarily throughout my development process, these consisted of:

Maya - 3D Animation and modelling software used to create and prototype 3D assets for the application.

Zbrush – Digital 3d sculpting software used to create most models.

Substance painter 2 – 3D painting software which allows for texturing and rendering.

Motion Capture Software

Brekel Pro Body 2 is a windows application that enables 3D animators to do body motion capture with the Microsoft Kinect Sensor 2.

Motion builder – 3D character animation software used for virtual production, motion capture and traditional key-frame animation.

Game Engine

With prior experience of developing in the Unreal Engine 4 (UE4, Epic Games, 2014) software, and Epic Games constant strive for enhancing visual graphic support, UE4 was a critical choice for designing the application.

Technology

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

Plugin for UE4

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

Initial Stages

This chapter will document my design process and how through iteration we achieved our final results. During the early stages of research the concept of mirror therapy was the basis of our applications development, however it was eventually excluded for practical reasons before we settled on a new basis. The new basis utilized was Action observation therapy as it was deemed a more feasible foundation to work from for our proposed rehabilitation application. The reasoning for this was due to a suggestion by our supervisor, and from practitioners in the research field, who communicated to us that the mirror in the initial digital prototype was not an accurate implementation of mirror therapy (Signal, N. & Taylor, D, Private communication, October 14, 2015).

Following from these established principles and beginning the visual development I initially began to experiment with the 3D modelling pipeline by producing various concepts of virtual realism and cartoon style graphics. The image above showcases the development process and different stages of the modelling pipeline to achieve a baseline 3D model. At the suggestion of my supervisor I began experimenting with photorealistic visuals by iterating these hand models. Once models had reached a satisfactory state, I began experimenting with different rendering and texturing techniques. Through the use of these techniques I was able to achieve a variety of results that were well received. Based on feedback given by tutors I was able to establish a framework for photorealistic texturing and real-time rendering that would allow me to explore the potentials of this aesthetic.

Experimentation

With this framework established I was now able to see how far I could push the limitations of the unreal engine in terms of photorealism, however I also had to take into consideration the performance of the engine and the functional capabilities of the application. Much like photorealism in commercial games, restrictions had to be considered to compensate for performance measures. I created a series of high quality textures ranging from 4k (3840 × 2160 pixels) to 8k (7680 × 4320 pixels) resolution, these included an ambient occlusion map, a normal map and lastly the diffuse map. These images are what turns the 3d model from its default colour to create the illusion of skin translucency, subsurface scattering, skin deformation and colouration.

The initial 8k textures were visually a success, however after continued experimentation with the hand models I realised a full body mesh had to be considered and that at these resolutions a textured full body model would not be practical. With this in mind and through iteration I began to scale down textures according to the functional needs of the engine, application and hardware.

Initial Prototype

With this pipeline now fully developed I now moved on to create a full body 3D model. Again the process remained the same as I developed the initial 3d mesh before applying the appropriate details and textures. I began by developing a male body for experimental purposes. This model was eventually rigged and textured, however at the suggestion of my supervisor and the knowledge we had gathered concerning stroke patients, it was decided that the model and textures had to represent or appeal to the appropriate demographic. Therefore new models were developed to represent said demographic.

Photorealistic Male and Female

After establishing the age demographic I designed both male and female 3D iterations that were representative of the ages shown in our research. These models were then rigged and textured so that they could be put to use within the confines of the proposed application.

Stylized Avatars

While finalizing the finishing touches of the photorealistic models I began experimenting with the stylized iterations of the Male and Female models. The development process was similar to that of photorealism, with less detail towards the body and facial features, brighter colour composition and exaggerated body types and features. The exaggerated style was intended to show that the model has its own unique traits and characteristics. This granted me more freedom to design visuals that met the requirement of the age demographic while allowing for a fun aspect of the modelling process to show through. For example, the body of the male and female featured longer arms and legs, larger hands and feet, with a bigger head and facial features. The colour scheme utilized a flat shading technique that allowed for bold colours and shadow with only a normal map needed to bring forth definition where necessary.

Motion Capture

When capturing animations for the models, through the use of the Kinect, Nicholas Wellwood and I experimented with the software Brekel Pro Body V2. This software allowed for motion capturing of the exercise routine in order to drive the core mechanics of the game. Although this method of motion capture is a low cost solution it had its

disadvantages. Namely the requirement of having to go through each frame of animation to find and remove unintended movements in the skeleton. For example a common issue was the tracking of foot placement. Occasionally these movements would register correctly, but sudden changes in the positioning caused the feet to malfunction and move left to right repeatedly.

