School of Computer Science and Engineering

SCSE22-0595

COGNITIVE FUNCTION IMPROVEMENT THROUGH VIRTUAL REALITY GAME

Submitted in Partial Fulfilment of the Requirements for the Degree of Bachelor of Computer Science by Nanyang Technological University

Done by:

Clarence Hong Shi Man

U1922950G

Project Supervisor:

Professor Shen Zhiqi

Abstract

The project is developed to design and develop a prototype Virtual Reality (VR) game that help improves one's cognitive function. Unity was adopted as the game engine and C# was used for the programming language. The game is made up of numerous minigames that are divided into multiple categories, such as Memory and Processing. As cognitive function is separated into many types, each category is aimed at improving that specific type of cognitive function.

Research has shown that computerized games intended for cognitive training have positive results and an increase in an individual's cognitive function. The target audience of this game is mainly older adults, aged 50 and above, however people of any age can benefit from cognitive training as well.

Acknowledgement

Table of Contents

List of Figures

List of Tables

1. Introduction

1.1 Background

Cognitive functions allow an individual to think, learn, reason, remember and many more [1]. It is described as the ability to carry out day to day activities, as well as performing simple to complicated tasks. Some examples of cognitive functions include memory, attention, logical reasoning, and visual processing. Generally, humans are known to have high capabilities of cognitive functioning, especially during adolescence.

However, these important abilities of the brain are hard to maintain and deteriorates over time due to aging. It is common for the majority to assume that cognitive declination starts around the middle of adulthood, but studies have shown that declination actually starts early, as young as 18 years old [2].

A well-known issue of cognitive degeneration is dementia. Dementia is not a disease, but a general term for the severe loss of cognitive functions, to the point of disrupting an individual's basic activities such as eating and drinking. According to the United Nations prognosis, there will be a 129% rise in the amount of people with dementia, from 25.5 million in the year 2000 to 63 million in the year 2030, and a 318% increase to 114 million later in the year 2050 [3].

In addition, dementia does not only affect the individual, but also their loved ones. When an individual loses their necessary cognitive functions, their family and friends will have to spend more time to tend to their needs. They will also be required to learn to accommodate to these new conditions. Therefore, there is a need to reduce or slow down the imminent declination.

A promising study have shown that computerized games may help with the improvement of an individual's cognitive functions. Individuals with early to mid-stages of dementia showed positive results after playing computerized games intended for cognitive improvement [4]. Thus, 'Brainworks' is a Virtual Reality cognitive training game that aims to mitigate the cognitive declination of mainly older adults, but also other people of all ages.

1.2   Objectives

The main objective of the project is to design and develop 'Brainworks', a prototype Virtual Reality game, that is able to effectively train an individual's cognitive function.

Presently, there are countless amount of cognitive training games available on the market. However, in terms of Virtual Reality cognitive training games, there are little to none currently.

The goal of the game is to be one of the pioneers in the Virtual Reality cognitive training field, while differentiating the game from usual non-Virtual Reality games by taking advantage of the interactivity provided by Virtual Reality, potentially increasing the effectiveness of the cognitive training.

1.3   Scopes

The project is divided into 3 main components:

1) Market Analysis
2) System Design
3) Implementation

1.3.1 Market Analysis

It is necessary to research and examine cognitive training games not only on the Virtual Reality platform but also from all other platforms such as android and web-based applications. Analyzing what other cognitive training games offer allows the game to be implemented with core features of cognitive training, while also understanding how different platforms utilize different controls to make their game unique. This will be further elaborated in Chapter 4, Market Analysis.

1.3.2 System Design

The game is required to be developed and optimized for the following platform(s):

- Meta Quest 2

As the Virtual Reality field in general is still in its infancy, there are no standardizations amongst different manufacturers. Since each manufacturer has their own standards on their respective hardware, such as different controllers with different inputs,

optimization on all Virtual Reality headset will be unpractical given the project duration and project resources. Thus, the game will be developed and optimized for the Meta Quest 2 headset due to its popularity and standalone structure [5].

1.3.3 Implementation

The game is required to provide the following key functionalities:

- Free Play Mode: An open room with a menu panel where all the minigames can be played in free play

- Challenge Mode: On the menu panel where the player can select a minigame and start a challenge

- Tutorial Mode: On the menu panel where the player can select a minigame and start a tutorial

- Leaderboard: On the menu panel where the player can view the high scores of each minigame

2. Project Overview

2.1   Resources

2.1.1 Hardware

Table 1 lists the hardware used:

Hardware	Function	Reason
Personal Computer	Workstation	The minimum requirement for Meta Quest Link is a GTX 1060 6GB, thus a mid-performance computer is required
Meta Quest 2	Headset	Virtual Reality headset used for testing

