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A3: Dissertation

DESIGN AND IMPLEMENT A MULTIPLAYER DIGITAL GAME FOR UPPER LIMB STROKE REHABILITATION.

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Abstract

Stroke is a disease effecting millions of people globally each year. Once a patient has been discharged from hospital upper limb stroke rehabilitation can be administered from home. However, this rehabilitation often offers low levels of motivation which can lead to patient non-compliance.

This project created a gamified solution encouraging its players to perform movements beneficial to stroke rehabilitation. The project is a two-player multiplayer fishing game.

The project was tested on adults and responses were gathered in the form of a System Usability Scale (SUS) and a Game User Experience Satisfaction Scale (GUESS). Feedback from the testers showed the game provides high levels of motivation and fun. Usability shortcomings were also identified which would have to be addressed should this project be taken further.

Acknowledgements

Firstly, I would like to thank my project supervisor Xi Guo for her continued support and investment in myself and the project. Due to your support a project has been created which I am exceptionally proud of. Secondly, I would like to thank my second supervisor Dr Liucheng Guo it has been a pleasure working with you and TG0. Additionally, thank you to the Real FLC community for providing the assets to be used in the project and thank you to the members of the unity for humanity grant team, it is truly surreal to see the project recognised by Unity. Thank you to all my family and friends who have provided their constant love and support and thank you to all the testers who have tested the project.

Table of Contents

Glossary

API	Application Programming Interface
FMOD	Software used to handle game audio in various game engines
GFX	Graphics
GPU	Graphics Processing Unit
GUESS	Game User Experience Satisfaction Scale
Shader	A program ran on the GPU
SUS	System Usability Scale
UI	User Interface
UL	Upper Limb
UV	Two-dimensional texture coordinates that correspond with the vertex information of the geometry

List of Figures

List of Tables

List of Equations

1 Introduction

This project covers the research, development and testing of a multiplayer video game designed to be used in an upper limb stroke rehabilitation setting. This is a preliminary test where player enjoyment will be the key metric.

1.1 Problem Definition

Each year millions are affected by stroke. Current upper limb home rehabilitation programs do not offer prominent levels of motivation leading to patient non-compliance.

As a preliminary test this project will seek to create a gamified solution, which encourages the players to move their arms in ways beneficial to stroke rehabilitation.

1.2 Scope

This project will be designed with considerations of a stroke rehabilitation context; however, it will be tested on adults. This is due to the project being a preliminary study focusing on player enjoyment.

1.3 Rationale

While gamified rehabilitation has been a research topic to combat patient noncompliance due to lack of motivation, the use of multiplayer gameplay is still somewhat of a fringe topic. This project will contribute to the body of knowledge by creating a highly motivational game which is controlled via arm movements. The project will be open-sourced allowing others to take the source code and adapt the project to be suitable for use with stroke survivors.

1.4 Project Aim and Objectives

1.4.1 Project Aim

The aim of this project is to produce a multiplayer game, utilizing etee controllers, which encourages movements beneficial to Upper Limb (UL) stroke rehabilitation and provides more motivation than conventional home therapy treatments.

1.4.2 Project Objectives

Table 1 Project Objectives

Objective Number	**Objective**
1	Identify characteristics of effective rehabilitation treatments.
2	Identify movements beneficial to providing effective rehabilitation treatment.
3	Use knowledge gained from objectives 1 and 2 to design, scope and plan the development of the game
4	Develop the game using the designs and plans produced in the previous objective using agile project management techniques
5	Test the game with a group of adults to observe the repetitions of the intended motions and motivation to play the game relative to other therapy options.
6	Use the knowledge learned from testing to evaluate the project's outcomes.

7	Summarize and report writing

1.5 Background Information

(Feigin et al) reported that there are over 101 million stroke survivors with over 12.2 million strokes occurring globally per annum.

Upper limb stroke rehabilitation typically sees heightened implementation after patients are discharged from the hospital. After returning home a patient should undertake home therapy programmes to further recover and better their quality of life.

Having a range of home therapy options is vital, crucially due to patient travel limitations. Almost 10 million people in England live in rural areas. (Gov.Uk, 2024:7) In these areas there are more people aged 50-59 years than any other age group with one in four people being over 65 (Gov.Uk, 2024:8). This correlates with the ages statistically vulnerable to having a stroke. According to the GRASP instructor manual (The University of British Columbia, 2021:9) the risk of stroke doubles every 10 years after age 55, with the typical age at the time of stroke being 70 – 75 and 25% of strokes occurring in individuals below the age of 65.

The brain has the most ability to repair itself in the first 3 months' post stroke (The University of British Columbia: 2021: 5) therefore it is vital that the patient completes as much therapy in this time as possible to maximise recovery. Currently there are home therapy programmes such as the GRASP manual. However contemporary home therapy programmes do not provide high levels of motivation to the patient, this can cause the therapy to be neglected leading to sub-optimal recovery or potentially other implications such as learned non-use syndrome (The University of British Columbia, 2021: 13).

Therefore, it is important to explore ways to provide more motivation to the patient. Gamification and even more so multiplayer gamification is one such way this goal can be achieved. Being able to play the game alongside family members, friends or caregivers may provide higher levels of motivation and reduce the neglect of home therapy, increasing its effectiveness.

2 Literature Review

2.1.1 Literature Search Methodology

To find relevant and useful papers PICOC in conjunction with PRISMA will be used to find and screen papers. PICOC is "a method used to describe the five elements of a searchable question" ("What is a PICOC? » CEBMa," n.d.). PICOC will be used to help think about and create searchable terms which will be used to find and screen papers as per the PRISMA guidelines.

PRISMA provides a set of guidelines ensuring systematic reviews and meta-analyses are comprehensive, transparent and reproducible. Prisma guidelines will be used in the selection process of relevant papers.

Table 2 PICOC Acronym Expanded in Relation to This Paper

PICOC element	Expanded acronym
Population (Who?)	General population sample
Intervention (What or How?)	A bespoke multiplayer gamified software solution designed to facilitate and encourage upper limb movements conducive to stroke rehabilitation
Comparison (Compared to what?)	Conventional physical therapy techniques used for upper limb rehabilitation (e.g. traditional exercises)
Outcome (What are you trying to accomplish / improve?)	Users perform therapeutic upper limb movements with increased motivation compared to conventional therapy.
Context (in what kind of organization / circumstances?)	Using the software for rehabilitation in a home setting.

Using this PICOC structure, keyword search terms and permutations can be generated and used in databases to find potentially useful literature.

Table 3 Generated Search Terms and Their Results

Search term permutation	Input to database search	Searched database	Literature retrieved count
(Population) AND (Intervention)	(general AND population OR stroke AND patients) AND (gamified AND rehabilitation OR virtual AND therapy)	Scopus	2
(Outcome) AND (Context)	(upper AND limb AND movements OR patient AND engagement) AND (home-based OR in-home)	Scopus	19
(Intervention) AND (Comparison)	(game-based AND software OR digital AND therapy) AND (traditional AND	Scopus	4

	rehabilitation OR conventional AND therapy)		
(Intervention) AND (Outcome) AND (Context)	(gamified AND rehabilitation OR virtual AND therapy OR game-based AND software OR digital AND therapy) (motor AND improvement OR adherence) AND (home AND rehabilitation)	Scopus	1
(Population) AND (Intervention) AND (Outcome) AND (Context) AND NOT (Exclusions)	(general population OR stroke patients) AND (gamified rehabilitation OR virtual therapy OR Serious Games) AND (upper limb movements OR patient engagement) AND (home-based OR in-home) NOT (lower limb) NOT (clinical) AND (multiplayer OR multi-user)	Google Scholar	247

These searches retrieved a total of 273 pieces of likely relevant literature. These results will then be screened using inclusion and exclusion criteria.

Table 4 Inclusion and Exclusion Criteria to Screen for Relevant Literature

Inclusion Criteria	Exclusion Criteria
Literature focused on gamified or digital interventions for UL rehabilitation	Studies not related to stroke or upper limb rehabilitation
Studies evaluating repetitions or engagement as outcomes	Interventions not utilizing gamified or digital methods
Research involving at-home or remote-based rehabilitation	Studies with a focus solely on lower limb
Papers published in peer-reviewed journals	Research involving clinical settings exclusively
Studies that compare interventions to traditional rehabilitation methods	Result past the second page of google scholar
	Research focusing on robotic intervention

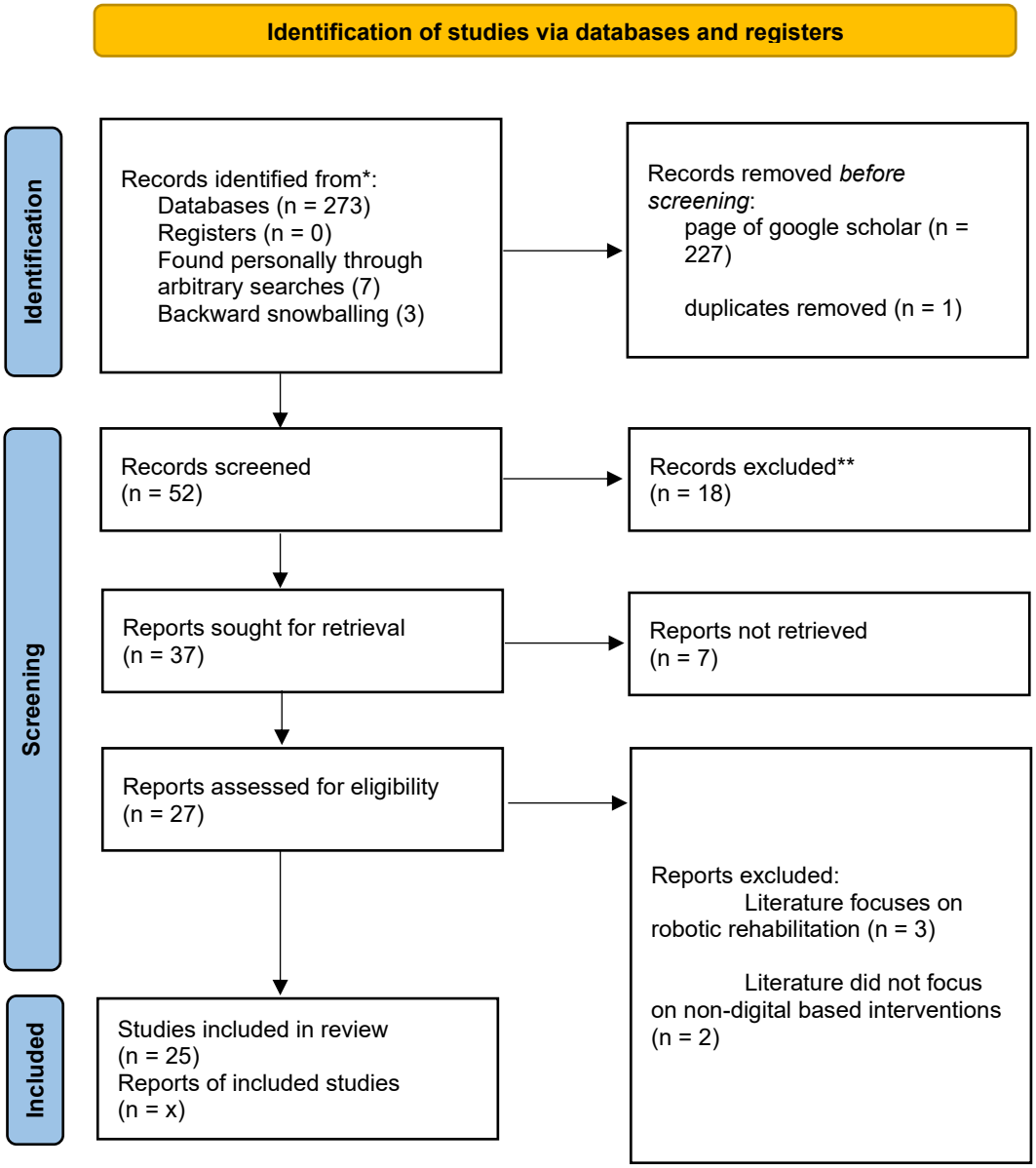


Figure 1 Identification of Studies Via Databases and Registers

2.1.2 Literature Review

2.1.2.1 Themes

Table 5 Identification and Justification of Themes for the Literature Review

Theme	Relevance
Gamified rehabilitation in stroke	Observe what gamification techniques have been applied in other projects to inform the approach to gamification in this project.
Digital application to enhance motivation for the therapy	The goal of this project is twofold, to create a therapy application where the user performs an adequate amount of movement while experiencing more motivation to do so. Knowing what game elements users respond well to will be important in creating an experience that users enjoy more than non-game therapies.
Digital application to enhance upper limb movement	Linked to the previous theme it is important to know what movements are beneficial to inform the design of the game and what it asks the user to do.
Haptics for rehabilitation game	Haptics is an implicit form of feedback correlated with effective rehabilitation and user experience.
Multiplayer games for stroke rehabilitation	A new and exciting topic for exploration which may provide large boosts to motivation.

2.1.3 Review of Literature

2.1.3.1 Gamified Rehabilitation for Stroke

Gamification is the application of elements typically found in commercial games. It is a technique which, when applied, results in greater levels of user motivation when completing a task. (Doumas et al, 2021) (Amorim et al, 2020) and (Triandafilou et al, 2018) have all found this to be the case in the context of stroke rehabilitation when compared to non-gamified therapies.

After reviewing relevant literature in the field of post stroke therapy gamification, (Tamayo-Serrano et al, 2018) identified a set of features commonly used in gamified rehabilitation applications. Some features which seem highly relevant to this project include meaningful play and feedback, social interaction, simple interaction devices and motivational rewards.

(Guo, 2024) discusses gamification and how it can be employed to create a gamified learning experience. The process of gamification is not a process of injecting game elements to the target context but instead requires systematic thinking to design game elements which help enhance and achieve the design goals (Guo, 2024).

2.1.3.2 Meaningful Play and feedback

(Tamayo-Serrano et al, 2018) describes Meaningful play as the ability for the player to perceive the immediate effects of his/her actions, which must have an impact in the game at some point in the future. The authors go on to state that the decisions made by the player will shape the outcomes of the game and this feedback can guide the player towards correct, and away from incorrect actions.

This type of feedback referred to as implicit feedback is one of the neurorehabilitation principles necessary for effective rehabilitation established by (Maier et al) cited by (Doumas et al, 2021).

2.1.3.3 Social Interaction

(Tamayo-Serrano et al, 2018) considers social interaction to be "the important motivational aspect to be implemented in a rehabilitation system". Widely used in commercial video games it can drive competition and collaboration.

Social interaction is linked with gamification in that gamification satisfies fundamental human desires (Toledo-Delgado et al, 2013). The human desire of self-expression which gamification can capitalize on is likely amplified by social interaction.

2.1.3.4 Simple interaction devices

The simplicity and usability of hardware device interfaces should be considered. (Tamayo-Serrano et al, 2018) states that older patients may struggle with learning complex interfaces and there is no guarantee that post stroke survivors will be able to effectively use the hardware should it be too complex.

Below is a table detailing the interaction devices used by applications included in the literature review.

Table 6 Interaction Devices Used in Reviewed Literatures

Interaction device name	Number of literatures used in	References to literatures
etee controller	1	[26]
Microsoft Kinect / other vision-based camera input	8	[25, 10, 22, 16, 28, 7, 4, 1]
Mobile device secured to patient	1	[6]
Immersive VR headset and Controllers	3	[5, 19, 17]
Tactile buttons	1	[23]
Haptic device (Novint Falcon, Omni Phantom)	1	[4]
Wii balance board	1	[4]
Nintendo Wii remote	1	[1]

The most common input device is a vision-based camera input, most commonly a Kinect device.

Studies [5, 19 and 17] all used VR headsets and controllers as the interface for their applications. (Chen et al, 2022) states that as VR technology is advancing it is becoming more cost effective and accessible to the public. This likely explains why the second most studied interaction device is immersive VR technologies.

One study [26] used etee controllers. etee controllers, designed to work in VR gaming applications have also been used in non-immersive VR contexts to create therapy applications. (Strong et al, 2022).

The use of haptic devices as mentioned by (Borghese et al, 2012) is interesting and novel and may be effective in UL rehabilitation due to the haptic feedback they provide to the user. However, the devices cost is likely what has caused them to be infrequently used in studies.

2.1.3.5 Motivational Rewards

Motivational rewards refer to points or ranking systems, and they are regarded by (Tamayo-Serrano et al, 2018) as effective ways of generating motivation, when paired with social interaction even being so effective as to generate addiction. (Toledo-Delgado et al, 2013) as referenced by (Tamayo-Serrano et al, 2018). This is important as according to (Gelineau et al, 2022: 2) “many people do not feel motivated to engage in new habits”.

(Koutsiana et al, 2020) found rehabilitation games are usually task driven (62.1% of reviewed material) but it is also common to see score driven games 41.1%.

2.1.4 Digital application to enhance motivation of the therapy.

(Koutsiana et al, 2020) explored the technologies used for UL rehab. It was found that researchers prefer to use commercial hardware over development of new hardware (62.7% of studies). Likely due to extra cost and project complexity.

When discussing the gameplay approaches for increased engagement and motivation, (Hadjipanayi et al, 2024), highlights the significance of the visual aspects of exergames. (Hadjipanayi et al, 2024: 1). “Patients appreciate beautiful environments and respond positively to them regardless of the level of sensory immersion” (Hadjipanayi et al, 2024). While (Hadjipanayi et al, 2024) agrees that the visual aspects of an exergame are important they also state “it is crucial to consider that beautiful scenery can be highly subjective” (Hadjipanayi et al, 2024: 6). They go on to reference (H.-T. Jung, et al, 2020) and (G. Burdea et al, 2021) stating that highly detailed and photorealistic graphics may cognitively overwhelm and cause discomfort to patients with neurological impairments.

Achievements were also found to have had an impact on the neurophysiology of the brain.

Certain types of on-screen visual feedback can activate mirror neurons potentially aiding in stroke recovery. (A. Warland et al, 2019) as referenced in (Hadjipanayi et al, 2024). Better yet synchronised virtual kinematic representation of an upper limb can help strengthen the control of the paretic limb (J. Rong et al, 2021), (H. -S. Choi et al, 2019) as cited in (Hadjipanayi et al, 2024).

2.1.5 Digital application to enhance upper limb movement.

Bespoke, non-immersive games of the casual genre were identified as being some, among others, as the most effective combinations of design elements. (Virera et al, 2021)

Upper limb functions can be separated into gross and fine motor skills. (Pan, W, 2018). Fine motor skills referring to small muscle movements like the hands and gross movements being larger, for example the coordination of the proximal joints such as the shoulder and elbow (Pan, W, 2018).

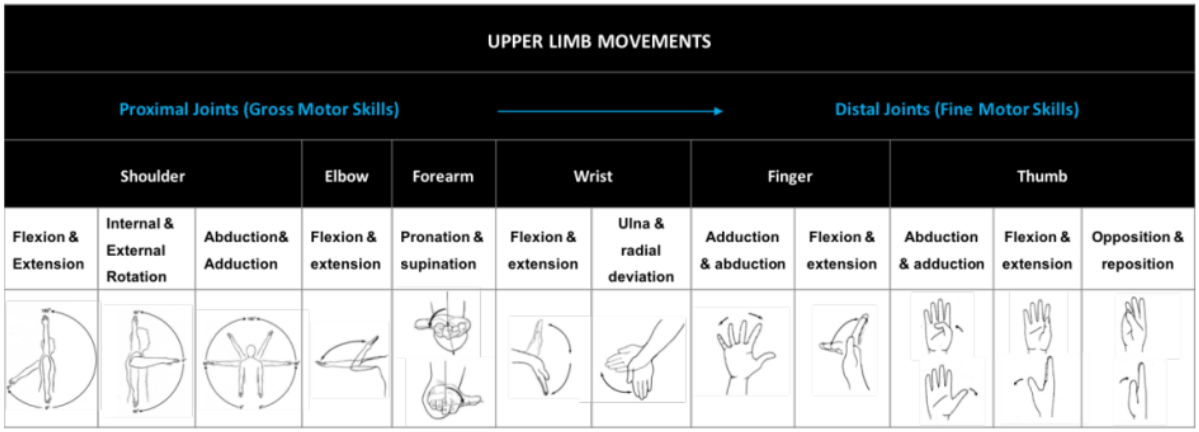


Figure 2 Upper Limb Movements Table

Due to the hardware being used and its sensing capacities the following movements will be omitted in this project. Wrist movements, finger adduction and abduction and thumb extension.

2.1.6 Haptics for rehabilitation game

Implicit feedback is an especially important feature in stroke rehabilitation games. Haptic feedback is one such way that this feedback can be provided. (Ning et al, 2022) considers haptic feedback to be one of three types of feedback. Visual, haptic and auditory. (Ning et al, 2022) goes on to state that the different forms of feedback contribute to different cognitive functions. Haptic feedback can provide more cognitive skills training than visual feedback while using less cognitive bandwidth. (Ning et al, 2022) states that when developing games for rehabilitation researchers should pay attention to the choice of feedback they can provide as well as the degree of feedback.

(Baur et al, 2018) states increasing haptic support can be used as a means of enhancing the individualization of a virtual reality therapy game. (Baur et al, 2018) also states “The benefit of social interaction could be increased by integrating visual, auditory/verbal, and haptic elements.”. The haptic elements here likely help to immerse the player in the game world and as stated earlier help to give implicit feedback.

2.1.7 Multiplayer Games for Stroke Rehabilitation.

The implementation of social interaction in gamified solutions has seen promising results. From the ability to share game related info and stats with a community of other patients and therapists (Borghese et al, 2012), to multiplayer games designed to be played competitively and / or collaboratively. (Alankus et al, 2010), (Pan, W, 2018), (Cordeiro d'Ornellas et al, 2015), (Triandafilou et al, 2018), (Baur et al, 2018).

(Alankus et al, 2010) rationalizes multiplayer games, be that competitive or collaborative, give more motivation. (Pan, W, 2018) found over a 12-week timeframe, patients playing a competitive game sustained player enjoyment while singleplayer and a control group saw a significant decline in player enjoyment. (Pan, W 2018: 4) concludes "competitive gameplay has significant effects on long-term motivation" Authors (Staiano et al, 2012), (Lin et al, 2006) and (Chin A Paw et al, 2006) as cited by (Pan, W., 2018) have also found cooperation and competition to improve engagement, adherence rates, motivation and energy expenditure.

An interesting observation made by (Alankus et al, 2010) is the opportunity for a patient and carer, who usually have a relationship where the patient is dependent on the carer, where they can collaborate as equals, facilitated through the context of the multiplayer game.

(Triandafilou et al, 2018) created a multi-user environment which allowed patients to interact with therapists and /or other patients. Unlike the other studies however, it was explicitly stated that this interaction is networked and so these interactions can occur regardless of physical distance. (Wang Pan, 2018) interpreted the work of (Nap et al, 2009) reporting that playing games with a virtual partner over the internet decreased satisfaction. However, the findings of (Triandafilou et al, 2018) contrast this, reporting that 13 out of their 15 participants either very much or extremely enjoyed training with another virtual partner, and 14 participants, of the same group, either agreed or strongly agreed that training with a virtual partner increased motivation. One reason for the disparity in the findings between these studies could be the changes in social norms between 2009 and 2018. As communicating virtually was still relatively new especially for people belonging to older demographics. However currently people of all demographics are much more familiar with communicating virtually. Modern increased familiarity with technology and communicating virtually may have broken down the barriers blocking the potential benefits of virtual peer play explaining why (Triandafilou et al, 2018) found such positive satisfaction in their user base.

2.1.8 Summary

After reviewing literature, it is evident that to create an effective gamified rehabilitation, game design elements such as meaningful play, simple interaction devices and motivational rewards should be considered. While not essential, social elements and even multiplayer game designs can be included in the design of the game to boost user engagement and motivation.

By providing a visually appealing world the game can be more motivational and by giving implicit feedback to the user, for example synchronized movements of virtual elements to the patient's limb, and haptic feedback can provide more effective therapy.

The game will encourage the movement of gross and fine motor skills as clearly presented by (Pan, W, 2018).

2.1.8.1 Scope of the games

There seems to be a trend in creating small-scoped. Sometimes 1 standalone game [7, 24] other times users are given the ability to choose from a selection of small games [5, 1, 6, 22, 23]. Smaller scoped games can put all their focus into solving a problem.

A single, low to medium-scoped game, set in a visually appealing environment incorporating multiplayer gameplay is the most appropriate design for the project.

A fishing game where the players must complete UL actions to catch fish, for example raising then dropping their arm to cast the fishing line is proposed to be the game created for this project.

2.1.8.2 Prototype design

Figure 3 The Proposed Input Device for The Game

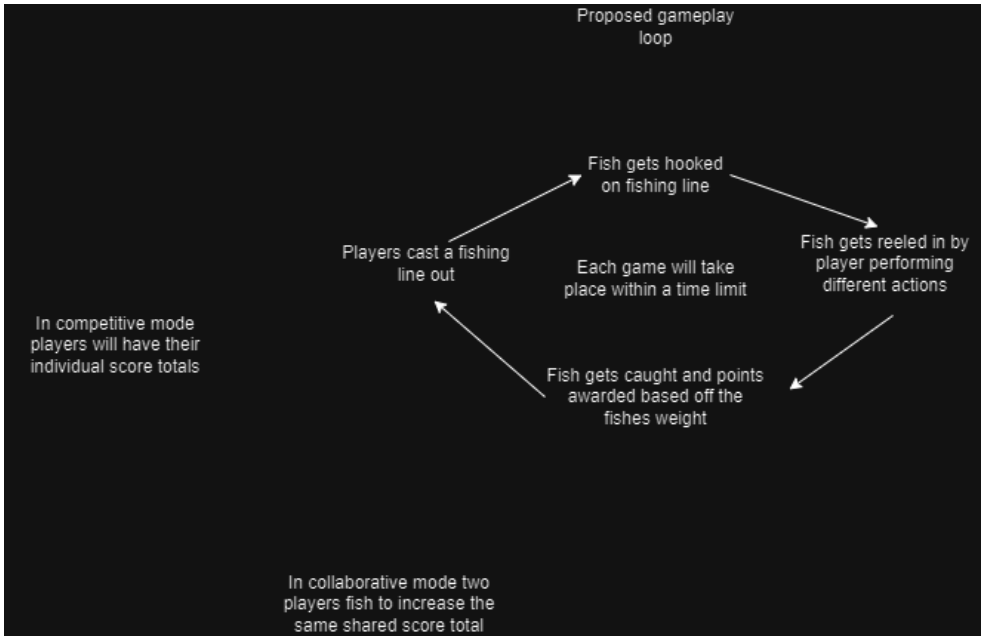


Figure 4 The Proposed Game Loop for The Game

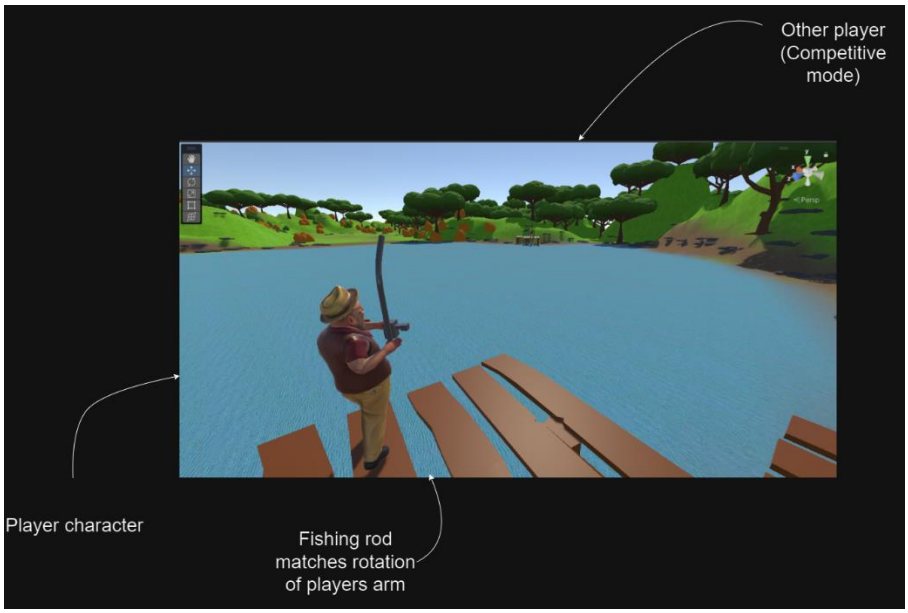


Figure 5 Concept Level (Competitive Mode)

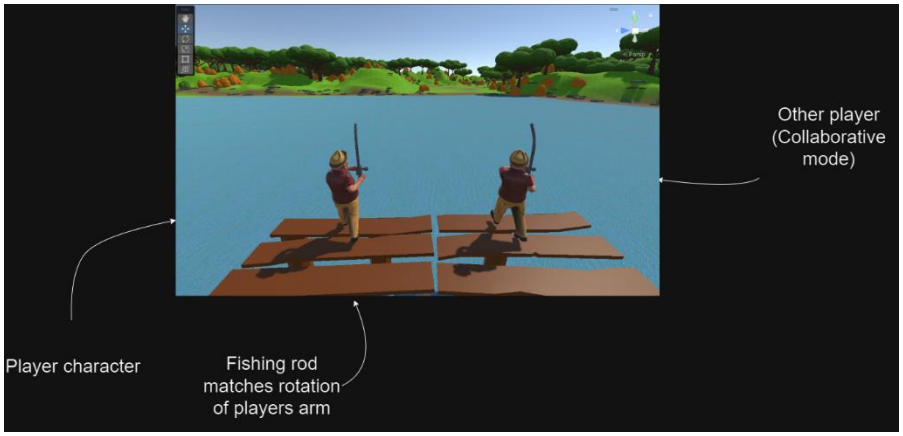


Figure 6 Concept Level (Collaborative Mode)

3 Method and Implementation

3.1 Methodology

The game will be developed using an agile methodology comprised of two sprints.