Dance Animations

Once the pipeline was established on how to incorporate the animations into the ue4 engine, the next task was being able to motion capture dance animations. This stage presented us with a lot of challenges as we needed a variety of animations ranging from slow to fast paced dancing movement. A few volunteers came forth to record their own dance routine and helped me build a library of motion captured dance animations. Although this was a time consuming process, where the technology lacked I would improve by hand adding key frames to adjust the animation creating a more natural sense of movement.

Retargeting animations for Photorealistic and Stylized models

Animation retargeting is a feature that allows animations to be reused between different models/ characters. As each 3D model (realistic and stylized) has a unique body shape, they also had a different skeleton that best suited their body type. The process to retarget animations required the altering of each 3D model to remove unintended overlapping of limbs. For example when the arms crossed paths in an animation frame, the arms would go through each other and would require changes in either the skeleton or the animation key frames.

Retargeting the Kinect Skeleton (UE4 Mannequin)

While developing the application we came to the realisation that the default mannequin skeleton used for real time body tracking with the Kinect plugin had to be used in all of our previous models. The reasoning for this was that our original skeletons were not compatible with the Kinects UE 4 plugins. This required the removal of the original skeletons models and their eventual replacement with the skeleton of the UE 4 mannequin. With no information on how to change the mannequin mesh I began experimenting with techniques to work around and replace our original models skeletons. We utilized various industry methods such as skeleton retargeting and joint reorientation, however the only workable solution was to use the skeleton of the UE4 mannequin the plugin was programmed to use and bind it to the realistic and stylized models.

Level Design

The level design was intended to make the user feel comfortable and not overwhelm them with any unnecessary detail. The realistic level confined the user to a virtual studio apartment, with a minimal layout using very few assets. The stylized level was intended to be fun and vibrant, however the general background and level design was to play secondary to the 3D character in terms of composition. This simplified approach was intended to emphasize the visual styles in both levels. Aside from the visual styles each level played the same way utilizing the same game mechanics and focusing on the same core exercises of rehabilitation. The only differences were in aesthetics, however this is where I wanted to see the user's reaction and determine how immersive the contrasting styles were. The reasoning being they could potentially react differently to each style even though they are, visuals aside, the same game.

User Interface and Assets

Visually I wanted the user to be greeted with renders of realistic and stylized characters, it was my intention to showcase the model while also making the selection process engaging and easy to follow, utilizing bright colours and a simple selection interface.

In Game UI

The in game interface utilized a combo meter displayed in the bottom right corner of the screen. The meter was divided in to five levels, and with each successful exercise completed the meter would build up towards a reward for the player. This reward would consist of various visual cues including character animation, particle effects and a change in music and audio cues. This remained the entirety of the UI as I felt anymore would clutter the interface and defeat the purpose of a clean and simple aesthetic in terms of both design and functionality. Initially there was the use of the Kinect window in the top left corner where a body stamp visual using the depth camera data was visible. This data was displayed as a silhouette and was initially intended to assist the user in tracking their own motion, however it did not prove to be successful. The Kinect data was often buggy and not displaying as intended and for these reasons it was removed from the overall interface.

Debugging and clean up

With all assets completed and the game now in a functional state, various debugging processes and fixes had to be applied to the application to reach a functional state. Early issues could be found with the UE 4 plugins. One of the plugins used linked data from the Kinect to the UE 4 mannequin system, however this meant only the skeleton for the mannequin was functional and the skeletons in my original models were not. To work around these issues I was required to export the mesh and skeleton data from the Unreal Engine to Maya. Once in Maya I would delete the mesh data and I apply my own models meshes to the mannequin skeleton. With this completed the Kinect data could be properly translated to my original 3D models.

Figure 5.1 Realistic Hand Prototypes.

Figure 5.2 Photorealistic Male.

Figure 5.3 Photorealistic Female.

Figure 5.4 Stylized Male Character.

Figure 5.4 Stylized Female Character.

Figure 5.6 Photorealistic Level Calibration.

Figure 5.7 Photorealistic Level Final.

Figure 5.8 Stylized Level Calibration.

Figure 5.9 Stylized Level Final.

Figure 5.10 User Interface Design.

