# Game for Rehabilitation of Hand Movements Post Stroke

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# Abstract

This dissertation researches how to design an effective game to rehabilitate patients who have suffered from stroke. In particular, it focusses on the implementation of hand tracking from a camera and voice translations from a microphone and evaluates their effectiveness. Multiple gamemodes are designed that retain the user's interest and successfully exercise their affected muscles, as well as improving some other aspects such as memory, cognitive ability and mental wellbeing.

A summary of the research undertaken in this project is presented and the program's implementation is explained in detail. The effectiveness of the hand tracking and voice translation functions are tested, evaluated and presented.

# Acknowledgements

I would like to thank my supervisor, Dr. Gary Ushaw, for the guidance and support provided to me during meetings and feedback throughout the project.

# Declaration

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

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# Section 1: Introduction

## 1.1 Introduction
This section details the structure and layout of the dissertation project and the author's motivation and rationale behind it, explaining the reason for the project's completion. The aims and objectives will explain the main expectations of the dissertation, allowing for a proper evaluation once completed.

## 1.2 Dissertation Structure
Section 1 explains the reason and motivation behind the project, detailing the requirement for a game for rehabilitation of stroke. The aims and objectives that the author plans to complete will be set out, allowing for an evaluation at the end of the project.

Section 2 provides a review of the background information researched for the project, including the requirements and restrictions of rehabilitation of stroke and the main practises to be followed when making a game of this nature. It also includes information found on accessibility features and hand tracking techniques. This information forms the foundation for creating a successful project following these key practises.

Section 3 explains how the program was constructed in order to meet the specified aims and objectives. This includes detail about how the hand tracking works within PyCharm and Unity and how the gestures are analysed. It also explains the different game modes that were chosen and how their in-game analysis functions to encourage improvement in the recovery process, as well as how the game is kept fun and interesting.

Section 4 talks through the tests carried out to ensure that the hand tracking and voice translation features worked efficiently to achieve their respective objective.

Section 5 provides a conclusion to evaluate the progress made towards the aims and objectives. The whole project will be critically evaluated to highlight areas that worked well and areas that could have been improved on or expanded in the future.

## 1.3 Motivation and Rationale
Strokes are a very significant health issue. In England, 1.81% of the population have been affected by stroke, with 124,624 people being admitted to hospital. Within the whole of the UK there are 1.3 million stroke survivors [1].

In the UK stroke is the most common disease that causes long term disability. This is caused by damage and loss of neural pathways in the brain. However, through repeated exercise, patients may relearn their lost limb movements and build new neural pathways [2].

The NHS provides rehabilitation for stroke patients, which is aided with apparatus such as supports and treadmills. When the team believes the patient is able to return home, they are discharged with exercises to perform on their own.

When at home success rates with rehabilitation vary. It is believed that the greatest barrier to home rehabilitation is a lack of motivation. Studies have shown that 50% of patients at home have diminished activity level which leads to further negative health effects. [3]

There are also issues with the capabilities of the NHS to see and care for patients. The proportion of patients directly admitted to a specialist stroke unit within 4 hours of arrival has been dropping dramatically since 2021. The proportion of patients receiving a 6-month assessment is dropping too, with most check-ups being by telephone or online instead of in person [1].

## 1.4 Aims

The overall aim of this project is to develop a video game to encourage stroke patients to keep active and moving at home. Due to my lack of access to the specialised equipment and apparatus typically available in hospital settings for immediate post-stroke recovery, the project will be focused on home recovery, where patients do not require as much support. This also helps to promote self-directed recovery in a familiar environment.

The game will utilise a camera to track hand movements made by the player. The player will play through multiple minigames chosen at random each day to encourage consistent movement and exercise of the muscles in the hand in an exciting and interesting way.

The patients progress will be assessed throughout each game to monitor their recovery. The facts will be presented through quantitative data. A positive attitude will be maintained with the patients to provide encouragement and prevent feelings of discouragement during gameplay.

The overall success of the program will be based upon the effectiveness of the hand tracking technology within Unity. If the hand tracking is efficient this provides a smooth gameplay experience for the player to complete their minigames and progress. Any issues with the smoothness of the gameplay experience have the potential to cause irritation, thereby compromising the success of the rehabilitation process.

## 1.5 Objectives

1 - Research and identify hand tracking and accessibility techniques to be implemented
The techniques used to implement hand tracking and successful voice to text translations need to be researched to ensure they can be implemented successfully. This includes their basic functionality as well as more complex techniques that ensures that the functions work efficiently. This covers methods such adjusting the sensitivity of the camera tracking and comparing different tools to figure out which works best.

2 - Implement effective hand tracking that has a success rate of over 90%
Given that the hand tracking is the central function, its implementation must be precise and accurate. The application should correctly calibrate and position the user's hands within the 3D Unity environment and should operate flawlessly without encountering any issues in accurately tracing hand movements across the screen. If this isn't effective it could potentially frustrate the user, causing them to stop playing. If the tracking is 90% effective or more, this should provide the user with smooth gameplay.

3 - Properly evaluate progress made by the user and display this as quantitative data
Given that the game is for rehabilitation the progress the user makes should be stored and analysed to ensure they are improving. This progress should also be incorporated into difficulty settings for the game so that there is an extra challenge to encourage the patient to improve at a level where they can remain comfortable. The data should be presented factually but always present positive feedback to keep the user feeling encouraged.

4 - Research and implement encouraging gameplay and supportive feedback
The gameplay should be constructive and encourage the user so they do not feel disillusioned if they are struggling to overcome a challenge. The overall aim is improvement and the app should provide positive feedback to motivate the patient to work towards that goal.

5 - Implement effective voice inputs that are over 90% effective
Given the user's limited mobility, the app needs to be easy to navigate. This will be achieved through voice inputs which would need to be accurate to ensure the user remains calm and does not get frustrated by their inability to utilise the application properly.

## 1.6 Evaluation method

The success of the program is based on the accuracy of the hand tracking and voice translation technologies. These tools need to be implemented effectively in order to not anger or frustrate the user and instead provide them with a smooth playing experience. As mentioned in the aims, these tools need to be over 90% effective to achieve this.

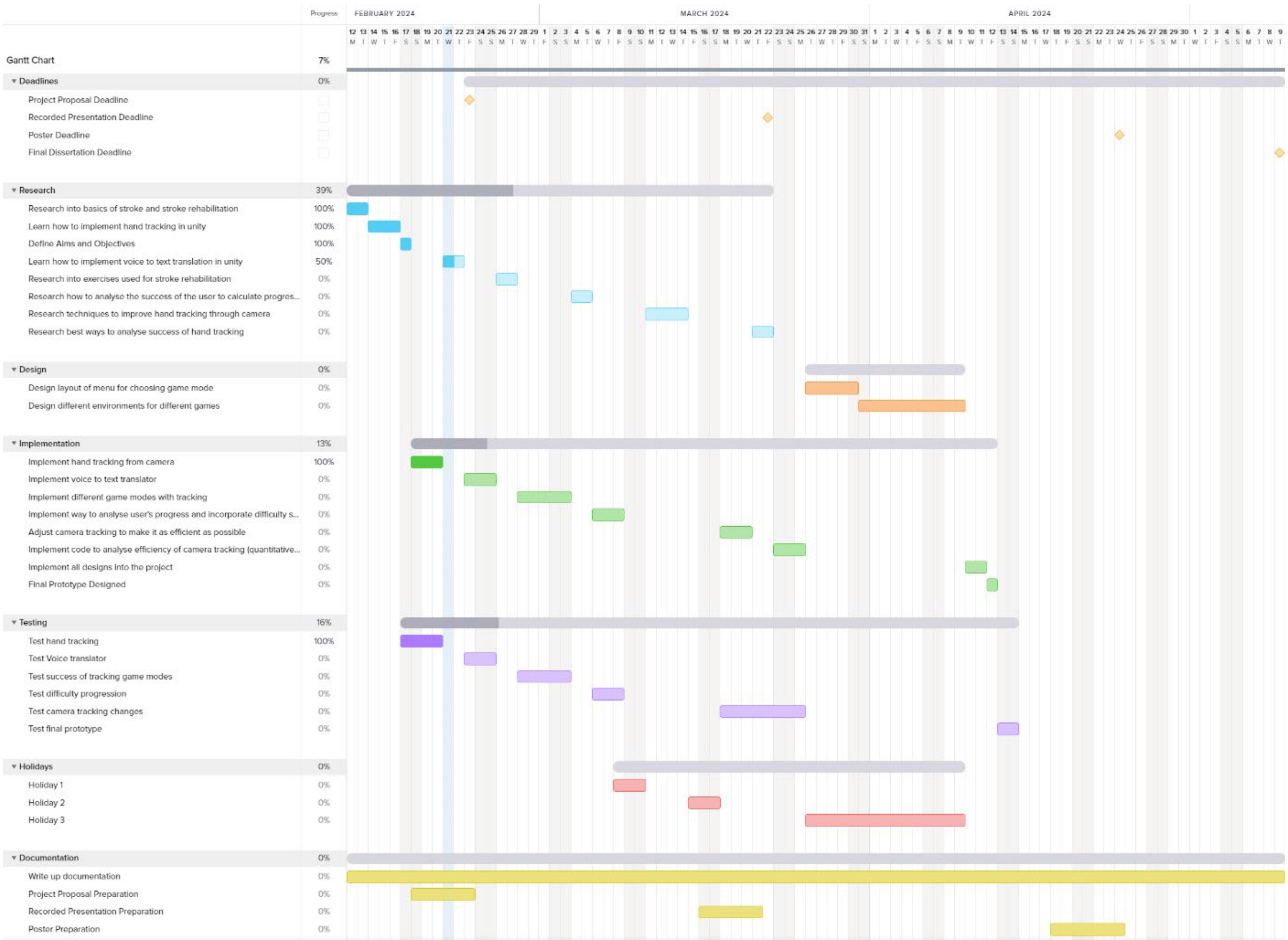
The effectiveness of the hand tracking was based on the number of frames that passed where PyCharm passed no data in about the hands to Unity. This was then compared to the total number of frames passed to calculate a percentage. After calibrating and aligning the screens together, as well as adjusting certain variables relating to sensitivity of hand tracking, all gamemodes created achieved over 90% accuracy, with 5 not passing a single frame without tracking.

The voice translation was tested by speaking 50 words into the microphone and checking if they were correctly translated. This was tested with 2 tools, HuggingFace and Dictation Recogniser, to find out which worked better. Both tools achieved over 90%, however, Dictation Recogniser was much easier to use, worked much more efficiently and was not as prone to error.

The game was designed with contrasting colours and positive designed to encourage the user, and the gamemodes were kept interesting and entertaining. The player's feedback was also provided through quantitative data to show their progress.

Overall, the system performed very well and the gameplay experience felt very smooth and accessible.

## 1.7 Plan
The Gantt Chart below sets out the plan for the project. It works through an agile model, constantly implementing, testing and improving the prototype until completion.




## 1.8 Summary
This section introduces the problem of stroke which is the main issue that the project is approaching. The author's motivation and rationale for the project have also been presented. This allowed for a number of aims and objectives to be drawn up to give the project more direction and allow for a proper evaluation of the success of the project upon completion.

# Section 2: Background Review

## 2.1 Introduction
This section provides a comprehensive overview of the research the author has conducted for this project. All this research will provide a base to work from when designing and implementing the program. Information from previous games and papers will ensure the game achieves all its aims and objectives.

## 2.2 The Effects of Stroke
In order to make a video game tailored towards a patient who is recovering from stroke, it is crucial to have a full understanding of the impact strokes have on the body. This is not only to ensure the game successfully achieves recovery in all the required areas but also for accommodating any limitations users may encounter as a result. The "Stroke Association" website [4] provides an in-depth explanation about all of the effects of stroke, serving as an invaluable source of information.

Stroke is a serious life-threatening medical condition that happens when the blood supply to part of the brain is cut off [5], which results in a sudden onset of loss of focal neurological function [6]. Around 80% of stroke survivors experience movement problems. Some of the most common effects of stroke are physical, including muscle weakness, paralysis and stiffness. The best way to treat both muscle weakness and stiffness is to exercise and practise the activities that are difficult to strengthen the muscles.

### 2.2.1 Cognitive
Stroke also causes cognitive problems. These involve problems with thinking, concentration and memory. It also affects the user's executive function, which controls planning and problem-solving. It can cause problems with moving or controlling the body, as well as issues with finding your way around and your visual perception. Spatial neglect is also a big problem with cognitive ability where the patient fails to notice things on one side of their body.

### 2.2.2 Communication and Aphasia
When communicating, the brain has to complete a series of tasks, with different parts of the brain being responsible for these tasks. If stroke damages these parts, it can cause problems with communication, such as Aphasia, Dysarthria and Apraxia of Speech.

Aphasia affects the patient's ability to speak and understand what others are saying. It is a common problem after stroke and around 1/3 of survivors have it.

Dysarthria is a condition where the patient cannot control the muscles in their face, mouth and throat very well, which makes it difficult to speak clearly, causing slurred, slow or quiet speech.

Apraxia of speech restricts the order of the muscles in the face, mouth or throat when speaking, which makes it difficult for others to understand.

Communication can be treated using speech and language therapy. It is also possible to learn to communicate in different ways if communication is proving to be difficult.

### 2.2.3 Vision

Vision problems affect two-thirds of survivors, leading to difficulty carrying out a lot of tasks. There are four main areas of visual problems, including visual field loss, eye movement, visual processing issues where you are not aware of things on one side and other problems including light sensitivity. Multiple exercises can improve vision impairments, such as eye movements and visual scanning training, where visual function is improved by training eye movements to be more efficient.

In a lot of cases visual field loss can improve and completely recover with exercise and rehabilitation.

### 2.2.4 Emotional and Behavioural

Stroke can have a massive effect on emotional wellbeing, as it has such a big impact on someone's life due to it being such a life changing medical condition. It can cause feelings of anxiety, frustration, anger and depression.

These emotions make it necessary to design a game with a friendly and encouraging environment where the patient's feeling of anxiety can be reduced. All aspects of the game should also be fully functional and efficient to ensure the user is not frustrated or irritated.

### 2.2.5 The Effect of Stroke on the Hands

The game is focused on the recovery of the hand. This is due to the pivotal role the hands play in facilitating recovery, enhancing motor skills, and improving overall hand functionality [7]. Manual performance is so central to human experience that we refer to hand motions when we discuss other topics. We say, "on the one hand and on the other," "I hope this grabs your attention," "These ideas go hand in hand," and so on [8].

In particular, the game will be concerned with hand movements. By reviewing "Grey's Anatomy" [9], which is a textbook of human anatomy, it is clear that the metacarpophalangeal joints should be focused on in particular. These are the joints in the hand where the fingers meet the palm, which allow for 4 main movements. These include abduction, which is the movement of the fingers away from the midline of the hand, flexion, which involves bending the fingers towards the palm, extension, which involves stretching the fingers away from the palm, and circumduction, which is a complex movement that involves a combination of flexion, extension, abduction and adduction to result in a circular motion of the fingers.