Table 1:Hardware resources used

2.1.2 Software

Table 2 lists the frameworks and libraries used:

Technology	Function	Reason
Unity Editor	Game Engine	Popular cross-platform game engine with large database of assets
Microsoft Visual Studios	IDE	Integrated development environment used to create C# scripts to be used in unity
GitHub	Version Control	Source control to track and manage code changes, serving as a safety net with an online copy of the source code

Table 2: Software resources used

2.2   Schedule

The project schedule is separated into 5 main components:

1) Project Planning – Information and requirements are gathered, this includes researching on the hardware and software resources needed
2) System Requirements Specification – Define system requirements
3) Game Implementation – Minigames are developed individually, then integrated as a full game during User Interface development
4) Testing – Separate testing for each component as well as the full game
5) Documentation – Reports that are required to be submitted during the project

ID	Name	Start Date	End Date	Duration
1	▼ Project Planning	Aug 08, 2022	Aug 19, 2022	10 days
2	Information Gathering	Aug 08, 2022	Aug 16, 2022	7 days
3	Requirement Elicitation	Aug 17, 2022	Aug 19, 2022	3 days
4	▼ Software Requirement Specification	Aug 22, 2022	Sep 09, 2022	15 days
5	Functional Requirements	Aug 22, 2022	Aug 26, 2022	5 days
6	Non-functional Requirements	Aug 29, 2022	Sep 02, 2022	5 days
7	Use Case Modelling	Sep 05, 2022	Sep 09, 2022	5 days
8	▼ Game Implementation	Sep 12, 2022	Feb 03, 2023	105 days
9	Minigame 1 Development	Sep 12, 2022	Sep 30, 2022	15 days
10	Minigame 2 Development	Oct 03, 2022	Oct 21, 2022	15 days
11	Minigame 3 Development	Oct 24, 2022	Nov 11, 2022	15 days
12	Minigame 4 Development	Nov 14, 2022	Dec 02, 2022	15 days
13	User Interface Development	Dec 05, 2022	Dec 23, 2022	15 days
14	Database Development	Dec 26, 2022	Jan 13, 2023	15 days
15	System Optimization	Jan 16, 2023	Feb 03, 2023	15 days
16	▼ Testing	Feb 06, 2023	Feb 17, 2023	10 days
17	Unit Testing	Feb 06, 2023	Feb 10, 2023	5 days
18	System Testing	Feb 13, 2023	Feb 17, 2023	5 days
19	▼ Documentation	Aug 08, 2022	Mar 17, 2023	160 days
20	Project Plan	Aug 08, 2022	Aug 19, 2022	10 days
21	Interim Report	Jan 03, 2023	Jan 23, 2023	15 days
22	Final Report	Feb 06, 2023	Mar 17, 2023	30 days

Figure 1: Project Schedule

2.3 Report Format

Chapter	Title	Description
1	Introduction	Introduce the background of cognitive functions and the project objectives and scopes
2	Project Overview	Overview of the project, the different project resources required and project schedule
3	Literature Review	Discuss the existing solutions for addressing cognitive degeneration
4	Technical Research	Research done to cover the technical aspects of the project
5	Market Analysis	Analysis done on the cognitive games available on the market to understand impacts of different platforms
6	System Specification	Specifications required of the project written in detail
7	System Design	Designs and models used to construct the project before implementation
8	Implementation	Describe the methodologies and ideas behind each component of the game
9	Evaluation	Analysis done on the different metrics to evaluate the effectiveness of the game
10	Conclusion	Conclude the project and its potential impact
11	Future Works	Discuss possible future improvements that could increase the benefits the project brings

Table 3: Report format

3. Literature Review

Currently, there is no cure for cognitive degeneration or similar illnesses such as dementia. However, there are a few treatments to manage it [6].

<u>Medications</u>

A common medication used to treat cognitive degeneration and similar illnesses is cholinesterase inhibitors. These medications boost the chemicals in the brain that are involved with memory and logical processing. However, there are side effects like any other medication that affect the brain's chemicals. Some side effects include but not limited to diarrhoea, nausea and vomiting.

<u>Therapies</u>

Another treatment method for cognitive degeneration and similar illnesses is therapies. Therapies are usually used as an initial method of treatment since it does not involve drugs. Some therapy includes, occupational therapy to help prevent accidents and changing the environment to make it safer.

<u>Mental activities</u>

The simplest method that is free and effective for treating cognitive degeneration and similar illnesses is mental activities. Mental activities have not only been proven to reduce cognitive degeneration but also reduce the risk of getting dementia. Mental activities are easily accessible by anyone in this day and age. An example would be downloading a chess game on their mobile phones and playing it. The goal of this project is created to fit this treatment method, by reducing cognitive degeneration as well as reducing the risk of similar illnesses through cognitive training using a cognitive game.