CHAPTER 6

User Testing

Questionnaire

The general questions discussed in our user testing stage were used to create a background profile of whom we were testing. The following questionnaire was developed to give us information on the user based on their background regarding stroke and previous rehabilitation experiences as well as their overall wellbeing.

General questions

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

The questionnaire concluded with the following profile of the participant.

I will refer to our user test participant as Participant Z

Participant Z is a Female of European decent and is 74 years old. In January, 2016 she suffered from an ischemic stroke resulting in left side hemi-paresis. With the loss of mobility and strength on her left side, she underwent rehabilitation post-stroke for one week and was based in the hospital during this critical stage in recovery. Throughout this process she explained that her treatment consisted of Physio therapy exercises with moderate exercises, for example having to step up and down various objects of different heights to regain strength in her left side.

Following release from the hospital, Participant Z was visited in home by a physio therapist. This was to go through an assorted range of household activities she could do to aid in her recovery process. During the time she had with the therapist she had written a list of goals she wanted to achieve to get return to her normal everyday life. These included using public transport, being able to hold her grandchildren and losing a general feeling of incompetence. After 3 visits the physio therapist left her with an assortment of exercise examples, documents and more information regarding the recovery process.

Over the next months, prior to our first meeting, Participant Z had recovered most but not all strength and mobility in her left side, however she still found fine motor skills in her left hand cumbersome. She believed that factors of good health and diet contributed to her own recovery process, with physical daily activities around home playing a key role. She found that the physio therapy exercises she was left with were hard to maintain over this extended period of time. This difficulty was due to the both the exhausting and time consuming nature of the exercises.

Questions on Visual aspects and immersion

1. Was the game design visually appealing?
2. Was anything confusing or did not enjoy?
3. Which type of visual style (look) did you prefer and why?
4. Did the visual assets enable you to be more engaged with the game?
5. Was there anything you would change? How? Why?
6. What style was more fun?
7. How realistic is the models?
8. Which style do you prefer and why?
9. How engaged did each visual style make you feel?
10. If you were to compare each visual style to something what would it be? (e.g. Photo, TV, CGI)
11. Did you enjoy the game?

User Test Session #1

Nicholas and I divided our first user test session with Participant Z into three parts. The first part was the introduction of each other and our respective fields of study, followed by the interview and general questions developing a thorough profile of Participant Z (mentioned above). In the second part of the session Participant Z tested the application several times, firstly partaking in the realistic level followed by the stylized level. The concluding portion of our session consisted of the secondary interview. It was here where she gave feedback on the application and my own questions concerning visual style and immersion.

User feedback

Participant Z, with her knowledge and through her experiences, made a notable contribution to the development of the application during the first user testing stage. She applied her thoughts and ideas where necessary and assisted in refining the visual cues and colour composition. She highlighted during the calibration stage that it was hard to follow some of the text and animation. With her age demographic considered she noted that text had to be clear to the user before any actions could be performed allowing the game to take place. With this feedback considered Nick and I were forced to make changes in the text prompts and animation sequences. Visually Participant Z was drawn to the photorealistic style of graphics and felt that the 3D model and level design was more engaging. She was amazed of the visual and graphic quality and fascinated at the level of realism now possible with computer generated graphics and high level of detail.

Iteration #1

Alterations were made to the application based on Participant Z's feedback. This included text cues and animations in the calibration level, Score cues that displayed “+100” each time the participant completed an exercise to provide better visual feedback for in-game progression. The rounds of the level were also increased from 3 to 5 to prolong the exercise routine as she felt the dance level was quite short timeframe wise.

User Test Session #2

The second user test session was divided into two parts, firstly we had Participant Z test the application several times going through both the photorealistic and stylized levels. During gameplay she became aware of new improvements describing them as easier to follow, and could now focus on mirroring the exercise animations. Second was a general discussion concerning her thoughts about the new changes followed by her feedback where she identified any other issues she had during the testing phase of the application.

User feedback

During our discussion Participant Z highlighted that even though the calibration level was now easier to follow, she was now able to recognise that the 3D models animations in certain scenes were out of sync. For example before the calibration level started some animation sequences began in a “T-Pose” before intended and she immediately reacted and thought to imitate. Participant Z also described how the UI changes of the application made a difference during the dance level, but identified that the white circles, used to show the amount of targets hit, were not clearly indicated to the user and suggested the addition of a text cue would help solve this. Recognizing that music was of a fast paced rhythm, she demonstrated how the exercises performed did not sync well with the tempo. Participant Z noted that she had a background in Scottish dancing and felt that the music had to match the movement's speed of the actions and animations for a more natural flow.