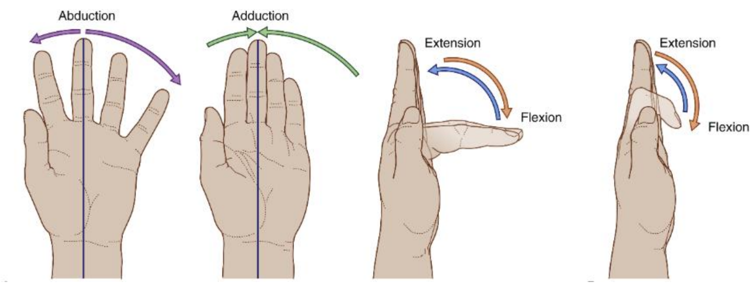



*Figure 1: Image of the 4 main movements in the hand*

In addition to the movements of the fingers, the radiocarpal (wrist) joint will also be focused on. At the radiocarpal joint, the hand can be abducted, adducted, flexed, extended and circumducted.

To gamify the movements, the author decided to use finger Abduction and Adduction, Flexion and Extension, and Wrist Circumduction. Finger Opposition was also included, which is where the fingertip and the tip of the thumb are touched, as this helps with hand-eye coordination, as well as muscle control.

More finger movements were selected than wrist movements for a number of reasons. Finger movements generally require less force and exertion compared to wrist movements, so the patient would not be over exercised playing the games. Finger movements allow for more ergonomic positioning of the hand too, so by keeping the wrist in a neutral position, stress can be reduced in the muscles and tendons. Finger movements can also offer finer control and precision and provide more functionality for the user than wrist movements can. In addition, all the wrist movements are encompassed within wrist circumduction so all the muscles are still being adequately exercised.

## 2.3 Games for Health

The theory of games for health and the validation of games in health care settings is gaining traction [10]. Games are being used much more to help patients through recovery and rehabilitation as it provides an entertaining gamification of exercises that would otherwise be quite uninteresting and dull. With tracking technology, users can exist within the 3D game world to complete simple tasks and minigames which complete their movements in a fun environment. These games also reduce the number of patients who struggle with home rehabilitation as they are more entertaining compared to traditional methods.

At present, with there being so many games in this field, there are many design practises that have been proved to be successful that should be implemented into such a game. Articles such as “Adopting Best Practises from the Games Industry in Development of Serious Games for Health” [11] and “Optimising engagement for stroke rehabilitation using serious games” [12] provide details about these design practises. Within the selected articles, there are 4 main sections that were of the highest importance;

- Structure and Simplicity
- Player Feedback
- Profiling and Data
- Providing Assistance

### 2.3.1 Structure

A level system within games for rehabilitation works successfully due to the games becoming more challenging for the user and accurately tests their ability.  In particular, modular game design works very well. This is due to the ability to change the order of level or challenges, depending on difficulty testing or individual requirements. It is also a less complex task to design each area as well as testing, as the levels are all isolated, meaning one game doesn’t impact another. Assessment of each challenge can also lead to removing the poorly performing ones, or promoting the ones that work well, without impacting the overall game.

The game should also be simple and easy to setup and play. The patient’s engagement will be much greater if it is easy to start and engage with. If the game genre and micro-level game loop are familiar then there is a lower barrier to involvement, meaning the game is accessible to all potential patients.

The game must also involve some sort of on-screen avatar that the user controls so that the user’s movements are shown on screen to provide immediate feedback if they are successful. This allows the user to know what they're doing is effective in the game. It also helps with calibration when using a camera.

### 2.3.2 Player Feedback
Player feedback is very important to show the user's progression throughout their rehabilitative process, as well as retaining their attention. The players should feel successful, so feedback should be encouraging, positive and rewarding.

A reward scheme should give the player longer term goals that they can work towards, which structures a rehabilitative scheme. In the short term, the player should constantly get positive encouragement as the game progresses through visual and audio effects when the player's actions translate into an increased score to show they're succeeding. Animations achieve this task very well.

Games should be lenient of failure due to the user's limited ability to perform tasks. If the patient is making a reasonable effort, they should succeed. This is because the goal for games for health is continued engagement, rather than skills shown.

### 2.3.3 Colour Theory
Colour theory plays a very important part in feedback, especially providing positive encouragement. If the user is making progress or losing progress, this should be fed back to them to inform them and must also be colour coded. Green is a good colour to use for positive encouragement, as it is associated with calmness, happiness and comfort [13]. If progress is not being made, reds should be avoided as people tend to associate it with negative, danger-bearing emotions, since it is the colour of fire, blood and anger [14]. Instead, colours such as orange should be used as it still grabs the user's attention, but is much less intense.

The colours used within the theme of the game are very important too and need to be considered carefully. Colour is believed to be the most important visual experience to human beings [13]. It functions as a powerful information channel to the human cognitive system and plays a significant role in enhancing memory performance. Choosing colourful palettes with plenty of contrast increases the user's attention to certain information, helps memory functions and keeps the user alert physically and internally so they can perform better.

### 2.3.4 Player Profiling and Data
Games for health support user profiling, which allows information about the user to be saved to help assess their own progress through multiple sessions over a long period of time. This allows for the potential of certain functionality to be implemented based upon this information. This includes functions such as an adaptive difficulty method and progress tracking. Data can be stored in a text document so progress is kept after the game has been closed.

### 2.3.5 Assistance
Players should be provided with help if mistakes are being made so they can be directed down the right path. A serious game for health should monitor the number of unsuccessful attempts made by a patient in order to offer further help and advice. These instructions should be presented on screen clearly and there should be an option to ask and receive help at any point if needed.

## 2.4 Similar Games

The main practises that all Games for Health should implement have been researched. However, it is important to look more specifically into the intended game topic which is rehabilitation of hands through camera tracking. Multiple games implement this mechanic, so it will be useful to see first-hand how these practises can be implemented and take inspiration from previous successful projects. It will be especially useful to take information from their evaluations and conclusions.

### 2.4.1 Example Game 1

The first game being analysed is "An interactive game for rehabilitation based on real-time hand gesture recognition" [15]. This game was designed to utilise a skeleton based hand gesture recognition which aims to assist rehabilitation exercises by improving the hand-eye coordination of the patients. The skeleton consists of nodes that denote the hand joints and edges which connect the nodes together, shown in Figure 2.

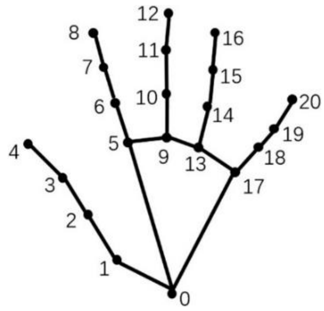



*Figure 2: Diagram of the skeleton of the hand, consisting of nodes and edges*

The aim of the game is to use the finger to control a virtual pen to complete drawing a Chinese character. To use the different functions of the pen, such as do and undo, different hand movements must be used, encouraging a variation of movements.

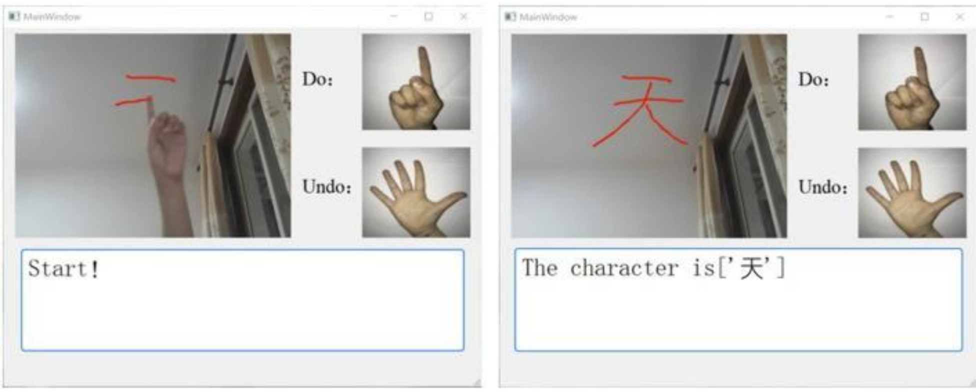



*Figure 3: Image of the patient drawing a Chinese character using hand gesture recognition*

The function was tested using different movements which required the tester to count to 9 on their fingers, which were then processed by the computer. The accuracy of these movements was then tested to ensure the tool was accurate, all achieving over 98% accuracy in all the models used. Feedback was also gathered from the users, which mentioned about how movements in the air were difficult and hard to control.

Within the evaluation of the game, the author also mentions about how important motivational rewards are and how they should be implemented in the future. It also states that the process should be smoother and more interesting, based from the previous user feedback.

### 2.4.2 Example Game 2

The second game that was analysed was "User-Centered Design of a Controller-Free game for Hand Rehabilitation" [16]. This game works from the point of view of the user and analyses their hand movements using the Microsoft Kinect sensor from 4-7 ft away. It is a cooking game that requires the user to take the steps involved to cook a steak using different hand movements, such as wrist rotation and pinching (finger opposition). The success of the game is based on the completion of these movements. No score, time or level systems were incorporated.


*Figure 4: Image of the user slicing lemons in the prototype minigame*

During testing a number of limitations were found. The tracking abilities of the Kinect were dependent on the size of the hands and fingers of the participant and didn't work at all in some scenarios, making the game unplayable. The prototypes lacked clinical utility, meaning the movements chosen didn't fulfil the requirements of the patients, defeating the whole point of the game.

Nevertheless, testers commented on many positives found from the prototypes. They enjoyed the fun nature of the exercises. They also liked how the game was responsive and produced a sound when certain actions were completed, showing an appreciation for positive feedback.

### 2.4.3 Example Game 3

In the final game, "Hand Gesture Controlled Game for Hand Rehabilitation" [17], the hand gesture that the user shows to the screen is mapped to a pre-defined gesture set which will cause a reaction. The user must move their hands and fingers in order to complete the corect function in the gesture set. These motions were used for application in a popular game "2048," making it very easy to understand due to the simplicty of the game's design.

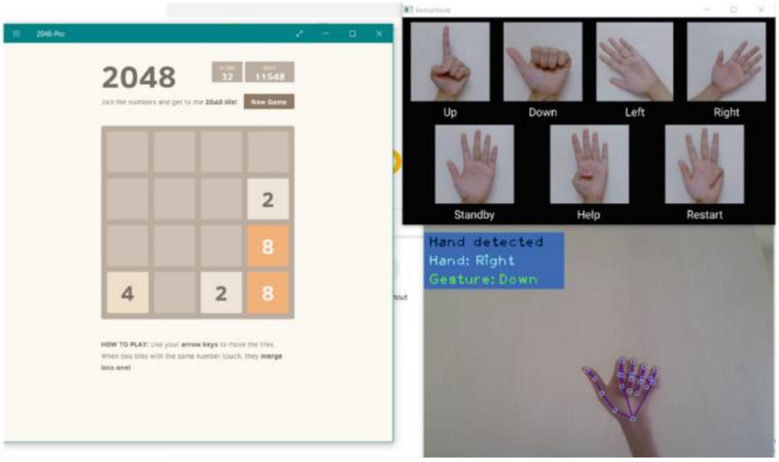



*Figure 5: Image showing the different hand gestures that play the 2048 minigame*

Tests were done on the tracking of the game once implemented. It was found that the system was best able to track the hand movements around a distance of 0.52m – 0.73m. It was also discovered that the accuracy of tracking was affected at different illumination conditions.

## 2.5 Technologies

To design a high quality, successful game it is imperative that all the technology functions seamlessly. Researching the best technologies is crucial to ensure the program functions successfully and efficiently.

### 2.5.1 Unity

Unity works best for the hand movements, as each joint can be treated as its own game object. This makes working with the coordinates of the hands a lot easier.

In addition, the isolation of gamemodes is much easier in Unity because of the use of scenes. This make a modular approach is easy to adapt. All games can be played and tested individually, making the development progress much quicker and easier.

### 2.5.2 Hand Tracking

There are many different hand tracking technologies available for this project, the best of which are highlighted in "Benchmarking Motion Sensing Devices for Rehabilitative Gaming" [18]. The best four are Wii MotionPlus, PlayStation Move, Kinect and Sixense. Even though these methods are proven to be accurate, they are all expensive pieces of kit, ranging from around £5 - £500, which is clearly not accessible for all users.

Several games have been developed which capture video data of the user's movement. The games have no significant change in performance with different resolutions, meaning there is no requirement for high end camera equipment [12]. According to Zugara [19], 79% of laptops now have webcams, meaning if a user has the means to run the program, they will likely have a camera to track the hands too, making it very accessible. In addition, due to the lack of extra hardware, the setup process would be swift, helping with the patient's engagement, as mentioned previously.

Multiple technologies work with Unity, the best of which was found to be OpenCV [20]. This package is able to track the hands successfully through a webcam, similar to other packages such as XR Hands [21]. They both work through tracking the coordinates of the anatomical joints of the hand. OpenCV was more preferrable as many of the joints in XR Hands would be useless in the intended program.  It also shows the joints within the game scene which XR Hands fails to, so debugging and understanding the package will be a lot easier.

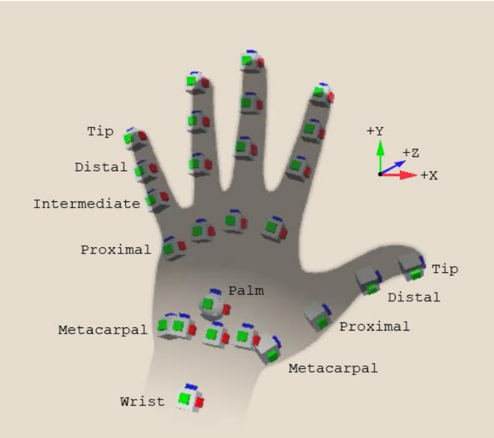



*Figure 6: Image showing the nodes in XR Hands*

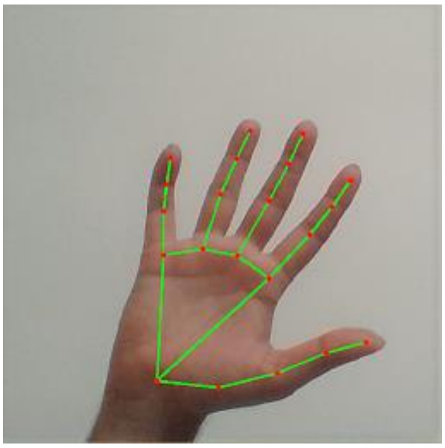


*Figure 7: Image showing the nodes and edges in OpenCV*

## 2.5.3 Accessibility

The term accessibility is associated with people with physical, sensory or mental disabilities [22].

As stroke causes issues with motor control and visual problems, accessible features need to be incorporated in order to appeal to all users. There are 3 complementary tools that a game designer has to make a game accessible to a specific player under specific playing conditions:

- Assistive technology: hardware and software suitable for a specific disability which compensates for it.
- Interaction techniques: Appropriate techniques for the player's interaction capabilities and preferences.
- Content and gameplay adaptation: The game should be in a format that can be optimally perceived and used through the employed assistive technologies and interaction techniques.

Hands free access to computer games can benefit those who struggle with motor impairment [23]. A speech recognition system does not require expensive hardware, meaning that its functionality is kept very accessible. In addition, the human language enables a limitless number of words and phrases to be uttered, each of which can be mapped to a discrete command to be executed. This is beneficial to controlling games that require numerous keystroke combinations to be executed. The ability to utter natural language commands compared to the need to remember and recall keystroke combinations can be easier for users that face problems with memory, making the game and the menus far easier to navigate and use.

