The use of virtual reality in serious games for health

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**Abstract**

This dissertation looks at the use of virtual reality for physical rehabilitation. Physical rehabilitation can cause anxiety which can result in people not doing the physical activity required for them to complete rehabilitation. This dissertation looks at current serious games for health and how they can be used in rehabilitation.

This dissertation also details the development of a virtual reality game played on a mobile device using a Google Cardboard headset. The game will contain task-oriented activities designed to replicate physical activities, that are used in neck rehabilitation, and distract the user from realising that they are doing exercise. The game will also measure the user’s range of movement of their neck and calibrate the activities accordingly.

**Declaration**

I declare that this dissertation represents my own work except where otherwise stated.

**Acknowledgements**

I would first like to thank my project supervisor Dr Gary Ushaw for allowing me to undertake this project. He helped me with the organisation of this project and gave me continued support throughout the project. I would also like to thank the other members of the gaming department for their support and advice in dissertation meetings, Dr Rich Davison, Dr Neil Spiers and Dr Graham Morgan. Lastly, I would like to thank my friends and family for giving me constant support when I needed it most and for helping me to remain sane throughout this project. To them I dedicate this dissertation.

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# Chapter 1. Introduction

This chapter will introduce the project to the reader and define an aim and the objectives required to complete the project. This chapter will also provide a structure of this dissertation and the definition of some key terms.

## 1.1 Motivation

Physical activity is key for living a healthy life [1] and is used in rehabilitation for a physical injury. However due to reasons such as a patient’s anxiety they may not complete physical activities due to the worry of making the injury worse. For some patients they must travel long distances to physiotherapy appointments and must do physical rehabilitation at home. Studies have shown that only 30% of rehabilitative exercises get completed at home by patients [2].

A solution to this problem is to use video games to help distract the user from their anxieties and virtual reality (VR) can be used to immerse the user further into an environment. Task-oriented activities can also be used to distract the user and give them a purpose while doing physical activities. Through task-oriented activities the user will do physical activities, required for their rehabilitation, without realising they are doing them.

This dissertation details how I developed a virtual reality game to help with physical rehabilitation. I will focus on neck rehabilitation and have task-oriented activities, such as a puzzle, that will replicate neck exercises. The game will measure the user’s range of movement and use the results to calibrate the game so that the game is possible for everybody. I will then finally evaluate if the use of calibration effects the time taken to complete activities. I will also evaluate the hardware sensors and how enjoyable the game is.

## 1.2 Aim and Objectives

My overall aim for my project was to create a VR game to help with physical rehabilitation. The purpose of the game is to make doing exercises a more enjoyable experience. In order to achieve this aim, I had the following objectives.

1. Research the current serious games for health and VR technologies and identify which technologies to use in my project.
2. Use the chosen software to develop a VR environment.
3. Design and develop activities to replicate neck rehabilitation exercises.
4. Determine the ability of the user and adapt the game accordingly.
5. Evaluate how the user’s ability affects the time taken to complete tasks.

Each objective is built upon the previous objective, thus the order in which the objective is completed is very important.

### 1.2.1 Changes made to objectives

My initial list of objectives (Appendix A) was based around making a VR game for stroke rehabilitation using hand tracking technologies. After undertaking my background research, I discovered that hand tracking on my chosen device does not work as intended and is in fact still a large research area in the field (Section 2.2.6). As a result of this finding, my objectives were modified to reflect the slight change in my project of creating a VR game for neck exercises (Section 2.2.7).

## 1.3 Paper Structure

**Chapter 1: Introduction**

An introduction to the dissertation detailing the problem domain and outlining the aim and objectives for the project. Sections include:

* Motivation
* Aim and Objectives
* Paper structure
* Terminology

**Chapter 2: Background Research**

Research into the project area and evaluation of current serious games for health. Project decisions made from research detailed and explained why. Sections include:

* Research Strategy
* Background Research

**Chapter 3: Design and Implementation**

A detailed account of what was carried out in order to complete this project and why. Section include:

* Virtual Reality Environment
* Range of Movement
* Puzzle
* Follow the Cube
* Modifying the Virtual Reality Headset

**Chapter 4: Evaluation**

A description of how the data was collected and an evaluation of the data. Sections include:

* Calibration effect on users
* Hardware sensors
* Game enjoyment

**Chapter 5: Conclusion**

Overall conclusion of the project which looks at how the aim and objectives were met and discusses future work for the project. Sections include:

* Satisfaction of Aim and Objectives
* Personal Development
* Future Work

**Appendix Pack**

Additional information and data that did not fit in the main body of the text. Sections include:

* Appendix A - Original Objectives
* Appendix B – PLEX Cards Experiences Descriptions

## 1.4 Terminology

Below follows a list of terms and acronyms used in this dissertation:

|  |  |
| --- | --- |
| **Term** | **Definition** |
| VR | Virtual Reality. The use of computer technology to create a simulated environment. |
| ROM | Range Of Movement. A medical test carried out to determine how much a person can move their neck. |
| SDK | Software Development Kit. A group of tools that enable programming on mobile applications. |
| API | Application Programming Interface. A set of functions and procedures allowing the creation of applications that access the features or data of an operating system, application, or other service. |
| Prefab | Unity’s Prefab system allows you to create, configure, and store a Game Object complete with all its components, property values, and child Game Objects as a reusable Asset. |
| Raycast | Raycasting is the process of shooting an invisible ray from a point, in a specified direction to detect whether any. |

# Chapter 2. Background Research

This section shows the background research I undertook during this dissertation. In this section, I will also use the background research to explain the early decisions I made.

## 2.1 Research Strategy

Research undertaken was conducted using both formal and informal sources.

Formal sources:

* Research papers that were found using Google Scholar and the university library.
* Online APIs found of the relevant developer’s website.
* Online articles that discussed relevant topics.

Informal sources:

* Forums such as Stack overflow and Unity Forum where issues about VR were discussed.
* Other web pages that evaluated VR and hand tracking technologies.

## 2.2 Background Research

### 2.2.1 Use of video games in rehabilitation

This sub-section looks at a current issue with physical rehabilitation and how video games can help overcome this issue.

During physical rehabilitation, some people experience an increase in their anxiety due to the nature of their injury [3]. This can cause people to not want to complete rehabilitative exercises at risk of hurting themselves and making the issue worse. Video games are a way to combat the issue of anxiety by “distracting” the user and allowing them to focus their attention onto something else [4]. One such example is the game ‘Dojo’, which was used by adolescents’ in a study carried out by Scholten et.al [5]. The adolescent’s anxiety levels were assessed pre-test, post-test and at a follow-up. The study reports that ‘Dojo’ had “improvements in anxiety symptoms” of the participants, with them saying the game is more engaging than just talking. An example of video games being used to reduce anxiety in a medical environment is to distract children before surgery, shown in a study by Patel et.al [6]. In this study, children were given a hand-held video game to play before their surgery. The results of the study show that the children given a video game demonstrated less anxiety than those who were distracted by family. The paper concludes by stating a hand-held video game is an effective method to reduce anxiety. From this evidence, I concluded that video games can be used to distract the user from their anxiety.

Another method used to “distract” the patient from rehabilitation is the use of task-oriented exercises. The goal of task-oriented exercise is to have the patient practice real-life tasks, like opening a window, with the intention to rehabilitate the parts of the body involved in the activity [7]. This essentially means that the patient is doing exercises without even realising it. This methodology was tested in a study by Van Peppen et.al [8]. The results of this study showed that there is “strong evidence of task-oriented exercise training to restore balance and gait, and for strengthening the lower paretic limb”. From this evidence, I concluded that task-orientated activities can not only help distract the user but can also be used as a form of exercise.

The concept of serious games for health is already a research area with many developing games. In the paper by Wattanasoontorn et.al [9], they look at the core process of serious games for health and propose three main classifications that a serious game for health should fall under. They surveyed one hundred-and-eight games from both academic and commercial environments. The three classifications proposed were, the game’s main purpose, stages of the disease being treated and the type of users of the system. When designing my game, I must consider these classifications and how my game fits them. The paper also concluded that the average game can be summarised as ‘a portable PC game that includes progress monitoring, performance feedback and adaptability.’ When creating my game, I again must consider how to integrate those features.