3.1.1 Sprint 1

Create a prototype which can be tested as part of a pilot test to get early feedback on the game and make necessary changes before testing and evaluation

3.1.2 Sprint 2

Incorporate feedback from the pilot test, finalize game features and add polish (e.g., final art, sound, UI) for the full version.

3.2 Design

Insight gained from performing a literature review informed the design of the artefact. (Vieira et al, 2021) found that of the studies which presented clinical improvements 25% (2) studies presented their game as being from the sports genre. As this is a genre which has been used in studies which showed clinical improvement this project will create a game which belongs to the sports genre.

(Hadjipanayi et al, 2024) found that patients appreciate and respond positively to beautiful environments highlighting a significance in the visual aspects of the game. (G. Burdea et al, 2021) as referenced by (Hadjipanayi et al, 2024) states that highly detailed and photorealistic graphics may be overwhelming for patients.

By drawing upon the two requirements presented a low poly art style was chosen which depicts a beautiful outdoors environment.

The game will feature a singleplayer and multiplayer mode. This decision is supported by findings from (Alankus et al, 2010), (Pan, W, 2018), and Authors (Staiano et al, 2012), (Lin et al, 2006), (Chin A Paw et al, 2006). In which social interaction has been proven to have clinical efficacy regarding patient motivation.

To align with the views of (Tamayo-Serrano et al, 2018) on meaningful play gameplay will be split into a series of small tasks, each task being completed in a defined sequence and each task advancing the players progress towards their goal in an obvious manner.

Players will work to increase their score and when they do gain a point this will be obviously communicated to the player using audiovisual multisensory feedback.

Commercial devices will be used as this reflects the preference of most other researchers in the subject. (Koutsiana et al, 2020).

Throughout the game the player will be asked to use different parts of their arm. This includes rotation of their shoulder, pronation and supernation of their forearm and flexion and extension of their fingers. These movements have been identified and categorised by (Pan, W, 2018: 21). The described movements comprehensively cover the scale of gross and fine motor skills identified by (Pan, W, 2018: 21).

Using the previously referenced information the design of the game can be finalized as follows.

A fishing game set in a beautiful outdoor environment with a low poly art style. Supporting a multiplayer and singleplayer mode where gameplay is divided into small sequential tasks clearly advancing the players progress. Players will be given audiovisual feedback throughout the game and the game will comprehensibly target both gross and fine motor skills.

Each player will follow a gameplay pipeline comprised of a cyclic sequence of steps:

Table 7 Gameplay Pipeline Tasks Presented to The Player

Task Description	Area of the arm utilized	Additional information	Feedback
Track a ripple in the water by rotating the forearm so the palm faces up or down.	Forearm.	The amount of time the ripple is tracked for will be informed by user testing. In single player mode the ripples will not be able to move outside of the players left and right rotation limits. In multiplayer the ripples will not be able to move outside of both players combined left and right rotation limits.	A visual countdown timer will display how long the current focused ripple needs to be tracked for. An arrow, as shown below, underneath the player will show how much the player is looking at / away from the closest ripple by interpolating the arrows colour between green and red.
Raising the arm - ideally using just the shoulder – although elbow assistance can be employed.	Ideally Shoulder however potentially assisted by bicep / upper arm.	While raising the arm the player will be asked to hold their arm still along several increments. The players arm will start at their side and be raised fully above their head.	Red squares, as shown below, will show the player where to hold their arm. When inside the increment area the box will turn green. When it is filled a sound will be played and the next incremental box will be displayed.
Lower arm to cast rod.	Ideally shoulder however potentially assisted by triceps / upper arm.	Before lowering arm, the player will have to fully raise their arm.	An up pointing arrow will be displayed so the player raises their arm, and a down arrow will be displayed so the

			player lowers their arm. As shown below. When the player lowers their arm a whoosh sound effect will be played as the rod is casted.
Wait for a fish to approach the hook and flick arm to hook the fish.	Bicep / upper arm.	Fish will wander randomly around the small to medium sized in game lake. A fish will likely be close to the hook when the rod is cast however the fish' wandering behaviour will introduce some randomness to this. The closest fish to the hook will be chosen to approach the hook and when the fish is close to the hook the player will flick their arm to hook the fish.	
Perform different hand gestures to reel the fish in.	Hand / fingers / forearm.	As shown below… The hand gestures used in the game will be fingers fully extended, fingers fully contracted, and the ring and middle fingers exclusively contracted.	A sound effect will be played when a hand gesture is matched, and the gesture image will turn green.
Watch the player character pull the fish out of the water and be awarded a point.	N/A.	A short animation will be played lasting about a second or two.	A fanfare trumpet sound effect will be played. additionally, a fish icon, as shown below, will be shown on the screen then animated towards the players score number while shrinking. Once

			the fish icon has fully shrunk and is on top of the player score the player score will be incremented and its size will pulse.

Figure 7 Arrow Used to Denote Player Alignment with Closest Ripple

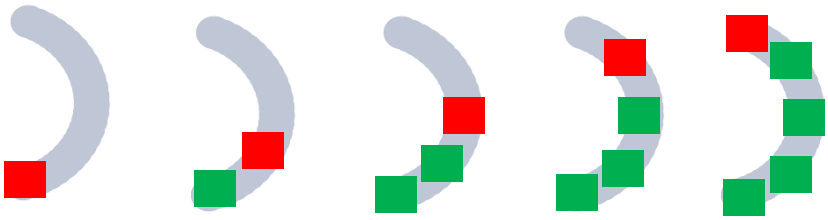


Figure 8 Incremental Arm Raise Boxes

Figure 9 Icons Directing the Player to Raise Then Lower Their Arm

Figure 10 Incomplete and Complete Hand Gesture Icons

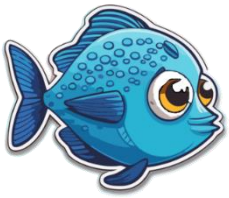


Figure 11 Fish Icon Displayed When the Player is Awarded a Point

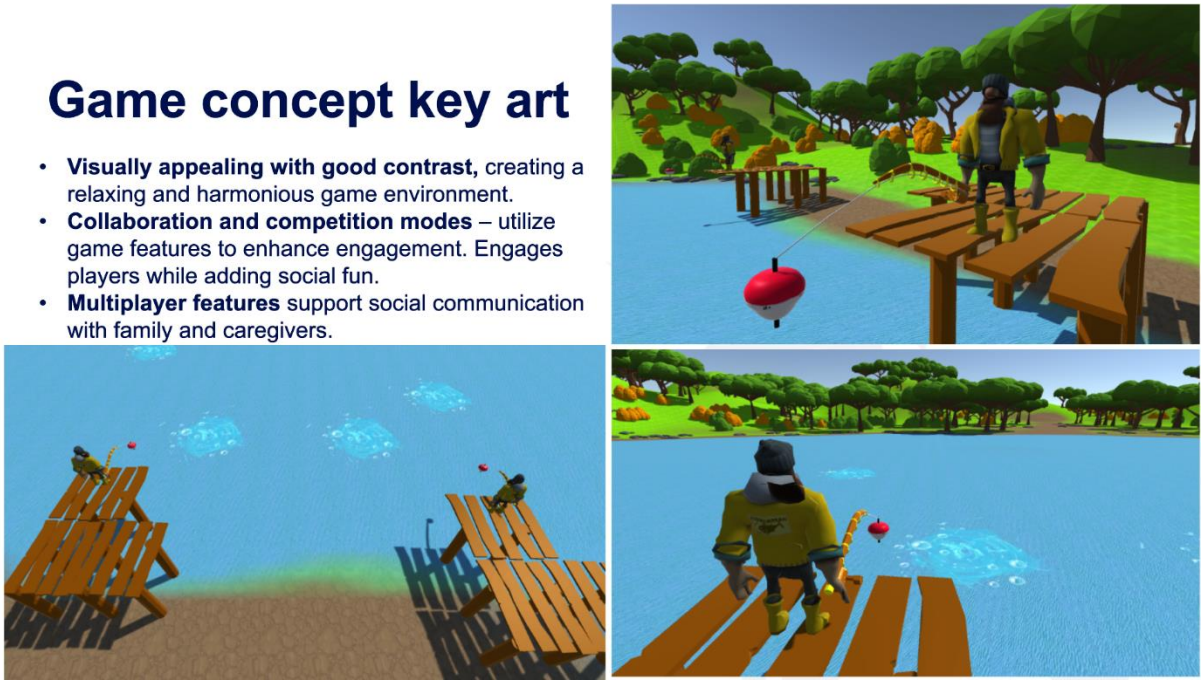


Figure 12 Game Concept Key Art

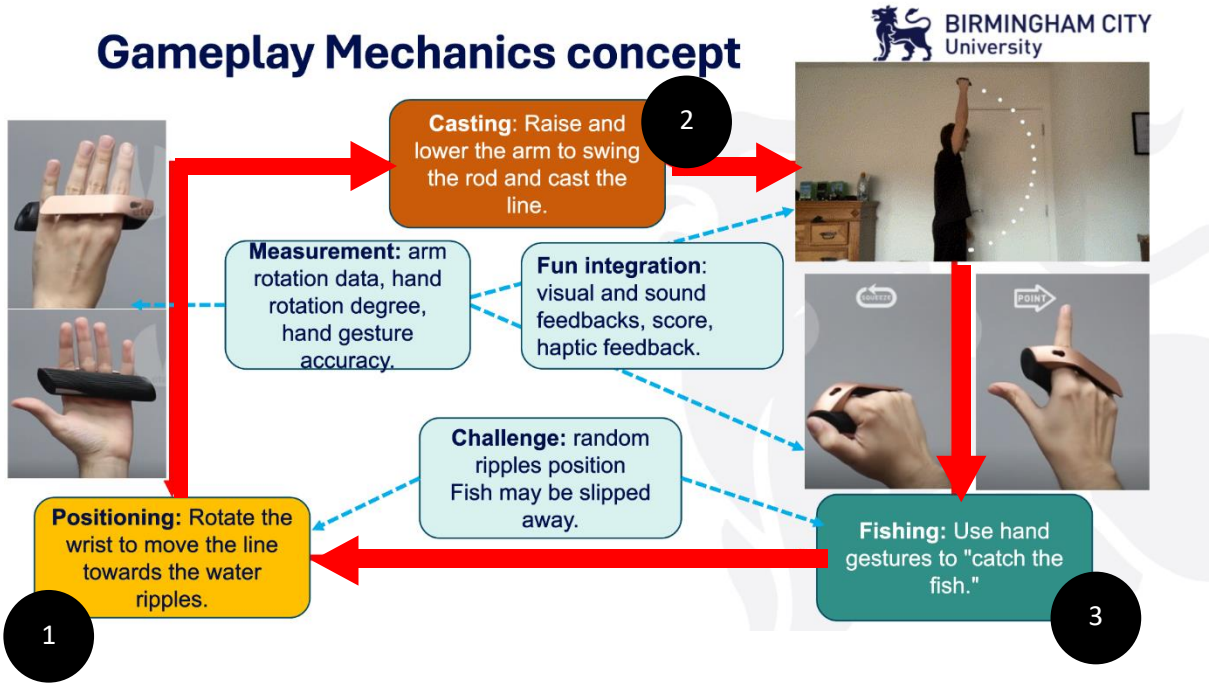


Figure 13 High Level Breakdown of The Gameplay Loop

3.3 Implementation

3.3.1 Sprint 1

3.3.1.1 Improvements made to the API prior and during development.

Before the development of the artefact, the etee API was improved. The etee API is an open-source API made to allow developers to create games to be played on the etee controllers using the unity game engine.

Adjustments were made to the API to make it more flexible and for it to be better integrated with the unity game engine.

These improvements include:

- Api processes being injected as sub systems of various unity player loop systems (update and fixed update) – this removed the need to have an etee API prefab present in the scene as any API functionality can be accessed globally through the eteeApi class without the consumer needing to maintain any scene references.
- The ability to turn the API on and off – this was good for testing because if the API is used when the controllers are not connected error messages are generated. But if the API is disabled there are no errors.

These adjustments improved the developer experience working with the API.

3.3.1.2 Adding environment and player character

Thanks to the support of the REAL FLC in BCU premium assets were able to be used to create the game scene. These assets include a premade environment and a player character. This allowed the game scene to be set up very quickly.

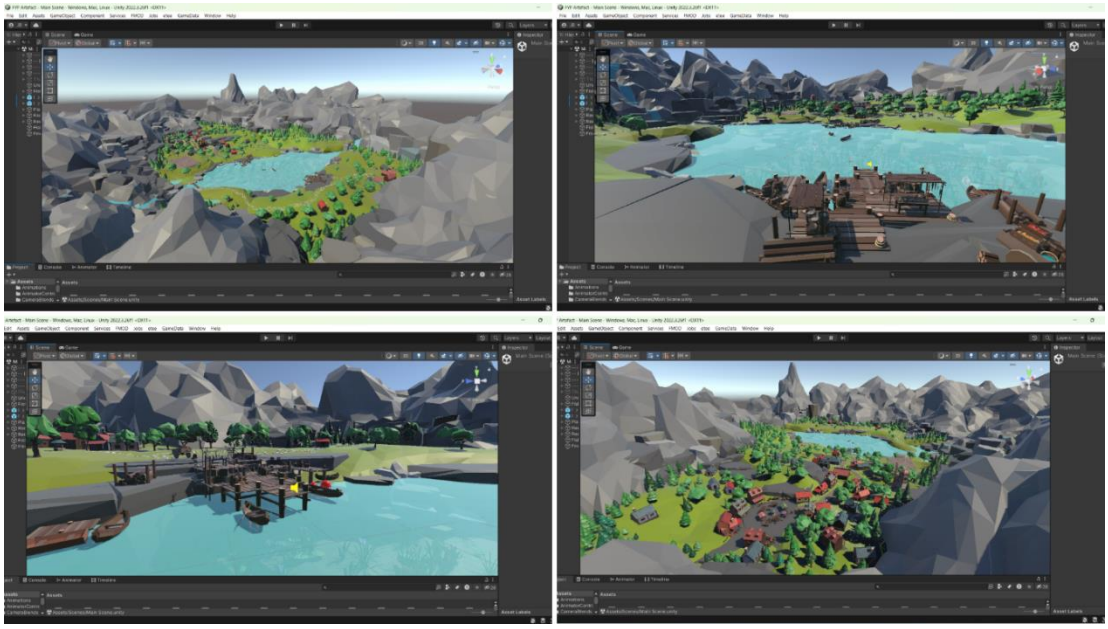


Figure 14 Game Environment

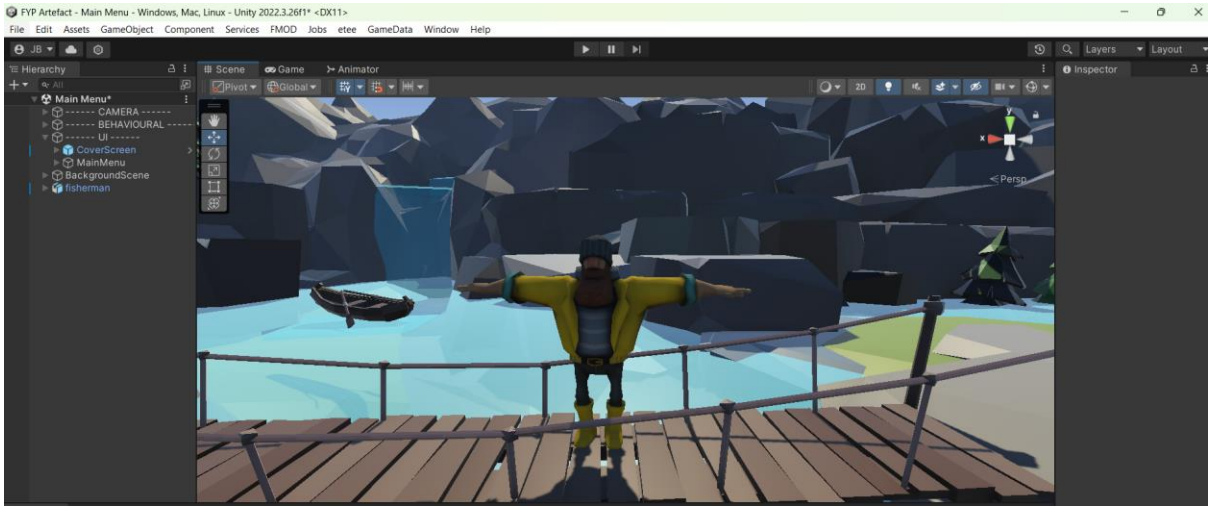


Figure 15 Rigged Player Model

As for the player character, it was rigged using an auto rigging tool. Then it can be animated in-engine using a variety of techniques. The techniques used in this project include.

- Procedural rotation of bones.
- Interpolation between poses using blend trees.
- Animation of characters using a timeline.

```
//rotate the player
this.boneToRotate.localRotation = Quaternion.Euler( x: ((eteeDeviceHolder.Device.euler.z + offset) * this.rotationMultiplier) + this.rotationOffset, y: 0, z: 0);
```

Figure 16 Code Used to Procedurally Animate the Characters Spine Bone

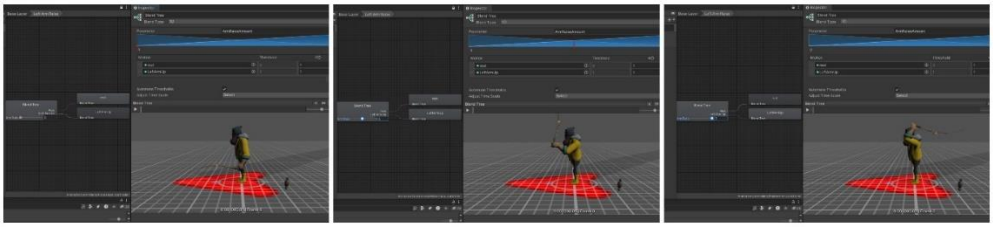


Figure 17 Player Raise Arm Animation Via Pose Interpolation

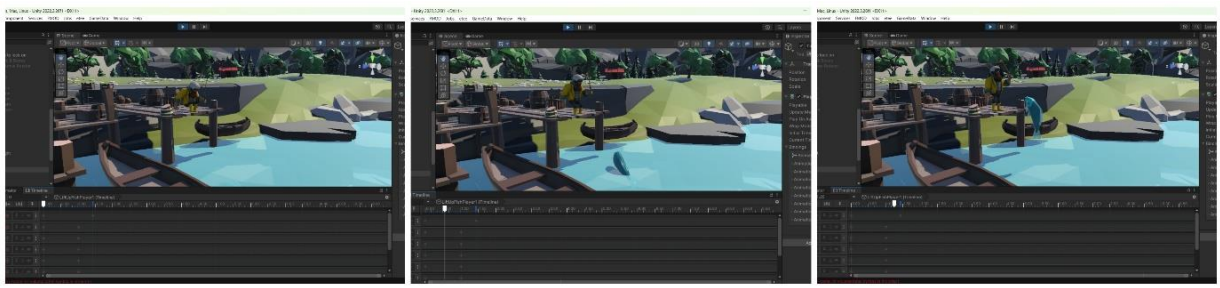


Figure 18 Timeline Animation Character

3.3.1.3 Main menu UI and navigation

The main menu UI was created using Unity's UI toolkit, a modern framework for creating UI.

It allowed reusable components to be abstracted into custom elements which could then be used in the main UI. For example, the high score menu and the buttons are custom components. The buttons are reused across other menu screens within the game.

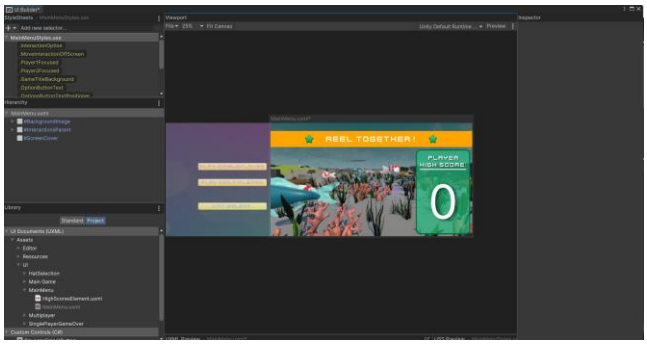


Figure 19 Game Main Menu in Ui Builder

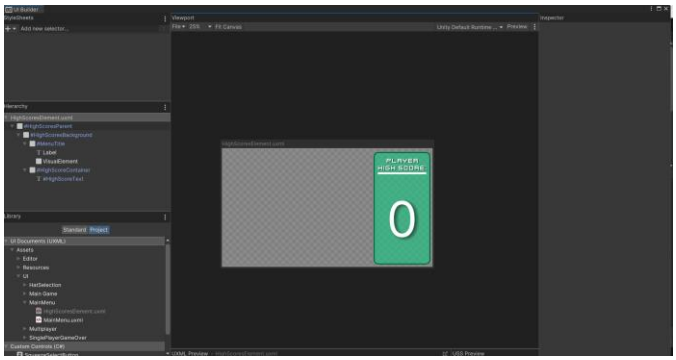


Figure 20 Reusable High Score Component

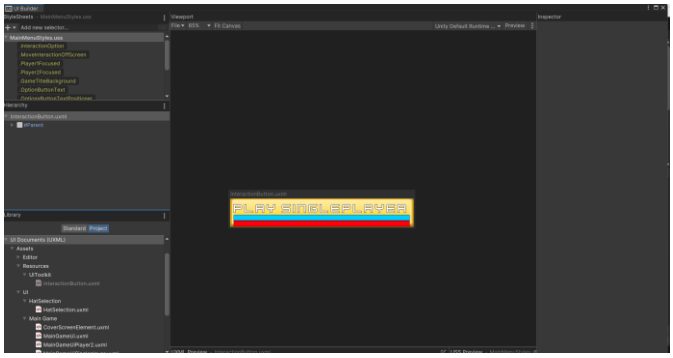


Figure 21 Reusable Button

Once the main menu is displayed the user must be able to navigate the menu using the trackpad on the top of the controller and interact with buttons by squeezing the controller.

The system built to navigate the menu is made up of four classes, with the most high-level classes being the UiPlayerInput class and the MainMenuNavigation class. Below is a diagram of how the various classes of the system link together.

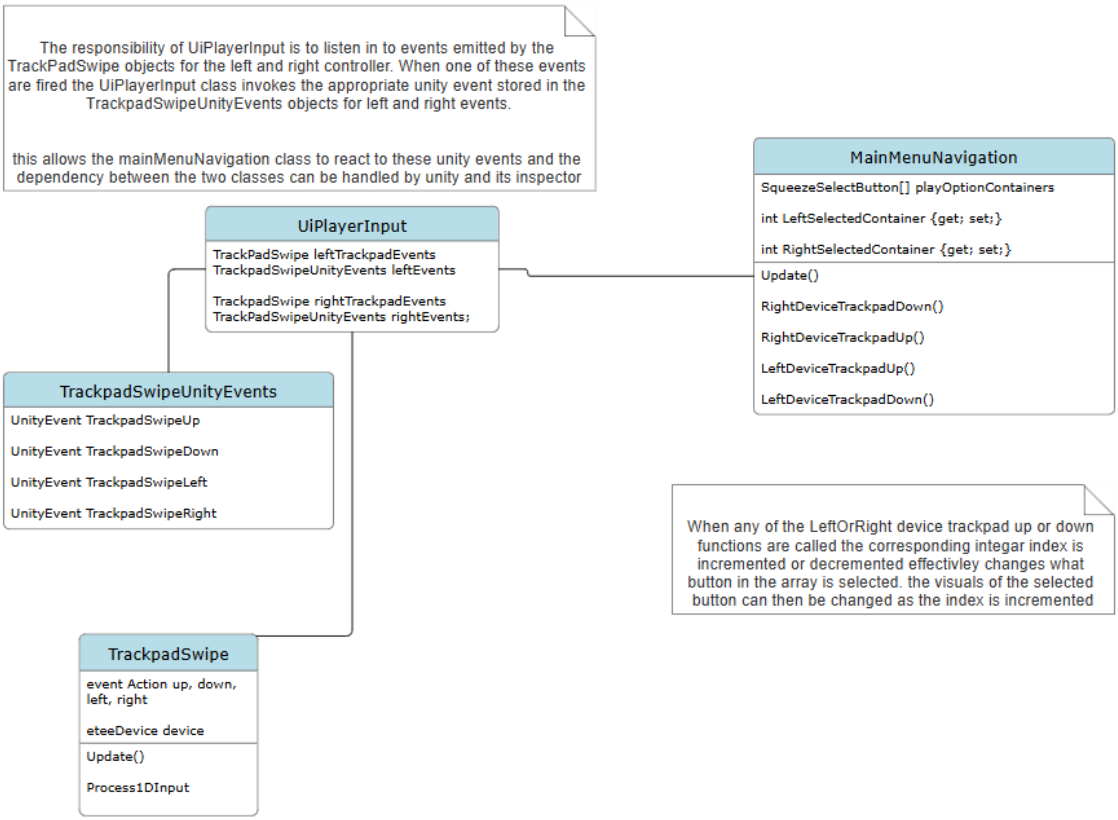


Figure 22 Diagram Showing the Different Classes Driving the Navigation Behaviour of The Main Menu

To interact with the menu the player must squeeze the controller. Therefore, each button should know how much the player is squeezing them. Each button should emit an event when one player fully squeezes it and another event when both players fully squeeze it. This can then be reacted to by another script. Below is a diagram showing how the button interaction system is architected.