Speech input can also have some limitations. Firstly, the time it takes a person to complete uttering a word or phrase can take a lot longer than using keystrokes. The processing time required to recognise this phrase also adds to the delay, which could cause frustration. The maximum number of utterances that can be recognised within a short period of time is also an issue. It is also unable to specify smoothly varying input. Output from a speech recogniser is discrete as the output is not generated until a word or phrase has been recognised. The result of this is a single string, making the outputs separate and confused.

These problems do pose an issue to the effectiveness of the voice tracker, however the way the tool is implemented can solve a lot of these functions. If the functions are kept to one-word requests, there will be no problem with varying inputs as they can just be treated as a single string. The functions should not be used for any time dependent aspects of the game, so processing time isn't as much of an issue. If the function is updated frequently, this should also reduce frustration by the user.

To achieve this accessibility feature, multiple voice translators were found, such as Hugging Face API and Windows Dictation Recogniser. Both technologies are effective, so they will be tested to find out how well they work in this project. The one which best suits the program and its requirements will be evaluated and chosen.

## 2.6 Conclusion from research

The discoveries from the research help contribute to the author's existing knowledge and offer valuable insights into aspects of Serious Games for Health that will be implemented into this project to make it effective and reach its objectives.

The research helps to identify what the effects of stroke are in great depth. This not only helps to design a game to rehabilitate these effected areas, but also highlights what restrictions the user might face when playing such a game. These restrictions must be considered to ensure the user can play the game without any struggles. It also helped identify what finger movements should be used to ensure every area of the hand is being adequately exercised.

The main practises that successful games implement have been highlighted, including structure and simplicity, positive feedback, the importance of colour theory, data handling and providing extensive assistance. The implementation of these practises was shown in three example games, which also provided constructive criticism, which will be improved upon in this project.

The technologies that were to be used were also investigated and the best tools were found. These include Unity, OpenCV and a variety of voice translators to test.

## 2.7 Summary

Within the research section the effects of stroke were highlighted to help to design the gamemodes in the implementation section. These consisted of:

- Cognitive
- Communication
- Vision
- Emotional
- Physical

The main practises that are used in similar games were also researched, the most important sections being:

- Structure and simplicity
- Player feedback
- Colour theory
- Player profiling and data

Other similar games that have been designed in the past were analysed to investigate in more depth how different practises can be implemented into games for health.

Finally, the technologies that will be implemented within the game were analysed to ensure the most efficient and effective tools would be used.

# Section 3: Design and Implementation

## 3.1 Introduction
This section provides details of the entire design process of the program. It explains how these designs have been implemented to achieve all of the aims and objectives set out at the start of the project.

## 3.2 Functional Requirements
The requirements identified by the research and the aims and objectives are listed below:
1. The tool should detect hand movements and gestures made by the user
2. The hands must be shown on screen to provide immediate feedback to the user
3. There must be 8 minigames encouraging different movements and exercises
4. The games must be simple and easy to understand
5. Each game must have a points system and timing system
6. Player feedback and analysis should be presented in an encouraging way
7. The user must be able to use voice inputs to complete certain accessibility functions

## 3.3 Program structure

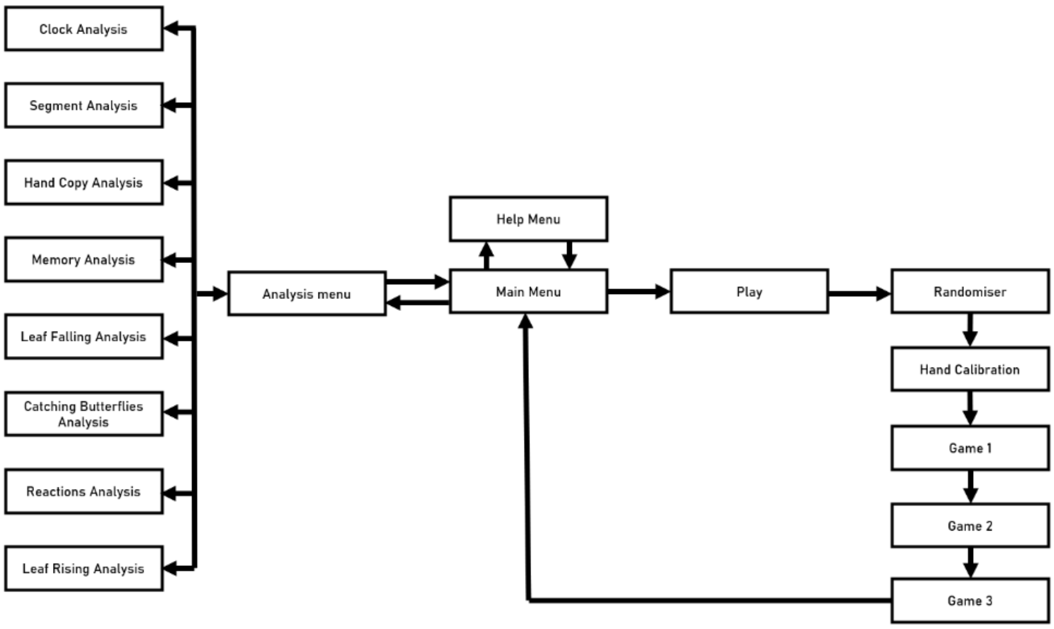



*Figure 8: Diagram of the structure of the program*

The layout of the program is shown in the diagram in Figure 8. The layout is kept simple so the user can easily traverse through the menus and quickly comprehend where everything is, as this is an important practise found within the research. There are 3 main sections. The play section is where three minigames are randomly chosen and played. The analysis section is where the user's data and progress is stored, as player profiling and data was found to be an important aspect of games for health in the research. The help section provides assistance to the user and helps them figure out how to use the application. Providing help to the player was also highlighted as an important practise in the research.

These sections consist of subsections, such as the individual analysis of the different games and the multiple stages of gameplay.

## 3.4 Hand Tracking

The hands are tracked through the use of the Open-Source Computer Vision Library (OpenCV) in PyCharm. It is a library used for computer vision and image processing tasks. To track the hands, it captures frames from a camera and identifies regions in the image that may contain hands. Once the program has determined that the hands are visible in the camera they will be tracked across consecutive frames.

There are 21 points in each hand that are tracked. These are called landmarks or key points. These positions are essential for analysing and recognising hand gestures and movements as they can provide information about the position and orientation of the hand. This skeleton that is used was implemented in 2 of the 3 games that were researched, showing their effectiveness.

Each point has a string of data linked to it which contains information stating which hand is being tracked (either left or right) and their x, y, and z coordinate so they can exist within the 3D Unity world. This information is then fed into Unity through the use of sockets.

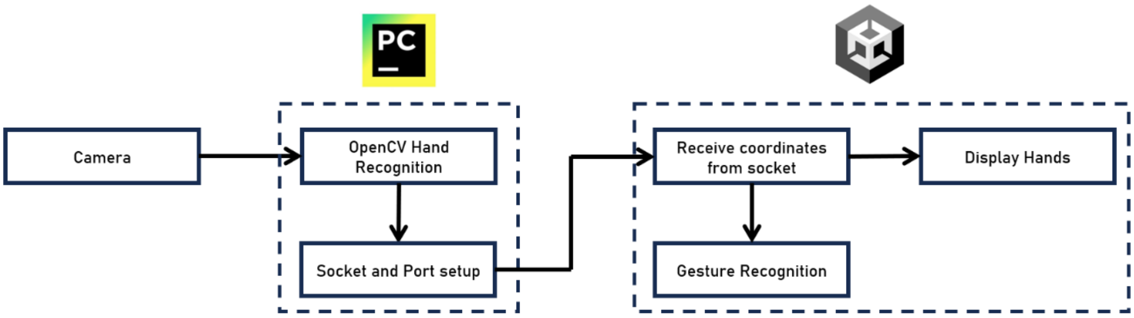



*Figure 9: Diagram of how the hand tracking functions through PyCharm and Unity*

In Unity all this data is then processed. Each position fed in is allocated to a 3D sphere object and is aligned with its coordinates to sit in the right place. All the spheres are connected with lines to provide visual cohesion and make it clearer what points of the hand are being shown.

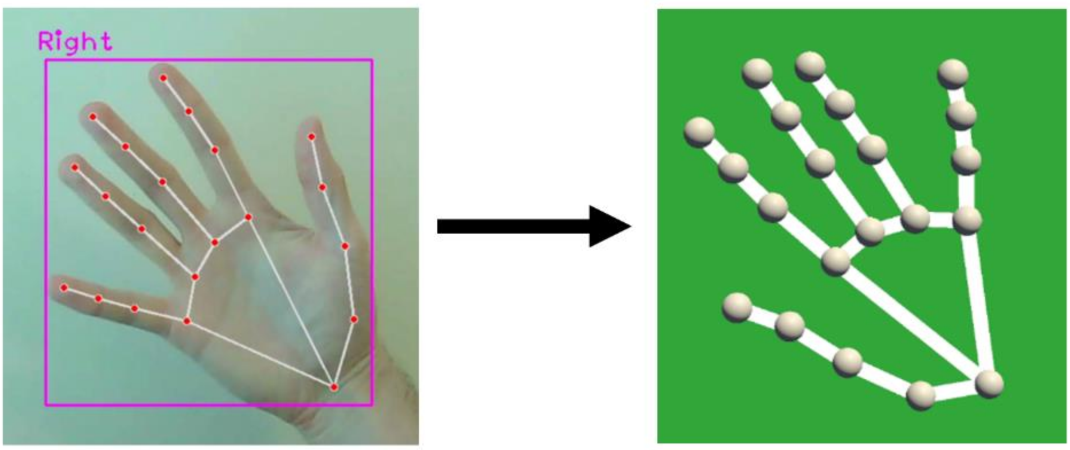



*Figure 10: Diagram to show how the hand is tracked in PyCharm and how it is displayed in Unity*

For most of the minigames, the hands are kept visible on screen. This is because in the research it was found that having some sort of on-screen avatar is helpful to provide immediate feedback. It also provides assistance when positioning the hands on screen.

## 3.5 Gesture Recognition

As the hands exist as points with coordinates within Unity, each point can just be treated as an individual game object for gesture recognition. The program determines the 4 motions by testing the orientation and position of specific points relative to others. These movements were found through analysing all the muscles and joints of the hand in Gray's Anatomy for students in the research.

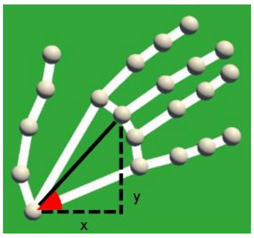



*Figure 11: Image to show how wrist circumduction gesture is calculated*

### 3.5.1 Wrist Circumduction

The games incorporating wrist circumduction expect the users to rotate their wrist to specified angles, rather than just doing one full turn. This requires the program to determine the angle that the wrist is at. This is achieved by getting the positions of the proximal interphalangeal joint (middle knuckle) and the bottom of the palm. The program calculates the difference of the x and y coordinates then uses trigonometry to determine the angle between them.

### 3.5.2 Thumb Opposition

The games using thumb opposition expect the user to bring the tip of a specific finger to the tip of their thumb. This is achieved by calculating the distance from the thumb to the chosen finger. If they are close, then the movement has been achieved. If not, then the movement has not been achieved.

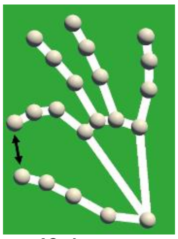


*Figure 12: Image to show how thumb opposition gesture is calculated*

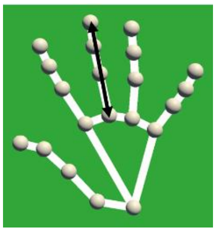


*Figure 13: Image to show how finger flexion and extension gesture is calculated*

### 3.5.3 Finger Flexion and Extension

The games with finger flexion and extension expect the user to curl in their fingers into a fist and then extend them out as far as they can. To check for flexion, the position of the finger tips and the knuckles of each finger are checked. If their difference is small the hand must be curled into a fist. If the difference is large enough the fingers must be extended away from the knuckles.

### 3.5.4 Finger Abduction and Adduction

The games utilising finger abduction and adduction expect the users to spread their fingers out so they are distanced from each other and return them together. This is tracked by getting the coordinates of each fingertip and checking their position in comparison to each other. If they are close and compact, the fingers must be brought in. If the difference is large, they must be spread out and far apart.

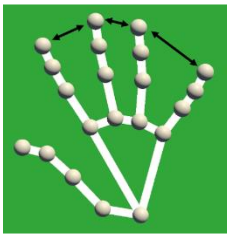


*Figure 14: Image to show how finger abduction and adduction gesture is calculated*

## 3.6 Game Modes

Eight game modes were developed, two for each hand movement previously mentioned. The main aim of these minigames is to train the muscles of the hand in different ways to help the recovery of the user's motor control. Other secondary aims are included within the minigames as stroke affects much more than just motor control.

The layout of the minigames was very carefully considered. A modular design was incorporated, as this was proven to be the most effective structure to use in the research section. It provides the ability to change the order of games depending on individual requirements. In addition, all of the games can be tested individually, making the process far easier.

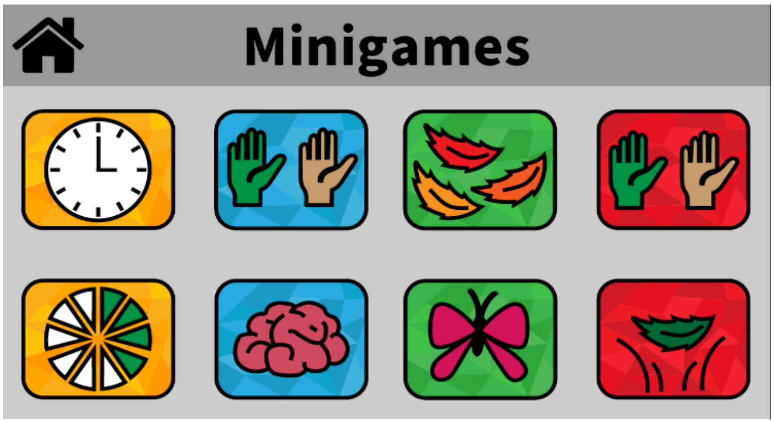



*Figure 15: Analysis menu showing all 8 minigame icons*

All of the gamemodes are designed and themed in similar ways with the same hand movements being colour coded. This makes it clearer to the user what muscles they are exercising and also makes the project easier to manage. The use of different vibrant colours also provides a significant role in enhancing their performance in the games, as shown in the research. Colour helps by increasing our attentional level and also increases arousal, which refers to the state of being alert physically and internally. The right combination of colours is important because it can produce a higher level of contrast, which can influence memory retention and attract more attention, as mentioned in the research.

Positive colours are always used when providing data for feedback. Feedback should be encouraging, positive and rewarding. Green colours have been used to signify progress being made. Orange has been used when less progress has been made instead of red as it conveys a sense of caution or areas for improvement without being as alarming or discouraging as red. In addition, when a positive action is completed, an animation and sound will be played to provide encouraging feedback, as this was a key part of the findings in the research section.

Even though the gamemodes are all similarly themed, there is enough variety and novelty within each game to keep the experience entertaining for the user. They are all made with simplicity in mind so the user can easily pick up the game and start playing. Within the research it was found that the barrier to involvement should be low, therefore there are screens explaining how the games work. In addition, most of the games all loop their functionality which will be made evident in the flowcharts of the games, so the user will quickly become familiar with what they are expected to accomplish. This repetition of movements also ensures the muscles are sufficiently exercised without exhausting the user. The menus and buttons are also all kept constant for familiarity so they are easy to use and all function the same.