4. Technical Research

There are many available game engines for Virtual Reality that exist now that are free. Therefore, it is necessary to research and understand the differences in the game engines before choosing 1 to be used during implementation. The 2 most well-known game engines that will be considered below are Unreal Engine and Unity.

4.1 Unreal Engine

Figure 2: Unreal Engine Logo

Unreal Engine owned by Epic Games is one of the most commonly used and prominent game engines. Some of the most popular games such as Fortnite, Tomb Raider and Kingdom Hearts uses Unreal Engine. Unreal Engine is able to provide one of the best graphics and gameplay compared to the other game engines.

After some research, Unreal Engine has a rather steep learning curve as compared to Unity. There are a good amount of help resources available online for Unreal Engine, it is still much lesser compared to Unity. Even though Unreal Engine is able to provide a lot of tools and customizability to create a unique gameplay experience, it requires a lot of skill and experience to develop that gameplay.

Due to the skill and experience required, or the time taken to learn and achieve that skill and experience, to use Unreal Engine to achieve its fullest potential, Unreal Engine does not seem suitable for this project. The project is a small-scale prototype game that is required to be developed under a year which other game engines will

achieve a better result. Unreal Engine seems to be better suited for large-scale games that provides an extremely unique player experience.

4.2   Unity

Figure 3: Unity Logo

Unity, another well known game engine was considered. Pokemon Go, Beat Saber and Among Us are some of the popular game examples made using the Unity Game Engine. Unity definitely does not seem to match the graphical capabilities of Unreal Engine but the amount of support provided is much more than Unreal Engine as stated above.

Unity Learn, a place where multiple tutorials and supports are posted on has a great tutorial, Create with VR [7]. Create with VR is a tutorial for beginners that just started with the Virtual Reality game development. This informational tutorial goes through the core functions of the Virtual Reality game development through step-by-step videos.
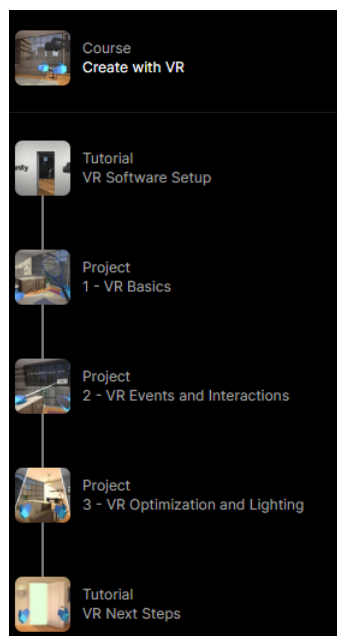
Figure 4: Screenshot of Create with VR

Since the skill and experience required to start with Unity is much lesser than Unreal Engine, Unity was chosen as the game engine for the project. Unity fits the project of developing a small-scale prototype game that is required to be developed under a year. Additionally, the vast amount of help resources available on the internet allows Unity to develop a working prototype with decent graphics and good gameplay.

5. Market Analysis

In order to understand the difference between the cognitive training games and their unique features, a review of the existing games is required. A game from each platform will be downloaded and reviewed upon so as to learn how they used various controls of each platform.

5.1 Virtuleap

Virtuleap [8] is a Virtual Reality game that aims to address cognitive disorders and illness. The game help increase attention levels by combining neuroscience and virtual reality. There are many minigames separated into different categories such as memory, attention and problem solving.

Figure 5: Screenshot of Virtuleap

After playing a few workouts provided in Virtuleap, the performance summary of Virtuleap is its most unique feature. The performance summary showcases the players performance as compared to their best performance at the end of each minigame. This is important as it allows the player to know whether if they are improving as well as allow them to know what are their weaknesses. This will be a feature that will be implemented in the project and improved on by providing comparisons to other players to further motivate the player to improve more.

5.2 Brain Dots

Brain Dots [9] is a mobile game that aims to train the logical processing of the cognitive function. The main goal of Brain Dots is to find the shortest and most efficient way to bring two balls together. It has a puzzle game with multiple stages that are increasing in difficulty.

*Figure 6: Screenshot of Brain Dots*

After trying a few stages of Brain Dots, the simplicity of Brain Dots is its most unique feature. By making the game surprisingly simple yet somewhat challenging, it allows the players to be engaged to the game for long periods of time. Simplicity is definitely an important point that is required by the project, especially since the project is targeted at older adults.