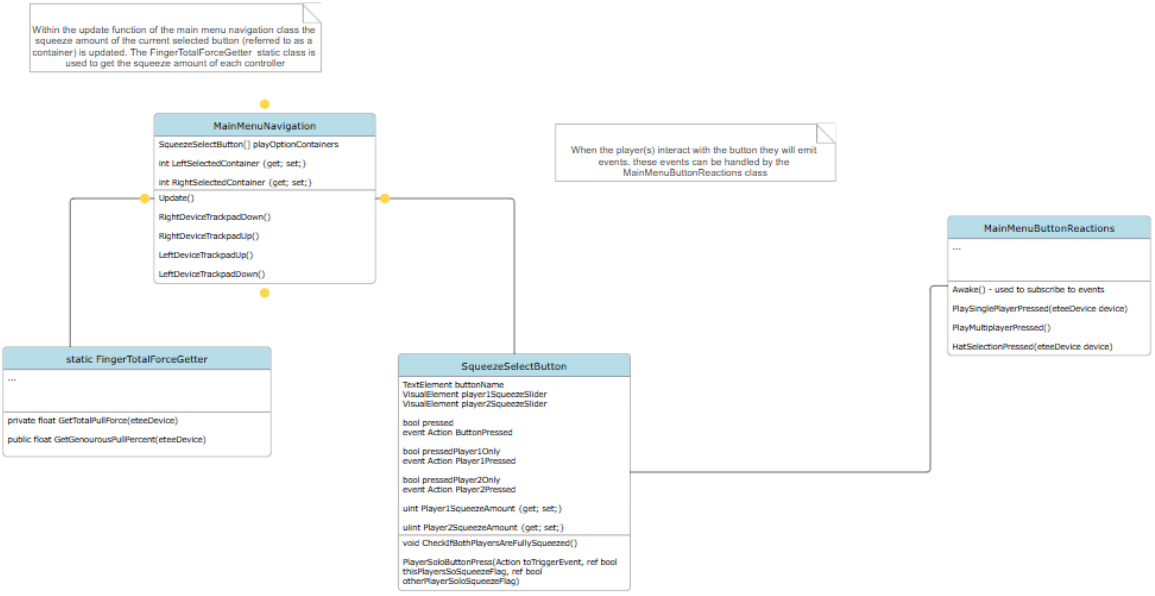


Figure 23 A Diagram Showing the Different Classes Driving the Interaction Behaviour of The Main Menu

3.3.1.4 *Player gameplay pipeline*

Because the game is designed to follow a cyclical series of steps or there must be an easily extendible way to order and execute these minigame like steps. This is where the player gameplay pipeline is used.

It is made up of two main parts the PlayerGameplayStagePipeline which is the hierarchical parent of all the GameplayPipelineStages.

In the screenshot below there is the gameplay pipeline which is attached as a child of each player. At the top is the gameplay pipeline and all its children are GameplayPipelineStages. They can have their own children which contain logic specific to that stage of gameplay.

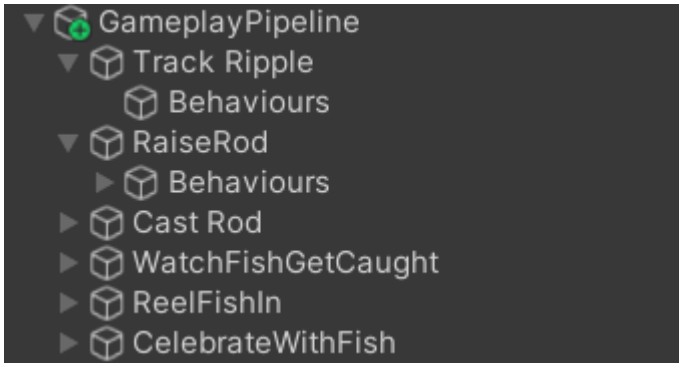


Figure 24 The Players Gameplay Pipeline as it Appears in The Unity Hierarchy

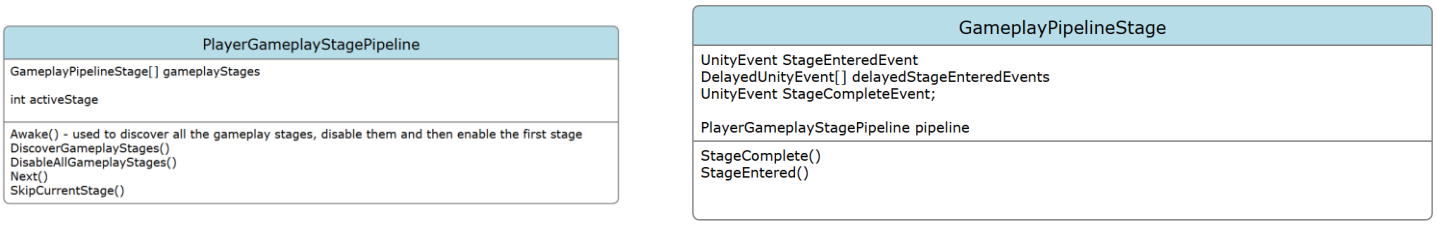


Figure 25 Class Diagrams of The Gameplay Pipeline and Pipeline Stage

Below is what the inspector of a gameplayPipeline stage may look like and what the inspectors of the stages children which contain the stage logic.

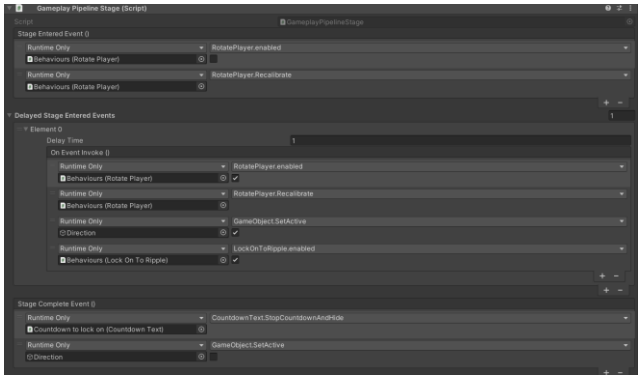


Figure 26 Inspector of A Gameplay Pipeline Stage

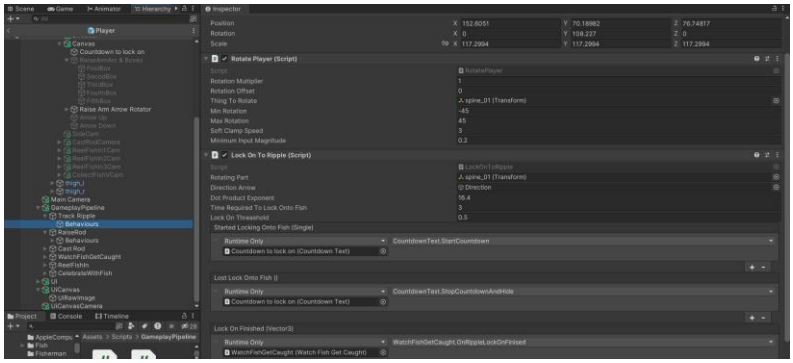


Figure 27 Inspector of Children of a Gameplay Stage Containing Logic

3.3.1.4.1 Stage 1

Now that the gameplay pipelines have been explained the business logic of each stage can be explored.

In the first stage of the game the player must rotate their forearm to make their character look left and right. Once the player character has been looking at a ripple in the water for long enough the next stage is entered.

3.3.1.4.1.1 Rotating the player

Rotating the player is managed by the RotatePlayer class. On update the spine1 bone of the player character is rotated according to the controller's z rotation and clamped to be within an appropriate range.

3.3.1.4.1.2 Ripples

Each ripple is a prefab attached to a game object. The ripple has bounds in which it can wander, and logic to generate a new target position within these bounds periodically. The ripple will move towards its target position. This is how the simple wandering like behavior of the ripples is controlled.

Additionally, on start the ripple registers itself with the RippleManager singleton, this way the ripple manager can maintain references to each of the active ripples.

3.3.1.4.1.3 How to tell if the player is looking at a ripple

This logic is managed by the LockOnToRipple class. Every frame it uses the RippleManager's VisitRippes method to perform some logic on each active ripple. The logic performed is checking how much the player is looking at each ripple using the dot product of the player's forward direction and the direction of the player to the ripple. This allows the method to store the ripple the player is closest to looking at.

Finally, if the closest ripple dot product is within some range the class knows the ripple is being looked at and can start a countdown timer. Once the timer reaches zero the next stage of the gameplay pipeline can be entered.

3.3.1.4.1.4 Ripple GFX

To maintain the pleasing visuals of the game it was important that the graphics effects for the ripple were implemented thoughtfully. The solution would require something more complex than a simple decal.

Therefore, the decision was made to use a custom material shader to render the ripples in the water. This would allow the ripples to deform the surface of the water to create more pleasing visuals. As the ripples should deform the water surface and will be contained to a single area, a highly subdivided mesh is placed in the area where the ripples will traverse. This highly subdivided mesh will be assigned the custom material. The highly subdivided mesh in the main scene is shown in figure 28 and a close-up view of it is shown in figure 29.

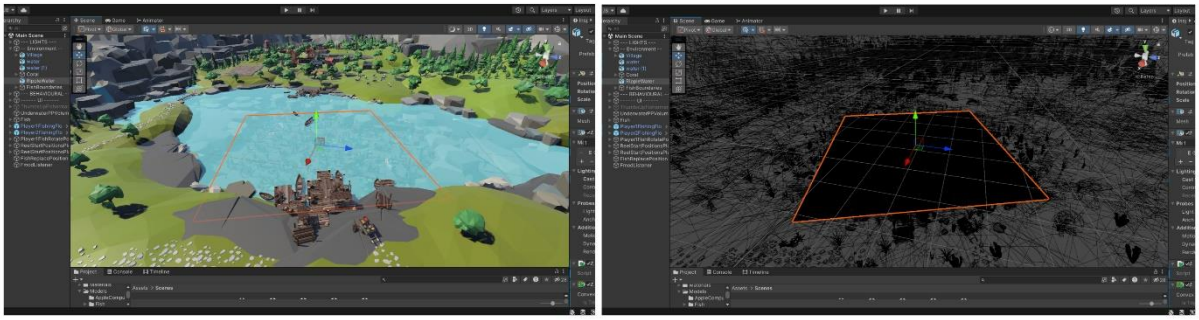


Figure 28 The Highly Subdivided Plane Used to Render the Ripples

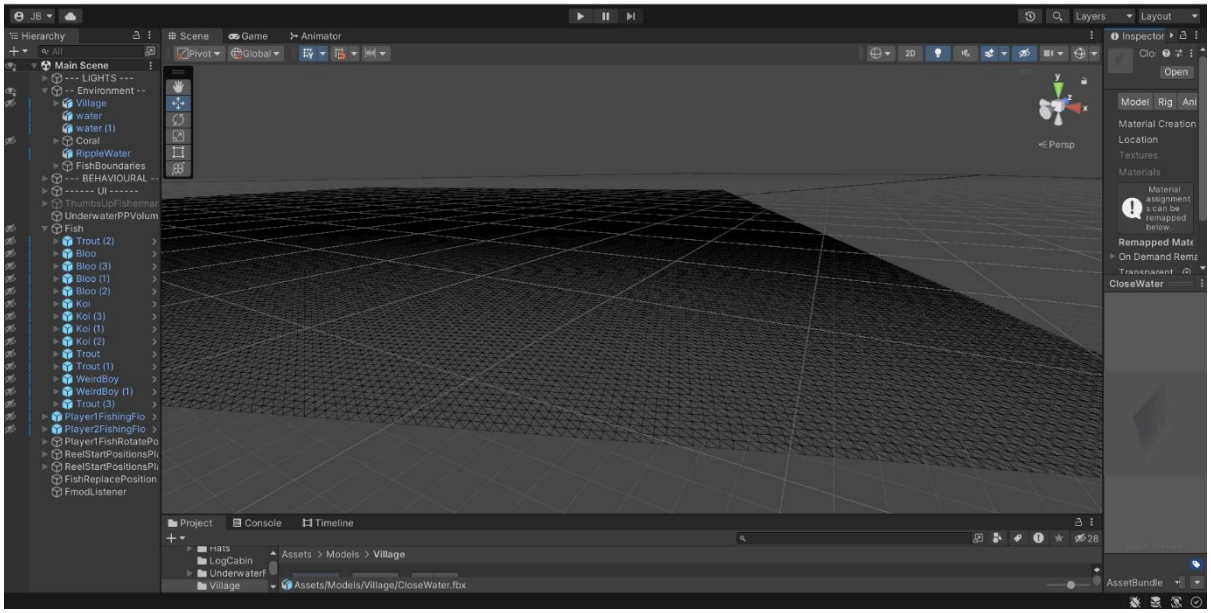


Figure 29 Closer View of The Highly Subdivided Plane

The shader has a series of parameters split into two conceptual groups. Parameters which can be tweaked from an art direction perspective to achieve a desired visual style. And parameters which are updated through code to drive the behavior of the ripples rendering. Below are tables detailing the function and grouping of these parameters.

Table 8 Art Directed Parameters Used by The Ripple Water Shader

Art Directed parameter name	Function
_Frequency	Influences how many rings of the ripple are present within a given area. This influences the gap between each ring of the ripple and the width of the rings.
_Speed	Controls how fast the rings of the ripple move away from the center
_RippleWidth	Changes the width or radius of a ripple. This also influences the width of each ring
_RippleHeight	Used to control the max influence of a ripple on the y position of a vertex.
_FalloffExponent	The falloff exponent controls how far a ripples rings can travel. This is different to the ripple width as it does not affect the width of a ring
_Color	The color of any pixels is not affected by a ripple. It is set to have an opacity of zero and a pale blue color like the water
_RippleColor	The color to be used to render a ring of the ripple which is being influenced.
_RippleColorStrength	Scales how much ripple influence is needed to color the ripple the full ripple color.

Table 9 Parameters Driven by Programmed Logic for The Ripple Water Shader

Business logic parameters	Function
_rippleOffset[20]	It is an array with one element for each ripple present in the world (max of 20). Each element holds the UV space position of a ripple relative to the center. As the values of the elements in this array move closer to -0.5 or closer to 0.5 the ripples in the water will move to the left or to the right of the ripple water plane, respectively.
_rippleCount	How many ripples are present in the world

The calculation for the ripple is done in the vertex shader. Then this data can be passed to the fragment shader for coloring.

To calculate the y offset and rippleValue of the current vertex, first the shader enters a for loop of rippleCount iterations. Each iteration the influence of the current ripple on the current vertex is calculated. If this influence exceeds the current highest recorded influence, then the ripples value is calculated, and the height of the vertex is influenced by this ripple value.

To calculate the ripple value the following equation is used.

Equation 1 The Ripple Value of a Ripple Water Vertex

$$rippleValue = sin(distanceFromCenterOfRipple * Frequency - Time.y * Speed)$$

rippleValue can then be used in the calculation of the height of the vertex.

Equation 2 Ripple Vertex Height Offset Calculation

$$vertex.y+ = RippleHeight * rippleValue$$

The color of the pixel can then be calculated using the ripple value and the following line of code.

```
return saturate(lerp(_Color, _RippleColor, i.rippleValue * _RippleColorStrength));
```

Figure 30 Code Snipped Used to Colour Ripples

Figure 31 In Game Ripple Effect

Below is the full shader and the ripple water code which drives the shader.

```
Shader "Unlit/RippleWater"
{
    Properties
    {
        _Frequency ("Frequency", Float) = 10
        _Speed ("Speed", Float) = 0
        _RippleWidth ("Ripple Width", Float) = 0
        _RippleHeight ("Ripple Height", Float) = 0
        _FalloffExponent ("Falloff Exponent", Float) = 0
        _Color ("Color", Color) = (1,1,1,1)
        _RippleColor ("Ripple Color", Color) = (1,1,1,1)
        _RippleColorStrength ("Ripple Color Strength", Float) = 0
    }
    SubShader
    {
        Tags
        {
            "RenderType"="Transparent"
            "Queue"="Transparent"
        }
        LOD 100

        Pass
        {
            Blend SrcAlpha OneMinusSrcAlpha
            ZWrite Off


            HLSLPROGRAM
            #pragma vertex vert
            #pragma fragment frag

            #include "Packages/com.unity.render-pipelines.universal/ShaderLibrary/Core.hlsl"

            struct appdata
            {
                float4 vertex : POSITION;
                float2 uv : TEXCOORD0;
            };
```

```
struct Interpolators
{
    float2 uv : TEXCOORD0;
    float4 vertex : SV_POSITION;
    float rippleValue : TEXCOORD1;
    float3 worldPos : TEXCOORD2;
};

sampler2D _MainTex;
float4 _MainTex_ST;

float _Frequency;
float _Speed;
float _RippleWidth;
float2 _RippleOffset[20];
int _rippleCount;
float _RippleHeight;
float _FalloffExponent;
float4 _Color;
float4 _RippleColor;
float _RippleColorStrength;
```

```
            Interpolators vert(appdata v)
            {
                Interpolators o;
                o.worldPos = TransformObjectToWorld(v.vertex);
                o.vertex = TransformObjectToHClip(v.vertex);
                o.uv = v.uv;


                float highestRippleStrength = 0;
                for(int i = 0; i < _rippleCount; ++i)
                {
                    float2 thisRippleCenter = o.uv + -.5f + _RippleOffset[i];

                    float distanceFromCenterOfRipple = length(thisRippleCenter) * _RippleWidth;

                    float rippleInfluence = pow(saturate(1 - distanceFromCenterOfRipple), _FalloffExponent);

                    if(rippleInfluence > highestRippleStrength)
                    {
                        highestRippleStrength = rippleInfluence;

                        o.rippleValue = sin(distanceFromCenterOfRipple * _Frequency - _Time.y * _Speed);

                        o.rippleValue *= pow(saturate(1 - distanceFromCenterOfRipple), _FalloffExponent);

                        o.vertex.y += _RippleHeight * o.rippleValue;
                    }

                }
                return o;
            }

            float4 frag(Interpolators i) : SV_Target
            {
                return saturate(lerp(_Color, _RippleColor, i.rippleValue * _RippleColorStrength));
            }
            ENDHLSL
        }
    }
}
```


Figure 32 Ripple Shader Code

```
    private Vector2 ConvertRipplePosToUvSpaceOffset(Vector3 ripplePos)
    {
        Ray ray = new Ray( origin: ripplePos + (Vector3.up * 1000),  direction: Vector3.down);
        if (Physics.Raycast(ray, out RaycastHit hit))
        {
        Vector2 uvCoord = hit.textureCoord;

        float remappedX = uvCoord.x.MapRange( oldMin: 0,  oldMax: 1,  newMin: 0.5f,  newMax: -0.5f);
        float remappedY = uvCoord.y.MapRange( oldMin: 0,  oldMax: 1,  newMin: 0.5f,  newMax: -0.5f);
        return new Vector2(remappedX, remappedY);
        }

        return Vector2.zero;
    }
}
```

Figure 33 Ripple Water Script Which Drives Values in The Shader

3.3.1.4.1.5 Arrow GFX

The arrow underneath the player denotes the direction the player is facing in. The colour of the arrow denotes how aligned the players direction and the direction to the closest ripple are. To change colour based on is alignment a custom shader is used. In the fragment shader the sampled colour of the arrow texture is tinted. The colour it is tinted by is calculated by interpolating between red and green using alignment as a t value. Alignment is passed to the shader by the LockOnRipple script mentioned under *how to tell if the player is looking at a ripple*. And is the result of a dot product operation.

```
float4 frag (v2f i) : SV_Target
{
    // Sample the texture
    float4 col = tex2D(_MainTex, i.uv);

    // Ensure transparency is respected
    clip(col.a - 0.01);

    col *= lerp(_NotAlignedColor, _AlignedColor, _Alignment);

    return saturate(col);
}
```

Figure 34 Fragment Shader for the Direction Arrow

3.3.1.4.2 Stage 2 and 3

3.3.1.4.2.1 How raising the arm is read and feedbacked to the player

During stages 2 and 3 how much the arm is raised has to be read. This is read using the player arm raiser script which rotates an empty object based on the rotation of the appropriate controller. Then, as seen below, the forwards direction (white line) of the object and the up direction (red line) are compared using the dot product. This can then be fed into the player character's animation to control the height of the character's arm using a blend tree.

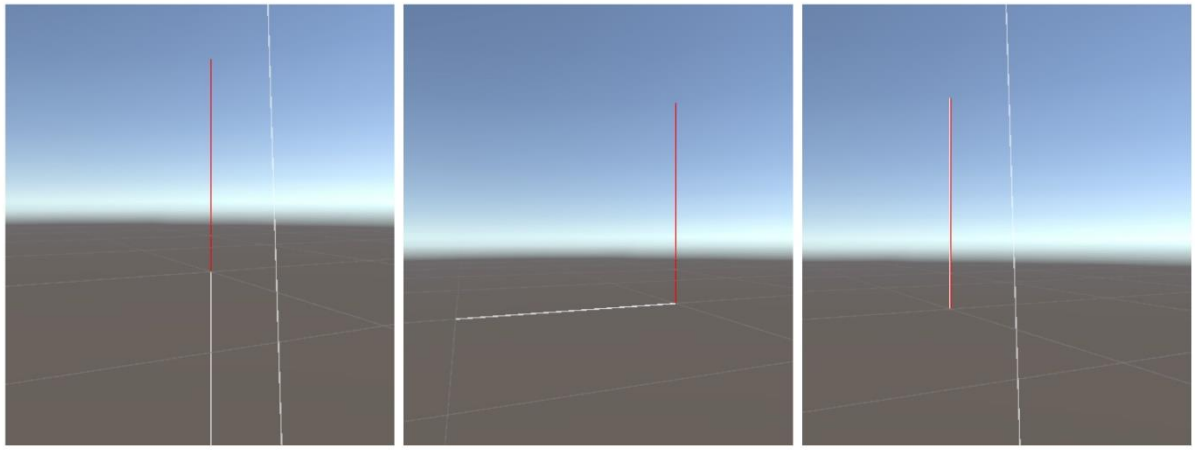


Figure 35 The Forwards Direction of The Empty Changing as the Player Raises Their Arm

Additional logic can then be added to the gameplay stage which uses the information gathered by the PlayerArmRaiser script.

3.3.2 Pilot testing and feedback:

Once a prototype of the game was created the game was tested with a few individuals to acquire early feedback and make necessary adjustments to the game before the project is tested with a wider audience.

Four users tested the game. The environment was set up as seen below. Figure 36 shows the users playing the game in single-player mode across various stages of the game loop.

Figure 36 Pilot Test Environment and Testers Playing the Game

These 4 users were all of the 18 – 24 age range. Most of these testers were male with one tester prefering not to disclose. Three testers described themselves as hardcore/ expert video game players

with one tester describing themselves as midcore/core. One tester had prior experience with etee controllers and most testers were confident to use the controllers. with one tester being unconfident to use the controller.

All testers were shown a video instructing them how to play the game and then each tester played the game in sequence. Assistence / additional instruction was given when needed.

After playing the game the testers completed the post test questionaire. Which was composed of a game engagement questionaire and a game user experience satisfaction scale. The social conectivity part of the questionaire will not be analysed as the testers only played the single player mode of the game.

Detailed below is the results of the SUS section of the questionnaire.

Table 10 Pilot Test SUS results

	I Think that I would like to use this system frequently	I Found the system unceccissarily complex	I thought the system was easy to use	I think that I would need the suppourt of a technical person to be able to use this system	I found the system very cumbersome to use	I thought there was too much inconsistency in this system	I would imaging that most people would learn to use this system very quickly	I felt very confident using the system	I needed to learn a lot of things before I could get going with this system
1	Strongly Agree	Strongly Disagree	Agree	Agree	Disagree	Disagree	Agree	Strongly Agree	Disagree
2	Agree	Strongly Disagree	Agree	Disagree	Strongly Disagree	Disagree	Agree	Strongly Agree	Disagree
3	Agree	Strongly Disagree	Agree	Strongly Disagree	Strongly Disagree	Agree	Strongly Agree	Strongly Agree	Disagree
4	Strongly Agree	Disagree	Agree	Neither agree nor disagree	Strongly Disagree	Strongly Disagree	Agree	Strongly Agree	Disagree

Overall the results from this part of the test showed a high level of engagement from the testers. However some testers thought that they would need the suppourt of a technical person to be able to use the system and there was too much inconsistency in the system.

As for written feedback from this part of the questaire one tester praised the games mechanics and the animation of the ui and also flagged bugs that occurred exclusively when using the right hand controller.

Another user noted the game was enjoyable to play and clearly seves its intended purpose of rehabilitation but noted that controlers had some input drift and some of the ranges of motion the player was being asked to perform was uncomfortable to hold for long periods of time. This user was sat down while playing the game. This caused their arms movement to be restricted by the arms of the chair causing other areas of their arm to compensate for restricted mobility by extending / stretching. This is likley what caused the discomfort. The future testers will be asked to stand up while playing to allow for free movement of their arms.

The testers scored the game highly on usability / playability, enjoyment, audio aesthetics and visuals. However the game scored poorly with testers in other areas.

Table 11 Pilot Test GUESS Usability Results

	I think the characters in the game are well developed	I am captivated by the game's story from the beginning	I enjoy the fantasy or story provided by the game	I can identify with the characters in the game	I am emotionally moved by the events in the game	I am very interested in seeing how the events in the game will progress	I can clearly understand the game's story
1	Strongly Agree	Agree	Agree	Agree	Agree	Strongly Agree	Agree
2	Disagree	Disagree	Disagree	Disagree	Disagree	Disagree	Agree
3	Disagree	Disagree	Agree	Neither Agree nor Disagree	Disagree	Neither Agree nor Disagree	Neither Agree nor Disagree
4	Strongly Agree	Agree	Agree	Agree	Somewhat Agree	Agree	Agree

As shown by the data in the table above the pleayers were not able to identiy with the characters well and were not emotionally moved by the events in the game. This is linked to a disinterest in seeing how the events of the game will progress. And demonstrats that the game naritive was a weak point of the prototype.

Additionally the lack of story in the game is reflexted in the feedback.

To address the players lack of ability to connect with the character in the second sprint of development a hat customisation feature will be added to the game. Allowing players to customize the look of their player characetr to better identify with that character.

Additionally the players showed low levels of play engrossment. Some players did not feel detached from the outside world while playing, disagreed that they don't care to check real world events while playing, they were aware of how tired they were while playing, did not forget about everyday worries while playing and disagreed that they were excited to play the game again after playing. To improve this multiplayer gameplay will be added in the next development sprint.

The users did not feel they had a large amount of creative freedom as shown in the responses below.