### 3.6.1 Copy Clock

The clock game is the first to utilise wrist circumduction. In the game the user must rotate their hands in order to mirror the clock shown on their left. The left hand controls the hour hand and the right hand controls the minute hand. Figure 16 shows what this gameplay looks like within the program.

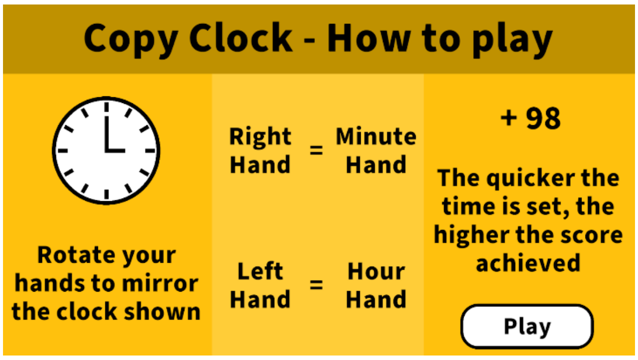



Figure 17: Pre-game menu explaining how to play the Copy Clock gamemode

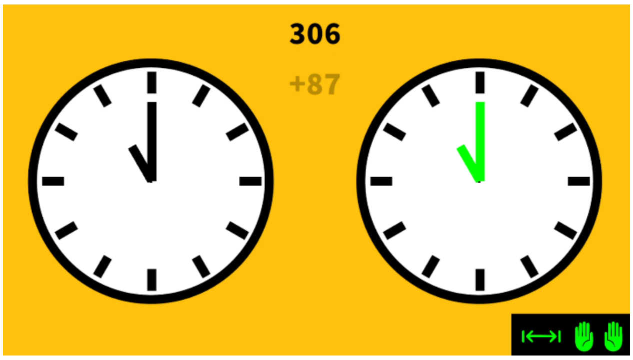



Figure 16: Gameplay from the Copy Clock gamemode

The patient must complete 10 repetitions of this to finish the minigame and will then be presented with their results. The structure of this gamemode is shown in the flowchart below in Figure 18.

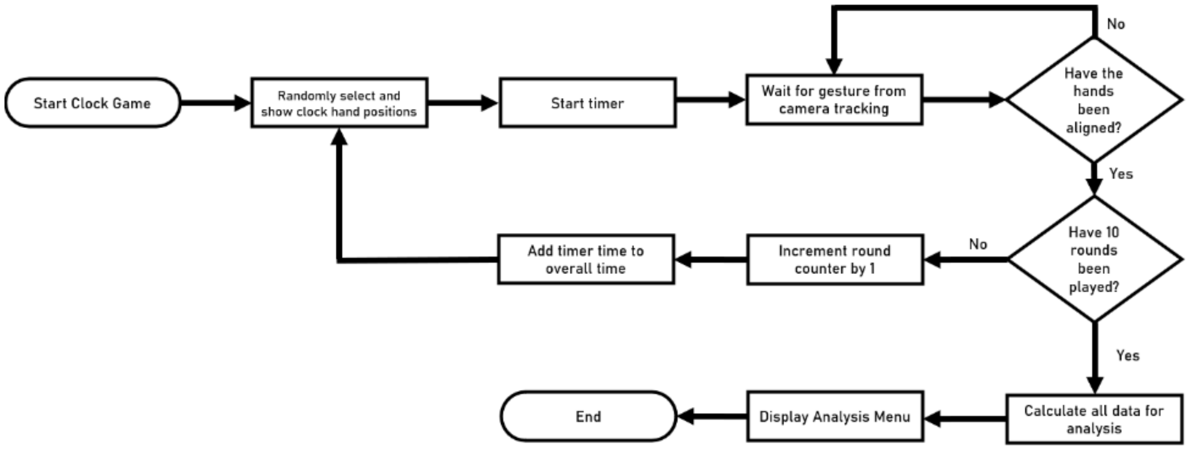



Figure 18: Flowchart to show how Copy Clock gamemode works

As previously mentioned, the game exercises more than just the muscles involved in the movements. The research highlighted how stroke survivors often experience cognitive difficulties including issues with attention and executive functions. The clock game allows the user to focus and plan out their next move to achieve the shown time. It also helps the user improve their bilateral coordination as both hands are being used simultaneously to move around in different ways. This can be especially beneficial for individuals with hemiparesis, which is the weakness of one side of the body resulting from stroke.

### 3.6.2 Segment Shuffle

Segment Shuffle also utilises wrist circumduction. The user must rotate their wrist to find the correct hidden segment, indicated by a dark green colouring. As the player rotates their wrist the appropriate segment will be highlighted to show their proximity to the correct one.

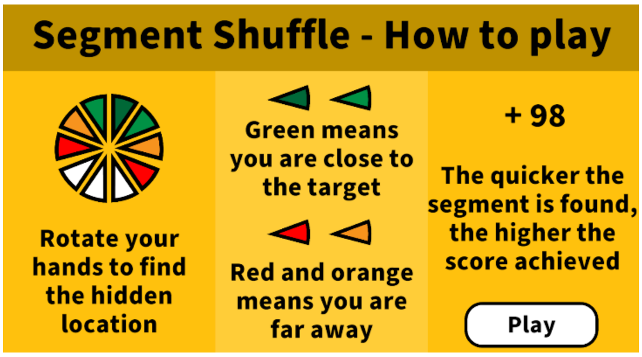



*Figure 20: Pre-game menu explaining how to play the Segment Shuffle gamemode*

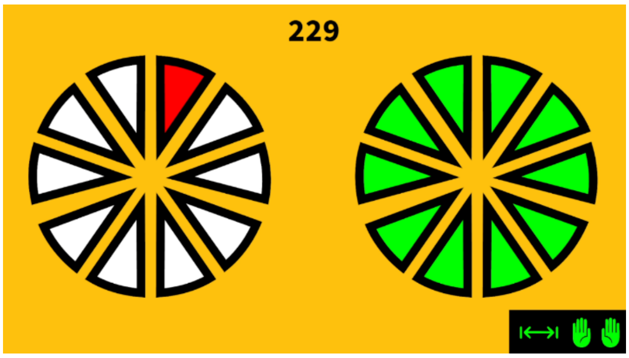



*Figure 19: Gameplay from the Segment Shuffle gamemode*

The player must again complete 10 repetitions of this for each hand to complete the game, and will be presented with their analysis. The flowchart for this game is shown below in Figure 21.

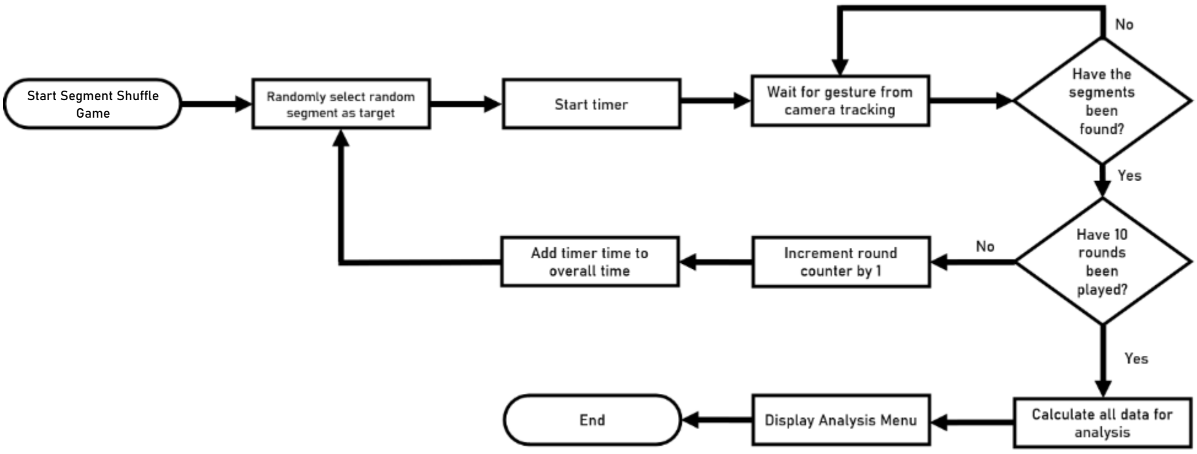



*Figure 21: Flowchart to show how Segment Shuffle gamemode works*

As this gamemode is similar in nature to the Copy Clock minigame, it enhances similar areas. The game helps with bilateral control as well as testing visual perception and attention. It also adds an attribute of problem solving by requiring the user to search for the specific segment. They are not just informed of what movement to complete, but they have to complete a puzzle to achieve it, adding a sense of adventure and achievement to the game.

### 3.6.3 Hand Copy

This gamemode uses thumb opposition, where the tip of a certain finger, indicated by the hands shown on screen, is touched with the thumb. As soon as the movement is completed the next finger is shown on screen, testing the players reactions. The faster the tips are touched, the higher the score.


*Figure 23: Pre-game menu explaining how to play the Hand Copy gamemode*

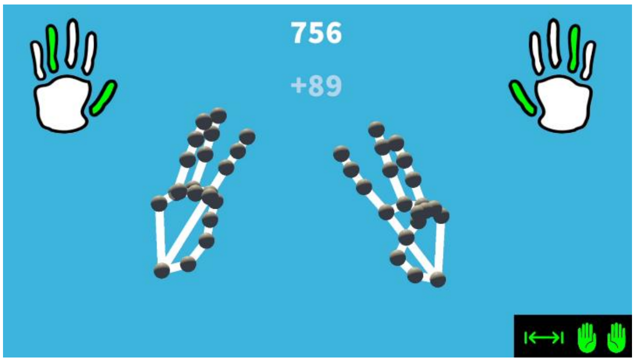



*Figure 22: Gameplay from the Hand Copy gamemode*

The user must copy 20 hand movement combinations to reach the analysis page. The structure of this minigame is shown in Figure 24.

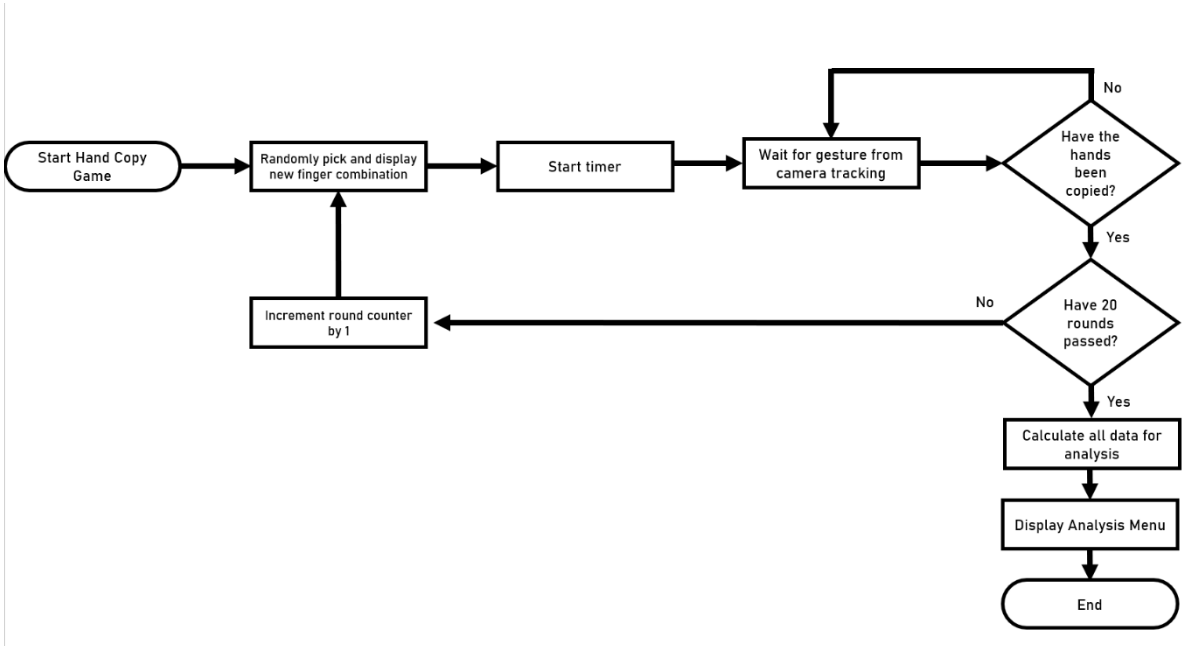



*Figure 24: Flowchart to show how Hand Copy gamemode works*

This gamemode assists with the user's cognitive engagement. The act of registering the required movement and copying it enhances the user's visual perception and ability to pay attention to changes on the screen. It also helps with hand-eye coordination, with the user having to focus on the tips of their fingers to bring them together successfully.

### 3.6.4 Memory

In the memory game the user is shown the same finger combinations for the same movements as the Hand Copy gamemode, but must remember and repeat them in a sequence. Every round a new movement is added to the sequence, making it more difficult for the user to remember what came beforehand. The longer the sequence becomes, the larger the potential score. If an incorrect movement is completed, the game ends.

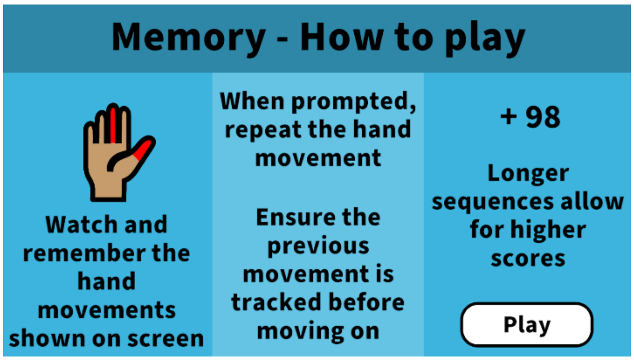



*Figure 26: Pre-game menu explaining how to play the Memory gamemode*

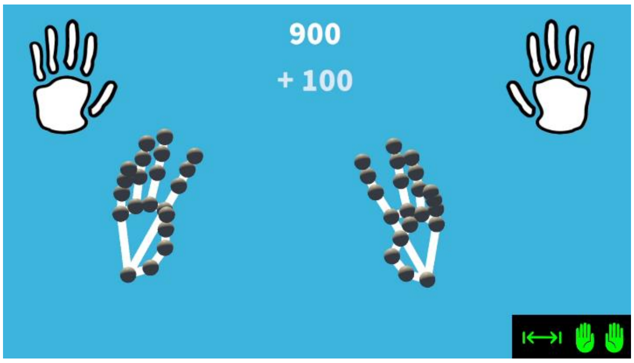



*Figure 25: Gameplay from the Memory gamemode*

The iterative layout of this gamemode is shown in the flowchart in Figure 27.