Iteration #2

Independent to the feedback, Nicholas Wellwood removed the realistic and stylized models in the calibration level and replaced them with the Kinect driven equivalent. The reason for this was to introduce the Kinect models earlier for users to identify and have a better transition to the dance level. Alongside this was the addition of new music tracks to compensate for the different rhythms and tempos of the exercises. The green silhouettes were also given a neutral pose (arms down to their sides) to eliminate any misunderstanding of what actions were to be performed during the calibration stage.

User Test Session #3

The final test with Participant Z, again consisted of two parts. We jumped straight into testing the new iteration of the application, having Participant Z attempt both the photorealistic and stylized levels several times each. During testing I asked Participant Z to think aloud and discuss anything regarding visuals to provide answers to our questions before sitting down and discussing these in further detail. This method was used so the user did not have to recall what she was experiencing during gameplay once finished. Finally Nicholas and I interviewed Participant Z. While reviewing the general questions discussed in the first user test to ensure all information was correct she also answered questions relating to the visual and immersive aspects of the application.

User Feedback #3

Participant Z praised the overall changes of the new iteration and felt gameplay had become a smoother experience and fixed a lot of details that she found difficult to understand within the application. She pointed out that having the Kinect 3D model within the calibration level allowed her to easily adjust to the dance level without confusion. Participant Z felt that both photorealistic and stylised visuals had their own unique fun aspects, but the photorealistic style was more engaging as the main 3D model resembles a real person and making the transition from reality to the virtual world is visually more relatable. However it does not come without its disadvantages. During gameplay, she explained in the realistic level visually it's beautiful, but you are always trying to critically determine what everything is, or make comparisons between computer generated models and real life objects. For the stylized level she stated that you engage with the models without being distracted because there wasn't a need to make a comparison with real life objects, noting "you just understood what was what".

Final Prototype

The final iteration consisted of a minor bug causing issues in the application. An overall clean-up of the level design (which included final light baking for static shadows) and modelling asset was performed which left only minor tweaks to the text prompts that did not display properly. There was no need to add more to the application unless the project was to go ahead with further development.

Figure 6.1 User Testing Process.

CHAPTER 7

Developed Design

As a whole, the state of the final application prototype was a success from both a visual and gameplay standpoint. While stroke rehabilitation was the driving factor behind the research, the developed application and its practical approach could easily be beneficial for other fields of study.

The Microsoft Kinect was, from early in development, the most viable solution with its support for the Unreal Engine and real-time tracking capabilities. Additional advantages were the low cost and small form factor, however it also had limitations in terms of its tracking accuracy. Though compatible, the Kinect plugin for the Unreal Engine presented new issues with its skeletons inability to work with my developed 3D models. Even though I was able to solve this issue there remained some mesh deformations in game that could not be corrected due to the plugins functionality. During gameplay users would not notice the deformations in the Kinect driven models however as the developer I noticed them immediately.

The animations motion captured with the Microsoft Kinect required a large investment of time as I was not only learning the software myself but also having to develop solutions to problems not encountered previously. Because the Kinect and Motion capture software Brekel had never been used in conjunction to my knowledge, I was required to develop solutions that had not been approached previously. When application development was stalled, due to the issues concerning ethics approval, I utilized this time to further iterate my aesthetics and development for the 3D modelling and animation pipeline.

From a technical standpoint the 3D modelling pipeline was a difficult process, requiring various models designed in both a photorealistic and stylised perspective to be developed to the state of immersion required. Photorealistic models, even with the specified age demographic considered, required far more attention to detail over longer periods of time. Textures were developed with the use of photo references, allowing me to accurately capture the amount of detail in features such as wrinkles, freckles, skin tension and other various skin characteristics. Although much detail and effort went into creating the photorealistic visuals, at some point production of these had to be stopped for the sake of hardware functionality and time constraints. The reason I began with the photorealistic models was because of the high amount of work required. However this style was also chosen first as it helped establish a general framework that could additionally be used for the stylized modelling pipeline. The stylized characters were developed to have a humorous appeal but still remain visually representative of the target demographic. The process did not require as much time as the photorealistic models but still required attention to detail in order to achieve the desired aesthetic. I exaggerated the limbs and facial features of the models giving them cartoon like proportions with an oversized head, large hands and large feet. Texturing utilized a more simplistic approach as only flat shaders were required in their clothing with the textures for facial features requiring the most significant amount of work.