Table 12 Pilot Test GUESS Creative Freedom Results

	I feel the game allows me to be imaginative	I feel creative while playing the game	I feel the game gives me enough freedom to act how I want	I feel the game allows me to express myself	I feel I can explore things in the game	I feel my curiosity is stimulated as the result of playing the game	I think the game is unique or original
1	Strongly Agree	Strongly Agree	Strongly Agree	Agree	Agree	Agree	Strongly Agree
2	Somewhat Disagree	Disagree	Disagree	Disagree	Disagree	Disagree	Agree
3	Disagree	Disagree	Neither Agree nor Disagree	Disagree	Disagree	Disagree	Somewhat Agree
4	Strongly Agree	Agree	Agree	Agree	Agree	Agree	Agree

Testers did not feel that they were able to be creative or imaginitive and the game was quite restrictive in terms of the freedoms and opeprtunities for expression or exploration in the game. This is absolutley a flaw in the design of the game. However, it is worth noting the target context, that being stroke rehabilitation. Due to the desieses varying impacts on cognition it is important that patients have clear instructions, guidelines and frequent feedback. The introduction of creativity may obvuscate the clarity of the instructions and deminish the games abilty to give clear feedback.

One tester in the personal gratification section disagreed with the following statements. “I am in suspense about whether i will succeed in the game” and “I feel successful when i overcome the obstacles in the game”. The introduction of multiplayer gameplay will be included in the next sprint to help adress this.

After gathering feedback from the pilot test the second sprint of development can commence and changes can be made to address the feedback of the pilot testers.

Improvements made to the game include:

- Right hand controller bug fix
- Future testers were encouraged to stand up to allow their arms to move unrestricted
- The addition of a hat customisation feature
- The addition of a multiplayer mode

3.3.3 Sprint 2

Following sprint two the game implementation will be complete and ready to be evaluated.

3.3.3.1 Addition of player character customization

Following the feedback from the pilot testers felt a lack of choice and ability to connect with the player character. Therefore, player character hat customization was added. First a new button was added to the main menu which when squeezed by any player would change to the hat selection scene.

Within this scene there is a player character representation standing on a bridge and a camera rendering the character to a render texture.

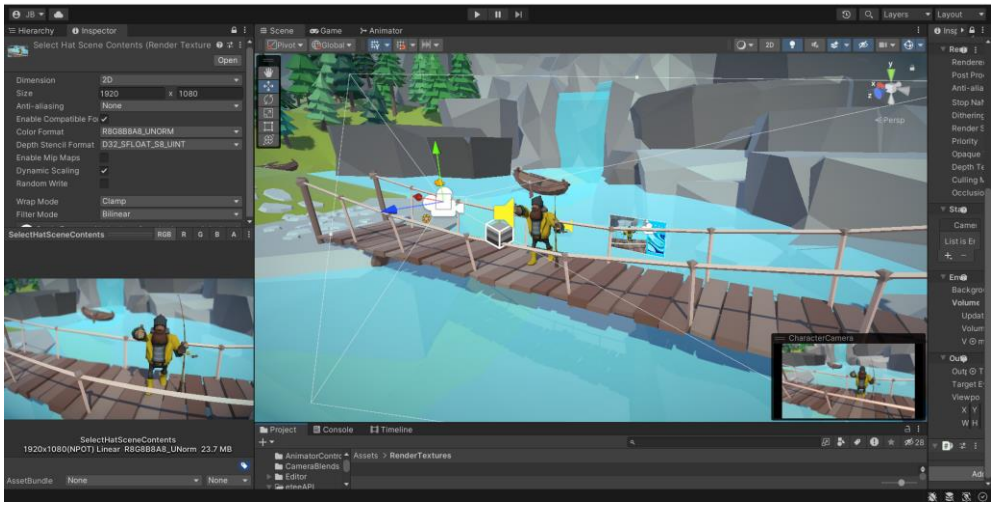


Figure 37 Player Character in Environment Rendered to A Texture

Additionally, a UI toolkit UI is being rendered to a render texture.

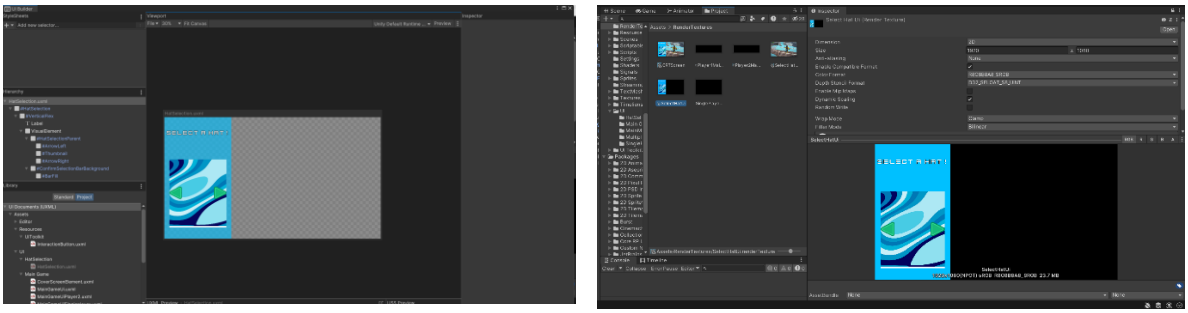


Figure 38 The Ui Created in Ui Builder, and Then Rendered to A Texture

Finally in a canvas the player character render texture and the UI render texture are composited and then rendered to a final render texture.

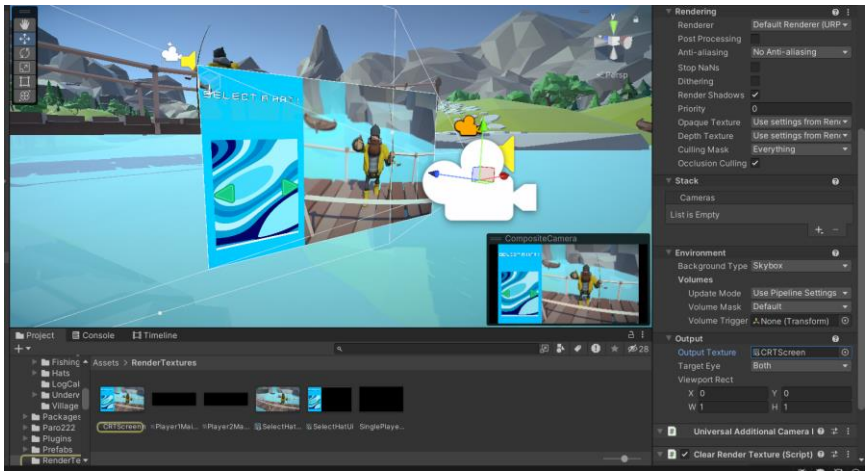


Figure 39 Canvas Used to combine textures from figure 36 & 37 into a render texture

Next a log cabin environment can be setup, and the camera can be positioned in front of a computer monitor. The material covering the monitors screen will draw the character and UI onto the screen using the render texture and a CRT effect shader.

Figure 40 Log Cabin Environment

Figure 41 Texture from Figure 38 Rendered to an In-Game Screen Using a Material

Finally, UI controls code can be added and the player selected hat can be saved to a scriptable object instance on selection allowing the selected hat to be saved between scenes.

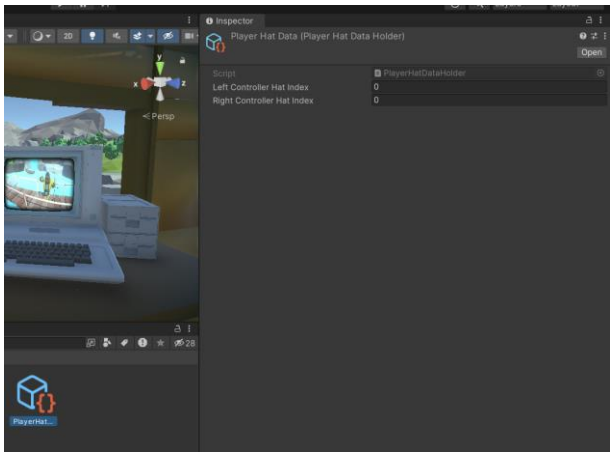


Figure 42 Scriptable Object Storing Each Players Selected Hat as An Index

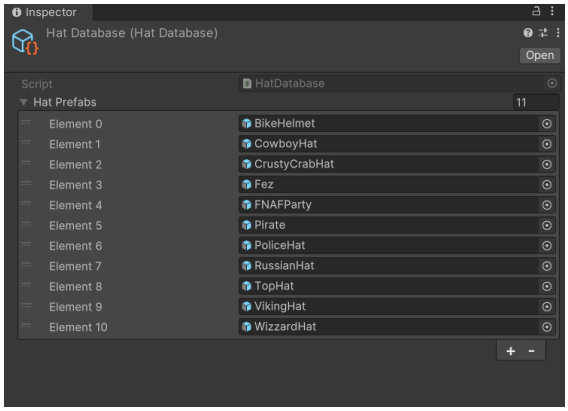


Figure 43 Hat Database Scriptable Object Which Holds an Array of Hats Accessed Via Index

3.3.3.2 Adding Fish

Fish models were collected from various online asset stores.

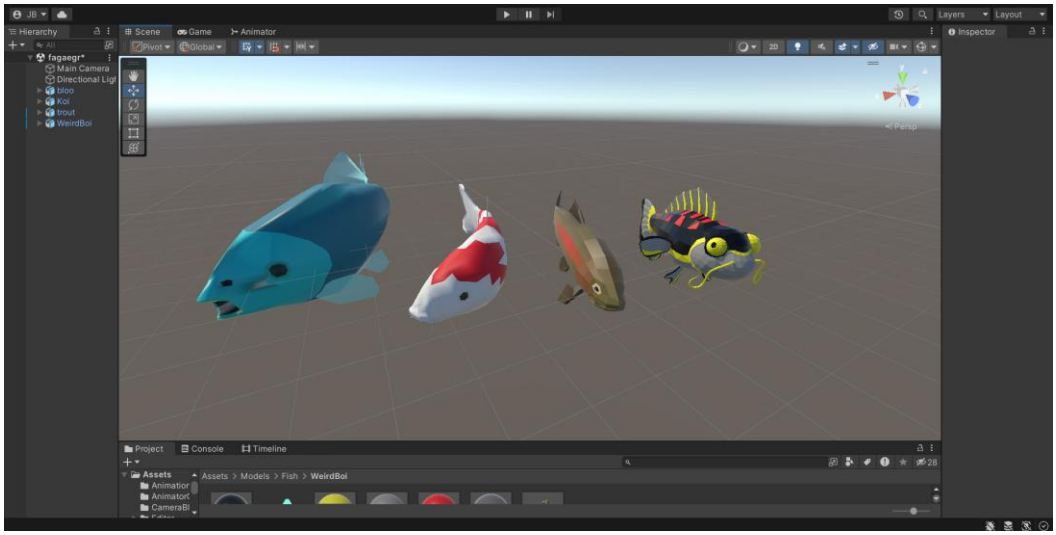


Figure 44 Game Fish Models

Prefabs were created for each fish containing the animated fish model, a fish script and a wander and stay in bounds script. The wander and stay in bounds scripts calculate a velocity which the fish script sums together and sets as the fish' rigid body velocity. This allows the fish to wander around space.

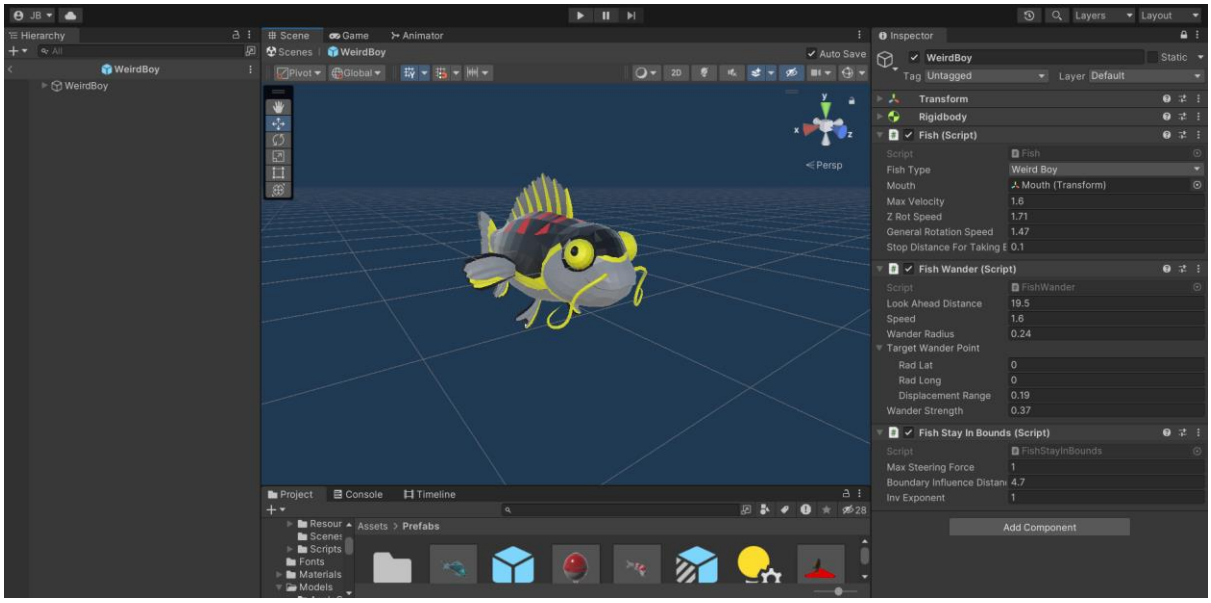


Figure 45 Example Fish Prefab

Figure 46 Fish Navigating an In-Game Aquatic Environment

3.3.3.3 Gameplay pipeline stage 4

In the fourth pipeline stage the player must catch a fish out of the water. When the stage is entered the FishManager class is instructed to tell the closest fish to the players fishing hook to override its steering behavior and move towards the hook. If the fish gets too close to the hook it will return to wandering.

When the fish is within range of the players hook the player should rapidly raise their arm to emulate the act of hooking the fish. To achieve this logic the player arm raiser script will be used to get how high the players arm is raised on a scale of 0 – 1. And a hookFish script will read this arm raised data to check if there is a sudden spike in the arm raised amount.

It does this by maintaining a list / buffer of arm raised values. This is a circular buffer so once the buffer pointer reaches a certain point the pointer will be reset to zero. Instead of the buffer being some arbitrary size its size is time dependent thus storing the arm raised values for the past x seconds. If the standard deviation is larger than some value, then the script can instruct the FishManager to attempt to hook the fish. If this is successful, the next stage of the gameplay pipeline can be entered.

3.3.3.4 Gameplay pipeline stage 5

During the final stage of the gameplay pipeline the player will be instructed to copy the hand gestures shown on screen. As per the design section these gestures include a closed fist, open hand and a closed fist with the index and pinky finger extended.

To tell if the player is making a hand gesture the HandGestureReader and HandGestureProfile classes were created. It is the responsibility of the HandGestureReader to coordinate the analysis of the players finger pull data and output what gesture is most similar to the players current hand position.

It is the responsibility of the HandGestureProfile to define the finger pull amounts that a hand gesture may represent and also have the ability, given access to the finger pull data, to return the pose likeness between the players finger positions and the defined positions for the pose (in a range of 0 – 1). As the gesture profile is a scriptable object (as displayed below) multiple of these profile objects can be created and stored as assets in the project.

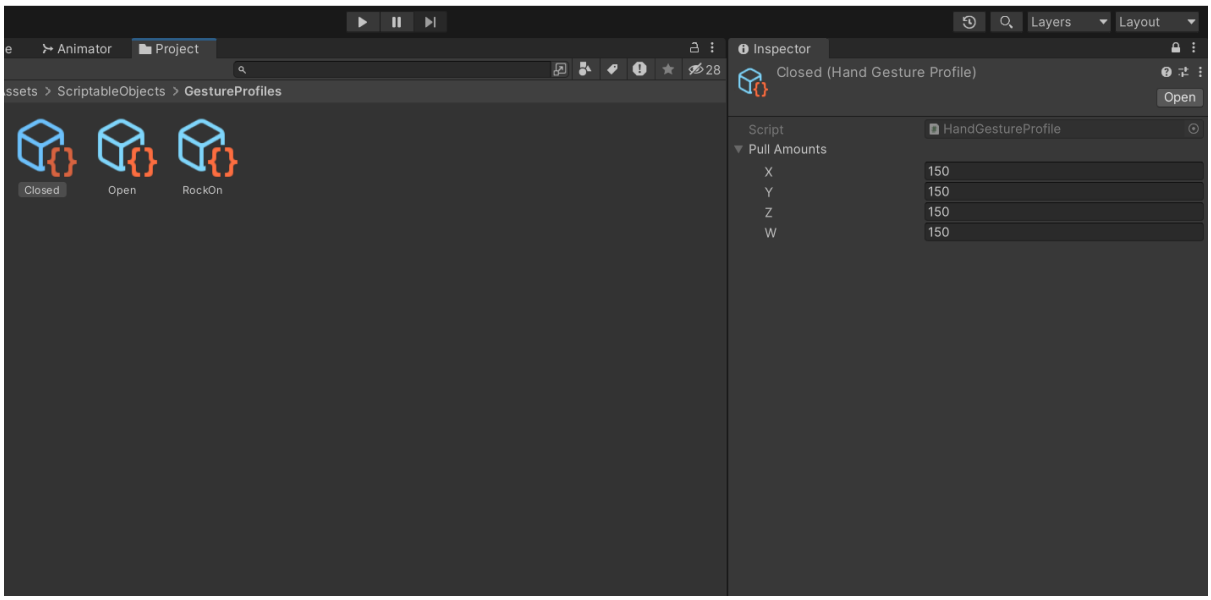


Figure 47 An Example Hand Gesture Profile

When the fish is hooked a float is positioned above the fish and the fish is taken to a starting point. Next the fish is parented to a game object which is rotated continuously in an oscillating pattern. A series of objects then look at this rotation value and when it is within a threshold the HandGesture Reader is used to get the hand gesture. If the hand gesture matches, then that hand gesture has been completed. Once nine hand gestures have been completed the game continues.

The player must match each of the three hands three times. Initially the camera was zoomed out, so all these layers were visible. However, after consulting with an NHS trust physiotherapist, feedback was given that the camera is too far away leading to the iconography being too small. This feedback was acted upon and now the iconography is large and clear to the player.

Figure 48 Gathering Feedback from A Professional Physiotherapist

Figure 49 Following Feedback the Game Camera Was Repositioned So the Ui Appears Larger

3.3.3.5 Balancing changes

Balancing changes were made following pilot test feedback. This included reducing the amount of time a player must look at a ripple in stage 1 from 10 to 3 seconds. And increasing the time between each hand gesture in stage 5.

3.3.3.6 Game mode system.

Due to the game having a single player and a multiplayer mode the need for a game mode system as apparent. A game mode can store data such as the ripple spawner prefab, the ripple spawner

position, player prefabs, UI etc…. The game mode will also contain key functionality such as spawning the ripple spawner into the game scene and setting up the game scene.

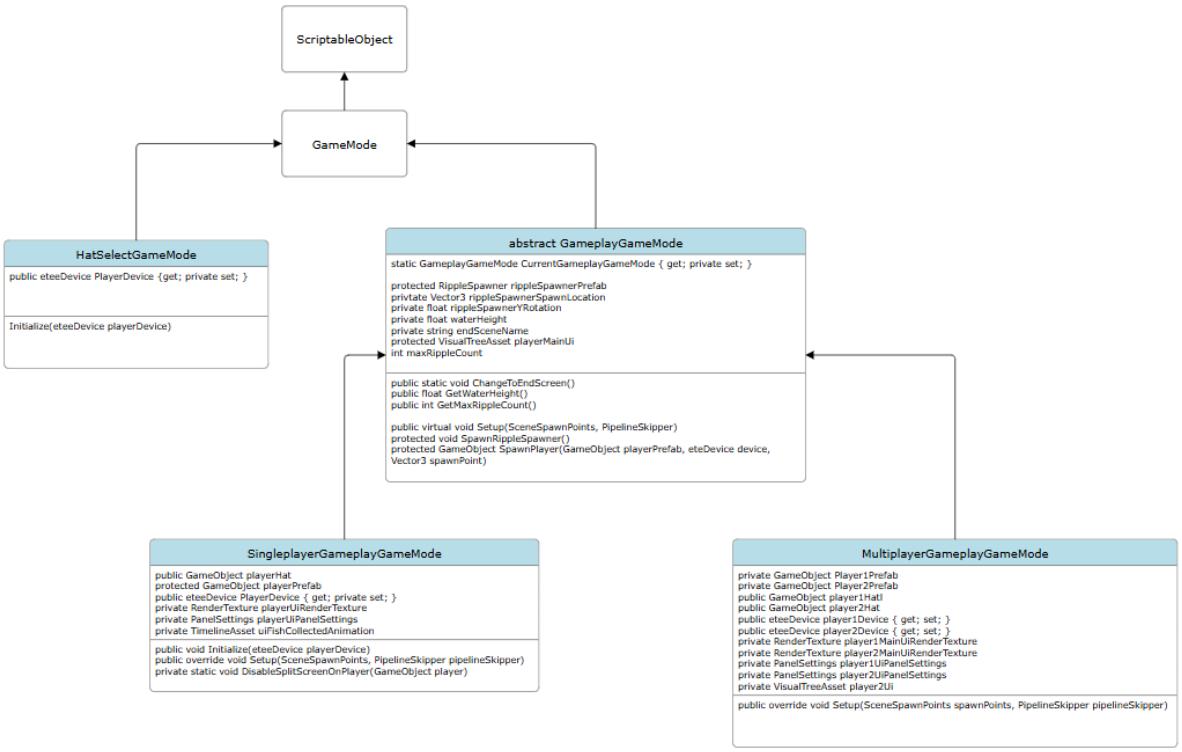


Figure 50 Game Mode Class Hierarchy

Because game modes are scriptable objects they can be instanced as an asset in the project. A game mode holder class can be created which is also a scriptable object which will hold a reference to the currently active game mode which can be switched out before changing scene. Additionally custom inspector code can be written to give inspector functionality to the game mode holder to be able to change the game mode in the inspector. This was especially useful for testing as the game mode could be set and then the main scene could be started without the need for the main menu.

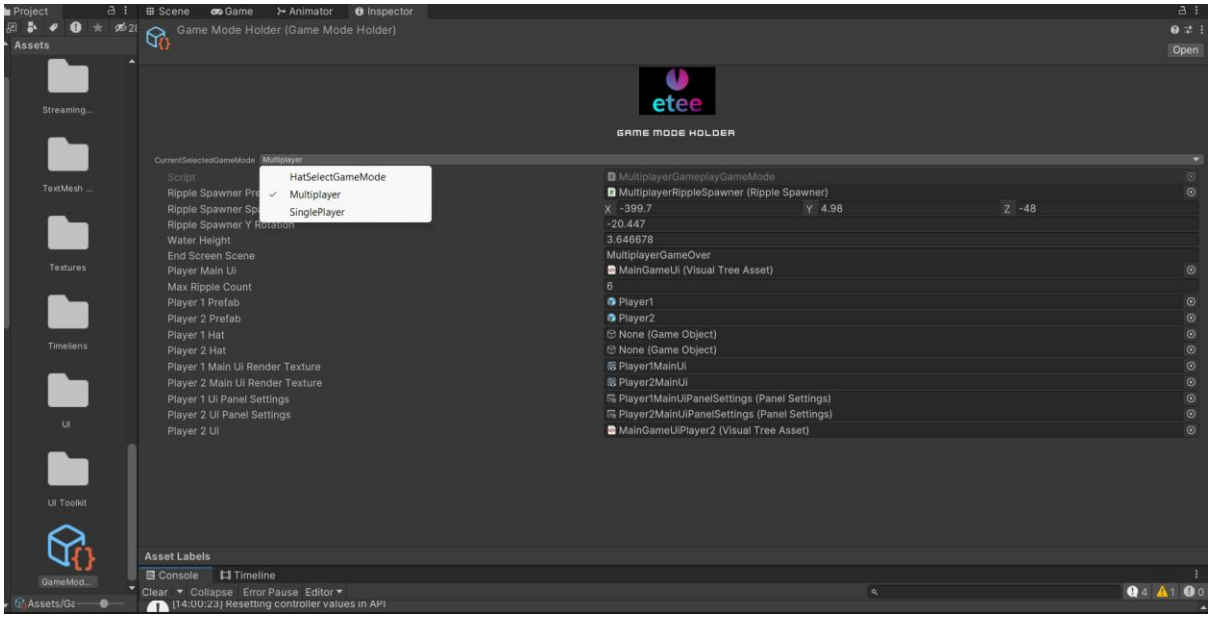


Figure 51 Custom Inspector Made for the Game Mode Holder Facilitating Editor Time Game Mode Changing and Parameter Adjustments

The MainGameSetup script has a reference to the game mode holder and when the main game scene starts the script calls setup on the gameMode held by the GameModeHolder.

3.3.3.7 Multiplayer

Due to most of the game logic being contained on the player prefab making the game split screen multiplayer does not require much extra work.

Two prefab variants of the player prefab were created (p1 & p2) and some values were adjusted such as position of certain elements and positions of elements in the scene that are specific to each player.

Multiplayer game setup logic can be added to the multiplayer game mode setup method and the cameras on the players can be set to only render to the top and bottom part of the viewport, respectively.

To store the spawn point of each player a spawn points class is used, which can draw gizmos to the screen to preview where each player will spawn. This spawn points object can be passed to the game modes setup function to spawn the players in the correct position.

Figure 52 Debugging Gizmos Showing the Spawn Points Stored for Each Player

3.3.3.8 Main game UI

All UI for the game is complete, and the UI works fully when playing in single player mode. However extra considerations must be made for the gameplay game UI to work properly in multiplayer mode.

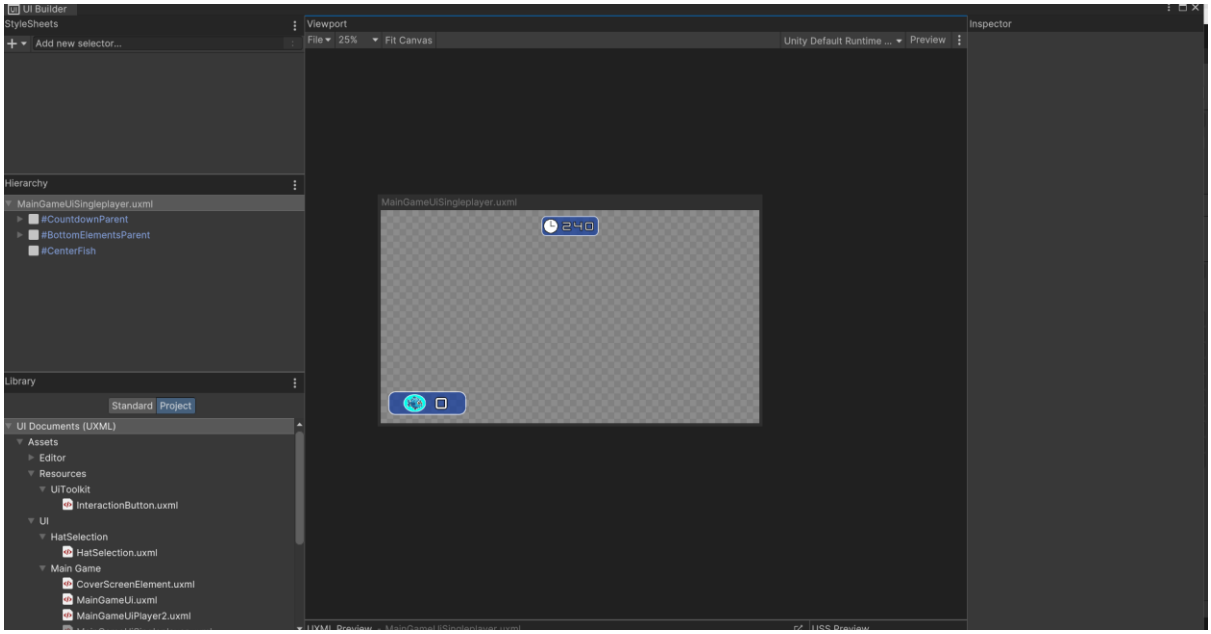


Figure 53 Main Game Ui as Created in Ui Builder

Above is the UI document for the single player game UI. However, when playing multiplayer, the screen is half the height and player 2 should use red instead of blue to differentiate itself.