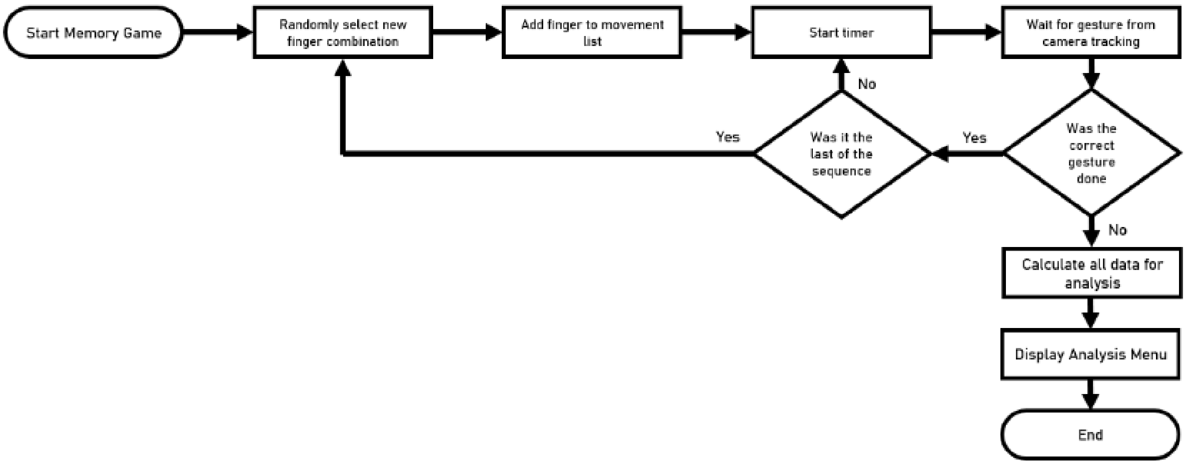



*Figure 27: Flowchart to show how Memory gamemode works*

As supported in the research, stroke survivors often experience deficits in both short-term and long-term memory. This game helps stimulate memory recall and retention, which can encourage the brain to form new connections and strengthen existing ones. It also helps with attention and concentration due to the user having to remember a whole series of hand movements.

### 3.6.5 Falling Leaves

The Falling Leaves gamemode utilises finger flexion and extension. The user must flex their fingers to grab the leaves that are falling down from above. The number of leaves falling per round is random, adding a sense of unpredictability. The quicker the leaves are grabbed, the higher the score.


*Figure 28: Pre-game menu explaining how to play the Falling Leaves gamemode*


*Figure 29: Gameplay from the Falling Leaves gamemode*

There are 30 leaves spawned in throughout the game. This consistency in numbers helps the analysis for the game much easier and more accurate. The layout of the gamemode is shown in the flowchart in Figure 30.

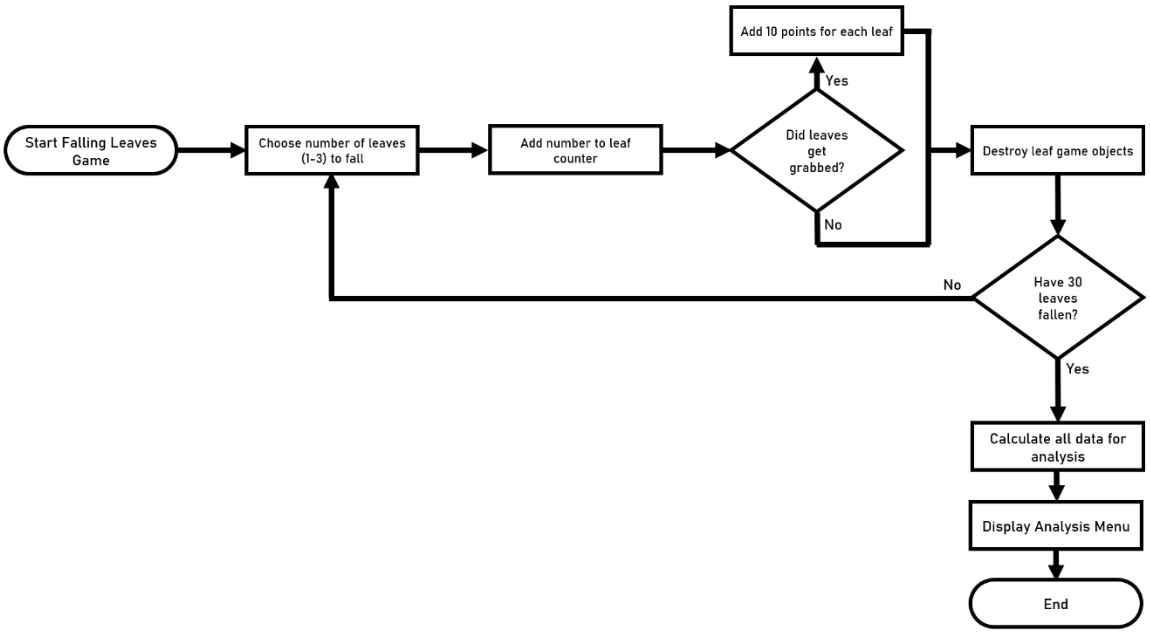



*Figure 30: Flowchart to show how Falling Leaves gamemode works*

This game helps to improve fine motor skills and hand-eye coordination, as the user must anticipate and visually track the movmement of the leaves in order to catch them and gain points. The motion of leaves falling can also provide visual stimulation which is important for cognitive engagement and sensory processing, as well as stimulating the brain and promoting visual perception skills. It can also have a calming and relaxing feel to reduce stress. This is very important during rehabilitation, as shown by the research into mental effects of stroke.

### 3.6.6 Catching Butterflies

In this gamemode, the user must once again use their fingers to grab at butterflies flying around the screen, coming in from all sides. Everytime a butterfly is grabbed or exits the area, another is spawned in. This keeps the user focused and on their toes for the 2 minute duration. The quicker the butterflies are caught, the higher the score achieved.

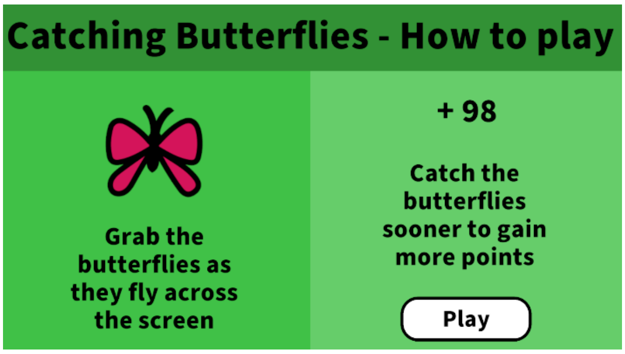



*Figure 32: Pre-game menu explaining how to play the Catching Butterflies gamemode*

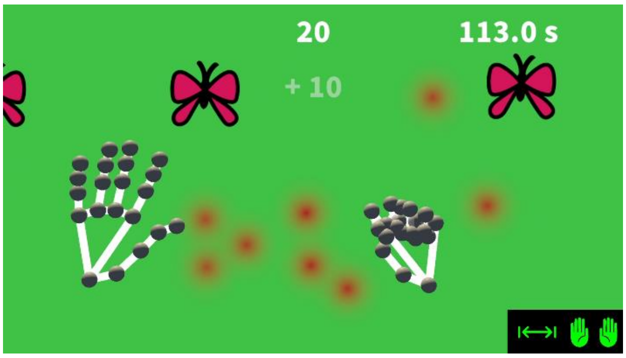



*Figure 31: Gameplay from the Catching Butterflies gamemode*

The structure of the minigame is shown in the flowchart in Figure 33.

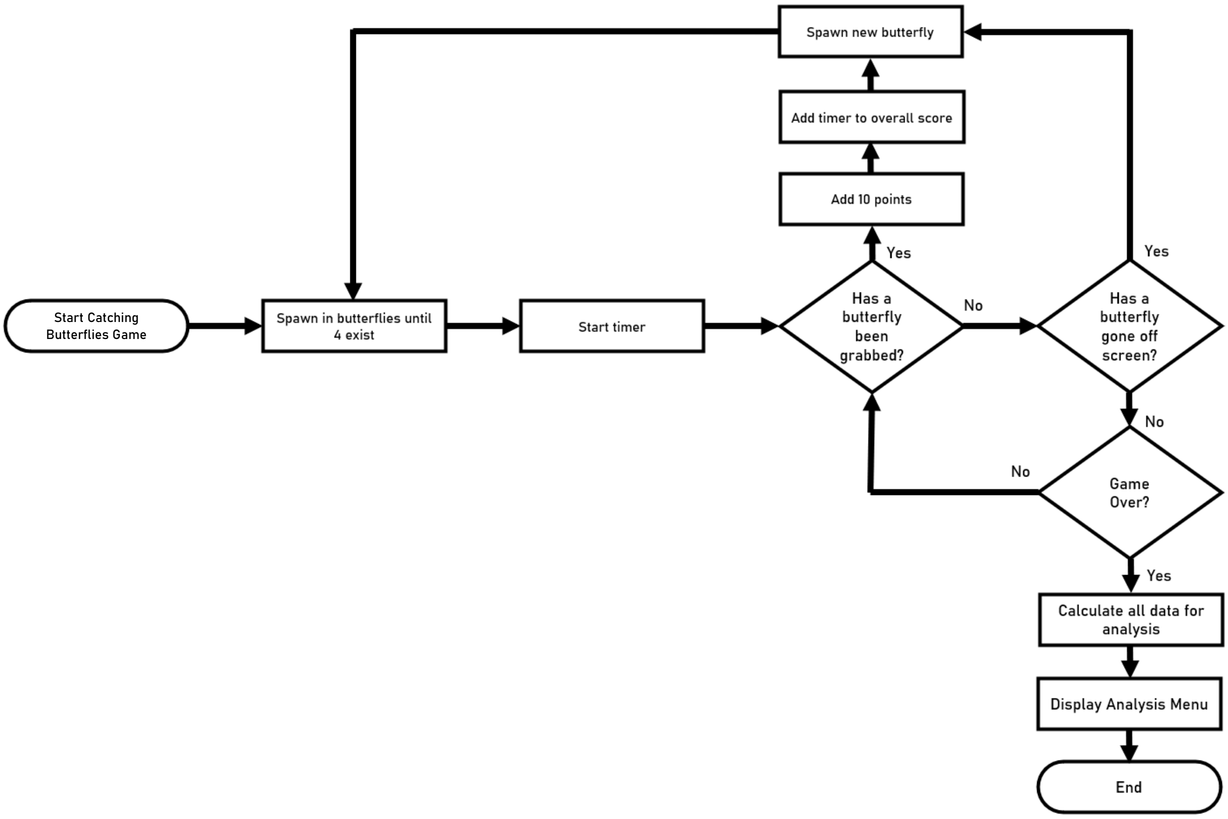



*Figure 33: Flowchart to show how Catching Butterflies gamemode works*

This game helps with the user's hand-eye coordination, similar to the previous game, and extends upon it. It provides more of a challenge to the user due to the unpredictability of the butterflies' movements. The user's movements must be more precise to intercept the butterflies' flight path. When the butterflies are grabbed, a particle effect is shown which provides positive feedback to the patient to show what they're doing is successful.

## 3.6.7 Reactions

The Reactions game tests the users reaction time through the use of finger abduction and adduction. The lights on the traffic light will turn on, from red to orange to green. The user must spread their fingers as soon as they see the red light turn on. The faster their reactions, the higher the score.


*Figure 34: Pre-game menu explaining how to play the Reactions gamemode*

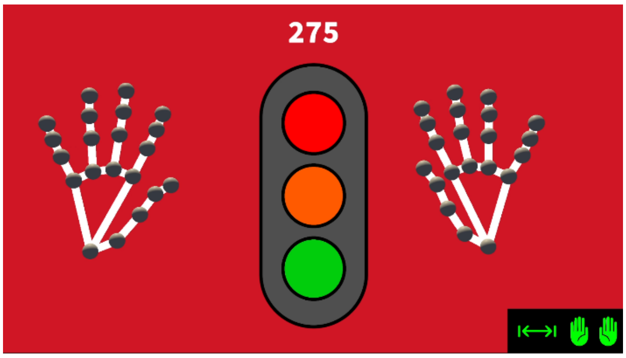



*Figure 35: Gameplay from the Reactions gamemode*

The player must complete 10 rounds of the game to view the analysis menu. The structure of this minigame is shown below in Figure 36.

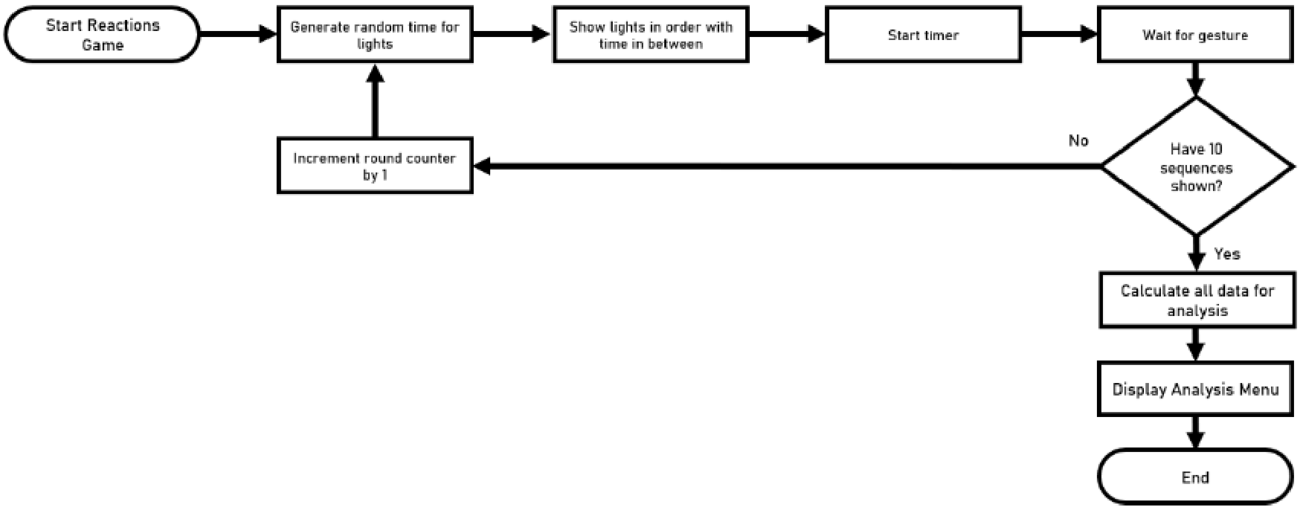



*Figure 36: Flowchart to show how Reactions gamemode works*

Stroke survivors may experience slower reaction times due to neurological damage. Training these skills can enhance the user's reflexes in daily life. The game also requires the player to quickly process the changing of the colours. This can help sharpen visual processing abilities, such as visual attention and discrimintation and help differentiate between different visual stimuli or features.

### 3.6.8 Floating Leaves

Within the Floating Leaves gamemode the user must transition between abduction and adduction. When the fingers are spread the leaf will move up. If they are together the leaf will float downwards. The player must ensure that the leaf is kept within the moving area to gain points. The longer the leaf is kept within the area, the higher the score.


*Figure 37: Pre-game menu explaining how to play the Floating Leaves gamemode*

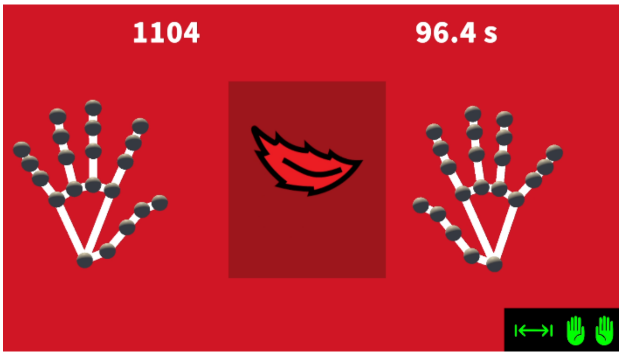



*Figure 38: Gameplay from the Floating Leaves*

This game is based on time. The user is given 2 minutes to try and control the leaf so it stays within the moving target. This time frame is kept short so it does not exhaust the user, however, it is still long enough to exercise the muscles.