5.3 Lumosity

Lumosity [10] is an online web-based game that aims to train core cognitive abilities. Similar to Virtuleap, minigames are separated into different categories such as, speed, flexibility, problem solving, etc. Each category has multiple minigames as well, and every day they will provide 3 games from different categories to play. However, access to other minigames is locked behind a paywall.
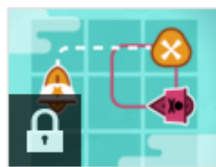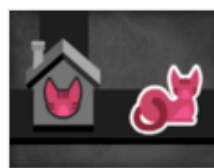
Figure 7: Screenshot of Lumosity

After trying the few games that were available for free on Luminosity, the different categories of games that Lumosity provide seems to be its most unique feature. As compared to the other games, Lumosity seems to provide a more effective targeted training method for each specific cognitive function. This is a good feature to be implemented in a cognitive game which will be followed upon by the project.

6. System Specification

6.1   Functional Requirements

Functional requirements refer to the core features that the game must be capable to execute.

5.1.1 Free Play Mode

- The menu panel must be able to be interacted by the player
- The game must exit when the player selects quit game from the menu
- The minigames must start in free play mode when the player interacts with their respective buttons

5.1.2 Challenge Mode

- The minigame must start in challenge mode when the player selects the respective game from the challenge menu
- The amount of time left and the player's current high score must be displayed during the challenge
- The minigame must exit whenever the player selects quit at any point during the challenge
- The summary panel must be displayed and the challenge must stop when the challenge timer expires
- The player's current score and high score must be displayed on the summary panel

5.1.3 Tutorial Mode

- The minigame must start in tutorial mode when the player selects the respective game from the tutorial menu
- The specific steps on how each minigame is played must be displayed clearly to the player
- The minigame must exit whenever the player selects quit at any point during the tutorial

5.1.4 Leaderboard

- The leaderboard must be displayed when the player selects the respective minigame from the leaderboard menu
- The top 10 high scores of the respective minigame must be displayed on the leaderboard

- The player's high score and position on the leaderboard of the respective minigame must be displayed

5.2 Non-functional Requirements

Non-functional requirements refer to the quality attributes that the game should perform.

5.2.1 User Interface

- The user interface components must be consistent throughout
- The fonts for readable texts must be consistent throughout
- The colour scheme must be consistent throughout
- The user interface must be clear, concise and consistent
- The text readable contents must follow the natural reading order

5.2.2 Software Quality Attributes

- The application must be able to operate smoothly on the Meta Quest 2
- The design of the game must be modular, low coupling and high cohesion
- The upgradability and upkeeping of the game must be easy and simple

5.2.3 Performance

- The time taken to load and open the game must be within 10 seconds
- The time taken for the minigames to load must be within 5 seconds
- The time taken to respond to player's input must be within 3 seconds