Therefore, an additional two UI documents were created for the two players when playing in multiplayer mode.

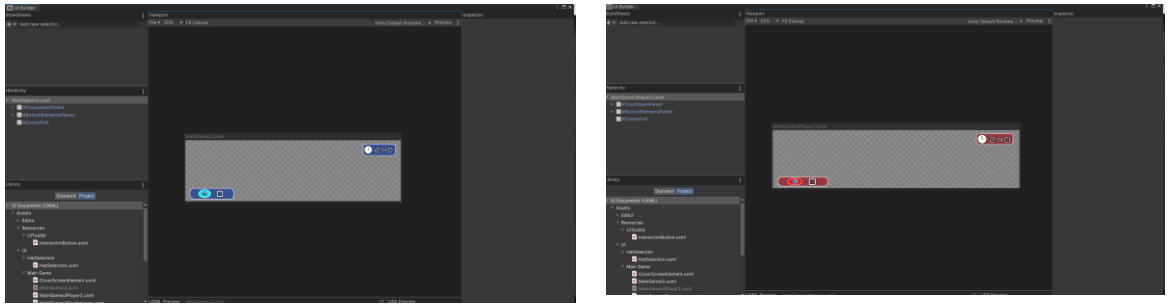


Figure 54 Player 1 & 2 Multiplayer Mode Ui's

When the game starts in multiplayer mode the multiplayer appropriate UI is instantiated and if the game is started in single player the single player UI is instantiated. This logic is within the SingleplayerGameplayMode and MultiplayerGamePlayMode classes.

4 Evaluation

4.1 Evaluation Methodology

To test the game testers will be grouped into groups of two, ideally both testers in each group are friends as this more closely mimics the intended environment the game will be played in, that being between a stroke patient and their family / caregiver.

The testing process of one group of two is conducted as follows.

1. Both testers read the project's information sheet and sign their consent forms to take part in the study.
2. Both testers complete the pre-test questionnaire
3. Both testers concurrently play the game in singleplayer mode – this gives each tester an opportunity to learn how to play the game.
4. Both testers play together in multiplayer mode
5. Both testers complete the post-test questionnaire

This process is repeated for each pair of testers.

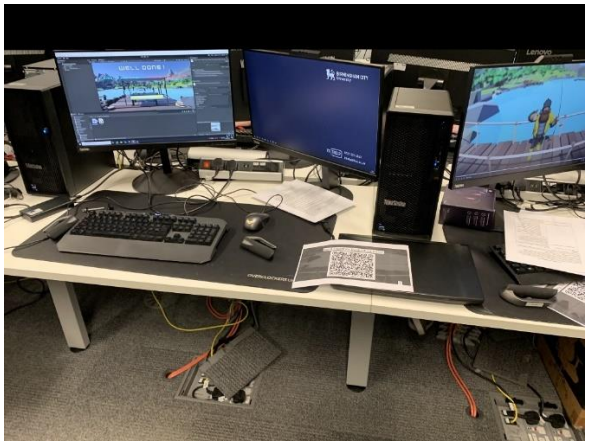


Figure 55 Main Test Setup

Figure 56 Testers Playing the Game in Multiplayer Mode

4.1.1 Evaluation Metrics

As mentioned previously this project is a preliminary study. While the context of stroke rehabilitation was a driving factor in many design choices for the project this study is focused on the user satisfaction and motivation from playing this game in a multiplayer setting.

Testers will complete a pre-test questionnaire and then a post-test questionnaire. Within this questionnaire there is a SUS (system usability scale) (as cited in Naturesa et al, 2023). And a GUESS (Game User Experience Satisfaction Scale) (Phan et al, 2016). These two sections of the questionnaire will comprehensively gather evaluation metrics on the user's enjoyment of the game.

The metrics gathered by the post-test questionnaire are as follows:

- Usability / Playability
- Narratives
- Play Engrossment
- Enjoyment
- Creative Freedom
- Audio Aesthetics
- Personal Gratification
- Social Connectivity
- Visual Aesthetics

Additional to the SUS and GUESS sections of the questionnaire which use Likert scales. There will also be opportunities for testers to write feedback which will also be discussed.

4.1.2 Dataset

The artefact produced was tested on 20 participants. The same parameters used during the pilot test were applied on this test. With the addition of testers being encouraged to stand.

- 19 testers were in the 18 – 24 age range and 1 tester was in the 25 – 34 age range.
- 17 testers were male, 2 were female and one preferred to not disclose.
- When asked to self-describe what type of video game player they are, 3 testers identified as casual game players, 6 described as midcore and 11 described as hardcore.
- The mean hours played a week for the testers was calculated by taking the midpoint of each of the ranges (more than 40 hours was clamped to 40), these midpoints were multiplied by the frequency, the mean can be calculated by these values. This facilitated the conclusion that the testers had a mean weekly playtime of 28.4 hours.

4.2 Results

Initially python and matplotlib was used to plot the distribution of responses from the Likert scale. These graphs can be found in the appendix and show the makeup of responses to each of the questions from the questionnaire.

To effectively analyse the data, graphs were plotted which show the average score on each response. For the SUS Likert scale this is in the range 1 – 5 and for rest of the Likert scales the range has been 1 – 7.

Graphs were plotted for the pilot test and main test separately. The pilot test graphs not used in the results section are available in the appendix. However, it should be noted that the pilot test had 4 participants, and the main test had 20 therefore the pilot test data is not as reliable.

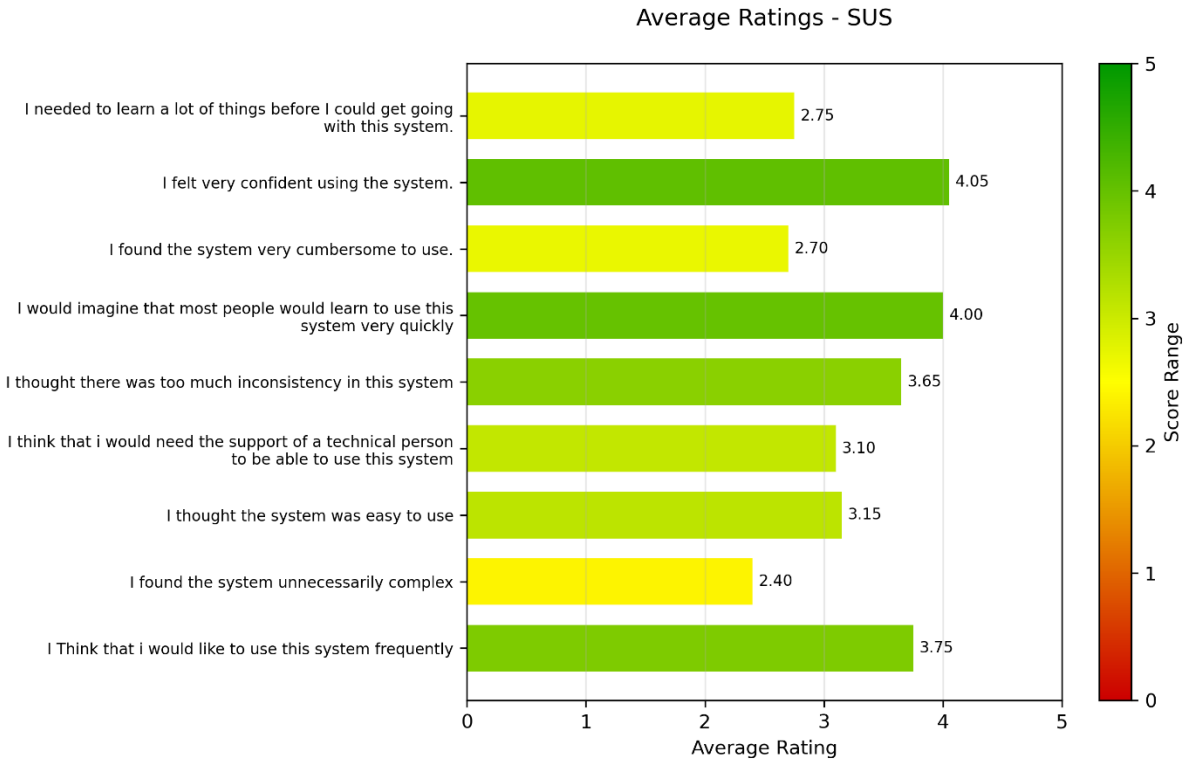


Figure 57 SUS Average Ratings

Overall, the Systems usability was identified as positive with some areas needing improvement. As indicated by the graph testers felt the system had too much inconsistency. Additionally, testers leaned more towards needing the support of a technical person to use the system.

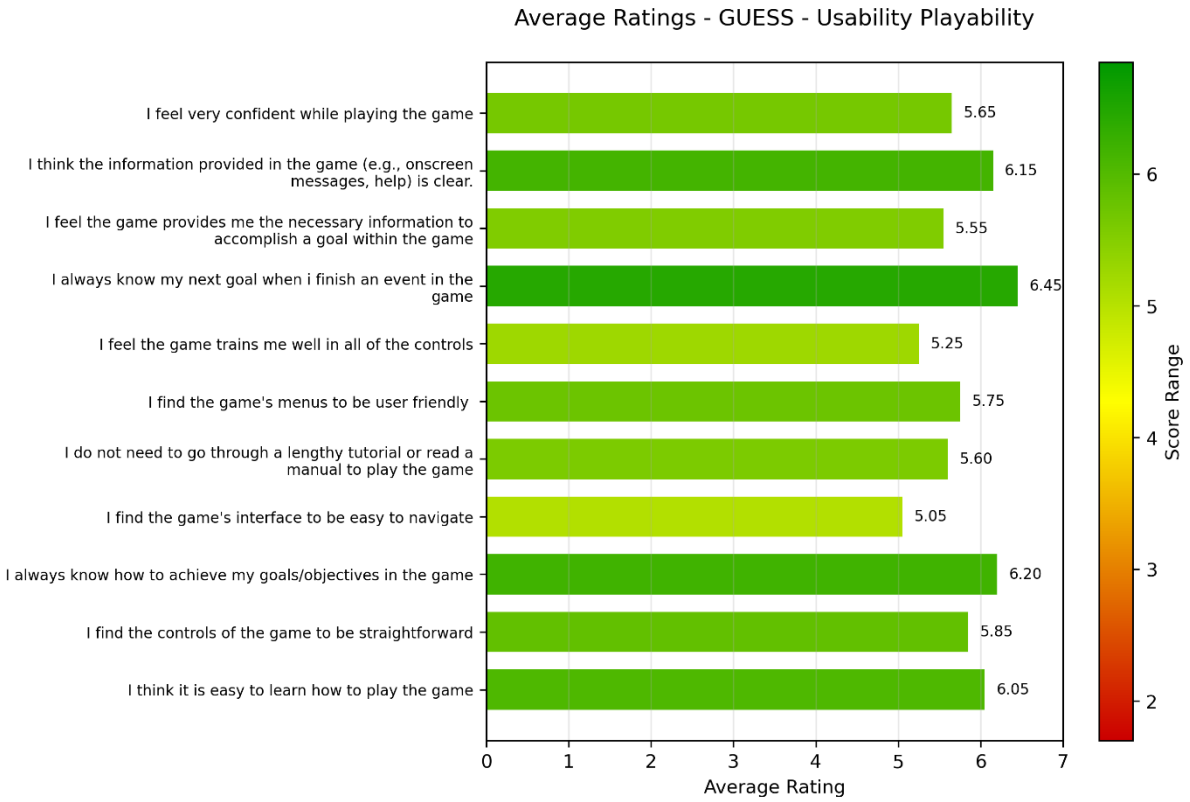


Figure 58 GUESS Usability / Playability Average Ratings

The playability part of the GUESS shows that users found the gameplay to be easily understandable. Featuring clear communication of information and direction. However, the users found that the game does not train them well in all its controls and the interface is difficult to navigate. The mean score across all the usability/playability Likert questions is 5.78.

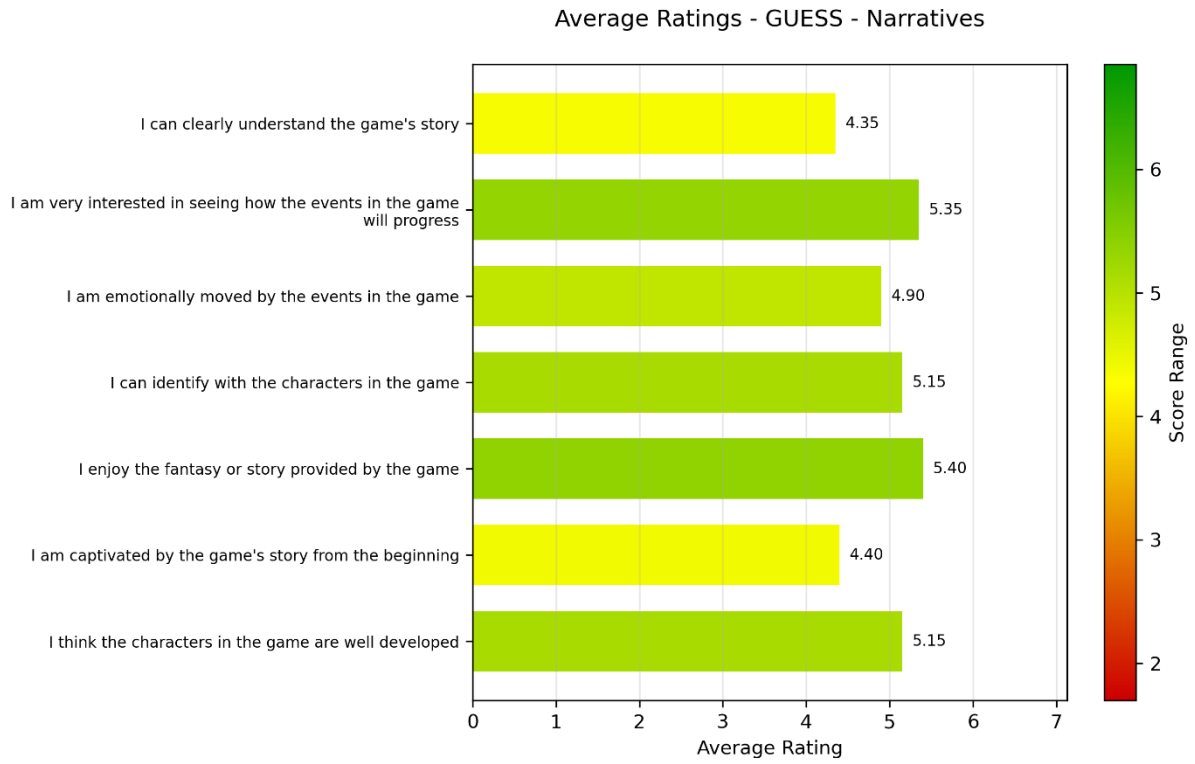


Figure 59 Guess Narrative Average Ratings

The narrative scores for the game shows that the players could identify with the characters in the game, and are invested in the game, showing interest in seeing how the events will progress. However, scores involving the games story were lower. The mean score for Narratives is 4.96.

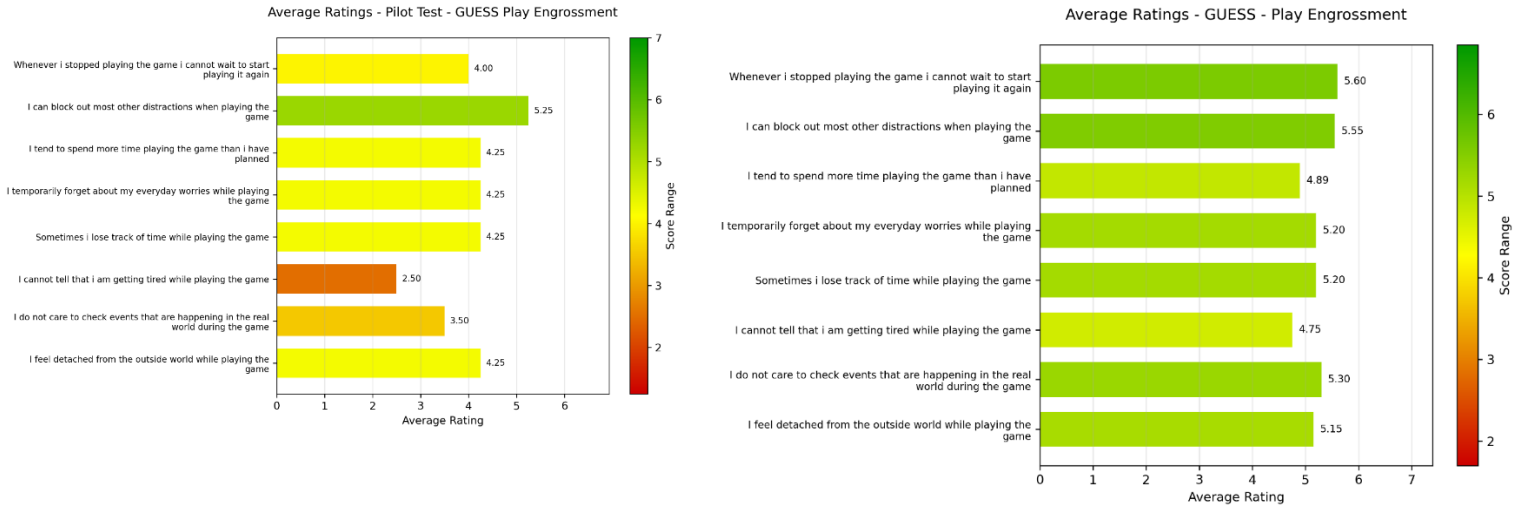


Figure 60 GUESS Play Engrossment Average Ratings. Pilot test and Main Test

Overall, the players were somewhat engrossed in the game. Particularly positive aspects were players wanting to play the game again and blocking out other distractions. Aspects of the scale which did not perform as well were the players spending more time playing the game than planned and not being able to tell they are getting tired. This score will have likely been influenced by the fact the players play sessions were controlled and therefore couldn't play longer than planned and couldn't

play long enough to judge if they forget about being tired. The average score for this section is 4 for the pilot test and 5.2 for the main test.

Compared to the pilot test players were more engrossed in the gameplay in every question.

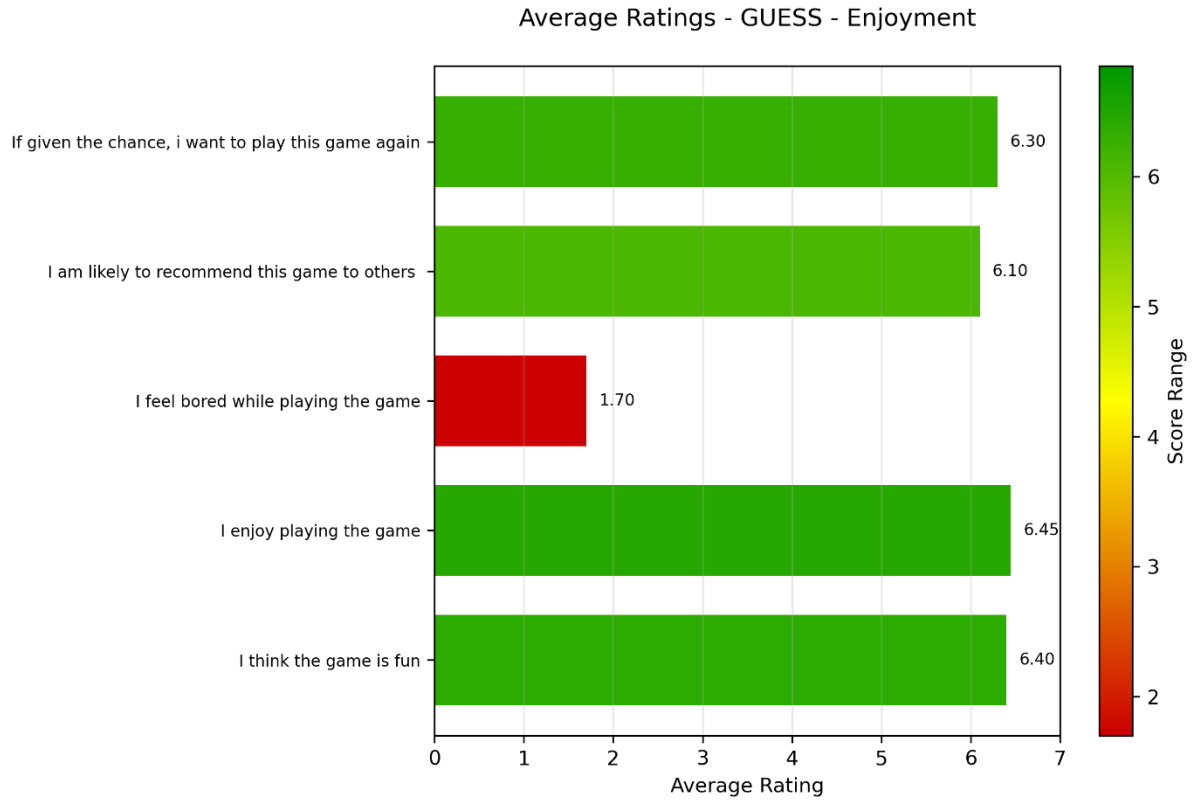
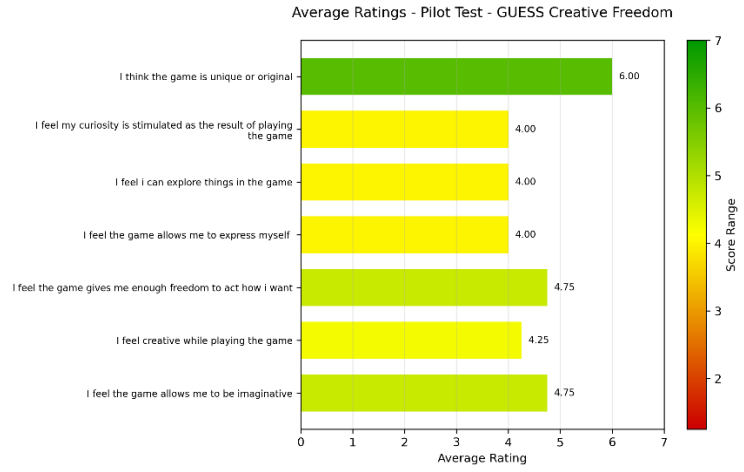


Figure 61 GUESS Enjoyment Average Ratings

The game saw an exceptional response regarding enjoyment from the testers.



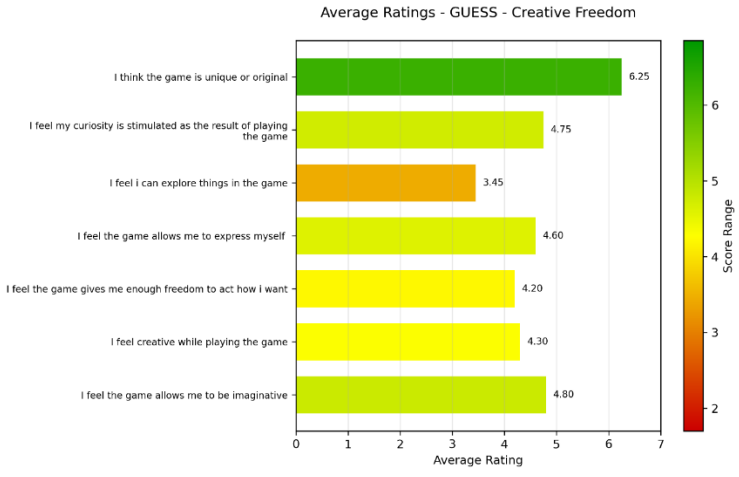


Figure 62 GUESS Creative Freedom Average Ratings. Pilot and Main Test

Across both the pilot test and main test, the consensus on creative freedom has largely stayed the same. During both tests players found the game to be unique or original. Additionally, the main testers felt more of an ability to express themselves.

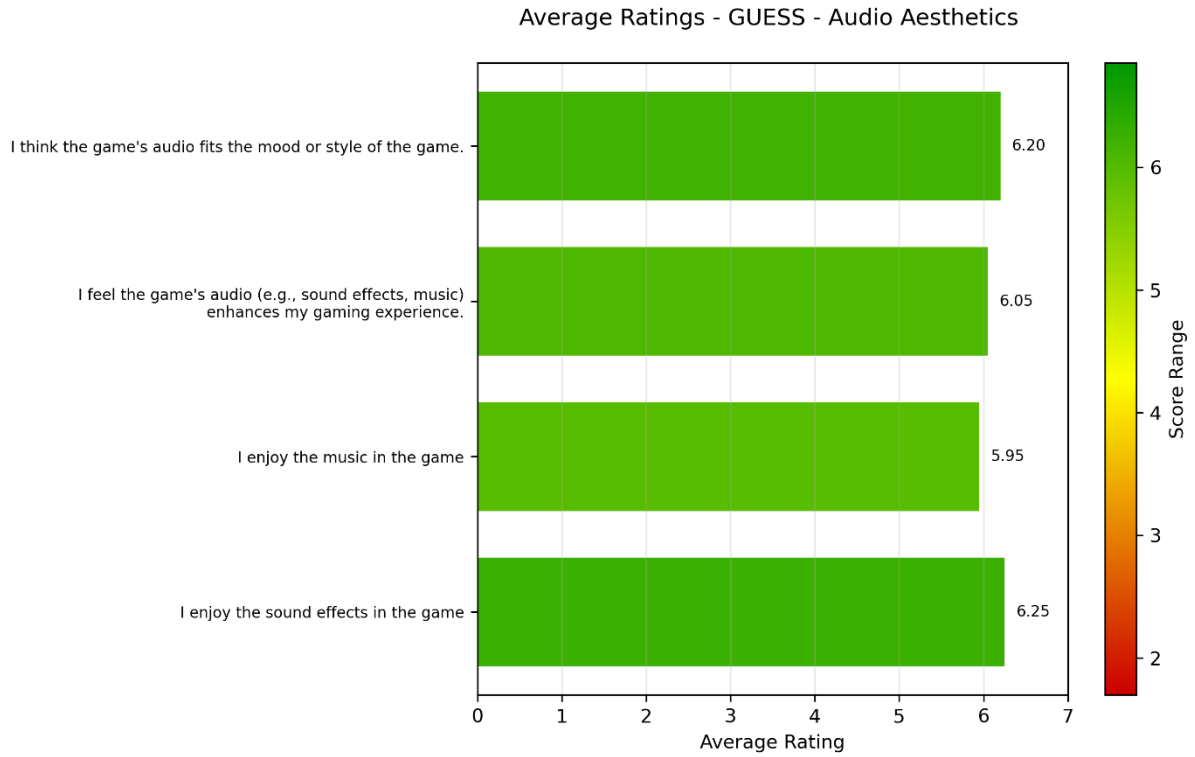


Figure 63 GUESS Audio Aesthetics Average Ratings

Players enjoyed the audio effects within the game. Audio was implemented using a middleware, in this instance FMOD. Which allowed the game to have high quality audio as reflected in the tester feedback.