Rehabilitation is a form of personalised health as it is focused on the individual needs of the patient. In the paper by McCallum [10], he explores the use of video games for personalised health. He mentions that one of the key benefits of personalised health is allowing the user to have a sense of control over their healthcare. He then mentions how video games also provide a sense of control, as the actions of the user determine the result. The paper concludes by saying that video games can be used to collect data that can be used to form treatment plans. This is relevant to my project as I plan on tracking the user's progress and allowing this data to be accessed by both the user and the physiotherapist, who can use the data to provide relevant changes to the user’s rehabilitation.

With the use of game consoles like the Nintendo Wii and the Xbox 360 Kinect, games can now track the physical movements of the play and thus can be used to check if the player has completed a certain activity. Combing the use of game consoles and the use of task-oriented activities video games can be used for physical rehabilitation. This concept has been demonstrated in the clinical trial by Arman et.al [11]. In the trial, the group that used real materials from daily life to complete activities (group 1) were compared to the group that practiced activities from daily life using the Xbox 360 Kinect (group 2). The results of the trial showed that group 2 was “statistically superior” to group 1 in almost all the muscle strength tests. Because the user was immersed in the game, they were able to complete activities without real-world distractions. These results further cement the use of video games for physical rehabilitation.

This sub-section showed one of the issues with physical rehabilitation can be the patient’s anxiety levels. Using video games, a patient’s anxiety can be reduced. Also, by using task-oriented activities, a patient can complete physical rehabilitative exercises without realising. Therefore, I decided to make a video game with task-oriented activities to help the user complete exercises in a fun and less anxiety triggering environment.

### 2.2.2 Current games

This sub-section looks at three different games, that used task-oriented activities, currently used for physical rehabilitation. I evaluate the advantages and limitations of each game and use them to make decisions about my game.

**Tele-Motion System**

The Tele-Motion system uses the Xbox Kinect to track the players as they complete a few different games [12]. The games include a puzzle, a memory game, and a pizza game. In the puzzle, the player will reach around themselves as pieces appear on the screen (Figure 1). The memory game has players finding pairs by selecting cards through touch. In the pizza game, the player will complete fast food orders by selecting the appropriate food item.



Figure . A User playing the puzzle game on the Tele-Motion system. [12]

The advantage of the Tele-Motion system is that it received very positive feedback in terms of enjoyment, which means people enjoy the mix of physical and cognitive activities. Another advantage of the game is the control over the level difficulty, where the difficulty level is adjusted to the user’s ability. The limitation of the system is the need to set up a Kinect. In order to connect a Kinect to a computer, users may require an adapter and additional software [13]. This may prove difficult to a user who is not computer literate and having a physical injury can cause additional problems.

**Rehability**

Rehability uses task-oriented games to help the elderly and promote active aging. Rehability can be used in a rehabilitation centre, or with the use of Rehability lite, can be played at home on mobile or tablets [14]. One of the activities the user can complete at home is a puzzle, where they must slide pieces into the correct position (Figure 2).



Figure . A Patient using Rehability on a tablet at home. [14]

An advantage of Rehability, like Tele-motion, is the use of a puzzle as an activity. The mix of physical and cognitive activities drive users to complete the task. Another advantage is that the users can play the games at home. One of the problems with physical rehabilitation is patients not doing exercises at home [2]. A way to combat this is to have the user complete fun activities at home like Rehability. A limitation of Rehability is that it does not track users while completing the activities. This means it cannot determine the user’s physical ability and not able to adjust the game accordingly.

**KineQuantum**

KineQuantum is a VR game that contains over 60 different activities the help with physical rehabilitation [15]. KineQuantum uses VR to track the user while they play the games and use the information gathered in a physiotherapy appointment. One game that is featured is whack-a-mole where the user will improve their upper body movement by reaching to whack the mole (Figure 3).



Figure . A User playing Whack-a-mole on the KineQuantum. [15]

An advantage of the KineQuantum is the use of VR to fully immerse the user. By putting the user into a different environment, they forget about their physical ability and try to complete the challenges. One user of KineQuantum stated, “We feel the gesture rather than thinking and doing it.” [15]. A limitation of the KineQuantum is that the VR technology that they use requires set-up and a computer powerful enough to run it [16]. This means that some people may not have access to KineQuantum because they do not have the correct hardware.

In this sub-section, I evaluated three systems that currently use task-oriented activities for physical therapy. Based on the advantages and limitations of each system I decided that my game will be on an Android mobile device so that it can be played at home and be accessible to as many people as possible. I also decided that my game will be VR so to fully immerse the user with a puzzle being a task-oriented activity in my game, as the cognitive aspects help to focus the user’s attention. I also decided that my game will be able to detect the user’s ability and adjust the game accordingly to ensure the same level of difficulty for all users. All these games focus on upper limb movement and rehabilitation; therefore, I will also focus on exercises to help this area of the body.

### 2.2.3 Designing an enjoyable game

This sub-section looks at how to create an enjoyable user experience.

The Playful Experiences framework is a categorisation of playful experiences developed from analysing various games [17]. This framework analysed what aspects of a game make it enjoyable and the reasons as to why people play. The framework developed the Playful Experiences (PLEX) cards which consists of 22 categories that a user can experience during a game (Figure 4).



Figure . The 22 PLEX cards. [17]

In this sub-section, I researched what makes an enjoyable playful experience. I researched the 22 PLEX cards which I will use when evaluating my game.

### 2.2.4 Game engine

This sub-section looks at two game engines. An evaluation has been carried out on each of the engines a decision has been made has to which engine will be used for this project.

**Unity**

Unity is an industry standard game engine that uses C# scripting language, used for creating games such as Call of Duty. It supports development for mobile games as well as VR and AR [18]. Unity also provides tutorials and how-to videos to help new developers, winning the developer choice awards in 2018 [19](Figure 5). Unity also has its own assets store and allows a lot of plugins like Google VR.

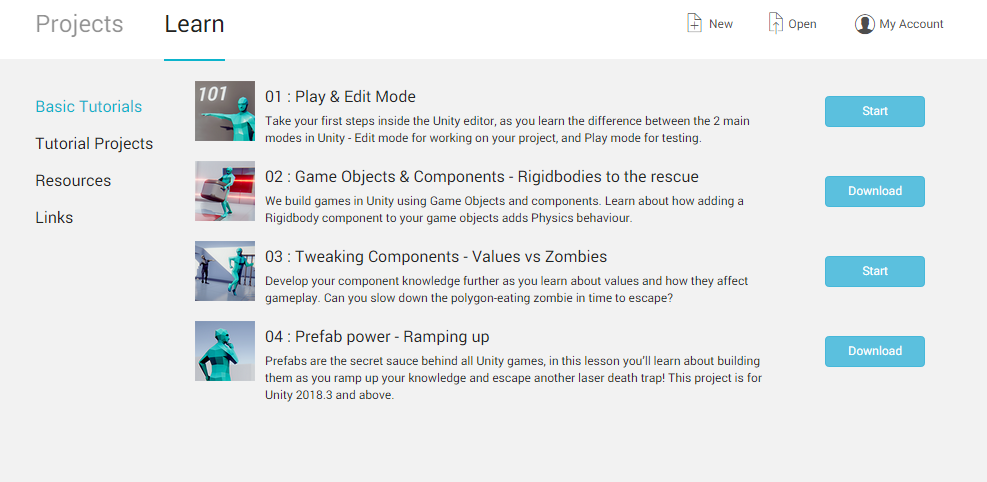


Figure . Screenshot of the Unity tutorials.

**Unreal Engine 4**

Unreal is also an industry standard game engine and uses C++ scripting language. Unreal is used for creating high-quality games for console and PC such as Fortnite. Unreal uses blueprints to visually show their scripting system [20](Figure 6). Unreal is also built for VR development and provides a full editor in VR mode.



Figure . Screenshot of Unreal engine’s blueprints.

In order to best decide which game engine to use I downloaded both and tried them out. For Unity, I completed the tutorials and found the C# scripting easy to pick up and the edit mode very intuitive to use. For Unreal engine, I watched and followed along a video tutorial on their website of how to use blueprints [21]. However, I found the blueprint system to be confusing and did not like developing in it. In an evaluation on SkyWell Software comparing Unreal and Unity for VR development, it concluded by stating that if developing for mobile then Unity is the better choice [22].