7. System Design

7.1   Use Case Diagram

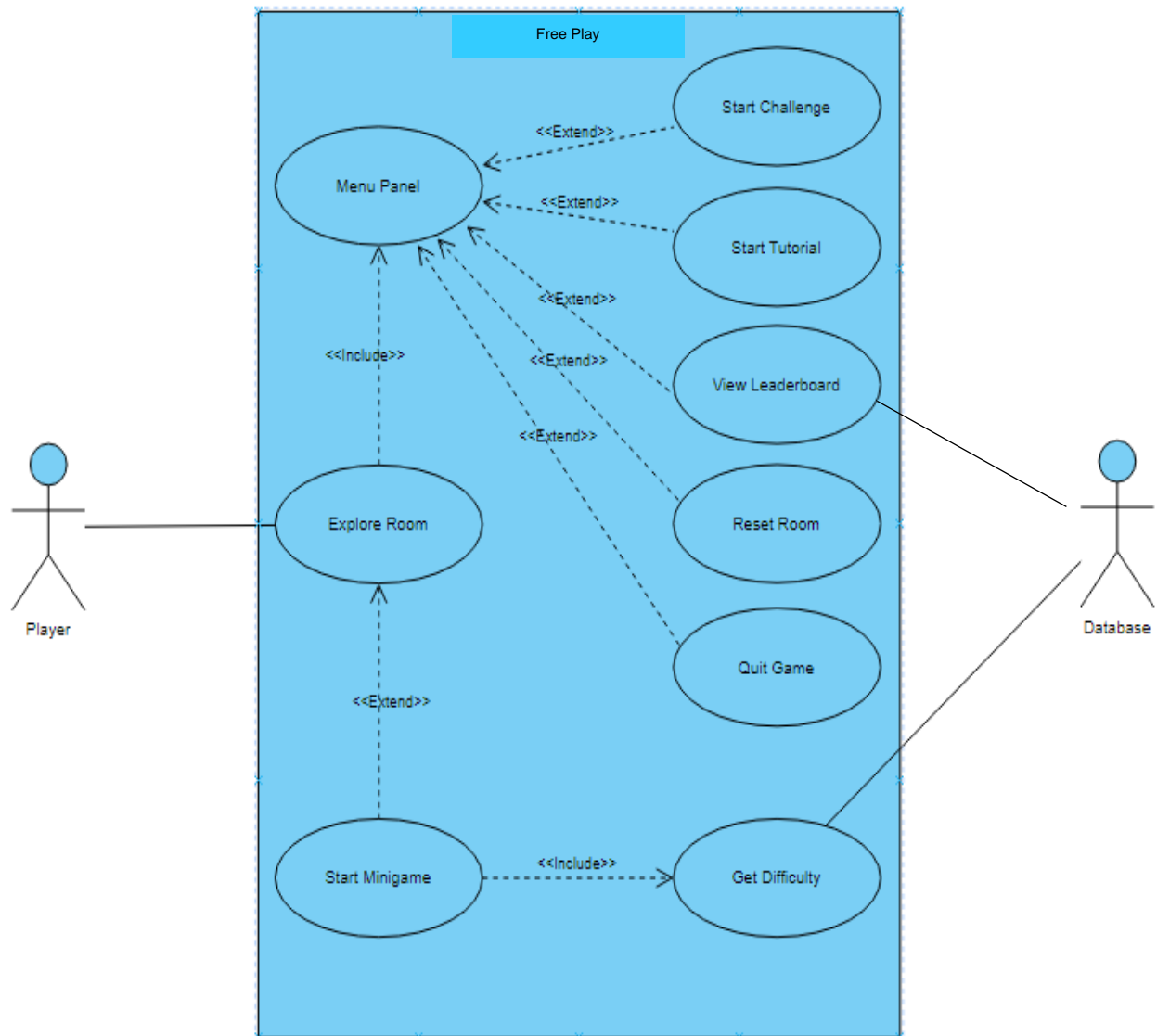Use case diagram refers to the graphical representation of the possible interactions between the user and the system.
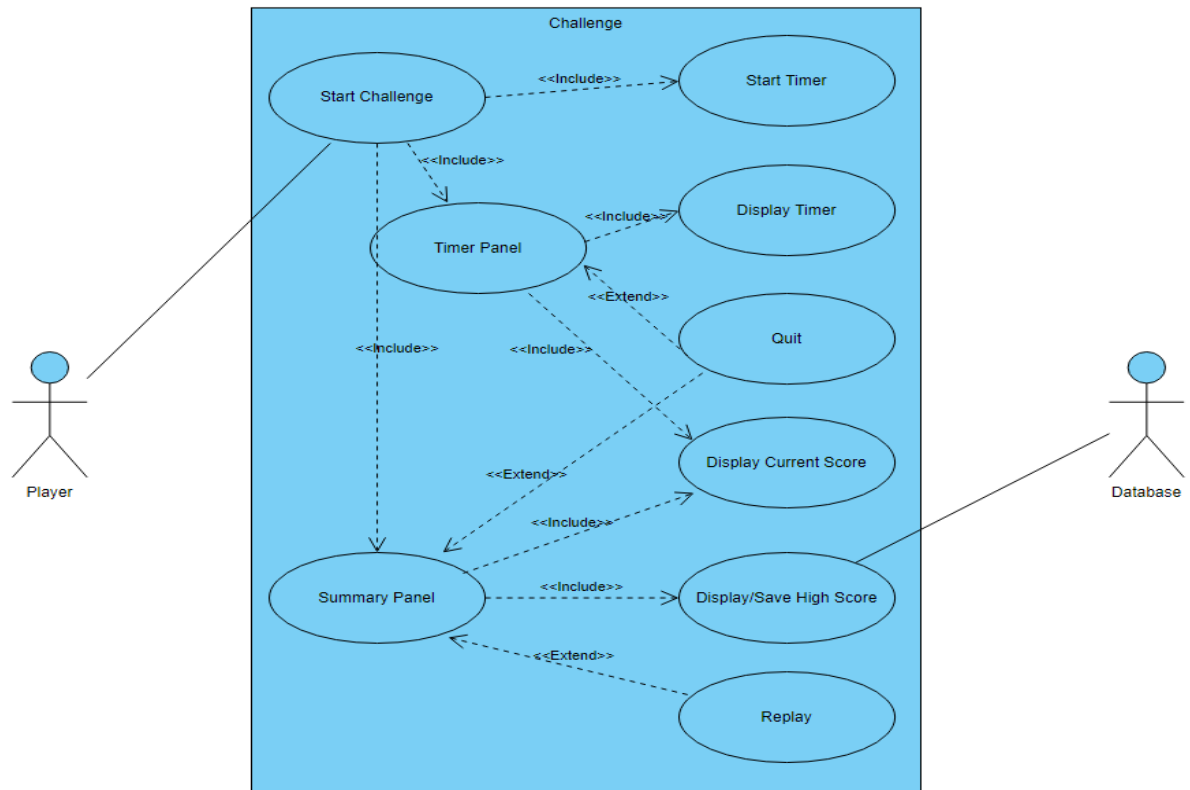