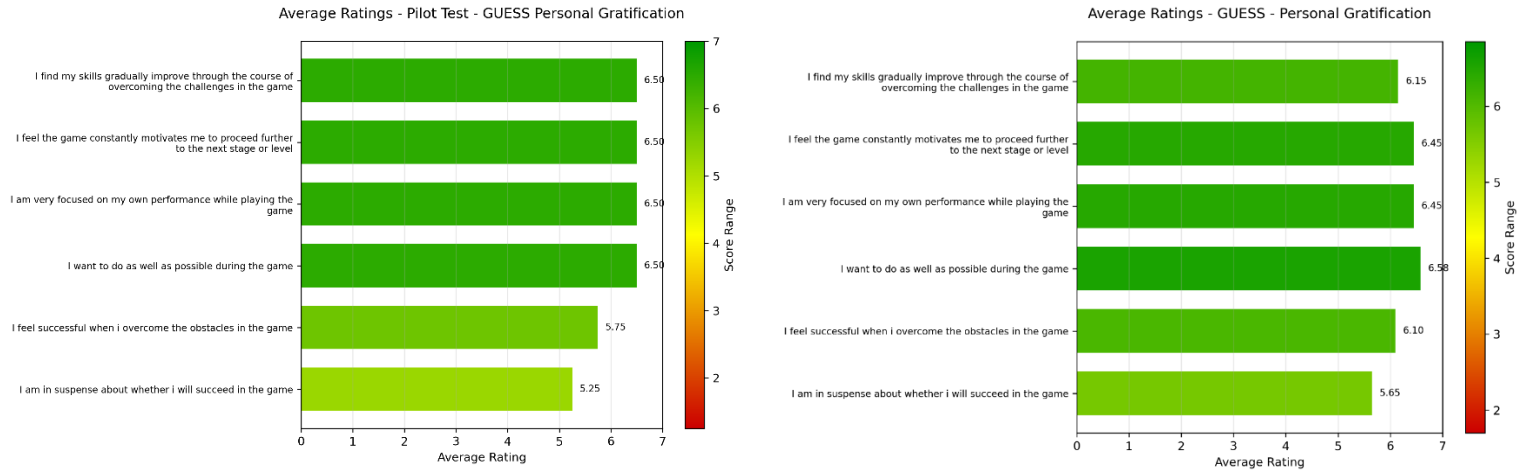


Figure 64 GUESS Personal Gratification Average Ratings. Pilot & Main Test

Testers throughout both tests found a high amount of personal gratification. The main testers felt that they wanted to do as well as possible more than the pilot testers, the main testers also had more of a feeling of success when overcoming obstacles and were in more suspense about whether they will succeed in the game.

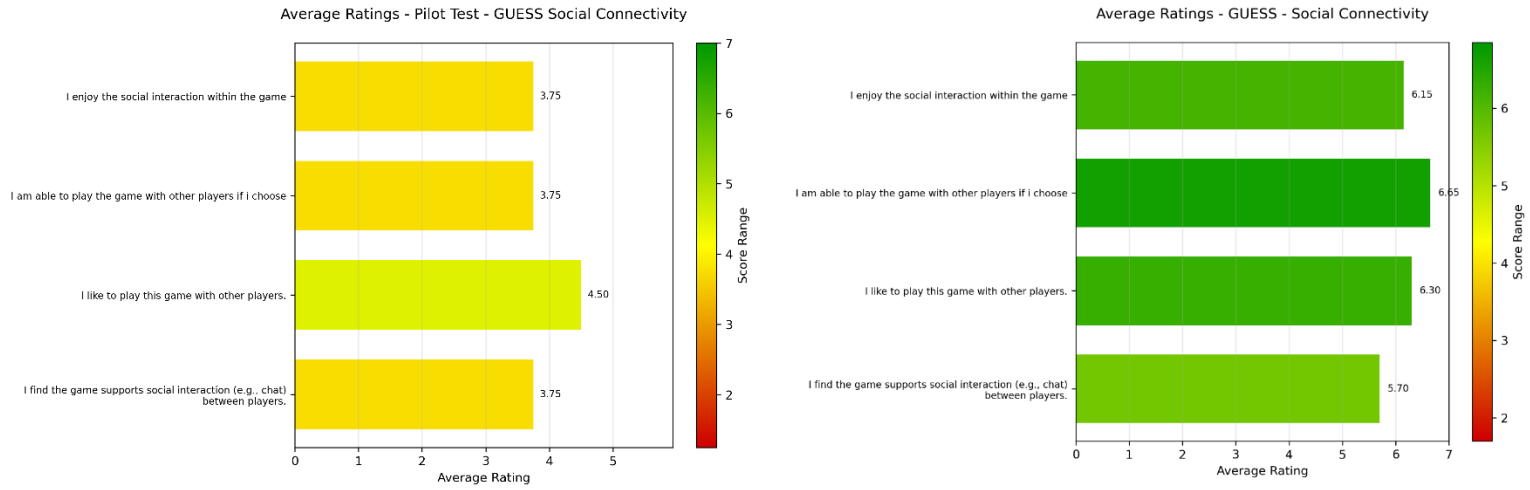


Figure 65 GUESS Social Connectivity Average Ratings. Pilot & Main Test

The main testers felt high levels of social connectivity, an obvious and large improvement than what the pilot testers had reported. The main testers were able to play multiplayer whereas the pilot testers did not have that option available to them. The average score for the main testers was 6.2. The biggest problem identified by the results is a lack of built in support for social interaction between players.

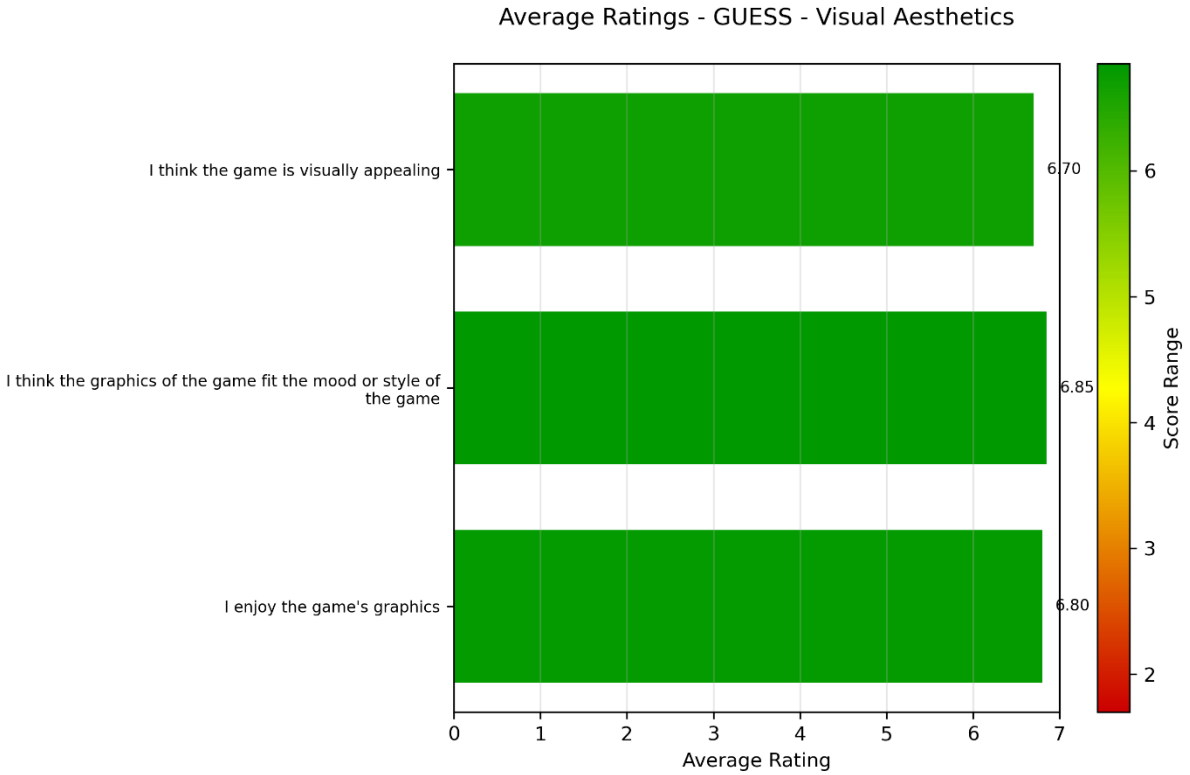


Figure 66 GUESS Visual Aesthetics Average Ratings

The visual aesthetics of the game resonated with the players. This sentiment was shared by the pilot testers. The average score of visual aesthetics was 6.78 an exceptionally high score.

To aid in evaluation on how the game can be improved the lowest rated question, (below a score of 5.7) of each section of the GUESS questionnaire section has been compiled. Any graphs with a minimum above 5.7 will not be considered as there is a relatively low need for improvement. This causes enjoyment, audio aesthetics and visual aesthetics to be omitted.

Table 13 Largest Areas of Improvement for The Project

GUESS section	Biggest area for improvement
Usability / Playability	Game Interface Navigation
Narratives	Captivating game story
Play Engrossment	Play engrossment to the point where players feel detached from the outside world and want to play more than planned.
Creative Freedom	The ability to explore things in the game
Personal Gratification	Suspense of if the player will succeed in the game
Social Connectivity	Supported in-game social interaction

4.3 Discussion

First the SUS will be reviewed allowing the usability to be discussed, then the game will be evaluated following the GUESS results.

Testers found that there was too much inconsistency in the system. Testers likely experienced this inconsistency in two places. The main menu of the game and when playing the game. The main menu is navigated by swiping on the track pad to highlight different buttons and then squeezing to select a button. Testers experienced problems with both actions. When navigating the menus the trackpad swipes would often be ignored causing frustration. When squeezing the remote to select a button, testers found that they had to squeeze too much. One tester commented that they “had to squeeze pretty hard”. This may have been due to the controllers not being configured to each tester using the etee connect app or alternatively due to threshold values in the game being set too high. A potential fix for this would be to have a system which adjusts the squeeze sensitivity if a player is struggling to select a button.

As for inconsistencies in gameplay one tester commented “The simplicity of the system is great, but the feedback it gives to the player in what movement is necessary to achieve any goal is incredibly inconsistent, as the movements are often too precise.” This seems to have been caused by logic errors in reading the gyroscope data of the controller. Addressing these issues would be a high priority task to allow stroke survivors to effectively use the system.

To review the effectiveness of the game in promoting patient motivation the GUESS section of the questionnaire can be analysed. Starting the usability / planarity. Testers found the game to be highly playable, a particular success in this area was the game providing clear steps to achieve the goals in the game and communicating the next goal to the players. This is extremely important in the area of stroke rehabilitation as the disease can affect cognition. Similar feedback from the SUS can also be

observed regarding the games interface navigation. Additionally, the tester response to the game training the player well in all the controls is an area of improvement at 5.25. Therefore, the game would likely benefit from an interactive tutorial to teach users how to play the game.

While testers where overall positive the narrative aspect of the game was found to be lacking. Players did enjoy the setting and fantasy of the game and could connect with the characters to an extent due to the customisation options. However, testers were not as confident in understanding the games story and being captivated by it. A games story is a large contributor to enjoyment and immersion in a game. Therefore, Reel Together would benefit from story elements. This could be a small cutscene that plays at the start of the game to set the scene or characters which are present throughout the game and talk to the player(s).

Play engrossment saw a substantial increase in score between the pilot and main test. While the pilot had an average score of 4 meaning overall testers were indifferent about play engrossment the main test had an average score of 5.2. A large difference between the pilot and main test was the addition of a multiplayer mode where players could play against each other. This clearly had a huge impact on play engrossment which corresponds to the findings of other research.

Additionally, during the main test some testers requested to play the game again, this was a very positive sign that the game offered high levels of motivation. This behaviour was not observed in the pilot test before multiplayer gameplay was introduced.

Creative freedom in both tests received relatively low score. This is to be expected due to the nature of the game as discussed in the pilot test evaluation it is difficult to say if more creative freedom would be beneficial.

The increase in personal gratification can also be largely attributed to the introduction of multiplayer play. Another multiplayer driven improvement in tester review is the ratings for social connectivity. Being able to play alongside someone else in a multiplayer environment took the pilot test average score of 3.9 to 6.2. Players appreciate that they can be playing the same game and can communicate about the state of the game. Many players took a competitive approach resulting in lots of communication and high focus and drive to win.

Testers found the game visually appealing. This is likely highly influenced using high quality premium assets. The simple art style is also likely an influencing factor.

Additionally professional feedback was received from a physiotherapist from the Birmingham NHS trust. After testing they gave useful feedback on the project. A strong emphasis was placed on modularity and customisability as stroke survivors can have vastly different needs. For example,

some may have access to more strength but lack precision and others may have the opposite abilities. This focus on modularity would be a way the game could be adapted and improved.

As shown in table x multiple areas for improvement have been identified from the results. The Game interface navigation can be improved by improving swipe recognition and reducing how hard the user must squeeze. A captivating game story could be introduced to increase engagement, more immersion this could potentially be achieved by utilizing first person view perspective. Introducing more player agency could help increase creative freedom, for example giving the player the choice of where to cast the rod. While suspense was improved by multiplayer gameplay there could have been more suspense. This could be achieved in a similar way to how Mario cart achieves suspense by modulating a player's game difficulty settings based on if they are winning or not. And finally in game social interaction this could be implemented in the form of emotes the player could perform or emoji like icons could be used to interact.

5 Conclusions

During development of the project characteristics of effective rehabilitation were and movements beneficial to UL stroke rehabilitation was identified. This knowledge was then used to design, scope and develop a game which, through gamification, encourages these beneficial movements.

Due to this being a preliminary study the project was tested on a group of adults. The project was evaluated based on tester feedback regarding the usability of the system and the satisfaction derived from different aspects of the game.

It was found that the game did encourage the users to use different parts of their arm to play the game, additionally the game had high levels of satisfaction providing high motivation to play the game. There is no doubt that the multiplayer aspect of the game had a high degree of influence on the perceived enjoyment of the game from the testers. Therefore, making multiplayer gamification an interesting and promising future area of research.

6 Recommendations for future work

As this preliminary study has shown that the game is indeed enjoyable and provides high levels of motivation an area for further development would be to improve the games accessibility so that it can be used by stroke patients. This would involve increasing the SUS score of the game by making menus easier to navigate etc… Additionally stroke specific usability concerns should be addressed for example restricted range of motion and cognitive impairment.

After receiving feedback from a physiotherapist, it was clear that modularity and parameterisation of gameplay is extremely important, therefore. Introducing a way to customise the gameplay pipeline would be extremely beneficial. This could even be linked to a website portal that the physiotherapist could interact with and receive data regarding how the patient has done.

One of the aspects of the game which ranked lowly in the GUESS section of the questionnaire was the creative freedom offered to the player. It would be interesting to explore a gamified stroke rehabilitation system offering high levels of creative freedom to its users.

7 References

[1] Alankus, G., Lazar, A., May, M. and Kelleher, C., 2010, April. Towards customizable games for stroke rehabilitation. In *Proceedings of the SIGCHI conference on human factors in computing systems* (pp. 2113-2122).

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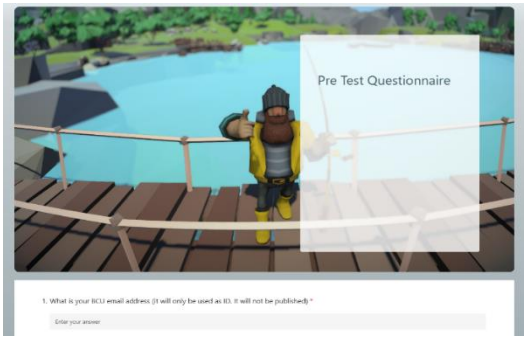
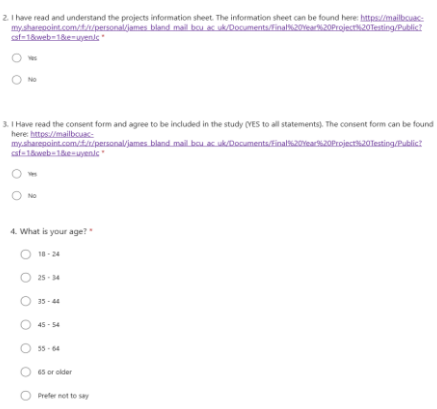
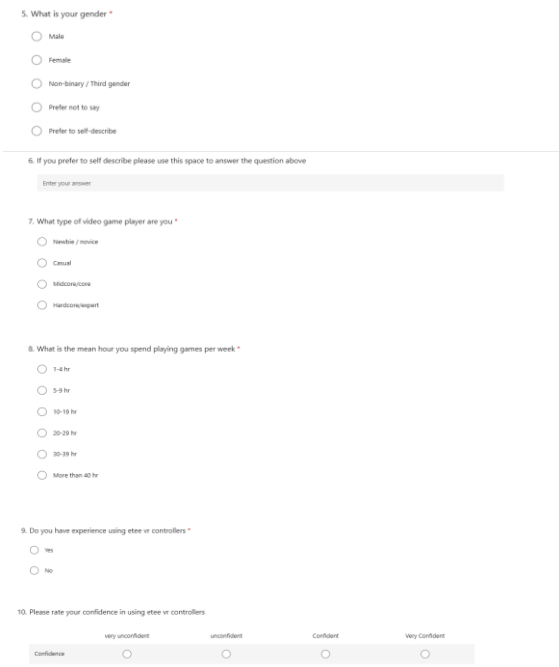
9 Appendices







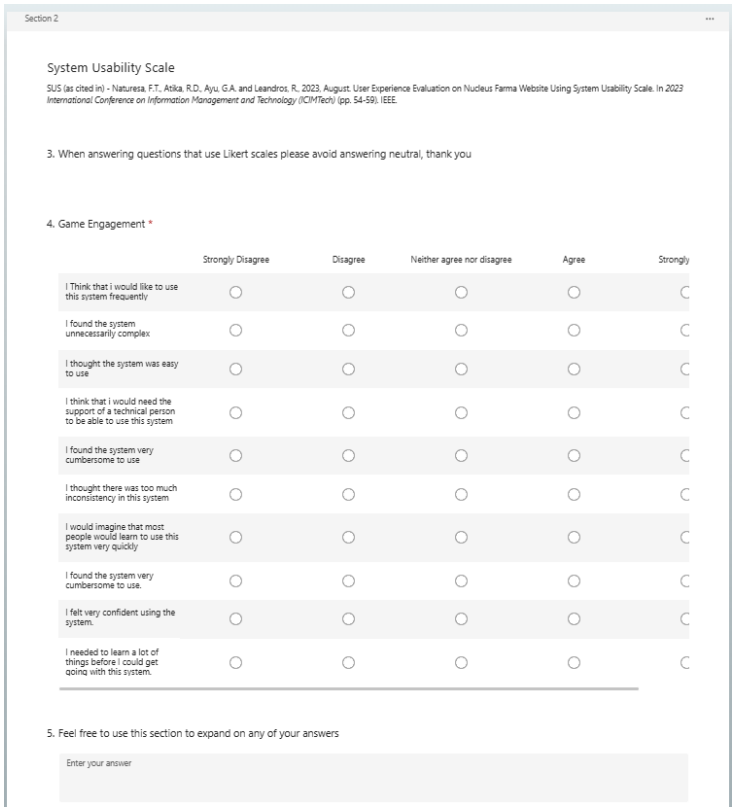


Figure 68 SUS Section of The Post Test Questionnaire

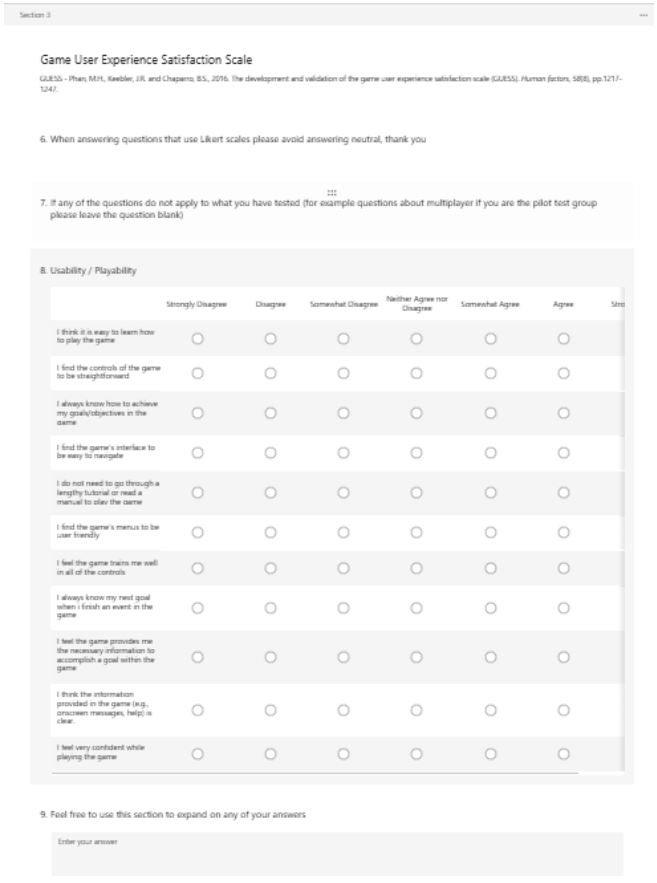
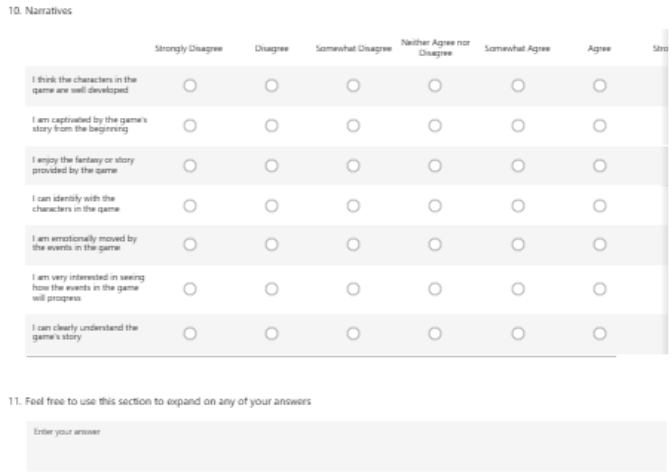


Figure 69 GUESS Usability/Playability Section of The Post Test Questionnaire

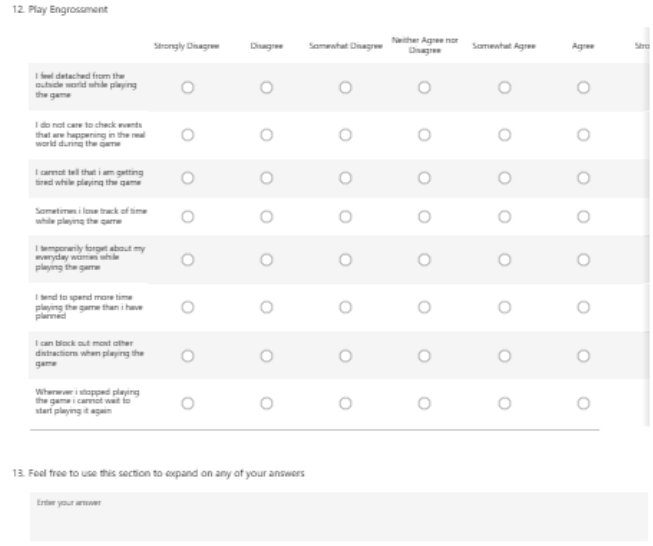

10. Narratives

	Strongly Disagree	Disagree	Somewhat Disagree	Neither Agree nor Disagree	Somewhat Agree	Agree	Stro
I think the characters in the game are well developed	○	○	○	○	○	○	
I am captivated by the game's story from the beginning	○	○	○	○	○	○	
I enjoy the fantasy or story provided by the game	○	○	○	○	○	○	
I can identify with the characters in the game	○	○	○	○	○	○	
I am emotionally moved by the events in the game	○	○	○	○	○	○	
I am very interested in seeing how the events in the game will progress	○	○	○	○	○	○	
I can clearly understand the game's story	○	○	○	○	○	○	

11. Feel free to use this section to expand on any of your answers

Enter your answer

Figure 70 GUESS Narratives Section of The Post Test Questionnaire

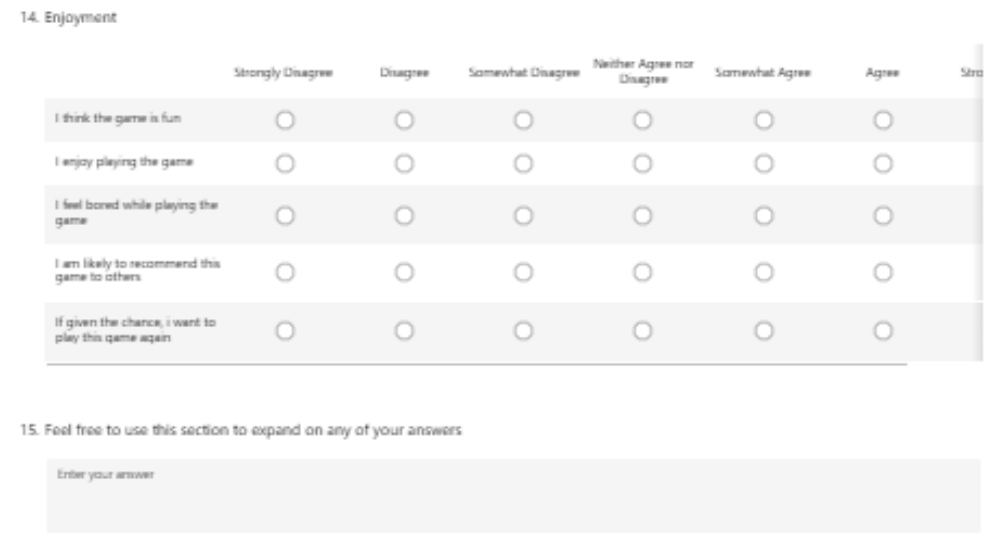

12. Play Engrossment

	Strongly Disagree	Disagree	Somewhat Disagree	Neither Agree nor Disagree	Somewhat Agree	Agree	Stro
I feel detached from the outside world while playing the game	○	○	○	○	○	○	
I do not care to check events that are happening in the real world during the game	○	○	○	○	○	○	
I cannot tell that I am getting tired while playing the game	○	○	○	○	○	○	
Sometimes I lose track of time while playing the game	○	○	○	○	○	○	
I temporarily forget about my everyday worries while playing the game	○	○	○	○	○	○	
I tend to spend more time playing the game than I have planned	○	○	○	○	○	○	
I can block out most other distractions when playing the game	○	○	○	○	○	○	
Whenever I stopped playing the game I cannot wait to start playing it again	○	○	○	○	○	○	