In this sub-section I evaluated two industry-leading game engines to decided which to use. I decided to use Unity as it has been stated to be the better choice for mobile development and when trying the two engines, I preferred Unity.

### 2.2.5 Virtual reality technologies

This sub-section looks at two currently available VR headsets for mobile. They will be evaluated, and a decision will be made as to which to use in this project.

**Gear VR**

The Gear VR is made by Samsung and powered by Oculus. The headset comes with a controller that allows the user to navigate menus via the touchpad, adjust volume levels, use the back and home keys and use the trigger to initiate an action. The headset also comes with a head strap so the user can comfortably wear the headset (Figure 7). A limitation to the Gear VR is that it is only compatible with the latest Samsung phones [23].



Figure . The Samsung Gear VR. [23]

**Google Cardboard**

Google Cardboard is made by Google VR and is the cheapest VR headset available [24]. The headset contains optical lenses that allow the user to see VR and has a magnetic conductive strip which is used as the input to the device [25] (Figure 8). Google VR can be used with any mobile device that can run VR apps. Google VR also provides an SDK that can be used in Unity to develop with. A limitation of the Google Cardboard is that there is no head strap and the headset must be held up to the users face for the duration of play.



Figure . Google Cardboard. [25]

In this sub-section, I evaluated two VR headsets and I chose the Google Cardboard as the VR headset for this project. The reason is that it can be used with all VR compatible smartphones whereas the Gear VR is only compatible with a select few meaning Google Cardboard is more accessible to users.

### 2.2.6 Hand tracking technologies

In this sub-section, I will research two hand tracking technologies that could be used in this project.

**ManoMotion**

ManoMotion is an SDK that uses the RGB camera in a smartphone for gesture detection and analysis. ManoMotion supports Android allowing the development of VR games on mobile [26]. However, ManoMotion is not currently available to the public thus meaning ManoMotion cannot be used on this project.

**Leap Motion**

Leap Motion is a hand tracking piece of hardware that uses infrared sensors and cameras to detect hand movements. Leap Motion also has its own software, (Orion SDK) which allows it to be integrated into both Unity and Unreal [27]. Leap Motion, however, at the time of this project, are yet to release their SDK for Android VR and Orion is not compatible with Android. In order to use the Leap Motion wirelessly on a mobile device, the use of a node.js server would be required [28]. Another problem with Leap Motion is that it has been reported on the Leap Motion forums that the software causes Unity to crash [29]. To test this issue, I downloaded the Orion SDK and the Unity core assets [30] to see if I experienced the same problems. I successfully imported the Unity assets and demo scene, but when I played the scene Unity would crash, and I experienced the same problem every time I attempted. This meant I would not be able to use Leap Motion for this project.

In this sub-section I evaluated two hand tracking technologies and discovered neither could be used for this project. Because there was no viable hand tracking available, I was not able to focus on upper limb movements such as hand and arm exercises. I decided to focus the activities on exercises for the neck instead.

### 2.2.7 Neck exercises

In this sub-section, I will research the cause of some neck problems and exercises that can help.

**Neck problems**

Neck problems can occur in many ways, such as sleeping in the wrong position, poor posture or holding the head in an unusual position for an extended period [31]. Many activities that people do in modern life involves holding the head in an unusual position, for example, texting, working on the computer or playing video games all can contribute to having neck pains [32]. Neck pain occurs when the head’s weight is magnified, this is caused by the head being tilted forward, to text on a phone or caused by bad posture while using the computer. This causes around 50 to 60 pounds of force applied to the neck, which it can not withstand over a prolonged period [33](Figure 9).



Figure . How the neck is affected by being tilted. [32]

**Solution to neck pains**

When a patient goes to a doctor or a physiotherapist for neck pain, the doctor or therapist will perform a Range of Movement (ROM) of the patient’s neck. During a ROM it will be determined how much the patient can move their neck in different directions (Figure 10). The directions are; forward flexion (moving chin to chest), extension (moving chin to air), twisting (moving the head left and right) and side bending (lateral flexion)(moving an ear to the shoulder) [34]. These measurements are important as the patient should not stretch more than they are able to. The exercises that a person can do to help neck pain are like the stretches carried out in the ROM. Exercises such as, neck tilt up and down and neck turn left and right [35]. Other exercises that help with neck pain are yoga-like stretches like a seated clasping neck stretch. This stretch involves sitting on the floor and clasping your hands behind your head pushing forwards slightly [36].



Figure . Movement direction calculated in a ROM. [37]

In this sub-section, I research some causes of neck pain and discovered one of the causes is prolonged use on a computer. While it may seem like fighting fire with fire by using a video game to help issues caused by computer use, video games have shown to be helpful for physical exercises (Section 2.2.1). I also researched exercises that help with neck pain. I decided to replicate a ROM in my game to first determine the user’s ability and use these results as a calibration for the game. The exercises I decided to focus on will be encouraging the user to move their head in four directions, up, down, left and right.

### 2.2.8 Summary

In this chapter, I researched and discovered that one of the boundaries of people completing physiotherapy is their anxiety towards the physical injury. I researched how the use of task-oriented activities can give the patient a focus while completing exercises. I also researched how the use of video games can further immerse the user and “distract” them from their physical rehabilitation. I looked at some of the current applications and video games that are used for physical therapy and decided to create a VR game on a mobile device that would promote task-oriented activities to help with exercise. For the three main classifications discussed in [9], my game classifies as the main purpose to be for health, the stage of the disease being treated is rehabilitation and the type of user will be patients and physiotherapists.

I decided to use Unity to develop my game as it is good for mobile and VR development and has the best tutorial videos. I also decided to use the Google Cardboard as my VR headset as it is compatible with all smartphones and therefore makes it accessible to as many people as possible.

After researching and trying different hand tracking technologies I discovered that there were no viable hand tracking solutions for this project. Because of this, I decided to focus my activities on exercises for the neck as neck pain, as I researched, is common and can be easily treated. I also decided that to make the game possible for everyone I will carry out a ROM on the user and use the results to calibrate the game. This means that no matter the user’s ability they can still complete the activities.

# Chapter 3. Design and Implementation

This section details what was done in this project and why. The game was created in Unity using C# scripting. For the development of this project, I followed an agile software development approach. First, I created a rough design for a section then I implemented that design, modifying if needed. I then tested the implementation in both the Unity editor and in VR, using Google Cardboard. After testing I made changes to the design and implementation according to issues and bugs if any were discovered.

## 3.1 Virtual Reality Environment

### 3.1.1 Unity Setup

The first section of the game that I created was a VR space where the player completes the activities and navigates menus. As this is the main area of the game, I wanted to ensure that it was a comfortable environment for the user, to do this I used Steven LaValle’s book ‘Virtual Reality’ as a guide of how to create a comfortable VR experience [38]. As the purpose of the game is to be able to be played at home, I designed an environment that looked like a person’s living room. I also made the decision to not allow the user to move around in the game as it would not be required to complete neck exercises and would cause motion sickness. I started implementation by setting up Unity for Google Cardboard and VR development. I imported the Google SDK for Unity [39] and loaded the demo scene. The demo scene ran correctly with no issues, so I started on my own scene.

### 3.1.2 VR Camera Setup

In the scene I started by setting up the VR camera controls by adding the GvrPointerPhysicsRaycaster component, this allowed the camera to interact with physics objects in the scene. I then added the GvrEditorEmulator to my hierarchy, this allowed me to simulate head movements in the Unity editor. I then added the GvrEventSystem to my hierarchy, the event system tracked events such as clicking or hovering. Finally, I added the GvrReticlePointer as a child object of my camera, this created a reticle so the user can interact with the world. During testing, I was able to simulate head movement by using the alt key and simulate rotating by using the Ctrl key. However, my reticle did not work as it did not show anything on the screen, where a white dot should have appeared. To fix this issue I replaced my camera with a VR camera prefab which contained scrips instead of the Gvr plug-ins [40]. I then tested the game again, with the new camera, and this time I was able to move the camera and see the reticle (Figure 11). After I got the camera working, I built the room that would be used for all my scenes.

![A close up of a beach

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Figure . A screenshot of the working VR camera.