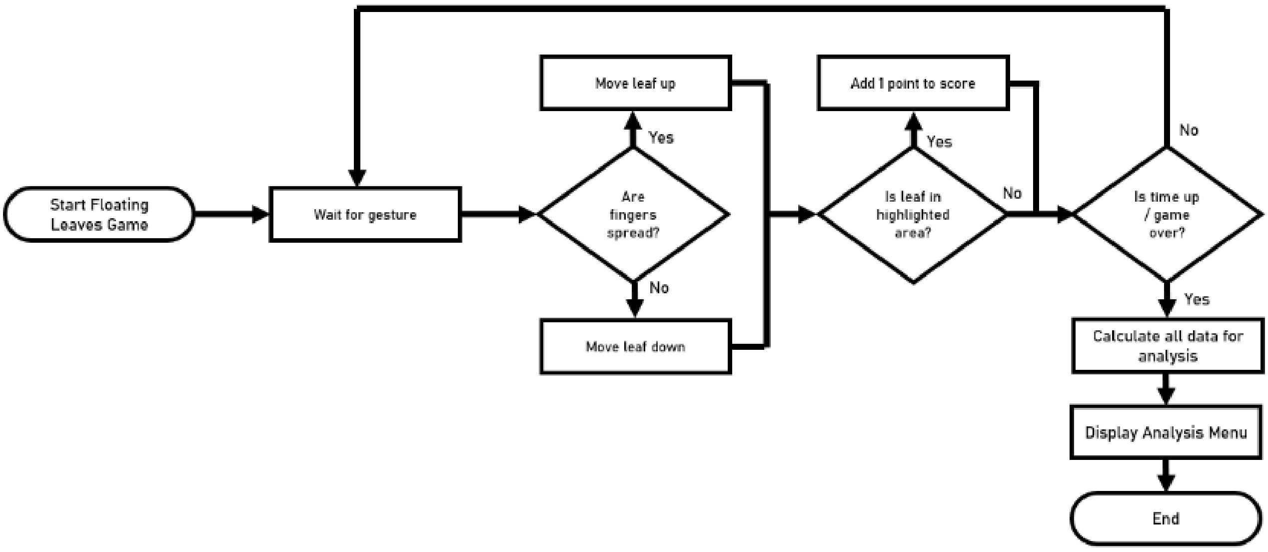



*Figure 39: Flowchart to show how Floating Leaves gamemode works*

This game challenges the user by requiring the user's attention and concentration for two minutes. The specific nature of the game makes the user's movements more accurate and enhances their motor control.

## 3.7 Game Analysis

Due to the importance of player profiling, highlighted in the research section, a lot of work went into game analysis. After each game is played, the analysis of their performance is presented in the format shown in Figure 40. This screen focuses on current progress rather than overall progress which is covered by the graphs in the analysis menu. The averages are calculated from the last 3 games and their score and time from the previous game is compared to see if they are progressing successfully. The inclusion of viewing progress in real-time can help motivation and can encourage the user to keep playing to keep seeing constant improvements in their motor control.

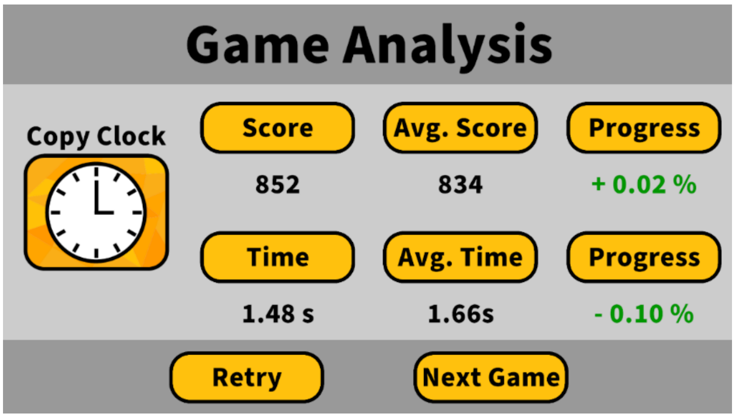



*Figure 40: Game analysis menu shown upon completion of the Copy Clock gamemode*

The user's overall progress can be tracked within the analysis menu where each game has data about their best scores and times, averages and progress. This data is set out in graphs that adjust in size depending on the user's scores and number of games that have been played. This allows for a personalised experience.

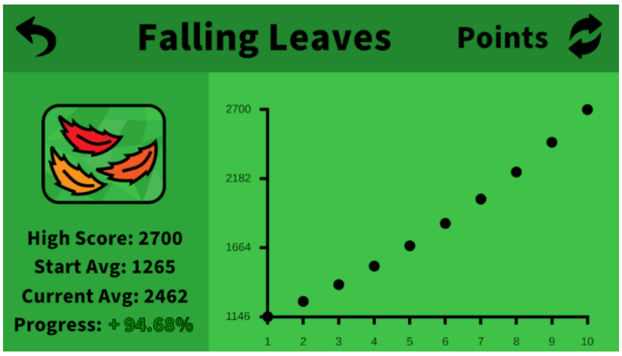



*Figure 42: Image of the Falling Leaves points analysis display*

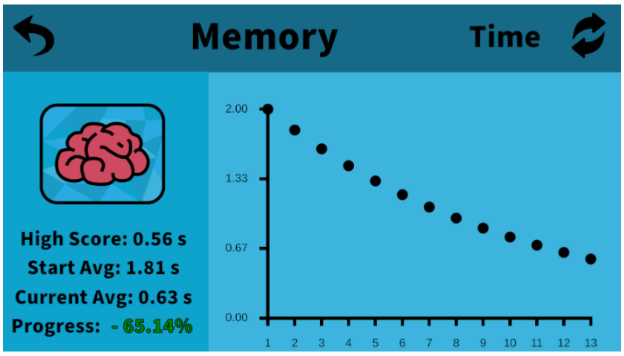



*Figure 41: Image of the Memory time analysis display*

Figure 42 shows the scores from the Falling Leaves gamemode and sets out their progress in the graph and in the details on the left side of the screen. Figure 41 shows the average times of the Memory gamemode along with its progress too.

This analysis shows the overall progress by finding the average of the first and last 3 games recorded and calculating their difference. These menus show the total progress that the user has achieved which allow for an overall evaluation of their success. It also allows for long provides for long-term goals, which were a very important practise found within the research. The research also details the importance of short-term goals, which is achieved throughout the real-time game analysis after each minigame.

## 3.8 Game Selector

To add in variation to the games played, randomness is added to the selection process. 3 games are randomly picked from the roster and shown to the player.

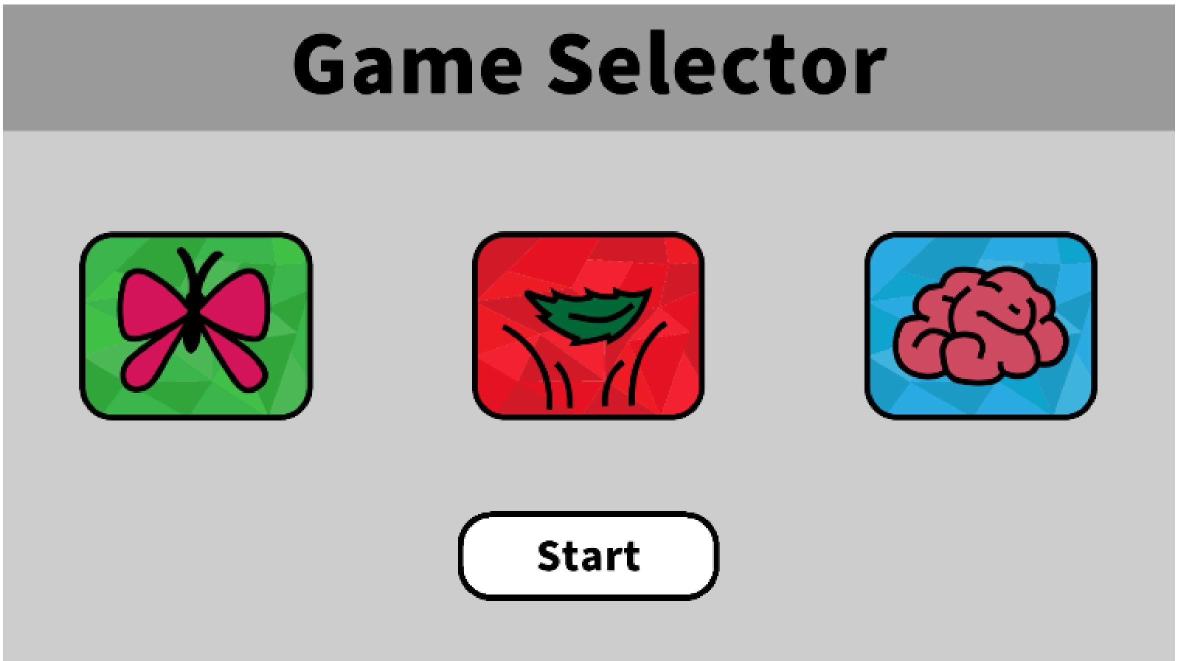



*Figure 43: Image of the Game Selector menu completing a random selection*

The probabilities for each game are originally all equal. However, after analysis the probability of each game being selected is altered. This is done in order to tailor the gaming experience to the user's abilities. If they are succeeding and progressing in a certain area this game will be more likely to show up in the selection menu to encourage improvement. The probabilities work with multiplication, therefore the more they improve, the more likely it is that the game will show up. This ensures that trend of improvement is continued. On the other hand, if the player is struggling in a gamemode or has reached a point where they can improve no more, the game will show up less. This will be because the game doesn't work well for the user or they have reached their potential.

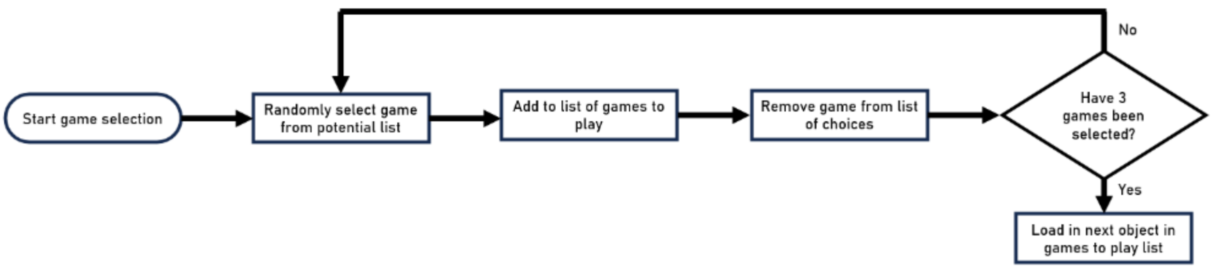



*Figure 44: Flowchart to show how Game Selector functions*

This ability to randomise the minigames is due to the modular structure of the program, which was highlighed as an important practise within the research. The games are selected depending on invidiaual requirements, making the game a lot more personalised.

## 3.9 Hand Orientation

The hand orientation screen ensures that the user is at the optimal position to get the best gameplay experience from the minigames. The display at the bottom of the screen, which is constant throughout all of the gamemodes, provides an indication of the presence of the hands on the screen. It also shows if the hands are at the right distance. If these variables are not met, the icons will be red. If they are correct, they will be green and the game will start.

This menu also helps resolve issues with errors, as the hands could not be found in some circumstances in the game as they had not been instantiated yet. With this function they have to be shown and generated in order to start playing.

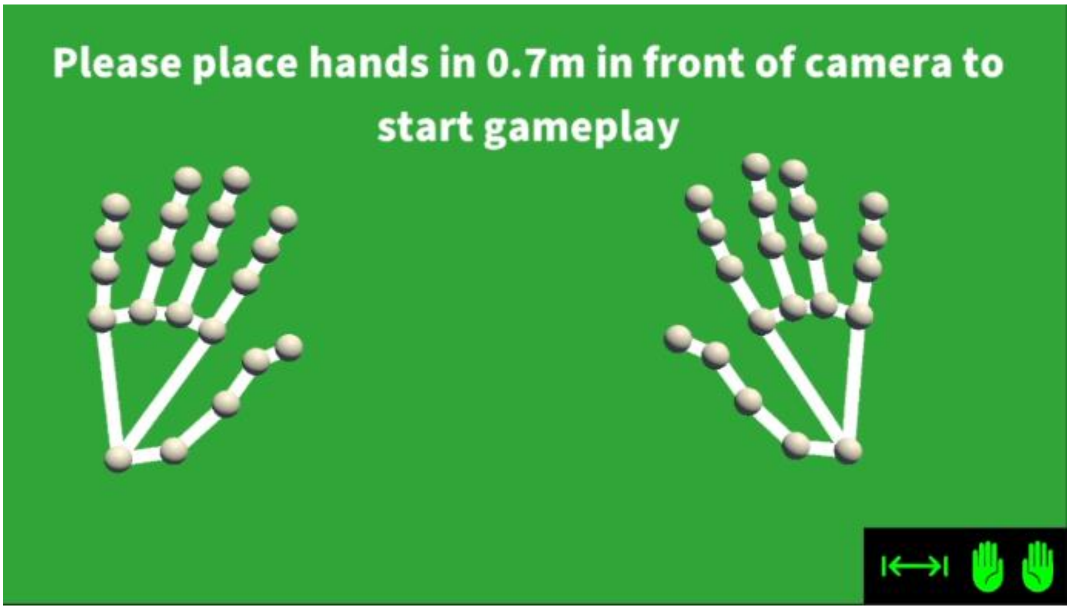



*Figure 45: Image of the Hand Calibration screen*

## 3.10 Summary

This section has introduced the design and implementation of the project, basing the designs upon the information found within the research section. The structure was kept simple and easy to navigate and the functional requirements were explained for the process's success.

There were eight different minigames designed, separated into four sections with four main movements. The games are not only designed to exercise the muscles but also help with other areas that stroke affects too, such as cognitive functionality and mental health.

A game selector was also designed to randomly select the gamemodes for an added sense of excitement and amusement when playing the game which ensures the user's retention.

Each section had an analysis section designed so that the user could evaluate their short-term and long-progress. This was presented positively and encouraged the user through the use of positive and vibrant colours.

All of this functionality successfully achieved the functional requirements set out at the start of the section, making for a fully working program.

# Section 4: Testing

## 4.1 Introduction
To ensure the program works as intended and achieves all the aims and objectives set out at the start of the project, all attributes of the system need to be tested. The hand tracking and voice translation also need to be tested and improved through an iterative process to guarantee they work as efficiently as possible.

## 4.2 Unit Testing
Throughout the development process each game mode was individually tested to ensure that they each worked properly on their own. This allowed for each hand movement and gesture to also be tested, with any issues with the tracking being highlighted throughout this process. Due to the modular design of the minigames, which was chosen through the research, this process was very easy and all bugs and solutions could be isolated.