During the user testing phase of the research there was a notable difference in the users' engagement determined by the art style she was playing through. Participant Z noted she felt more engaged when playing through the level with photorealistic visuals. Participant Z found the transition from reality to the virtual easier during her play through feeling that the photorealistic visuals allowed for smoother transition between the two. The user found the photorealistic visuals more appealing, however Participant Z noted that over long periods of play she began focusing on comparisons between the real world and virtual as opposed to focusing on her own rehabilitation.

As a visual preference the photorealistic level was the one observed by Participant Z to have the most appeal. The visual elements worked together, making the interaction easier to interact and engage with. This correlates with Georgios Christous (2014) statement that “players who find a game appealing will also find it more immersive” (p. 98). Participant Z remained impressed by the visuals, interestingly however she noted similarities between the photorealistic level and the Pixar animation film Toy Story, while highlighting the Stylised level resembled comical characters she read when she was younger. This statement is interesting in that while she found the photorealistic imagery more appealing and immersive, her first comparison made with said imagery would be to that of a stylized animated film. This statement shows that immersion is not entirely linked to visuals, as a user's perception, preference and opinion will always come into play when determining how immersed they find themselves in a virtual or digital world.

Participant Z also noted that over time she began focusing on imitating the on screen green silhouette and not on her own in game character, failing to recognise whether she was completing her rehab exercises. This interaction highlights the fundamental concepts of action observation therapy whereby the user focuses on the exercise without realising the physical demand of her rehabilitation. With this achieved during the rehabilitation process there is an increase in the “potential of functional enhancement” (Park et al, 2014, p.795) and a high possibility for repeated therapy.

The user interface in its final state could have used more time in development to create something more visually cohesive as some of the elements clashed producing, in my opinion, conflicting visual design. However the UI did not receive the same amount of time nor focus due to its fairly limited role in the scope of both the application and my own research. Though UI plays a key part in communicating to the user it was not considered to be as crucial to the projects development therefore was less considered.

CHAPTER 8

Conclusion

The standard procedures in physiotherapy utilize specific tools and methods for stroke rehabilitation, without recognizing the potential benefits of an immersive environment, whether real world or virtual. In this thesis we presented a study that explored computer generated imagery and its use to create an immersive rehabilitative experience for post stroke motor rehabilitation. I feel that this project demonstrates the potential of immersive qualities not just in the context of post stroke rehabilitation but potentially in other programs of recovery or rehabilitation. The ability to lose ones sense of surroundings and immerse themselves in an engaging environment distinct from the real world could greatly benefit those who are recovering from both mental and physical trauma. Though the restricted scope and amount of user testing and user feedback limited our potential findings there was still valuable information and insight gained. However to develop further insight a more thorough investigation would be required, potentially building upon our established application, using the modelling pipelines developed and pushing even further.

Concerning the computer generated imagery I found each style had both a positive and negative effect regarding the level of immersion the user felt through the duration of the application. These results demonstrate that imagery can improve both immersion and appeal but remains only one aspect of a wider spectrum of elements that create this sense of immersion. To truly create a sense of immersion all facets of the experience must be considered but from my findings imagery appears to be a key factor.

In terms of the imageries ability to assist in a patients overcoming of post stroke related impairments it was difficult to make conclusive findings. Due to the inability to follow up with patients, and our user testing being limited to one participant, we were unable to follow up on users rehabilitation post user testing. We remain uncertain as to whether Participant Z either overcame or was in the process of overcoming her post stroke impairments. Judgement is also difficult as when we tested Participant Z she was six months in to her rehabilitation and had already recovered most of her motor skills in her affected side. Therefore most of the improvements we would have noted would have been relatively small when compared to the progress she had already made in the preceding months.

In conclusion the potential for immersion in this particular area of research remains. Though no conclusive results could be established, enough has been noted to demonstrate the potential for such an application and the contribution of computer generated imagery to said application. Immersion allows people to lose their grasp on their surroundings and separate themselves from or lose track of reality, and in the context of rehabilitation this is a potentially powerful advantage in the process of both physical and mental recovery. If developed further the application could lead to promising results in terms of user engagement and immersion. This could potentially put a focus on the visual design qualities of rehabilitative gaming creating not only a more enjoyable rehabilitation experience but potentially one more successful.

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