### 3.1.3 Building the Room

I designed the room to have bright colours as to help maintain a positive attitude during rehabilitation [41]. The walls of the room were created using the cube object rescaled and duplicated three times, then positioned accordingly. I chose to use the colour green for the walls of the room and decided to no have a ceiling and have an open top room. The reason for this is because I felt it made the environment more open and less claustrophobic. Because the room was open top, I decided to keep the skybox a peaceful colour too. I decided to use a skybox texture of a bright blue sky on a sunny day, obtained from the Unity assets store [42]. For the floor of the room, I used a cube object which I scaled and positioned appropriately. The texture of the floor was of a light-coloured wood texture found in the assets store (Figure 12) [43]. After the room was created, I tested it in VR to ensure it looked appropriate. Upon testing, I discovered that the wooden floor texture looked stretched and hurt the eyes while in VR. To overcome this, I decided to just use one solid colour for the floor instead of a texture. I decided to change the floor to a dark brown. After testing with the new floor colour, I decided it was much easier on the eye and made for a pleasant VR experience (Figure 13). As the environment was to replicate a person’s living room, I designed a table and a chair to be in the scene to make if feel more lifelike. I created the table and chair out of the cube and capsule game objects and positioned them in the room. Upon testing I realised that the table and chair were behind the user so if they wanted to look at them would have to turn completely around, something not possible if the user is sitting while playing the game. I tried moving them to the front of the room, so the user does not have to move to see then but I felt that they caused a distraction from the menus. I also discovered that the table and chair were too large for the scene as they were much bigger than the user, I attempted to make the chair smaller, but it became disfigured and no longer looked like a chair. As a result of this I decided to remove the table and the chair from the environment as I felt they did not add enough to the scene and would only serve as a distraction from the activities.

![A picture containing athletic game

Description automatically 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Figure . A screenshot of the VR environment with wooden floor.

![A picture containing nature, sky

Description automatically generated](data:image/jpeg;base64,/9j/4AAQSkZJRgABAQEAYABgAAD/4RDuRXhpZgAATU0AKgAAAAgABAE7AAIAAAAMAAAISodpAAQAAAABAAAIVpydAAEAAAAYAAAQzuocAAcAAAgMAAAAPgAAAAAc6gAAAAgAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAEpvZSBEdWRnZW9uAAAFkAMAAgAAABQAABCkkAQAAgAAABQAABC4kpEAAgAAAAM1NAAAkpIAAgAAAAM1NAAA6hwABwAACAwAAAiYAAAAABzqAAAACAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAA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Figure . A screenshot of the VR environment with light brown floor.

### 3.1.4 Menus

For the user to navigate around the game they will use menus. I designed the menus to be simple with a small amount of text and buttons to press to navigate around. The menu was created by using a UI panel with text and button objects. The panel was coloured black and made slightly transparent so that the player can still see the world behind the menu. I used TextMesh pro asset for the text as it allowed for more variation in colour and style [44]. The colour I used was a gradient of yellow as this fitted in with the peaceful environment theme (Figure 14). Once the menu was made, I tested it in the Unity editor and discovered a bug with the button objects not doing anything when pressed. To overcome this bug, I used a VR button prefab that works for all VR headsets [40]. Once the buttons worked in the Unity editor, I tested in VR and realised that the menus were too close to the user and in order to read the text and press the buttons too much movement was required. This was a problem as the game is for neck rehabilitation and if the user is unable to move enough to see the menus then the game is unusable for them. To overcome this issue, I moved the menus further back into the scene so that the text is still readable and ensured the buttons were not smaller than the reticle and did not cross over (If crossed over, when pressed, two buttons would be pressed at the same time which may result in an action the user did not want). Even with the menus being moved back there is still a small limitation, as the user still needs to move slightly to press buttons. This issue will require more time to be rectified and to find a suitable solution. All this functionality is programmed in the MenuController script.

![A picture containing screenshot

Description automatically 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kKcoCjCgAewocroCXNGajzS5qRj80ZpmaM0CJM0ZpmaM0APzRmmZpc0APzRmmZozQBVzRmmZozUGo7NGabmkzQMfmjNMzRmgB2aM03NJmgB+aM0zNGaAH5pM03NGaAHZozTM0ZoAfmjNMzRmgB+aM0zNLmgB2aM03NGaAH5ozTM0ZoAfmjNMzRmgB+aM0zNGaAH5ozTM0ZoAfmjNMzRmgB+aXNR5ozQIkzRmo80ZoAfmjNMzRmgQ/NGaZmlzQA/NGaZmjNAh+aM0zNGaYh+aM0zNGaAH5ozTM0ZoAfmjNMzRmgB+aXNMzRmgB+aM0zNGaAH5ozTM0ZoAfmlzTM0ZoAfmjNMzRmmA/NLmo80uaQD80ZpmaM0wH5pc1HmlzQIfmjNMzRmgZJmjNMzRmgQ/NLmo80ZoAkzRmmZozQA/NLmo80uaAH5ozTM0ZoAkzRmmZozQBVzRmm5ozUmo7NGaZmjNADs0ZpuaM0AOzRmmZozSAfmkzTc0ZoAdmjNNzRmgB2aM0zNGaAH5ozTM0ZoAfmjNMzRmgB+aM0zNGaAH5ozTM0ZoAfmjNMzRmgB+aM0zNLmgB2aM03NGaAHZozTM0uaAHZpc0zNGaAH5ozTM0ZoEOzRmm5ozQA7NLmmZozTEPzRmmZpc0AOzS5pmaM0CH5ozTM0ZoAfmjNMzS5oAdmjNNzRmgB2aXNMzRmgB+aM0zNLmgB2aM03NGaAHZozTc0ZoAfmjNNzRmgQ7NGabmjNMB2aXNMzS5oAdmjNNzRmgB2aXNMzRmgB+aM03NGaAHZpc0zNGaAH5ozTM0uaAH5ozTM0ZoAfmjNNzRmmA/NGaZmjNAFeiiioNAooooASiiigAooooAKKKKACkoooAKKKKACiiigAooooAKKKKACiiigAooooAKKKKACiiigAooooAKBRRQAtFFFAgooooAKKKKACiiimIKWiigAooooAKKKKBBRRRQAUUUUAApaKKACiiigApRRRQIKKKKBhRRRQAtFFFAgooooAWiiigAooooAKWiigBaKKKACiiimAUtFFABRRRQB/9k=)

Figure . A screenshot of a menu in my game.

I added a final feature to the main page of when the puzzle and the follow the cube activities are completed another button appears. This button allows the user to save the data collected while playing the game. Such data includes the angles collected in the ROM and the time I took to complete each activity. This data could then be used by a physiotherapist to monitor the users progress.

## 3.2 Range of Movement

To ensure the game is possible for all users I created an activity that would calibrate the rest of the game. This activity was designed to replicate a Range of Movement (Section 2.2.7). The user would be instructed to move their head in different directions and once in a comfortable position the user will press the input button on the headset. The angle will then be recorded at the position the user is looking. The angles were stored in a static class so that they can be accessed by any script at any point in the game and be used for the calibration of each activity. After the user has looked in the first instructed direction, the text on the UI panel changes to a new direction, for example from look left to look right, this is continued until all four directions are recorded (Figure 15). When testing this activity, I discovered that the angle for when the user looked left and up could not be correct as they were over 300 degrees. I then worked out that the reason for this bug was because the method “Camera.main.transform.eulerAngles” records the angle in 360 degrees clockwise from the origin position, and as looking left and up meant moving anti-clockwise this caused the high readings. To rectify the bug when recording the angle for left and up I subtracted it from 360.

Another issue I found while testing was that it was unclear whether the game had recorded the angle. The only indication was the text changing on the UI, however, the user would be moving and looking away from the UI and not able to see the text changing. To rectify this, I moved the UI with the user so that they can always see the text and know when it has changed which indicates the angle has been recorded. Upon testing this solution, I realised that the UI moving with the user caused disorientation as it felt like I had not moved at all. To solve the problem, I kept the UI static and used sound to indicate when the angle had been recorded. When the user moves to the direction and presses the input button, they hear a ‘dong’ to indicate that the game has recorded the angle information correctly and allows the user to continue with the calibration. The audio sound was found in the assets store [45]. All this functionality was programmed in the ROM script and attached to the UI panel to control the scene.