## 4.3 Full System Testing
When the game modes were all working and the program had a functional structure where every scene could link together, the system was tested as a whole. This highlighted some problems with the ports used with the hand tracking, amongst other small issues that were quickly fixed. The testing of the full system showed how the traversal to different menus worked and how the game randomiser linked into the actual gameplay. This was made a lot smoother during testing to make the game feel fluid rather than just different individual games.

## 4.4 Analysis of Hand Tracking
The hand tracking works through a plugin called OpenCV in PyCharm. This plugin uses a camera and is able to track the coordinates of the joints in each hand. PyCharm then uses a socket with the right server address port to feed all this data into Unity.

To ensure a clear understanding of the potential improvements in the hand tracking's accuracy when implementing more features, it was essential to assess the baseline effectiveness of the original hand tracking system in Unity. This served as a reference point for gauging improvements.

The test consisted of a game being played for its entirety. The number of frames where the hands have not been passed in, meaning they are not being tracked successfully, will be noted and compared to total frames passed to get an accuracy percentage, shown in figure 46 below.

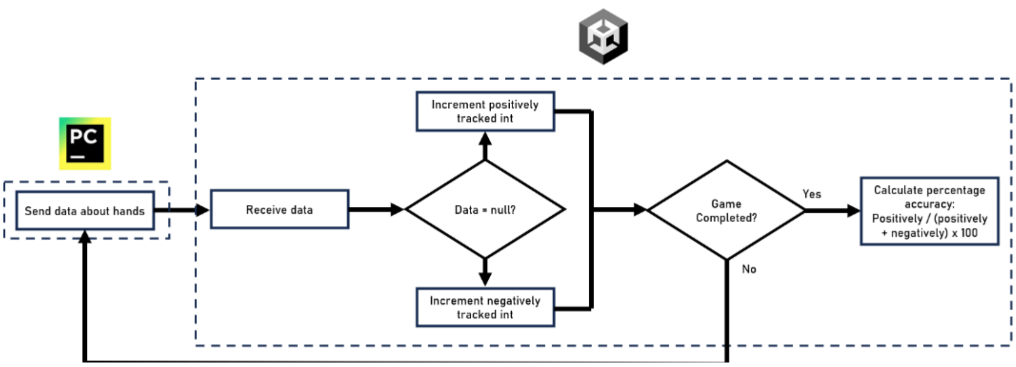



*Figure 46: Flowchart to show how hand tracking was analysed*

Each of the tests were completed on the Butterfly Grabbing minigame, as this was one of the few games that utilises the whole screen space. This ensured that the screen was correctly calibrated and lined up with the camera's space.

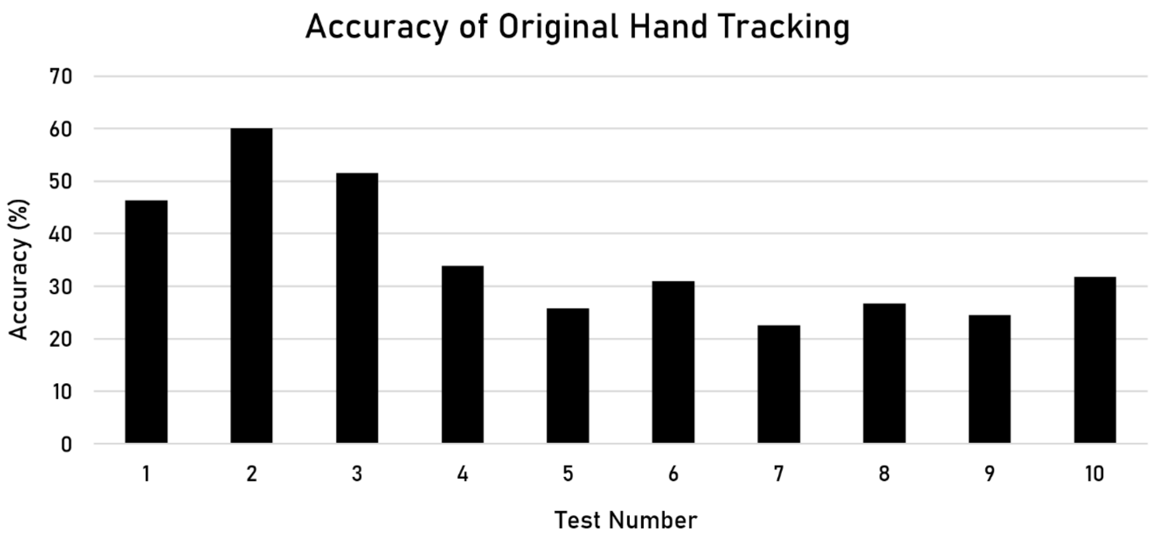



*Figure 47: Graph to show accuracy of original hand tracking*

The original hand tracking algorithm was tested 10 times as there exists the potential for human error where the hands can leave the tracking area and can be impossible to be tracked. The results showed very low accuracy with the hands being tracked an average of 35.4% of the time during the game. This was mainly due to the calibration of the screen in Unity. The Unity screen showing the game and the PyCharm screen tracking the hands were not aligned, meaning there were spaces in the Unity scene where the hands could reach or be tracked, shown in Figure 48.

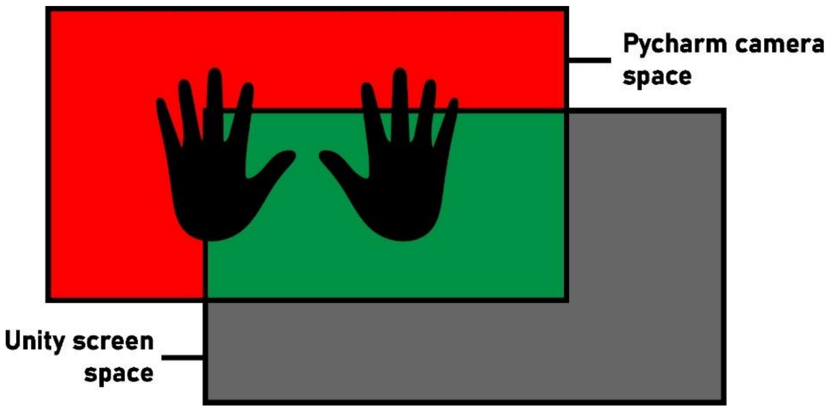



*Figure 48: Diagram showing the orientation of screens before calibration*

To resolve this problem the bounds of the camera were found in the Unity scene and lined up with the bounds of the unity camera. The Unity camera was then zoomed in so that the PyCharm space was slightly larger than the Unity screen space and the hands could be tracked in the furthest corners of the screen with no problems.

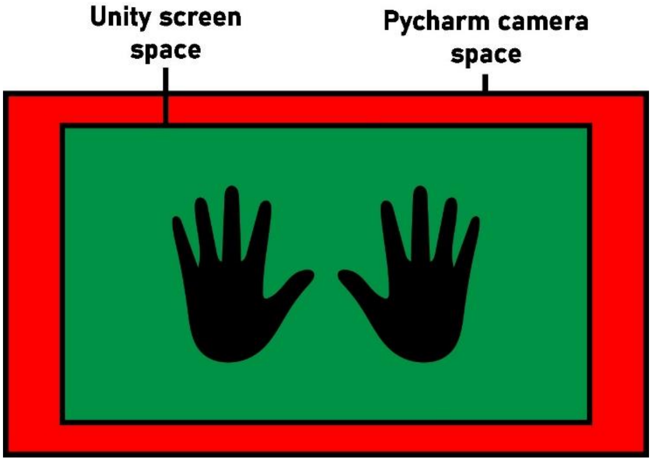



*Figure 49: Diagram showing the orientation of screens after calibration*

Once the screens had been calibrated the gamemode was tested a further 10 times, providing much higher accuracy. Making this change improved the average accuracy from 35.4% to 98.9%.

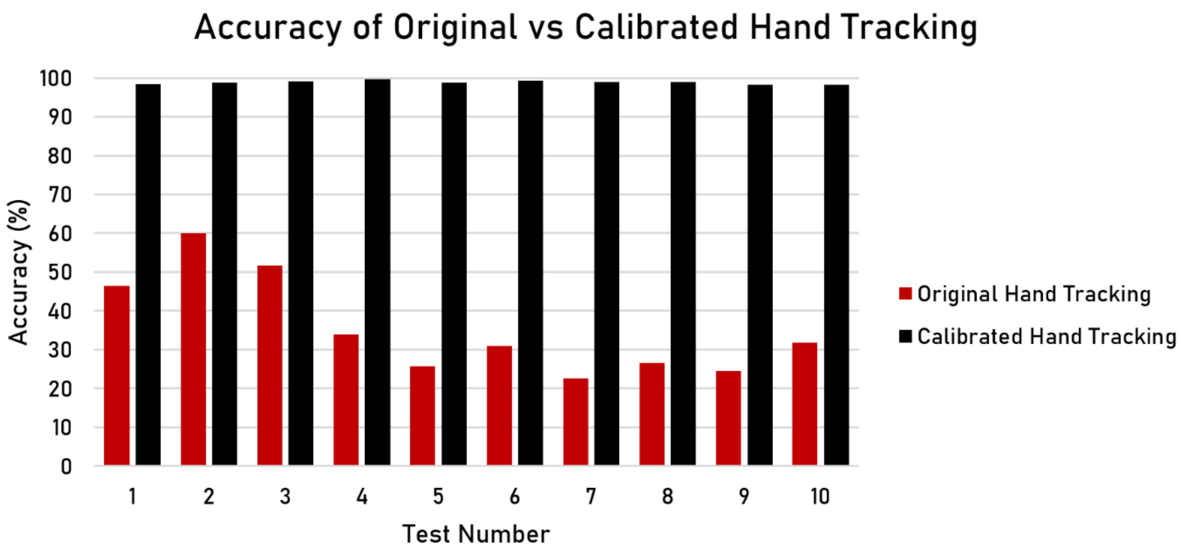



Figure 50: Graph to show accuracy of original hand tracking vs calibrated hand tracking

This does surpass the goal of 90%, however, the movements still do not feel as fluid as possible with many frames still being dropped.

### 4.4.1 Detection Confidence

The OpenCV tool has a parameter called Detection Confidence. This represents the minimum confidence level required for a hand detection to be considered valid during the tracking process. Each detected hand is assigned a confidence score which indicates how confident the detector is that the detected region corresponds to a hand. The Detection Confidence works as a threshold value, with any value below this threshold being ignored.

The Detection Confidence allows a trade-off between accuracy and robustness. Higher values provide more accurate hand detections and fewer false positives and lower values provide more detections overall, but may increase the number of false positives tracked and provide less reliable detections.

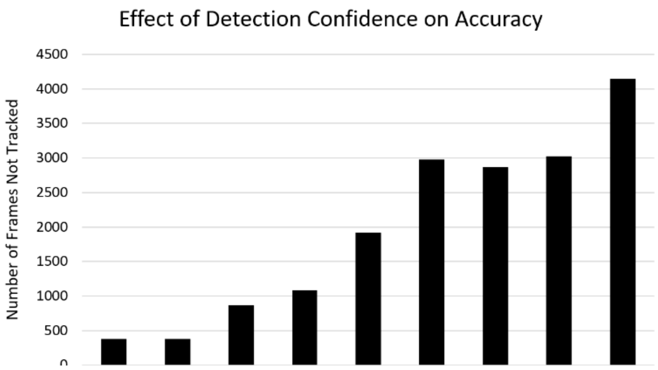



*Figure 51: Graph to show effect of detection confidence on accuracy of hand tracking*

The Butterfly Game was tested five times at each Detection Confidence. The average number of frames that passed where the hands were not being tracked was found. It is evident that with higher values more frames were lost. When testing, the hand movements shown on the screen at higher levels felt a lot choppier and more unresponsive, especially when it came to quick hand movements, where the hands were not tracked at all. At lower values the movements felt a lot smoother, with the hands showing their correct position most of the time.

Lower values are clearly the best option. The Detection Confidence of 0.1 and 0.2 were very similar, therefore 0.2 is the best option as it provides less false positives while still being very smooth.

### 4.4.2 Minimum Tracking Confidence

Using the newfound best value for Detection Confidence, the value of Minimum Tracking Confidence could be evaluated, which is the minimum level of confidence required for the hand tracking algorithm to continue to track a detected hand across multiple frames.

The Minimum Tracking Confidence allows for a trade-off between accuracy and robustness. A high value ensures more precise tracking and will only continue to track a hand if its confident it is seeing a hand. This means that the tools would be more accurate, but would become choppier with less values being passed in due to uncertainty. A low value will keep tracking the hands even if it is unsure, meaning the movements are smoother, but could lead to mistakes and track objects other than the hands and interfere with the program. Low values are also better for quick movements, as the program is less selective and will analyse the hand when blurry and moving.

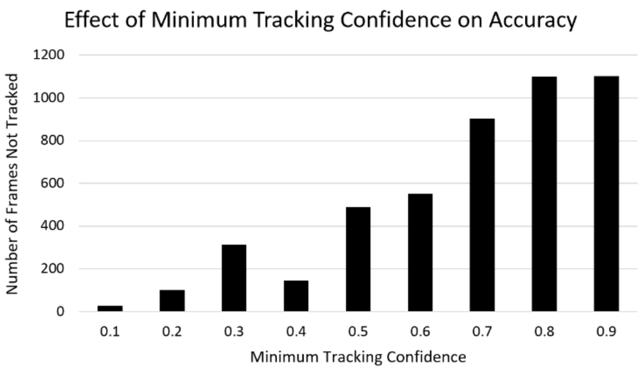



*Figure 52: Graph to show effect of minimum tracking confidence on accuracy of hand tracking*

The graph shows the positive correlation between the Minimum Tracking Confidence and the number of frames lost. Again, it is clear that the lower values provide the smoothest experience as well as very accurate results, with very few false positives arising in testing. By using a value of 0.1, there was an average of 26.7 frames where the hands were not showing.

### 4.4.3 Ideal Distance

As the hands are tracked through the z axis as well, there needs to be an ideal distance found from the camera to position the hands in order to get the best game performance. This distance will be highlighted to the user when playing to help orientate their position to obtain the best results.

To test the ideal distance, the distance between the top and the bottom of the hand was constantly tracked within Unity. A tape measure was used to test what this value would be at different distances from the camera in order to generate an exponential equation to calculate distance within the program. This then allowed the author to play through different games at different calculated distances. The best distance was found to be 0.7m away from the camera, as it provides plenty of space to move the hands around without going out of bounds. This distance was found to be very similar to that of the third example game in the research, reinforcing its effectiveness.

This distance allowed the author to correctly adjust the movement's threshold values. The movements work by finding the distance between the two selected parts of the finger and check if this distance is smaller than the threshold, which is when the movement will be completed. This threshold was specified for the 0.7m distance from the camera to ensure all movements are detected properly.

To highlight the ideal distance to the user, an icon is shown on screen which presents feedback to the user. It is green if the distance is optimal, orange if the distance is near optimal and red if the user is too close or too far away to play the game properly.

### 4.4.4 Final Analysis of Hand Tracking

Each game mode includes very different motions of the hand and different gesture recognition. To ensure that the adjustments made to the hand tracking work for all scenarios each game mode is tested to check how many frames are dropped each run to ensure that the accuracy objective is met. Each game mode was tested 5 times to ensure the results were accurate.