13. Feel free to use this section to expand on any of your answers

Enter your answer

Figure 71 GUESS Play Engrossment Section of The Post Test Questionnaire


14. Enjoyment

	Strongly Disagree	Disagree	Somewhat Disagree	Neither Agree nor Disagree	Somewhat Agree	Agree	Stro
I think the game is fun	○	○	○	○	○	○	
I enjoy playing the game	○	○	○	○	○	○	
I feel bored while playing the game	○	○	○	○	○	○	
I am likely to recommend this game to others	○	○	○	○	○	○	
If given the chance, I want to play this game again	○	○	○	○	○	○	

15. Feel free to use this section to expand on any of your answers

Enter your answer

Figure 72 GUESS Enjoyment Section of The Post Test Questionnaire

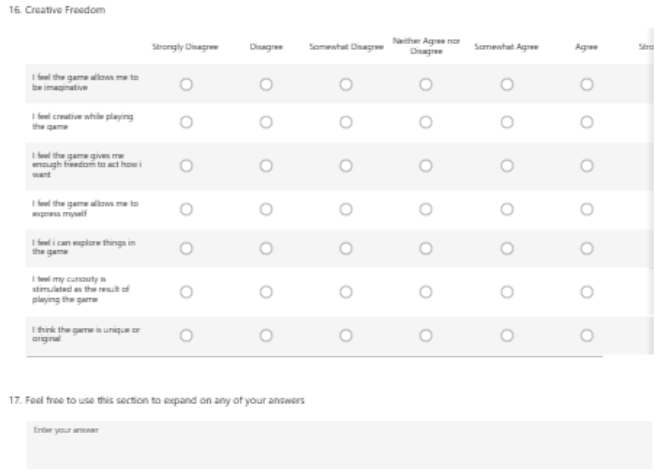


Figure 73 GUESS Creative Freedom Section of The Post Test Questionnaire

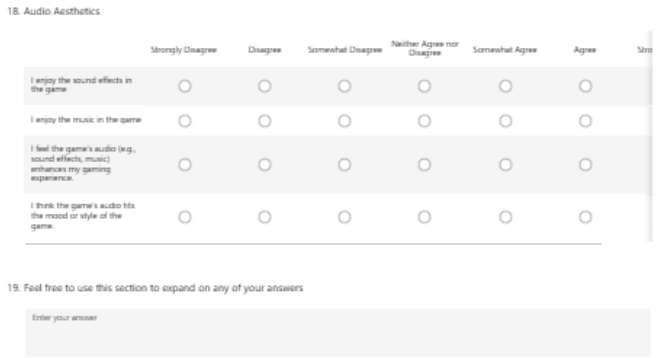


Figure 74 GUESS Audio Aesthetics Section of The Post Test Questionnaire

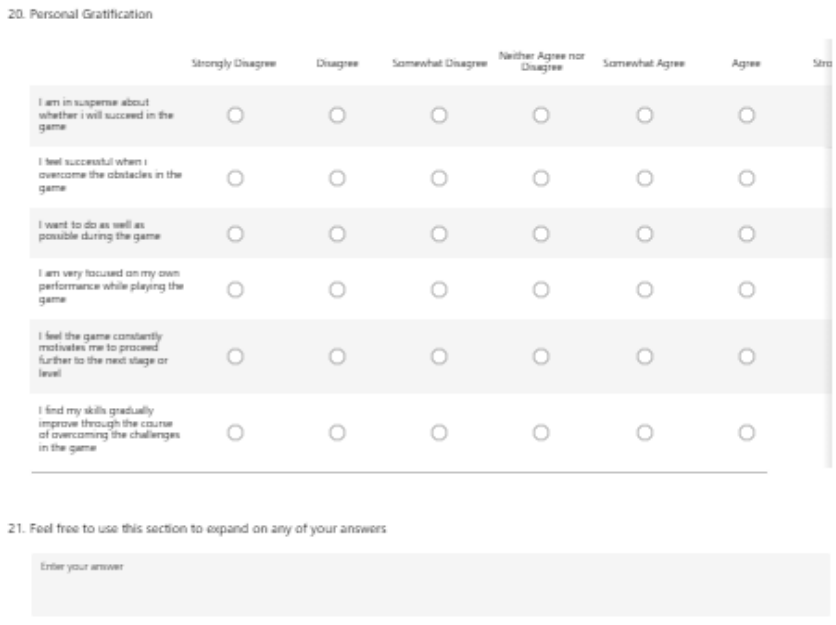


Figure 75 GUESS Personal Gratification Section of The Post Test Questionnaire

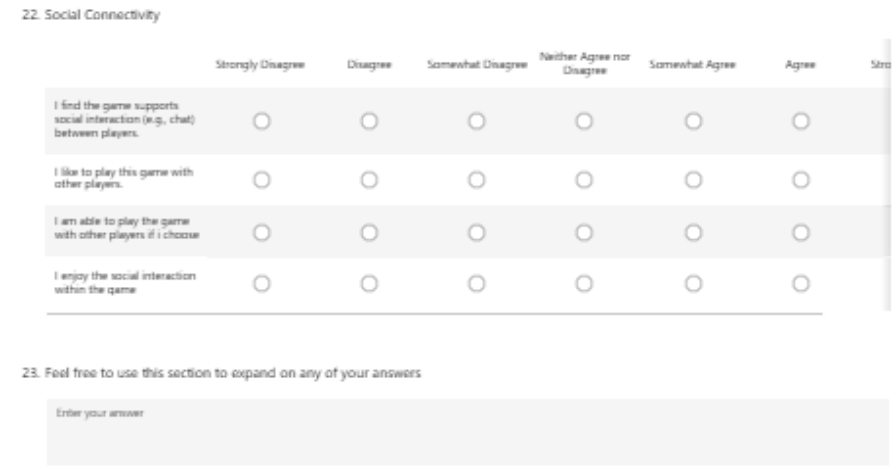


Figure 76 GUESS Social Connectivity Section of The Post Test Questionnaire

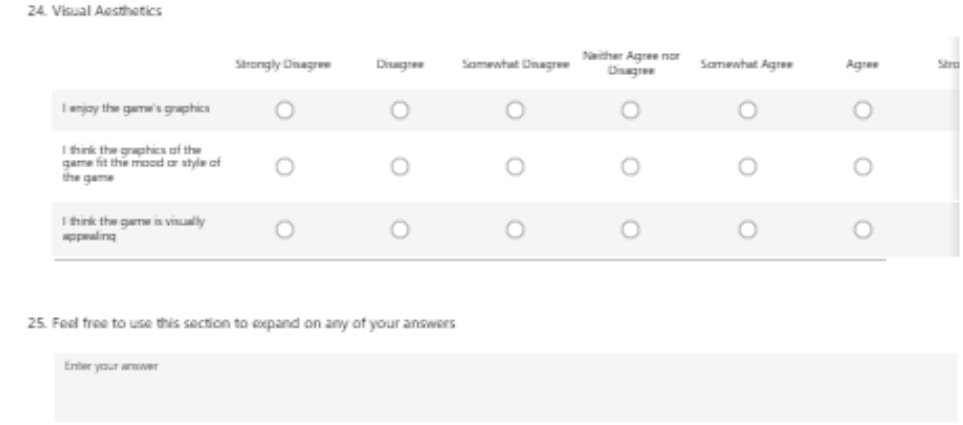


Figure 77 GUESS Visual Aesthetics Section of The Post Test Questionnaire

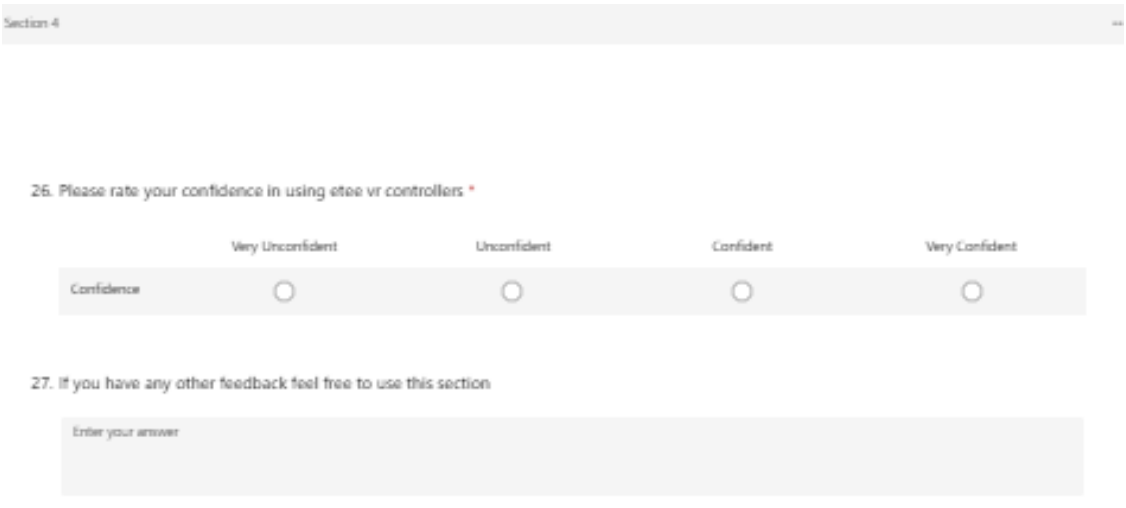


Figure 78 Final Section of The Post Test Questionnaire

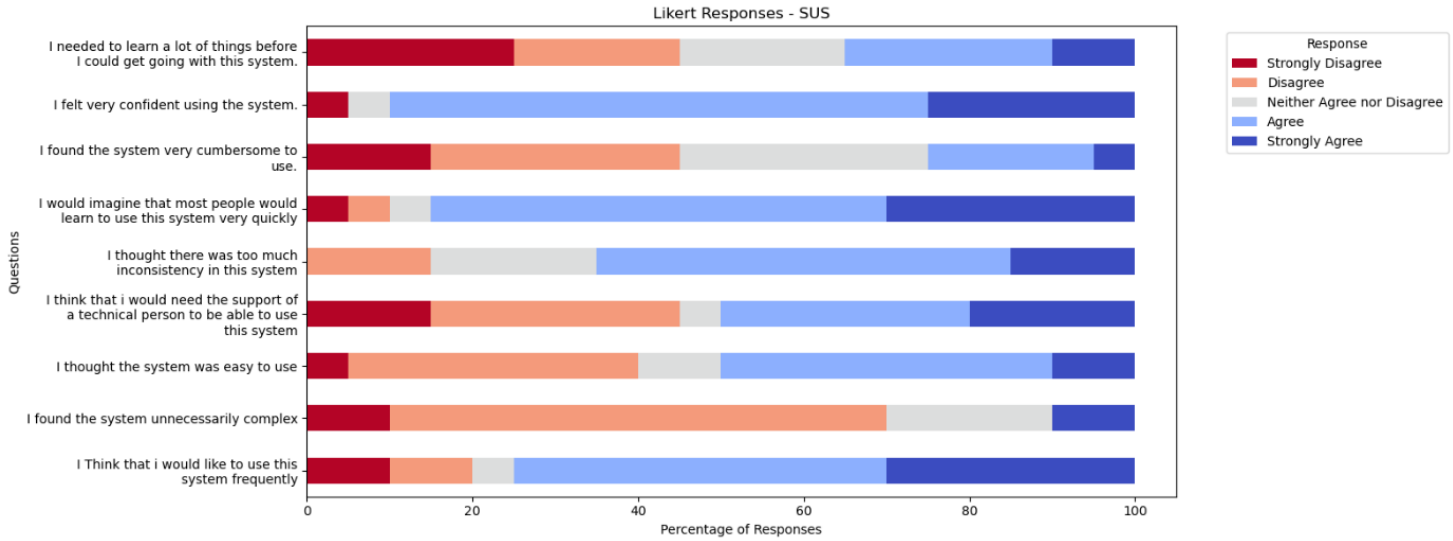
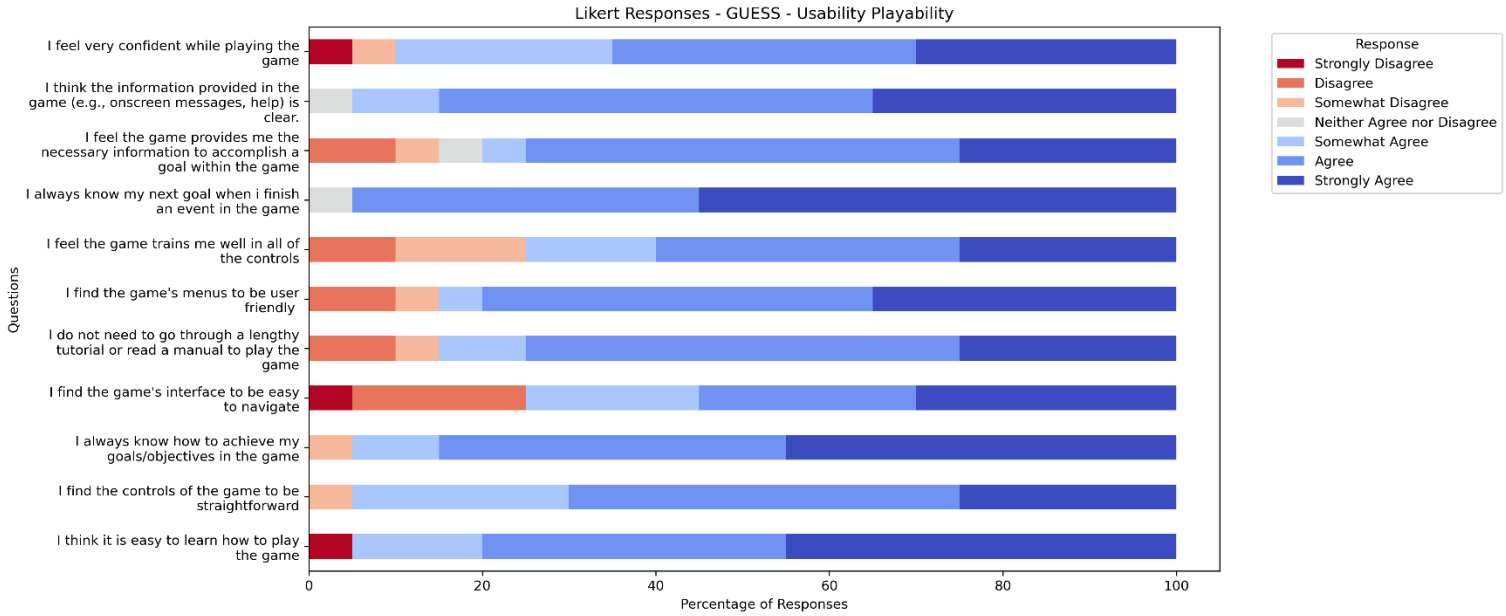


Figure 79 Main Test SUS Response Distribution



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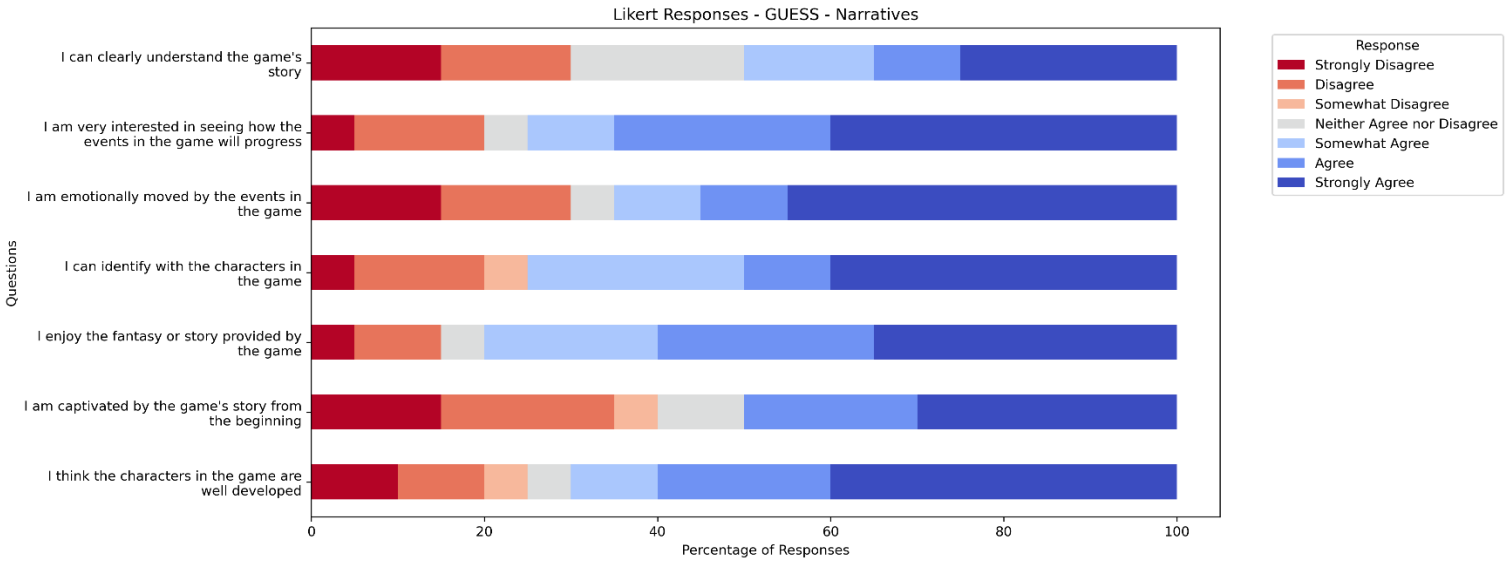