Figure 8: Free Play Use Case Diagram

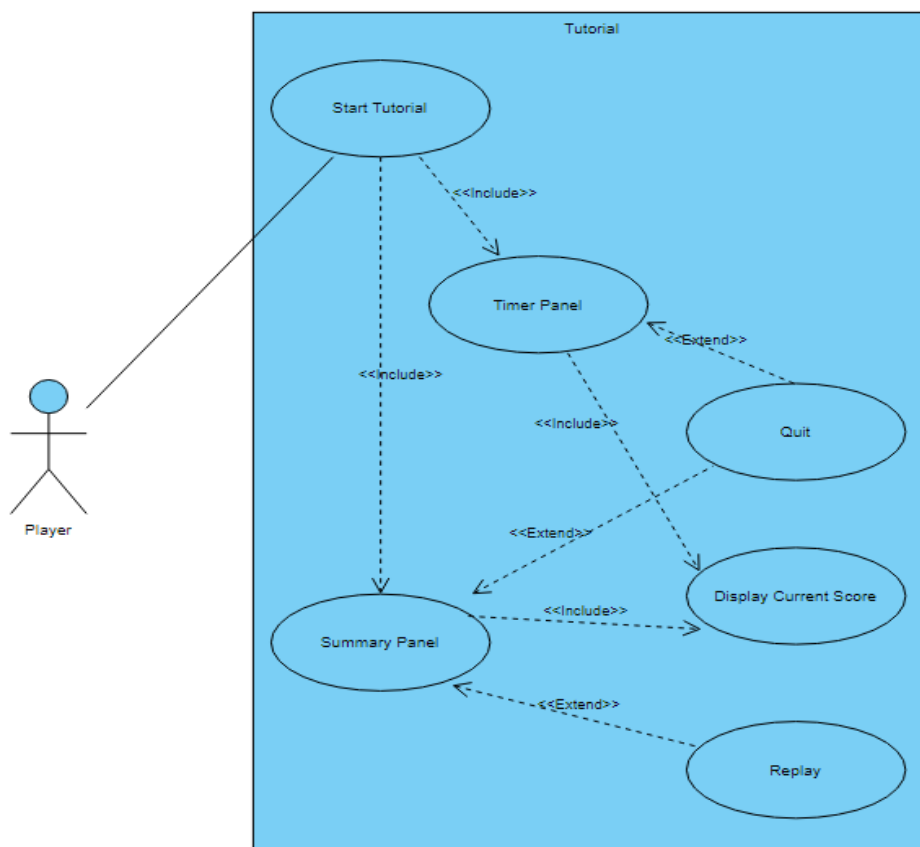*Figure 9: Challenge Use Case Diagram*

Figure 10: Tutorial Use Case Diagram

7.2   Use Case Description

Use case description refers to the detailed written representation of the possible interactions between the user and the system.

Use Case ID:	1		
Use Case Name:	Explore Map		
Created By:	Clarence Hong	Last Updated By:	Clarence Hong
Date Created:	05/09/2022	Date Last Updated:	05/09/2022

Actors:	Player
Description:	Player is able to move around and explore the room
Preconditions:	1) Player must have launched the game
Postconditions:	1) The game's camera position will move according to the input given
Normal Flow:	1) Player inputs movement by moving around in the Virtual Reality headset, teleporting using the trigger button or snap turning by turning the joystick left, right or down 2) The game's camera will move to the corresponding position in the free play room based on the respective inputs given 3) Player interacts with the minigames button to start a minigame
Alternative Flows:	A.1) Player interacts with the menu panel A.2) Player clicks on any button on the menu button
Exceptions:	E.1) Player teleports to an object or wall E.2) The game will detect that it is not a teleportable position, highlighting the teleport ray red and remaining stationary

Includes:	-
Priority:	Very High
Frequency of Use:	Very High
Special Requirements:	-
Assumptions:	-

Use Case ID:	2		
Use Case Name:	Start Minigame		
Created By:	Clarence Hong	Last Updated By:	Clarence Hong
Date Created:	05/09/2022	Date Last Updated:	05/09/2022

Actors:	Player
Description:	Player starts a minigame in free play mode
Preconditions:	1) Player must be in the free play room
Postconditions:	1) The respective minigame that the player interacted with starts
Normal Flow:	1) Player presses a minigame's button 2) The game retrieves the respective minigame last known difficulty that the player has reached 3) The game starts the respective minigame with the corresponding difficulty retrieved
Alternative Flows:	A.1) Player leaves the minigame area
Exceptions:	-
Includes:	-
Priority:	High
Frequency of Use:	High
Special Requirements:	-
Assumptions:	-