To ensure that the user does the calibration before the activities when the user first loads the game, they will only have access to this activity. Once this activity is completed, they will be able to do the other activities. There is a limitation in this activity of not checking the user has done the directions in the correct order. For example, there is nothing stopping the user looking right when they were supposed to look left and the angle being recorded for the left angle. This does mean that there is a level of trust in the user to ensure they calibrate correctly.



Figure . A screenshot of the ROM calibration activity.

## 3.3 Puzzles

### 3.3.1 Overview of Activity

This activity is a puzzle which is designed to promote exercise of the neck by moving left and right. The goal of the activity is to complete the puzzle by clicking on the pieces and dragging them onto the panel into the correct position. The puzzle is placed onto a panel, which is a cube object, that has been divided into a two by three grid meaning the puzzle has six pieces. The pieces, which are a prefab object [40], are located three on the left and three on the right, of the panel, with their exact positions determined by the difficulty and calibration.

There are three puzzles to complete all with a different image to create. The images are open source pictures found online (Figure 16)(Figure 17)(Figure 18) [46] [47] [48]. The puzzle will combine both physical activity and cognitive activity as the pieces for each puzzle will not be in the same place. However, the pieces for each individual puzzle will always be in the same position order. For example, the top left piece in puzzle one will be in a different position than puzzle 2 but will always be in the same position order when the game is played over.

### 3.3.2 Development of Puzzle

The user completes the puzzle by clicking and dragging the pieces. This is done by using a draggable script which is attached to each of the pieces. A piece can have one of three states, ready, dragging or blocked. In the script there is an event that handles the click of the input button. On click, the distance from the user to the piece will be checked to see if the piece is within range to be picked up, the state of the piece will also be checked to see if it is ready. If a piece can be picked up it will appear at a short distance away from the users view and they will be able to move it around. If the state of the piece is dragging when clicked the script will change the state of the piece to ready and call the onDrop event stored in the PieceController script.

The PieceController script stores the correct cell position of each piece, which was inputted using the Unity editor, and stores the current cell position. The initial position and rotation of the piece after calibration is stored in the script for later use. The script also includes four events, HandleDrag, HandleDrop, HandleCompletion and HandleFailure. The HandleDrag event is triggered when a piece is picked up and only changes the isPlaced flag to false. The HandleDrop event is triggered when a piece is dropped. The event checks if the piece has been placed onto the puzzle panel by using a Raycaster from the piece, to check if it collides with the panel. If the piece is placed on the puzzle, then the HandlePuzzleDrop method is called. If the piece is not placed onto the panel the event exits. The HandlePuzzleDrop method get the cell location from the PuzzleController script and checks if there is already another piece there. If there is, the piece goes back to its initial position which is saved in the PieceContoller script. If the cell is free, then the piece will snap into the cell and the CheckCompletion method from the PuzzleController script will be called. The other two events are triggered by the PuzzleController class defining what happens to the pieces. HandleCompletion sets the state of all pieces to blocked as the puzzle is complete, HandleFailure sets all the pieces back to their initial positions as the puzzle was incorrect.

The CheckCompletion method, in the PuzzleController script, first checks if all the pieces are placed on the panel. If they are not, then the puzzle cannot be completed, and the method exits. If they are all placed, the method then checks if the pieces are in the correct cell. If they are not in the correct cells, then the OnFailure event is triggered which triggers the HandleFailure event in PieceController. If this event is triggered all the pieces go back to their original positions. If all the pieces are in the correct cells, then the OnCompletion event is triggered which triggers the HandleCompletion event. The menu appears which allows the user to either go back to the main menu or to the next puzzle. If the user has completed all three puzzles, they will only be able to go back to the main menu.

After the scripts were wrote I tested the scene in both Unity and VR and discovered that when the pieces were picked up, they were too close to the user and it made it difficult to see the puzzle behind, adding an unintended difficulty. To resolve this issue, I tweaked the value, in the draggable script, that defined this distance until I found a suitable value of 3 Unity units.

Once the functionality of the puzzle was complete, I added textures to the pieces so that the user can identify which piece goes where. To do this I used an online tool [49] to split the images [46] [47] [48], into six equal parts. I imported the images into Unity and used them to create materials. I put the materials onto the pieces prefab by dragging and dropping in the editor. Upon testing I discovered a bug in the prefab of that the name of the piece is not the same as the texture and correct position, i.e. piece 0-0 with texture 0-0 does not go into position 0-0. To overcome this issue, I moved the textures around so that they match the correct position and not the name of the piece, for example piece 0-0 has texture 2-1 and correct position 2-1. It is worth noting that as the piece is a prefab, I was unable to rename it.

### 3.3.3 Calibration and Difficulty Setting of the Puzzle

To ensure the activity is possible for everyone, no matter their ability, I used the angles recorded from the ROM to calibrate the activity by positioning the pieces into positions that the user can reach. The calculations for this were done and applied in the PuzzleController script. The first thing I did was read in the left and right angles from the static script and make slight changes to their value based off the difficulty. I then used a static value on the x axis and trigonometry to calculate a position on the z axis from the angle recorded. I did this for both the left and right angles as the user may be able to look further in one direction. I then checked if the piece was on the left or the right of the origin by checking its x value (positive on right, negative on left) and changed the z value of the piece to the appropriate position. To ensure the pieces did not overlap I also used an offset value of 1 Unity unit applied to the z value of the left and right pieces separately. The offset value meant the furthest out piece would be at the position calculated from the angle and the other pieces would be further in towards the panel. After the pieces have been moved their position and rotation is saved in the PieceController script. Upon testing, I discovered that if the user can only move 10 degrees either left or right then the pieces would spawn too far away from the user and in some cases not even in the room. To overcome this, I check the value of z after the position is calculated and if it is greater than 5.15 Unity units, I limit it to 5.2 Unity units and change the x axis as well, using the same trigonometry method.

To determine the difficulty of the puzzle a timer is used. The timer starts as soon as the user presses start on the puzzle and stops when the puzzle is completed; all pieces are blocked when the timer is not running so that an accurate time to complete the puzzle can be determined. If a puzzle is completed under 10 seconds the difficulty of the next puzzle will increase. This is done because if the user can complete the puzzle without an issue they should be challenged to move further and do more exercise. It is important not to increase the difficulty if the user did not easily complete puzzle as they do not want to hurt themselves or make any injury worse. At difficulty one, the pieces will be calibrated at the angle from the ROM – 2.5 degrees. At difficulty two, the pieces will calibrate at the angle from the ROM. At difficulty three, the pieces will calibrate at the angle from the ROM + 2.5. The timer is shown to the user after they complete the activity so they can see how long it took and can monitor their own progress. The timer for each puzzle is also sorted in the static class so that they can be saved as part of the data that can be used by a physiotherapist to monitor progression.

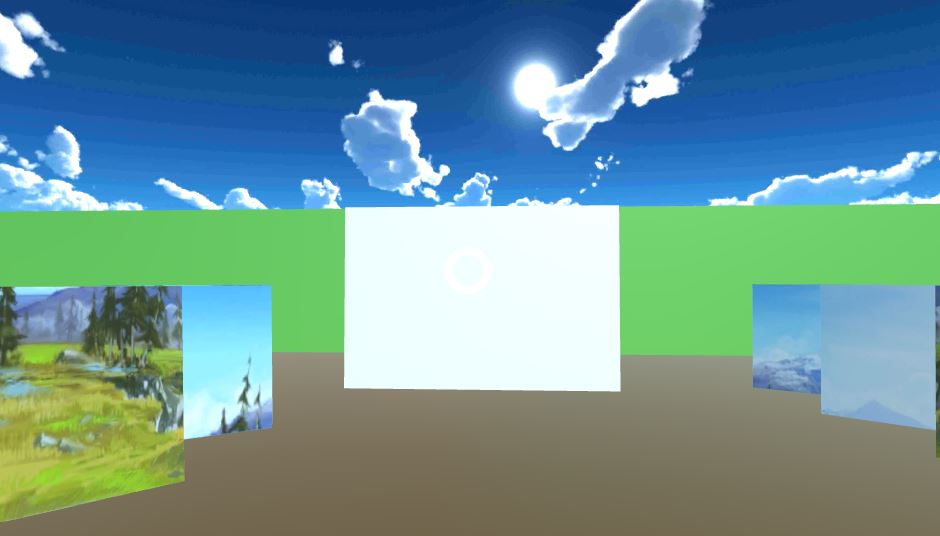


Figure . A screenshot of puzzle 1 showing the pieces after calibration.