Figure 81 Main Test GUESS Narratives Response Distribution

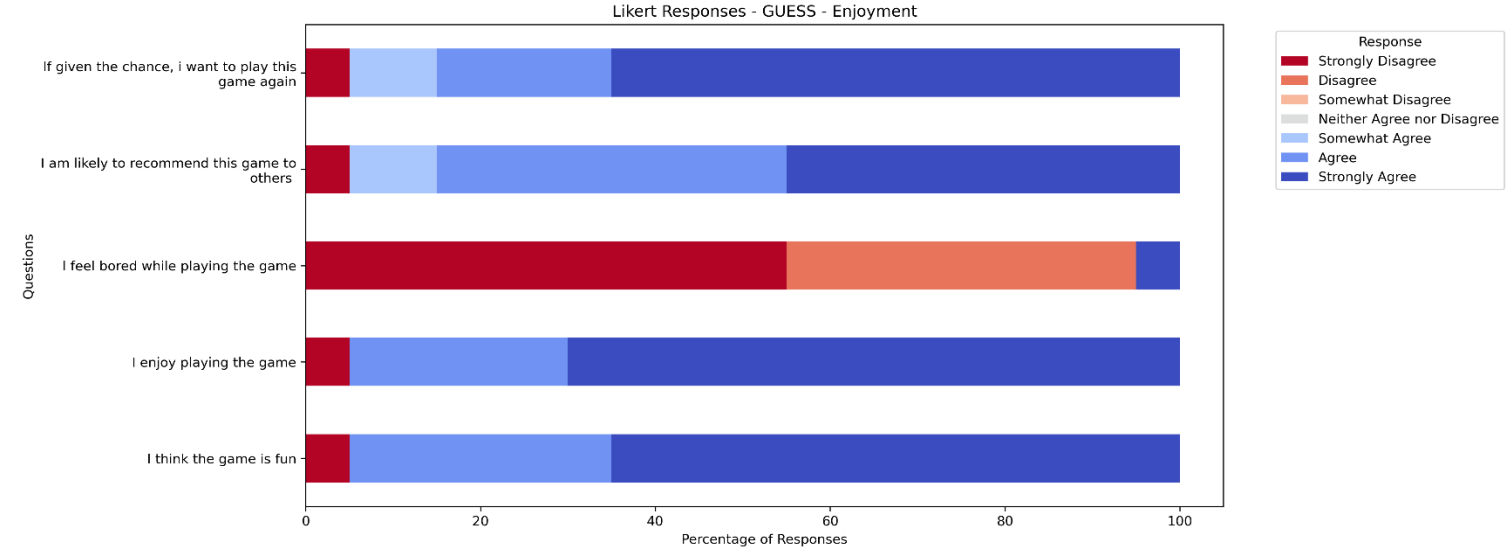


Figure 82 Main Test GUESS Enjoyment Response Distribution

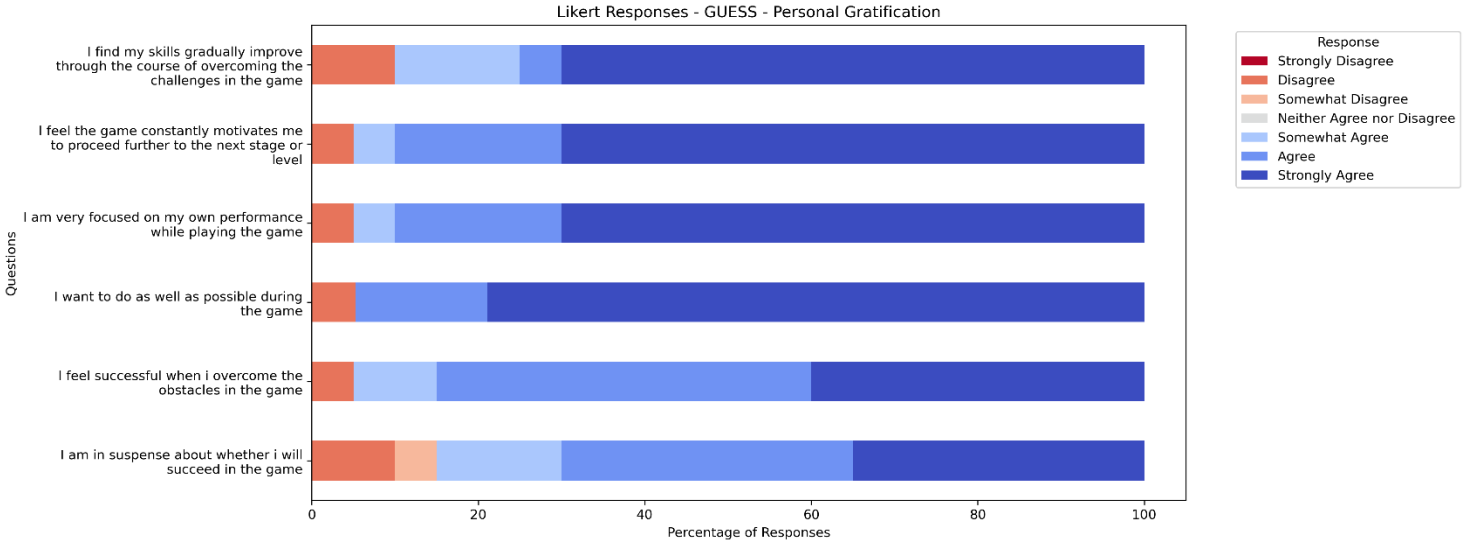


Figure 83 Main Test GUESS Personal Gratification Response Distribution

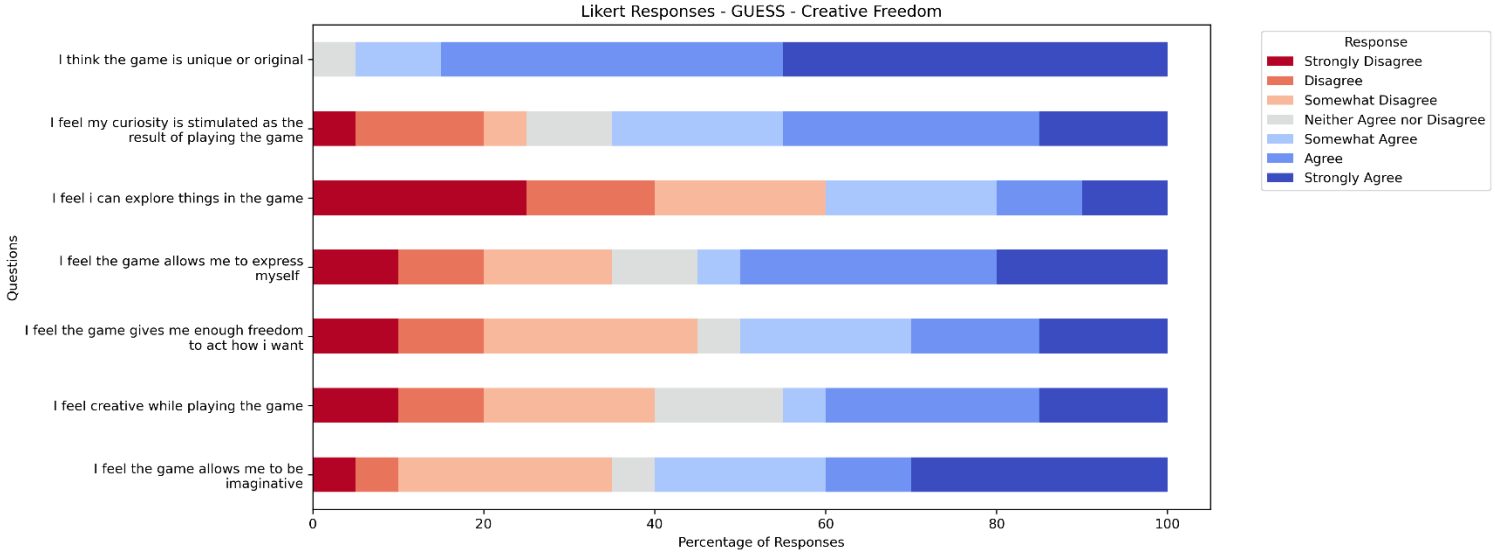


Figure 84 Main Test GUESS Creative Freedom Response Distribution

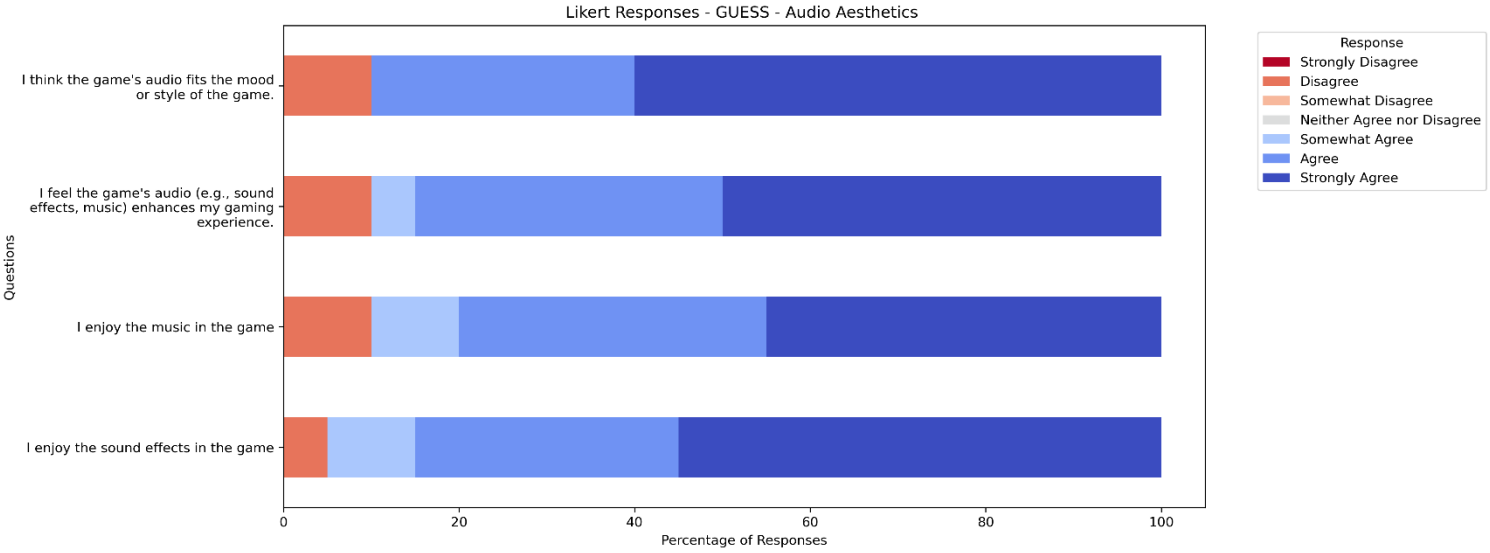


Figure 85 Main Test GUESS Audio Aesthetics Response Distribution

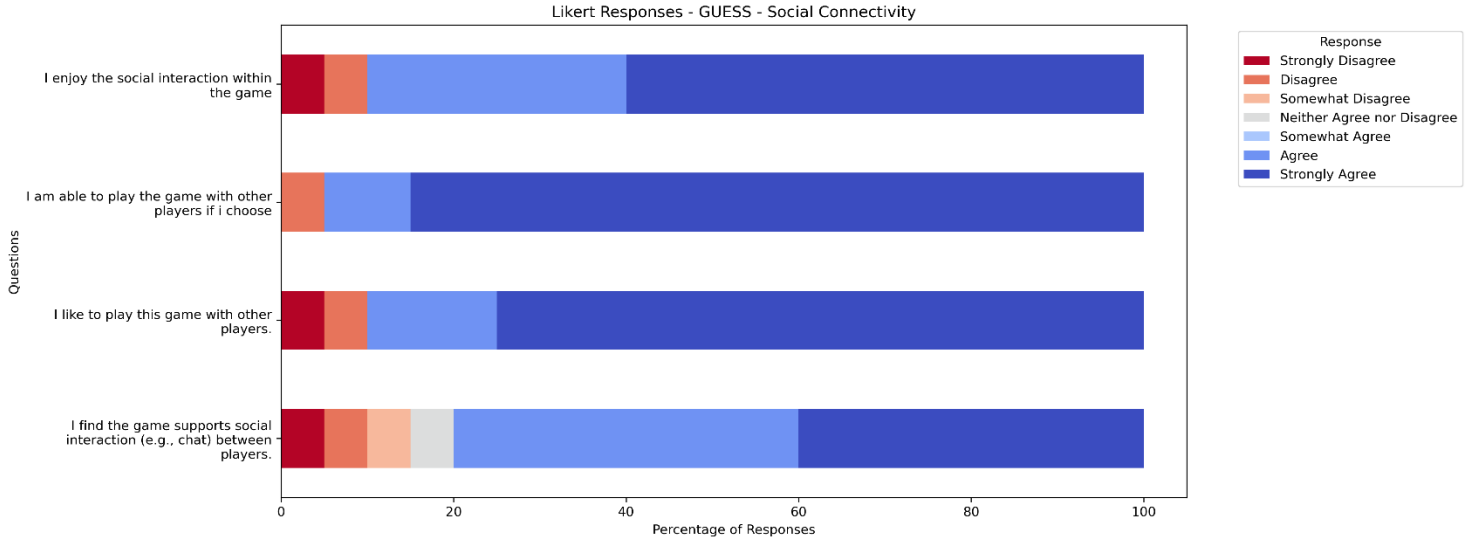
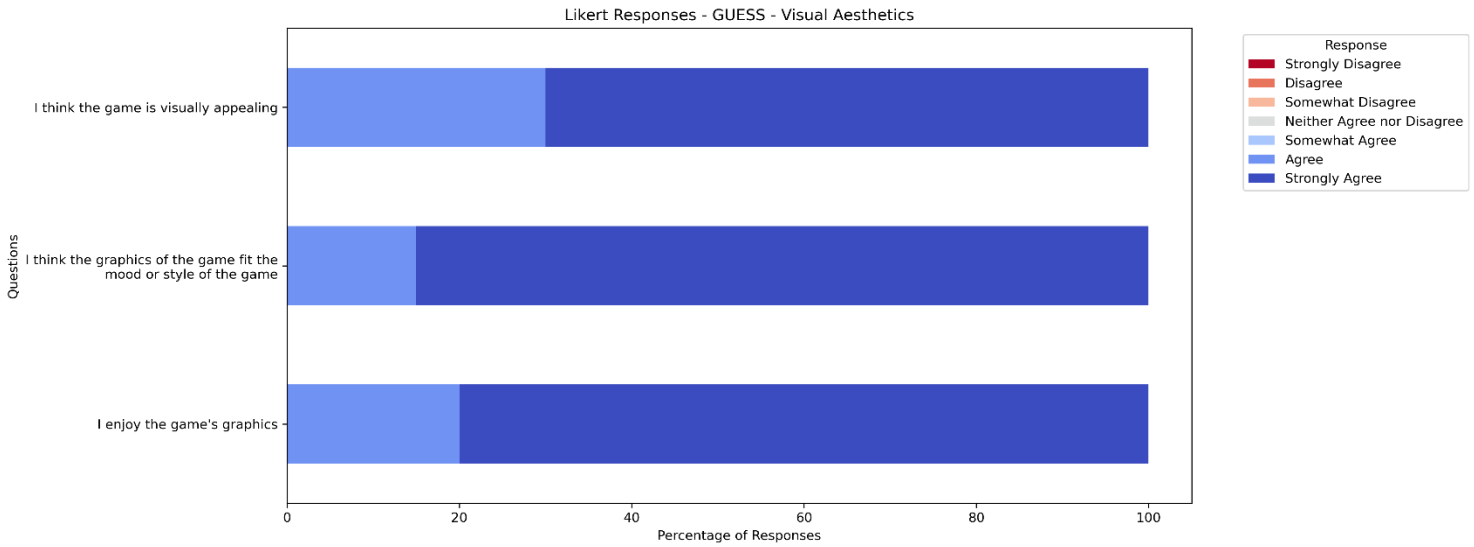


Figure 86 Main Test GUESS Social Connectivity Response Distribution



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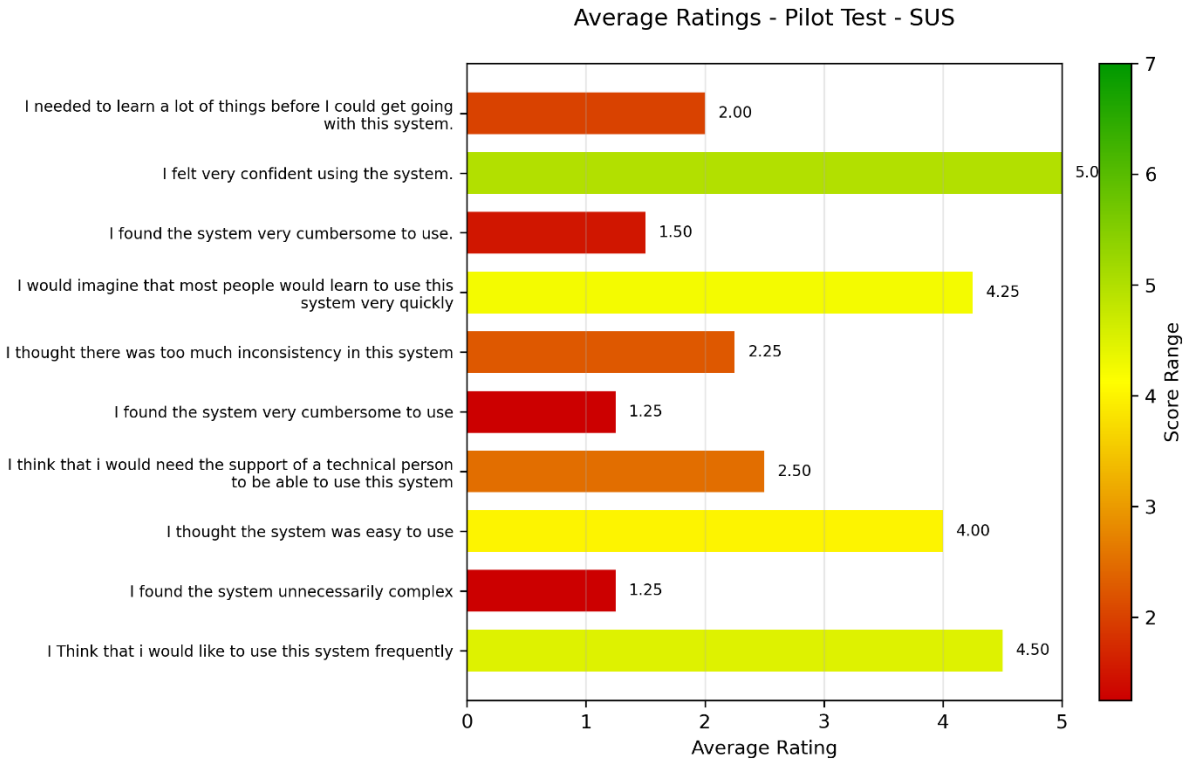
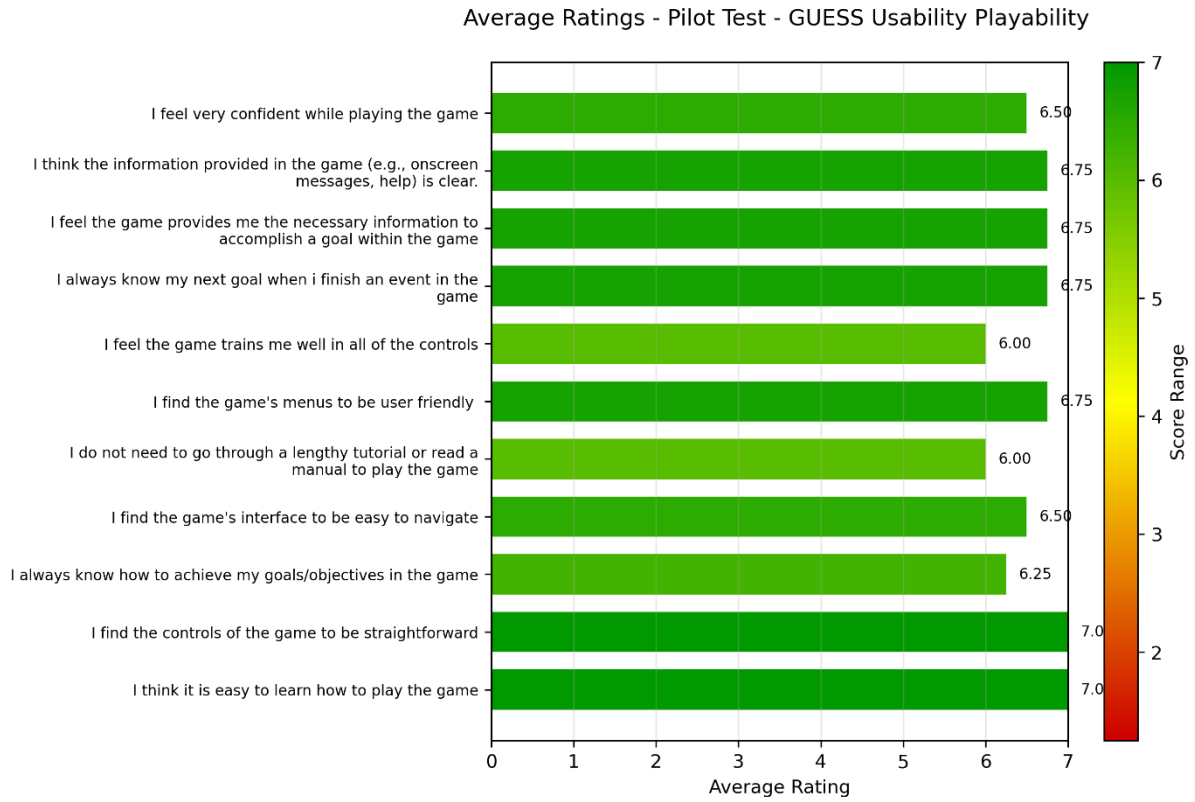


Figure 88 Pilot Test SUS Average Ratings



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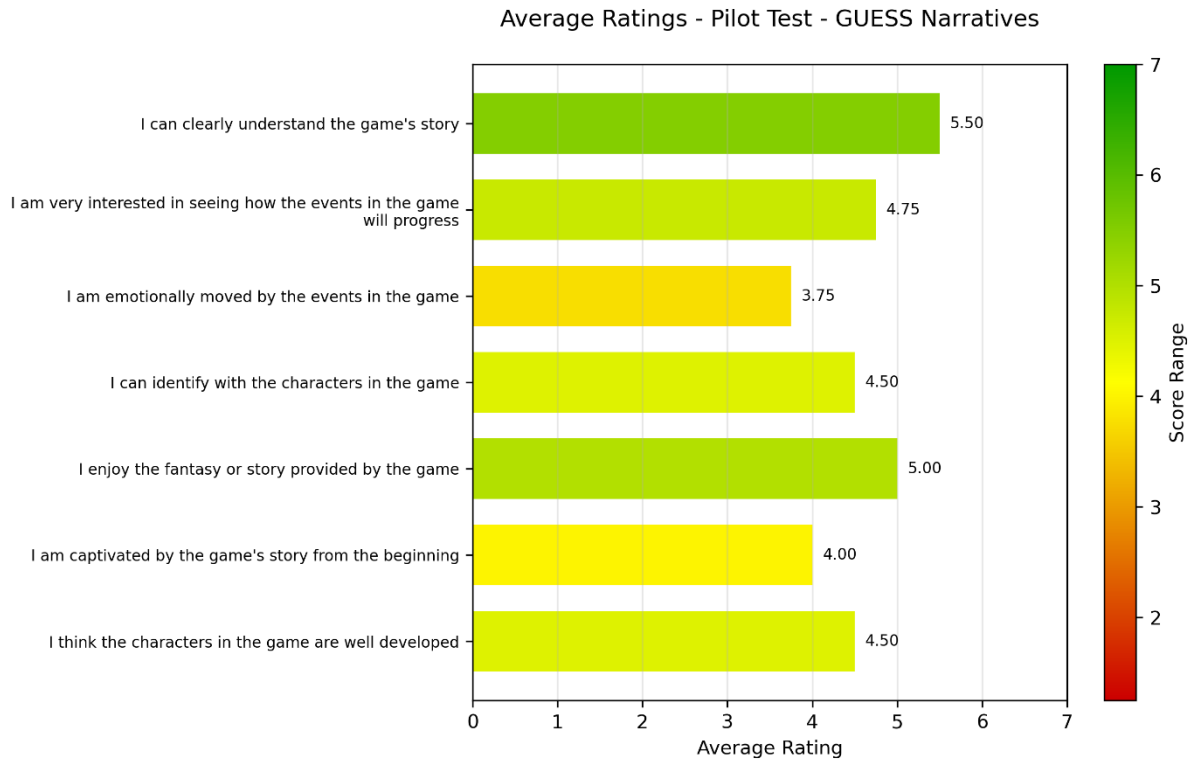
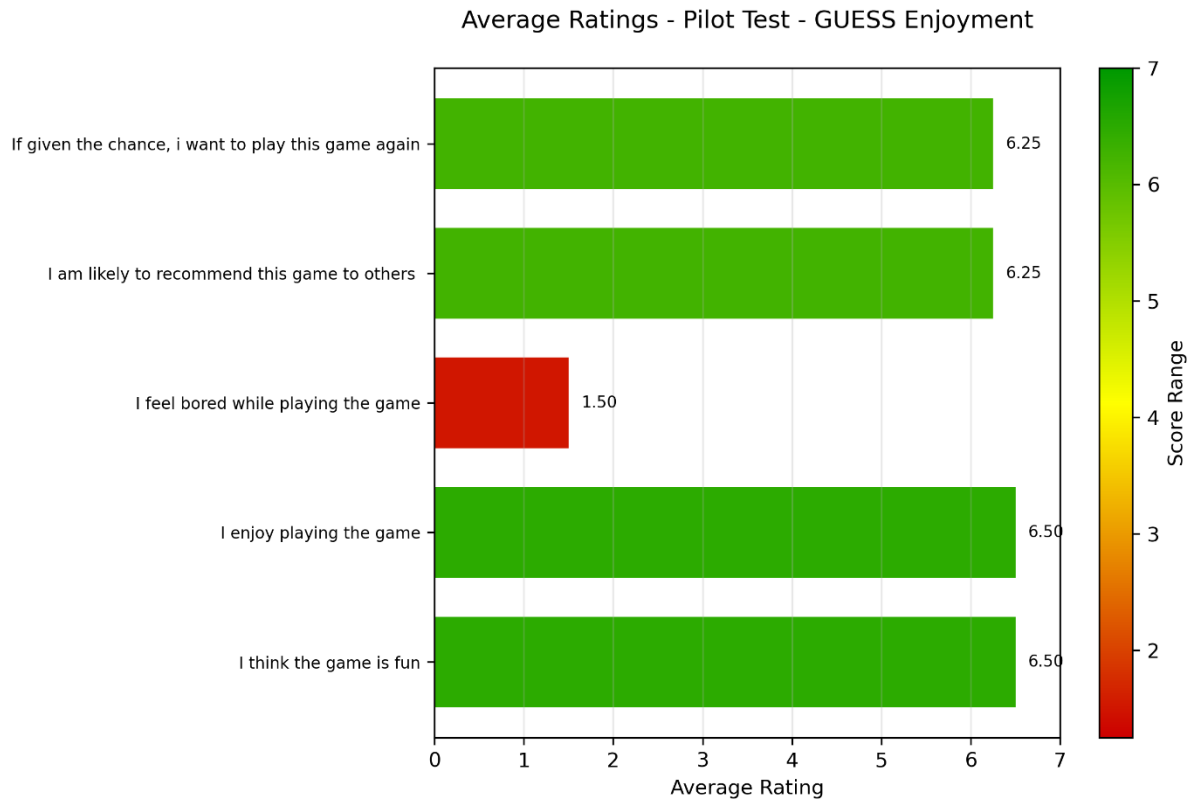


Figure 90 Pilot Test GUESS Narratives Average Ratings



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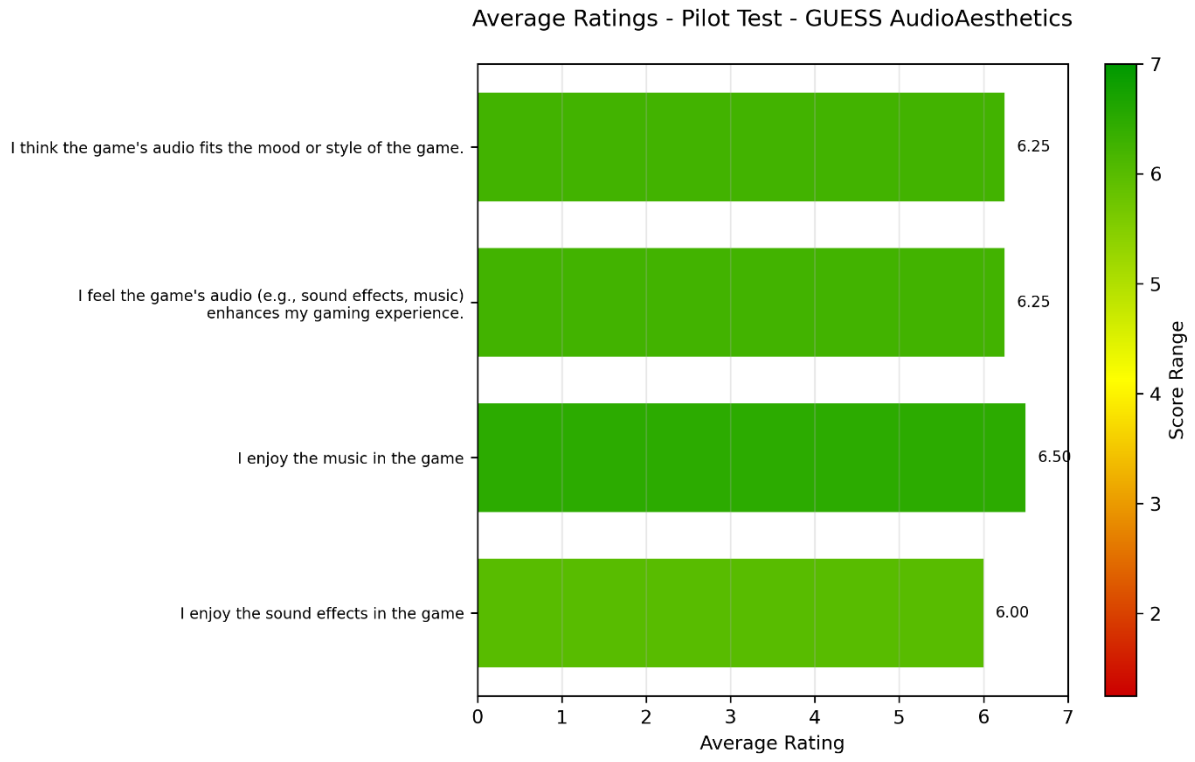

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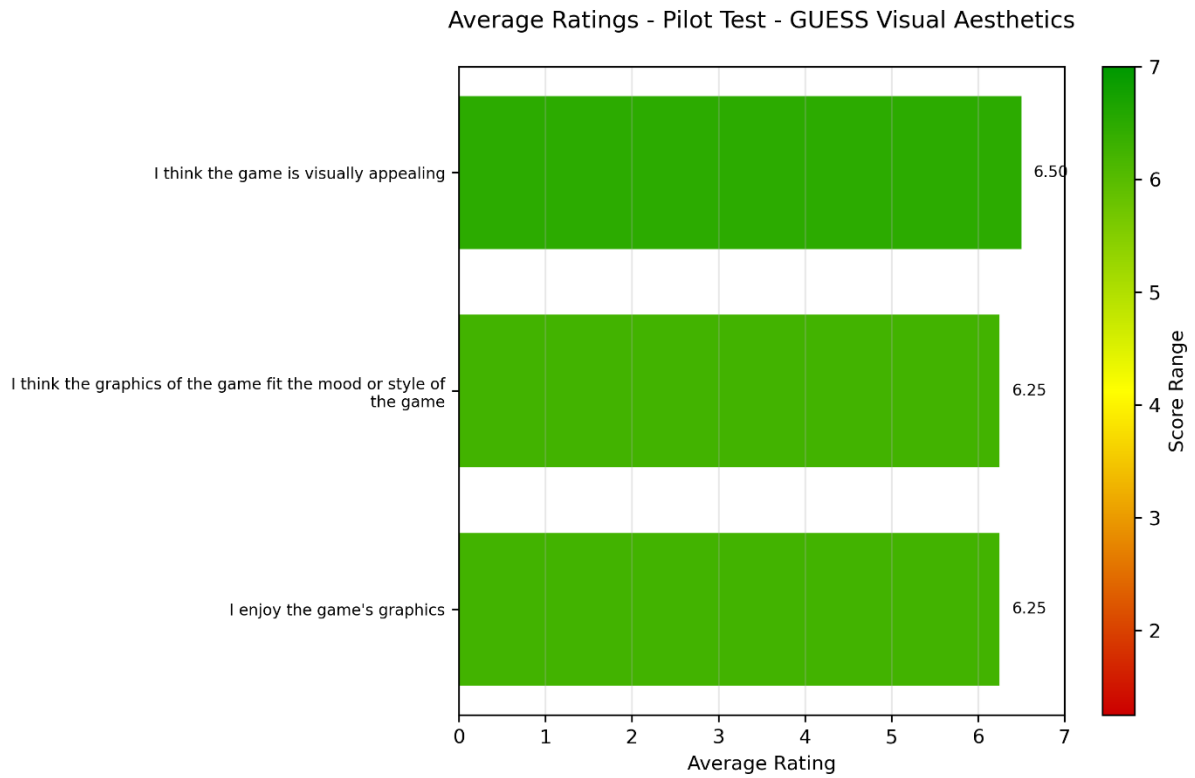

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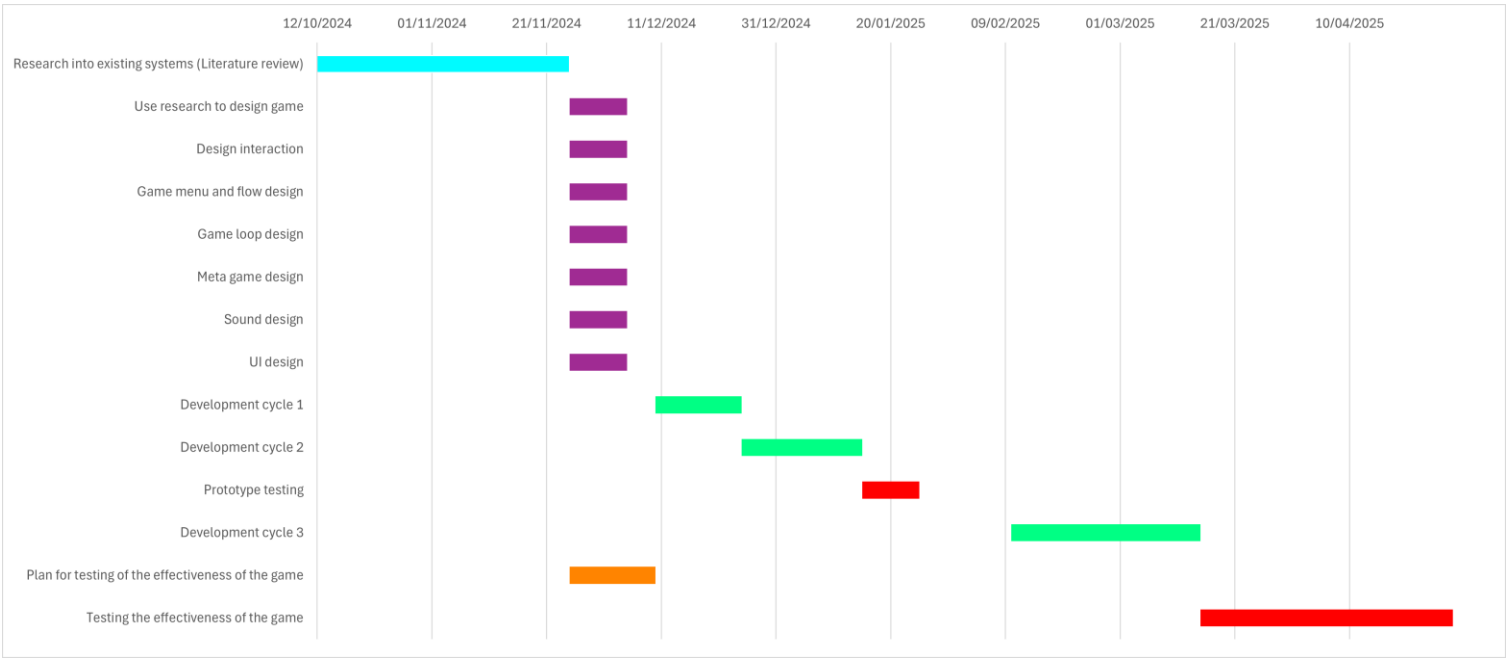

Figure 94 Project Plan Gannt Chart