Use Case ID:	3		
Use Case Name:	Reset Room		
Created By:	Clarence Hong	Last Updated By:	Clarence Hong
Date Created:	05/09/2022	Date Last Updated:	05/09/2022

Actors:	Player
Description:	Player chooses to reset room
Preconditions:	1) Player must be in the free play room
Postconditions:	1) The free play room resets back to the default
Normal Flow:	1) Player clicks on 'Reset Room' on the menu panel in the free play room 2) The game unloads all game objects in the scene 3) The game reloads the free play room scene 4) The game loads all game objects in their default state in the free play room
Alternative Flows:	-
Exceptions:	-
Includes:	-
Priority:	Medium
Frequency of Use:	Medium
Special Requirements:	-
Assumptions:	-

Use Case ID:	4		
Use Case Name:	View Leaderboard		
Created By:	Clarence Hong	Last Updated By:	Clarence Hong
Date Created:	05/09/2022	Date Last Updated:	05/09/2022

Actors:	Player
Description:	Player chooses view leaderboard
Preconditions:	1) Player must be in the free play room
Postconditions:	1) The leaderboard is loaded successfully
Normal Flow:	1) Player clicks on 'View Leaderboard' on the menu panel in the free play room 2) The game retrieves the top 10 high scores from the database 3) The game retrieves the player's high score and position from the database 4) The game displays the top 10 high scores in descending order on the menu panel 5) The game displays the player's high score and position in the menu panel
Alternative Flows:	A.1) Player clicks on 'Back' on the leaderboard panel A.2) The game closes the leaderboard panel A.3) The game opens the menu panel
Exceptions:	-
Includes:	-
Priority:	Low
Frequency of Use:	Low

Special Requirements:	-
Assumptions:	-

Use Case ID:	5
Use Case Name:	Quit Game

Created By:	Clarence Hong	Last Updated By:	Clarence Hong
Date Created:	05/09/2022	Date Last Updated:	05/09/2022

Actors:	Player
Description:	Player chooses to quit the game
Preconditions:	1) Player must be in the free play room
Postconditions:	1) The game application is closed successfully
Normal Flow:	1) Player clicks on 'Quit Game' on the menu panel in the free play room 2) The game unloads all game objects in the scene 3) The game exits
Alternative Flows:	-
Exceptions:	-
Includes:	-
Priority:	Low
Frequency of Use:	Low
Special Requirements:	-
Assumptions:	-
Use Case ID:	5

Use Case ID:	6		
Use Case Name:	Start Challenge		
Created By:	Clarence Hong	Last Updated By:	Clarence Hong
Date Created:	05/09/2022	Date Last Updated:	05/09/2022

Actors:	Player
Description:	Player starts a minigame in challenge mode
Preconditions:	1) Player must be in the free play room
Postconditions:	1) The minigame that the player chose is loaded in challenge mode
Normal Flow:	1) Player clicks on challenge then chooses a minigame on the menu panel 2) The game loads the respective minigame 3) Player presses the minigame's button to start the challenge
Alternative Flows:	A.1) Player quits the minigame
Exceptions:	-
Includes:	-
Priority:	High
Frequency of Use:	High
Special Requirements:	-
Assumptions:	-

Use Case ID:	7		
Use Case Name:	Start Tutorial		
Created By:	Clarence Hong	Last Updated By:	Clarence Hong
Date Created:	05/09/2022	Date Last Updated:	05/09/2022

Actors:	Player
Description:	Player starts a minigame in tutorial mode
Preconditions:	1) Player must be in the free play room
Postconditions:	1) The minigame that the player chose is loaded in tutorial mode
Normal Flow:	1) Player clicks on tutorial then chooses a minigame on the menu panel 2) The game loads the respective minigame 3) Player presses the minigame's button to start the tutorial
Alternative Flows:	A.1) Player quits the minigame
Exceptions:	-
Includes:	-
Priority:	High
Frequency of Use:	High
Special Requirements:	-
Assumptions:	-

7.3   State Machine Diagram

State machine diagram refers to the graphical representation of how each entity responds to the different user events that results in one state changing to another.
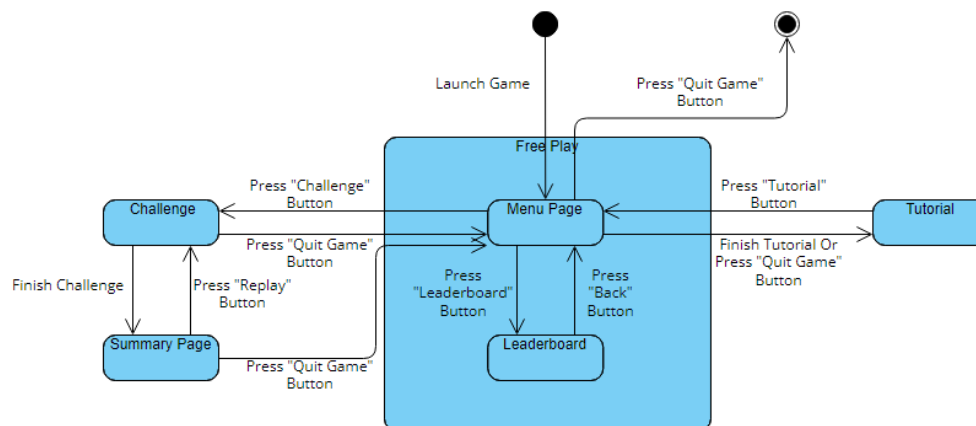