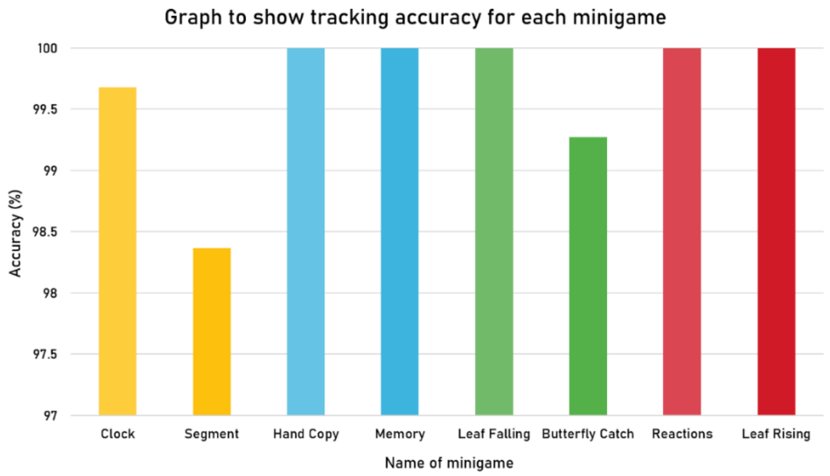



*Figure 53: Graph to show tracking accuracy for each minigame*

Figure 53 shows the accuracy of each game mode, which are colour coded by their specific movements. The hand tracking proved to be very accurate with 5 minigames not dropping a single frame throughout the 5 test runs.

The clock and segment games, which are both based upon wrist circumduction, dropped frames as a result of the program not being able to detect the hand from certain awkward positions when rotating, however, this did not impact the quality of gameplay. In addition, the Butterfly Catch game mode dropped a few frames too due to the quick and jagged movements involved in reaching out to the butterflies as fast as possible. These dropped frames also did not impact the game.

With all these features adjusted and improved with the hand tracking, it successfully achieved over 90% throughout all the different minigames, meaning it achieved the goal set out in the project's aims.

## 4.5 Analysis of Voice Commands

The quality of the voice translator is very important. This is because it will enable the user to traverse the menus and the game if they struggle with motor control, which many stroke survivors do. This is why the commands spoken must be converted and processed with over 90% accuracy. The accuracy will be tested by speaking 50 words into the microphone at each iteration and testing if they are picked up or not. This value will provide a percentage to show how accurate each tool is.

### 4.5.1 Hugging Face

The Hugging Face API is the first of the two voice translators found in the research. The results of the test are shown in the graph in Figure 54.

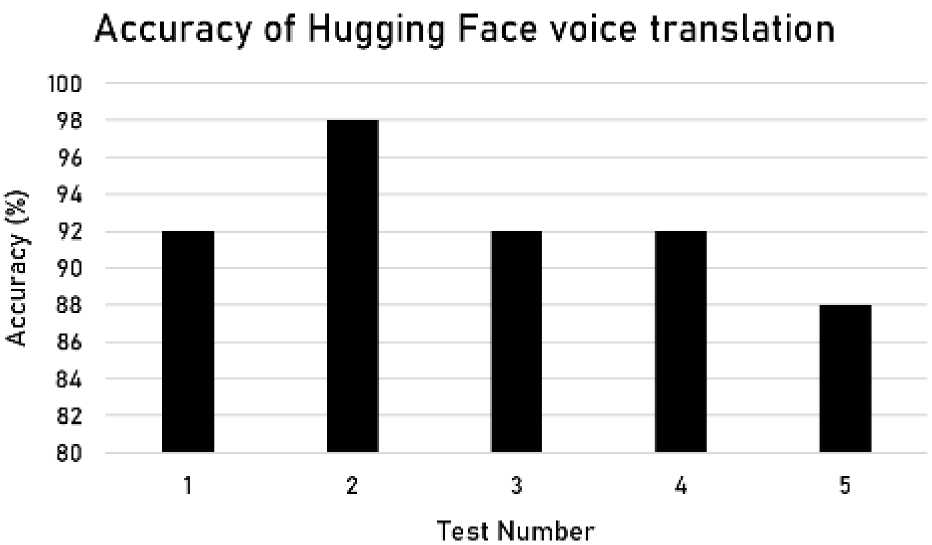



*Figure 54: Graph to show accuracy of Hugging Face voice translation*

The Hugging Face program did achieve 90% accuracy to meet the objective, however, there were a lot of issues with the tool that diminished its quality. The tool only allows a limited number of requests for translation in a certain timeframe meaning they had to be spread out over a few seconds. This slowed down the translation process and resulted in a very frustrating experience having to wait to get any sort of feedback.

In addition, there were many errors on the server side with this tool, such as the service being unavailable or not responding, causing the waiting times to increase or not provide any response at all, leading to frustration. The Hugging Face API also required connection to the internet, so would be troublesome with slow Wi-Fi. The service would also timeout if the voice prompt was too long, which caused more issues.

### 4.5.2 Dictation Recogniser
The results from the Windows Dictation Recogniser are shown in Figure 54.

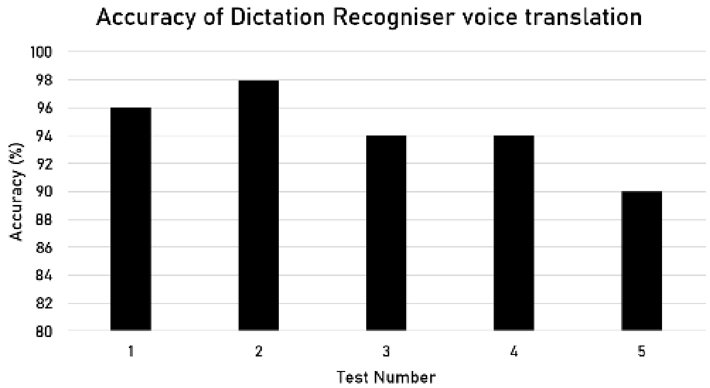



*Figure 55: Graph to show accuracy of Dictation Recogniser voice translation*

This tool would constantly be listening and would build up the response for as long as the user is speaking which presented more accurate passages of text. It also functioned using a hypothesis to predict what the user was going to say, then build upon this prediction to give very accurate results which were almost always correct. Due to this tool's speed and lack of issues, it was the clear choice to use as the voice to text translator.

Even though the best accuracy was found, other factors have a much more influential impact on the quality of the tool, such as the speed and clarity of speech, reduction of background noise and other factors in control of the user. In order to achieve the best results, the user must speak clearly and calmly so their functions are picked up.

With this effective voice translator, it allows users to use voice inputs rather than using a mouse and keyboard to perform functions.

## 4.6 Summary
The testing phase consisted firstly of unit testing of each of the different modules in the project to ensure they work separately. They were then combined and tested as an entire system to make sure everything works and runs smoothly. Both methods brought up some errors, which were then resolved.

In addition, the hand tracking and voice translation functions were tested iteratively and improved until they had over 90% efficiency to achieve the goals laid out in the first section of the project.

# 5 Evaluation and Conclusion

## 5.1 Introduction
This section provides a conclusion to the project and explains if the aims and objectives from Section 1 were met and how this was achieved. This will be justified with the data shown through the tests completed in Section 4. It also provides a personal evaluation, discussing the time frame and progression of the project compared to the original plan and how things changed to meet the deadlines set. It also discusses the positive aspects of the project and the areas which could have been approached better. It provides details about potential future plans that the project presents, as well as explaining what useful skills and knowledge the author learnt from designing the project.

## 5.2 Conclusion

### 5.2.1 Aims and Objectives Evaluation
At the start of the project its aims and objectives were explained, detailing what the project would achieve and how It would perform. To see how well the program was implemented these aims and objectives now have to be evaluated to check that they were successfully met.

Objective 1 - Completed: Research and identify hand tracking and accessibility techniques to be implemented

Different methods of hand tracking were investigated and OpenCV through PyCharm was found to be the most effective and compatible tool. Methods such as adapting the confidence of the tracker and adjusting their position on screen can work to make the hand tracking much more accurate and efficient.

Due to the nature of voice tracking relying on a lot of user inputs, little can be done on the program's side, however, multiple APIs for voice to text translation were researched, found and tested to figure out which was the most effective.

Objective 2 - Completed: Implement effective hand tracking that has a success rate of over 90%

The success of the hand tracking was originally tested in the Butterfly Catching minigame as it utilises the most screen space and requires the most movement. As this gamemode requires so much movement it would be the least accurate tracker and provide a baseline value to work on.

The tracking was originally tested in game with an accuracy of 35.4%. It was then calibrated and the screens were aligned to provide a much-improved accuracy of 98.9%. Multiple variables, which dealt with the way the hands track and their confidence with tracking, were then tested further and adjusted to provide more accurate tracking.

The tracking was then tested for the 8 different minigames to see how it would manage in different scenarios. 5 of the games tracked the hands successfully 100% of the time and all of the games achieved over 98% accuracy. Evidently, this exceeds the goal of 90% set out at the start of the project.

Objective 3 – Partially Completed: Properly evaluate progress made by the user and display this as quantitative data

Data about the reaction times and the points gained are retrieved from each gamemode. After each gamemode is complete, data about the game and current progress is presented to show any short-term improvements that are being made. There is also more in-depth data about the games within the analysis menu. Each game presents a graph showing the trends of improvement found in each gamemode for both the score and the reaction time.

Some games, such as the Memory game, give a better insight to the player's improvement in specific areas such as reaction times. Overall, all the games provide enough information to show the user's progress and highlight areas where they are stronger or weaker, which can be focused on more.

The objective was only partially completed due to the absence of the adaptive difficulty function mentioned in the introduction. Many other aspects of implementation took priority and as this project was so big it was difficult to allocate time for its completion. However, within the research it was mentioned that the modular approach that was taken could result in varying difficulties as well as varying choices specialised to the user. The author believes that the implementation of the randomiser achieved the same goal as the adaptive difficulty function, therefore it was not as important to implement.

Objective 4 - Completed: Research and implement encouraging gameplay and supportive feedback

During the research period, the author found multiple articles providing information about the best practises to follow when making a serious game for health in order to keep the gameplay encouraging and retain activity.

The importance of colour was shown in the research, having effects on memory and cognitive performance, as well as having mental effects with colourful feedback. The game was kept colourful with contrasting, positive and encouraging colours. Encouragement was also implemented through animations and sound to commend the user for completing the correct action.

All of this support would help the user to feel far less stressed and provide a more immersive, enjoyable experience.

Objective 5 - Completed: Implement effective voice translation that produces outputs that are over 90% effective

To allow the app to be accessible to users who struggle with motor function, the voice translator must be over 90% effective in order to work efficiently and not frustrate the user. Two tools were tested, all providing results that were over 90%, achieving the aim. The best tool was chosen, based upon effectiveness as well as other factors such as input delay and presence of errors.

In addition to the five objectives, there was a main aim to develop a video game to encourage stroke patients to keep active and moving at home, as set out in Section 1. This was also met, as the movements researched in Section 2 have been successfully gamified while following the practises of previous games for health.

# 5.3 Evaluation

## 5.3.1 Time Scale

The original time plan for the process was presented at the start of the project in the form of a Gantt Chart. It presented the original time scale the author thought would be required to complete the project. The plan also contained three weeks between the original planned prototype deadline and the ultimate dissertation deadline. This provided plenty of time for documentation, testing and allowed for certain deadlines to be pushed back and manipulated to complete the project in time, proving a very flexible project timetable. Overall, the plan was followed, but some changes were made during development.

Originally, the author was unsure whether to implement all of the gamemodes first or whether it was more efficient to test the hand tracking, then make the games afterwards. The plan set out the hand tracking first, then the minigames, however, this turned out to be more of an iterative process with tracking being tested within each gamemode after completion.

The implementation and testing of the voice tracking was pushed back to the end of the project. This was because it was believed to have a lower priority compared to the development of the gamemodes and the implementation of the hand tracking, as without these key attributes the game would not be functional. The voice tracking provides an additional accessibility feature but the menus are still accessible through the use of the mouse and keyboard.

The original plan provided plenty of time to work on the design and implementation of the gamemodes. However, the deadline of the final prototype was missed due to the gamemodes requiring much more time than originally allocated. In addition, other small improvements and tests needed to be carried out to the program which pushed the deadline back further.

During development, new time slots were introduced for areas of implementation which were not included in the original plan. Time for setting up the coordination menu and similar aspects were not initially considered meaning space had to be found within the timescale to include these.

All of these changes allowed for the project to be managed better and still allowed the project to be completed before the ultimate deadline.

## 5.3.2 What was Learnt

It was the author's first experience with using external libraries within PyCharm, so learning to work with OpenCV and implementing the hand tracking technologies made the author a lot more familiar with how useful these kinds of libraries can be, and how easy they are to implement.

## 5.3.3 What Went Well

To start the project, the hands needed to be implemented through PyCharm in OpenCV. Even with my lack of experience with OpenCV and similar packages, the author was able to quickly and effectively implement hand tracking. The process of feeding this data over to Unity using sockets and ports went very well too, especially since the author had very little experience in this area.

The development process of gamemodes went very well. This was already planned to take a long time but due to taking a modular approach, which was found to be the best structure to use within the research, a lot of the code could be reused in every game, which saved a lot of time and made the process far quicker.

The construction of the analysis page and the progress graphs also used a modular approach so it could be repeated for each gamemode. The creation of the graph was very quick and easy and the author was very happy with how it looked with results.

### 5.3.4 How the Project Could Have Been Improved

Overall, the project was a success but some aspects could have been improved during development.

The different movements within the game are recognised by checking the finger's points' proximity to each other. This is calculated using their x, y and z coordinates; however, gesture recognition is only optimal at 0.7m away. At different distances the hands become bigger or smaller on screen and the points in the hands are closer or further away, so the threshold is not met to complete the movement, making the game unplayable. This optimal distance is highlighted in the game by a colourful display but the movements should work at any distance. The distance required should scale with distance from the screen to ensure this.

## 5.4 Further Work

If development was to continue past the deadline date, additional minigames would be created and integrated to provide increased variety. There are currently eight minigames, two for each movement. In addition, more movements could be incorporated into different minigames so that more muscles can be exercised, as stroke affects extra motor control than just the hands. This could include more hand movements, such as finger circumduction or wrist flexion. It could also include arm and shoulder movements, which would make the game tailored towards upper limb rehabilitation or more general movements of the body for whole body rehabilitation. These implementations would be useful as the user would not have to find other ways to exercise the other areas, as the game is currently limited to just one area in great depth.

A lot of work was done on trying to make the hand tracking accurate, which was successful in good lighting. All users have different lighting depending on their environment. Darker or brighter settings were found to lower the accuracy of the hands, as they weren't being tracked. To improve upon this, additional work can be done to adjust the light level of the camera so the hands can be tracked no matter what the brightness.

There also exists the requirement to test the game with users who will use the game for rehabilitation and evaluate its success in a real scenario. This does require following the correct ethical principles, as there are considerations with taking in people's private data.

## 5.5 Summary

All of the aims and objectives were successfully met, with proof being provided within the testing of the project which allowed an effective Game for Health to be produced.

The author provided an in-depth evaluation, explaining what went well in the project, what didn't go so well and how the plan changed from the original. Areas for future work were also identified:

- Additional movements and minigames to provide a greater variation of gameplay
- Video tracking with adaptive lighting
- Potential to test prototype with future users

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