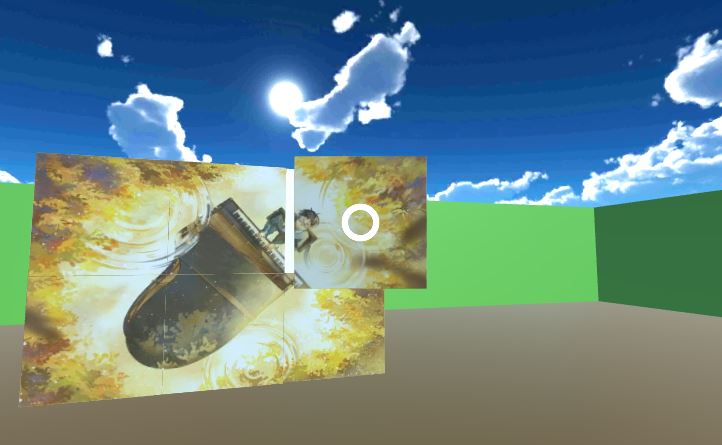


Figure . A screenshot of puzzle 2 nearly completed.

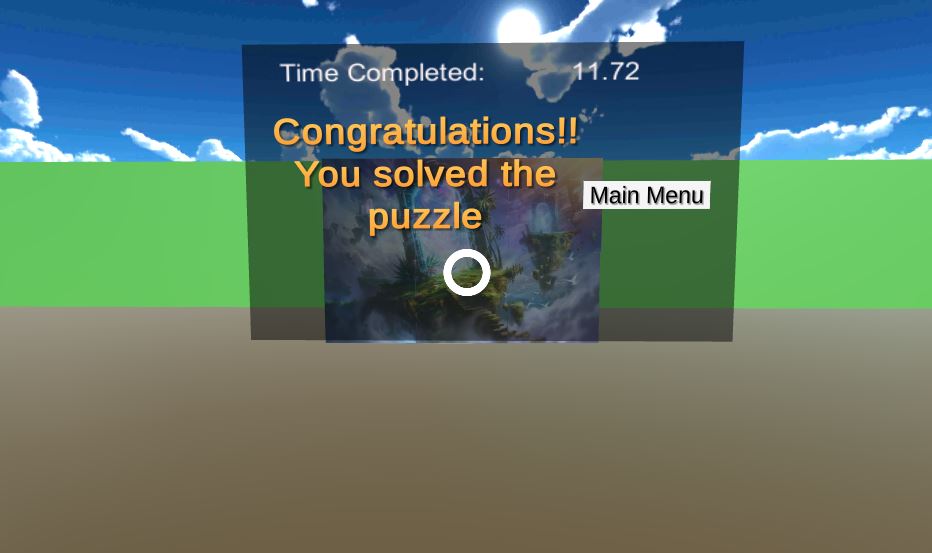


Figure . A screenshot of puzzle 3 completed.

## 3.4 Follow the Cube

### 3.4.1 Overview of Activity

The second activity in the game is follow the cube. The aim of the game is to look at the cube as it moves around the world. This helps with neck exercise by getting the user to move their head up, down, left and right (Figure 19).

### 3.4.2 Original Design

I originally designed this activity to be Simon says and the user would move in the direction instructed. During the activity I would track the movement of the user by calculating the change in angle over a period and using this to determine which direction the user has looked. To do this I wrote a HeadTracking script that would read the angle the user was looking at the start of the activity and after 5 seconds would read the angle again and calculate the difference. If the difference was greater than a specified threshold then a movement would have been detected. If a movement had been detected the difference was used to determine which direction the user looked in, for example if the difference was positive on the x axis the user looked right. After testing this script, I discovered that it would not set the origin point correctly as when the activity started the user is not always looking at 0,0. Another issue I discovered with this approach is that if the user moves their head rapidly the direction does not get detected. Another issue was that if the user looked left then back to the centre the game detects this as looking right, not back to the origin. To overcome this, I decided it was best to create objects at positions I wanted the user to look and use raycasting to determine if the user is looking at them. This spawned the design for follow the cube.

### 3.4.3 Development of Follow the Cube

For the activity I created five cube objects and named them, north, south, east, west and centre and arranged them into a plus shape with the centre cube in the middle. When playing the game, a round will consist of looking at the cube then back to the centre then another round starts. At the start of the game I set all the cubes to not be active and a direction, one of north, south, east or west, is chosen at random. That cube will appear on the screen and the user will look at it, when the look as been detected the cube will disappear and the centre cube will appear. The user will then look at that cube and when the look has been detected a new round will start and another direction randomly chosen. This functionality is programmed in the FollowTheCube script. The maximum rounds are set at 6 but can be changed in the Unity editor, and in real world application could be changed by a physiotherapist. In order to detect where the user is looking, and subsequently if they are looking at the active cube, I created the HeadMovement script. In the script a Raycast is used every frame and returns the object that the user is looking at. After each round the cubes move out from the centre by 0.25 Unity units in order to encourage more movement and exercise. Upon testing the activity I discovered a similar problem as to the ROM, when the user looked at the cube it just disappeared and there was no indication that the game was progressing, as depending on how far the cube was, the user may not see the centre cube appear. To overcome this, I added and audio response [45] to trigger when the user is looking at the cube so they can tell if they were successful.

### 3.4.4 Calibration of Follow the Cube

To ensure that the user can move far enough to be able to look at the cube and complete the activity I calibrated the maximum distance that the cubes can move. To calculate this, I used the angles collected in the ROM and for each direction calculated the maximum value for either the x or y axis. I used a constant value on the z axis and trigonometry to calculate the maximum distance. This distance was used when moving the cubes to ensure they did not go further than what the user could reach. Upon testing the activity, with the calibration, I discovered that it could still be difficult for the user to reach the cube. To overcome this, I added timer for each round, when the timer reached more than five seconds the cubes started to slowly move back towards the centre, to a position the user can reach. An overall timer of the activity was also recorded and is passed as part of the data to the physiotherapist.

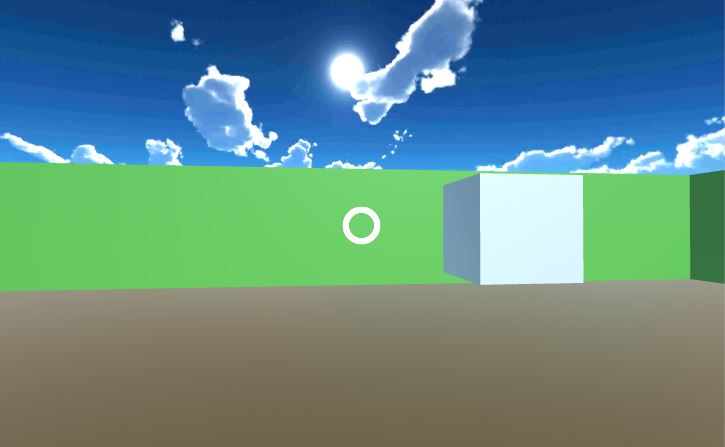


Figure . A screenshot of the Follow the Cube activity.

## 3.5 Modifying the Virtual Reality Headset

In section 2.2.5 where I evaluated the VR headsets that could be used for this project, I decided to use the Google Cardboard despite it having a limitation of having no head strap. While testing my game using the headset, I discovered that it could cause arm pain by having to hold it up to the face. To rectify this I, along with the help of the owner of a craft business [50], made a headband for the headset so the user can where it without the use of their hands (Figure 20). The headband is elastic and will stretch to fit most people and is attached via Velcro meaning it can be removed. Upon testing the headset, I discovered that the bottom of the headset would dig into the face and cause discomfort. To overcome this, I stuck some foam felt to the headset so that it sits on the face more comfortably.



Figure . A photo of the modified Google Cardboard.

# Chapter 4. Evaluation

In this chapter I will evaluate my game in three different aspects. Firstly, I will evaluate how the calibration of the game affects the user’s ability to complete the activities. I will then evaluate the sensors of the hardware and how discuss how the data collected can be used. I will then also evaluate the enjoyment of the game, as the purpose of the game is to distract users from their anxiety.

## 4.1 Calibration effect on users

In this section, I will evaluate if the calibration of the game affects the user’s ability to complete the game. The calibration is calculated from the users range of movement (Section 3.2) and it is important to ensure they are still able to complete the game in a similar amount of time as somebody with a different range of movement.

To gather the data for this evaluation I calibrated the game at random angles in the directions left, right up and down. The reason why I chose to do them randomly was because I wanted to replicate real life as closely as possible as people can move a variety of distances and are not structured, for example a person is unlikely to be able to move exactly 20 degrees. I also ensured for some calibrations that the left and right were different values as some people can move one direction more than the other due to the nature of their injuries. Another reason for gathering the data myself was that I already knew where the puzzle pieces went therefore removing most of the cognitive aspects of the activities as the calibration only affects the user’s physical ability. An additional reason for gathering the data by myself as that due to the nature of the game, to help rehabilitation for a neck injury, if I used users with a neck injury and the game did not calibrate correctly there is a risk of making the user’s injury worse. This was a risk I felt was not needed for this evaluation. A limitation of gathering data in this method is that I can also evaluate up to the maximum direction that I can move. This means that I have not fully evaluated all the angles that a person could look but can only infer from the data gathered. In the future I would like to have other users calibrate the game and play the activities. I would have to ensure that the users do not have any past neck injuries and if the user started to struggle, I would stop the evaluation immediately. The use of other users would however introduce the cognitive aspect which would have to be considered when evaluating the data.

After the data was collected, I calculated an average calibration angle for left and right and an average calibration angle for all four directions. I also calculated an average time to complete the three puzzle activities. The full tables of results can be seen in the supplementary material (Calibration data). From the data I created the following graphs. Graph 1 shows the average time taken to complete the puzzles at different calibration angles. The calibration angles used for this graph were the average of the left and right calibration angles. Graph 2 shows the average time taken to complete follow the cube at different calibration angles. The calibration angles used for this graph were the average of all four directions.

Figure . A graph to show the average time taken, to complete the puzzles, at different calibration angles.

Figure . A graph to show the time taken, to complete follow the cube, at different calibration angles.

The results I expected to see is that the calibration angle does not influence the time it takes to complete the activities as the game has calibrated to the user’s range of movement. From the results gathered and from the graphs I can see that as the calibration angle changes there is very little effect in the time taken to complete the activities. In graph 1 the average time taken to complete the puzzles is between 12 to 14 seconds, as indicated by the trendline, no matter what the calibration angle is. In graph 2 the time taken to complete follow the cube is between 9 to 10 seconds and creates a nearly flat trendline. From the graphs and the data, it can be evaluated that the calibration angle has no effect on the time taken to complete the activities. It can be inferred from this result that the game calibrates correctly to the users range of movement. It can also be evaluated that no matter the users range of movement they can still complete the activities in a similar amount of time as anybody else and are not restricted by the extent of their physical injury.

## 4.2 Hardware Sensors

In this section I will evaluate the hardware sensors of my device and determine whether jerk can be detected. Jerk is the 3rd derivative of displacement and is causes by rapid changes in acceleration. Jerk can be felt by human when stopping in a car suddenly, or in this case, tremors in the head. The tremors can occur due to physical activity and can be a sign of the user struggling to complete an activity [51]. In this project jerk can occur when the user is trying to look further than they can reach and causing physical pressure on the neck. It is important for the hardware to detect jerk as it can be used by a physiotherapist, when reviewing the data, to determine when the user has had an issue in game.

To gather data for this evaluation I played the game on my device and exported the time and the angle to which I was looking every frame. My device is a Samsung Galaxy S8 [52]. In order to collect the data, I played the puzzles activity only moving the pieces on the right, after about 2 seconds I simulated a tremor by shaking my head rapidly left and right over a short distance. A limitation of this method is that I only used one device and, in the future, would like to ensure jerk can be detected on all devices that can run the game. After I exported the angles, I used trigonometry to calculate position and in turn calculate displacement. I then differentiated displacement three times with the change in time to calculate jerk. A full table of calculations can be seen in the supplementary material (Jerk data). Graph 3 shows the change in jerk as time progresses.

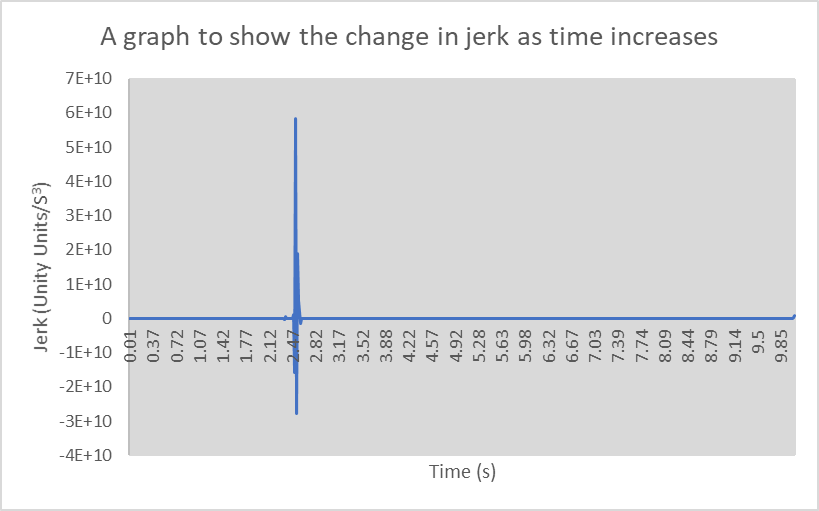


Figure . A graph to show change in jerk as time increases.

The expected result for the data would be a flat line along the x axis until around 2 seconds where large peaks in both directions would occur. From graph 3 as I was moving the pieces there was not a rapid change in jerk. At around 2.47 seconds, when a tremor was simulated, large peaks in both the positive and negative y axis occurs signifying a rapid change in jerk. From this date it can be evaluated that the hardware is able to detect jerk and when a large change occurs. Currently my game does nothing to help the user that data only shows when a tremor occurs.

## 4.3 Game enjoyment evaluation

In this section I will evaluate how many of the PLEX cards (Section2.2.3) [17] my game has and uses this to determine if my game is enjoyable. A description for each experience can be seen in Appendix B. Table 1 shows which of the experiences my game has and the rationale of why my game has the experience is found beneath the table. Table 1 also shows the experiences that the tele-motion game has (Section 2.2.2). As tele-motion is not available to the public, I have made this evaluation based off their paper describing the game [12].

|  |  |  |
| --- | --- | --- |
| **Experience** | **Does my game contain the experience?** | **Does tele-motion contain the experience?** |
| Captivation | ✓ | ✓ |
| Challenge | ✓ | ✓ |
| Competition | ✓ | ✓ |
| Completion | ✓ | ✓ |
| Control | ✓ | ✓ |
| Cruelty | ✕ | ✕ |
| Discovery | ✓ | ✓ |
| Eroticism | ✕ | ✕ |
| Exploration | ✕ | ✕ |
| Expression | ✕ | ✓ |
| Fantasy | ✕ | ✕ |
| Fellowship | ✓ | ✓ |
| Humour | ✕ | ✓ |
| Nurture | ✓ | ✓ |
| Relaxation | ✕ | ✓ |
| Sensation | ✕ | ✕ |
| Simulation | ✓ | ✓ |
| Submission | ✕ | ✕ |
| Subversion | ✕ | ✕ |
| Suffering | ✕ | ✕ |
| Sympathy | ✕ | ✕ |
| Thrill | ✕ | ✕ |

Table . A table to show which playful experiences my game has, and tele-motion has.

The following is an explanation why my game has the experiences indicated in table 1.

Captivation: My game has this experience as the user is in a VR environment and can only see and focus on this environment.

Challenge: My game does have an aspect of challenge in the puzzle activities.

Competition: My game has a slight aspect of competition as the user would want to complete the activities faster than their previous attempt.

Completion: My game has an aspect of completion as the use completes activities throughout the game.

Control: My game has a slight aspect of control as they can decided which activity they want to do and can control the movement of the puzzle pieces.

Discovery: My game has an aspect of discovery as using VR can be a new experience for some people.

Fellowship: My game has a slight aspect of fellowship as the game is designed to be used in conjunction with a physiotherapist.

Nurture: My game has an experience of nurture as the main purpose of the game is for physical rehabilitation.

Simulation: My game does have an experience of simulation as the game is designed to replicate physical activities completed in physiotherapy. My game also replicates a range of movement of the neck.

Overall my game has some playful experiences and while the framework does not specify how many experiences a game must have to be considered enjoyable, I would conclude that my game would need more playful experiences to defined it as enjoyable. I feel like my game could have experiences such as, humour, expression and exploration to further increase the enjoyment of my game. The aim of this project was to create a game to ‘distract’ users and help with physiotherapy, while I do have the captivating experience which will help the distract and the nurture experience which is the physiotherapy, I also wanted the user to enjoy playing the game and completing the activities, something I do not think I have quite done. My game in comparison to the tele-motion system has less enjoyable experiences. Tele-motion has an experience of expression by allowing the user and the clinician to customise the games where as my game does not. The tele-motion also has an experience of humour by using cartoon like graphics in the pizza game. A limitation of this evaluation is, that due to time constraints, that the evaluation is my opinion only and, in the future, I would like to have users play my game and see which experiences they fell the game has.

## 4.4 Summary

In this chapter I evaluated my game in three different aspects. First, I evaluated if the calibration in my game effected the user’s ability to complete the game. I evaluated that a user can complete the activities in the game at a similar time to another user even if they have different calibrations and thus a different range of movement. Secondly, I evaluated if the hardware was able to detect jerk while the user is playing the game. I evaluated that the sensors can detect jerk and when rapid increases in jerk occurs. This rapid increase could be caused by a tremor and the information can be used to determine if the user is struggling to do a certain activity. Finally, I evaluated the enjoyment of my game. I evaluated that while my game has some playful experiences, I would not define it as enjoyable.

# Chapter 5. Conclusion

## 5.1 Satisfaction of the Aim and Objectives

The overall aim for this project was to create a VR game to help with physical rehabilitation. To do this I split the aim into 5 objectives:

1. Research the current serious games for health and VR technologies and identify which technologies to use in my project.

This objective was fulfilled in my background research, in chapter 2, through researching academic papers on serious games for health and evaluating current serious games for health. I also researched the available hardware and software. For this objective I chose to use Unity and Google Cardboard as the technologies for my project.

1. Use the chosen software to develop a VR environment.

This objective was fulfilled by using Unity to build a VR room environment where the user would partake in activities. The implementation of the VR environment is detailed in chapter 3.

1. Design and develop activities to replicate neck rehabilitation exercises.

This objective was fulfilled by the implementation of the puzzle activities and the follow the cube activity. The exercises replicated are moving the neck in four directions; up, down, left and right. The implementation of the activities is detailed in chapter 3.

1. Determine the ability of the user and adapt the game accordingly.

This objective was fulfilled by the implementation of the range of movement activity. The data calculated in the activity was used to calibrate the activities to the user’s ability. The implementation of the Range of movement activity and the calibration of the other activities is detailed in chapter 3.

1. Evaluate how the user’s ability affects the time taken to complete tasks.

This objective was fulfilled by the evaluation of the calibration effect on the time taken to complete the activities. The evaluation is detailed in chapter 4. For this objective the term user’s ability should have be redefined to the user’s range of movement, as it is not clear what area of the user’s ability was to be evaluated.

Overall, I have met all the objectives set up to complete this project. I have also met my overall aim as I have created a VR game that helps with neck rehabilitation.

## 5.2 Personal Development

Throughout this project I have learnt that project management has been a key part of my success in this dissertation by setting soft deadlines for milestones which must be reached to keep the project flowing. I have also learnt how to efficiently and effectively research problem areas. This has been done using academic papers and online articles and pages. I learnt about how video games can be used for education and rehabilitation not just for enjoyment and learnt the process of neck rehabilitation.

Also, throughout this project I have developed my programming skills and taught myself how to use Unity as it is software I have never used before. I have also learnt how to write programming scrips in C# a language I have never used. Another new area that I have never worked with was creating a game for VR. I learnt how to not only program for VR games but how to design a VR game to be an enjoyable experience for the user. I also developed my problem-solving skills by being able to overcome and solve any issues in my game during development.

## 5.3 Future work

The future development of this project I have split into 2 sections. What I would like to change about my game or add to it. How I would implement my game so that it can be used in the real world.

### 5.3.1 Further Development to the Game

If I had more time to work on this project, I would make some minor changes to my game. One change I would make would be to my menus as they do not currently calibrate to the user’s range of movement. I would like the buttons to be closer to the origin of the screen. I would also like to change the input of instead of having to press the input button on the headset the user could just stare at an object to select it, with the use of a progression bar (Perhaps the reticle starts to fill with a different colour) so the user knows that they are selecting an object.

I would like to add to my game by developing more activities that help other parts of the body. I would also like to have different activities to replicate the same exercise so that the user has a range of activities to do during their rehabilitation without the activities becoming repetitive. I would also like to add a range of different locations that the user can complete the activities in. For example, at the beach or in a park. I would also like to add a feature where the user could take a 360 picture and use that as their environment, to allow personalisation. Another feature I would like to add to my game is for it to react to when the hardware detects a tremor through jerk. I would like the game to not only record when a tremor occurs but aid the user, for example move a puzzle piece closer to the origin.

I would also like to add more playful experiences to my game. Experiences such as, fantasy, where the user could complete activities in a fantasy world, for example, in space. Relaxation, this could be done through an activity that focuses on relaxation breathing techniques. Sensation, this could be done using haptic feedback, for example if the user is in a park environment, they would be able to feel the sensation of wind blowing. I will use my evaluation of the tele-motion to develop ideas as to how to make my game more enjoyable.

### 5.3.2 Real World Application

In the real world my game would be used by physiotherapists to give to patients to complete physical activities required for their rehabilitation at home. The physiotherapist after a rehabilitation appointment would give the user the game so that they continue doing the activities in their own time, but the data can be recorded and used to determine the progress of the user and make changes to their rehabilitation. From the data the physiotherapist can see how long it took the user to do each task and can see if they had a tremor at any point and what caused it. They would also be able to see the user’s range of movement and can determine if the user needs help in a direction.

I would also like to develop a companion interface that would be used by the physiotherapist that controls some aspects of the game. For example, they can change the number of rounds in the follow the cube activity, like in the Unity editor. This interface could also allow for personalisation of the game by allowing the user to import their own pieces for the puzzle activity.

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# Appendix

## Appendix A - Original Objectives

The following is the list of my original objectives for this dissertation.

1) Research the current VR and hand tracking technologies and identify which are the best for use in my project.

2) Use the chosen software to develop a VR environment.

3) Design and develop three activities to replicate physical rehabilitation for stroke victims.

4) Evaluate the accuracy to which the game can recognise hand movements and the completion of activities.

## Appendix B – PLEX Cards Experiences Descriptions

The following table give a description for each of the PLEX cards as defined by Lucero, A *et. al* [17]*.*

|  |  |
| --- | --- |
| **Experience** | **Description** |
| Captivation | Forgetting one’s surroundings. |
| Challenge | Testing abilities in a demanding task. |
| Competition | Contest with oneself or an opponent. |
| Completion | Finishing a major task, closure. |
| Control | Dominating, commanding, regulating. |
| Cruelty | Causing mental or physical pain. |
| Discovery | Finding something new or unknown. |
| Eroticism | A sexually arousing experience. |
| Exploration | Investigation an object or situation. |
| Expression | Manifesting oneself creatively. |
| Fantasy | An imagined experience. |
| Fellowship | Friendship, communality, or intimacy. |
| Humour | Fun, joy, amusement, jokes, gags. |
| Nurture | Taking care of oneself or others. |
| Relaxation | Relief from the bodily or mental work. |
| Sensation | Excitement by stimulating senses. |
| Simulation | An imitation of everyday life. |
| Submission | Being part of a larger structure. |
| Subversion | Breaking social rules and norms. |
| Suffering | Experience of loss, frustration, anger. |
| Sympathy | Sharing emotional feelings. |
| Thrill | Excitement derived from risk, danger. |

Table . Descriptions of the playful experiences defined by the PLEX framework.