Figure 11: State Machine Diagram

The menu page in free play will be the first state when the game is launched.

Menu Page

In menu page, the user can choose to:

- Start a minigame in free play by interacting with the minigame
- Start a challenge by pressing the 'Challenge' button
- Start the tutorial by pressing the 'Tutorial' button
- View the leaderboard by pressing the 'Leaderboard' button
- Quit the game by pressing the 'Quit Game' button

Leaderboard

In leaderboard, the user will be able to view the top 10 users in each minigame, as well as their own high scores. The user can press the 'Back' button to return to the menu page.

Free Play

In free play, the minigames started by the user will continue from the previous difficulty that the user stopped at. The user may choose to leave the minigame at any point of time to interact with the menu page.

Tutorial

In tutorial, the user will be guided through the minigames step-by-step. The user can choose to leave the tutorial at any point of time by pressing the 'Quit' button. There will be a confirmation page before quitting the minigame.

Challenge

In challenge, the user will have 60 seconds to play through the minigame. A score will be given for every right answer the user provide. The user can choose to leave the challenge at any point of time by pressing the 'Quit' button. There will be a confirmation page before quitting the minigame. When the time expires, a summary page will pop up.

Summary Page

In summary page, the user can see the leaderboard of the respective minigame they are in, as well as their own high score and current score. The user can choose to replay the minigame by pressing the 'Replay' button or leave the minigame by pressing the 'Quit' button.

8. Implementation

8.1   Minigames
Hat Game

Figure 12: Screenshot of Hat Game

Hat Game is a minigame under the 'Memory' category. The goal of Hat Game is to memorize the location of the hats randomly spawned by the game, as well as which hat it is. The player then proceeds to place the hats on the correct hooks, before pressing the button to check their answer. Hat Game will slowly increase in difficulty by increasing the number of hats spawned based on the number of correct answers the player has given so far.

Hat Game also allows the player to have a small workout. Since the hooks has some verticality, it requires the player to lift their arms to reach the hooks that are slightly higher. Hat Game associates the action of placing objects on hooks, such as hats, coats or hanging clothes on a hook. This allows the player who are mainly older adults to have a minor physical work out as well as help reduce cognitive declination with an action associated with daily life.

```
for (int i = 0; i < score + 1 && i < sockets.Length; i++)
{
    while (used[index])
        index = Random.Range(0, sockets.Length);

    used[index] = true;
    Instantiate(prefabs[Random.Range(0, prefabs.Length)], sockets[index].transform.position, sockets[index].transform.rotation);
}
```

Figure 13: Screenshot of Spawning Script

The script shown in Figure 13 shows how the randomized spawning works, as well as the scaling difficulty based on the current score. This script is made such that other minigames can use the same exact script with different number of XR Sockets and Game Objects without any issues.

Book Game

Figure 14: Screenshot of Book Game

Similarly, Book Game is a minigame under the 'Memory' category. The goal of Book Game is to memorize the type of books randomly spawned by the game. The player then proceeds to place the correct books in order, before pressing the button to check their answer. Book Game will slowly increase in difficulty by increasing the number of books spawned based on the number of correct answers the player has given so far.

The focus of Book Game is more towards memory as compared to Hat Game. The number of hooks Hat Game have are only 9, but for Book Game, there are 20. This is a more difficulty 'Memory' game but less of a workout, allowing the players to choose between the minigames based on what they currently require. Book Game associates the action of placing books on a shelf, allowing the older adults to associate the game with day-to-day actions.

Word Game

Figure 15: Screenshot of Word Game

Word Game is a minigame under the 'Processing' category. The goal of Word Game is to read the given prompt and process it by swapping the colour and the word around. An example would be 'Yellow' (Red coloured) means that the player needs to find a Yellow (word of the prompt) Tomato (colour of the prompt). The player will then have to place the item near their mouth. Word Game will slowly increase in difficulty by increasing the number of prompts in the pool of possible prompts based on the number of correct answers the player has given so far.

The aim of Word Game is towards the processing capabilities of the cognitive function. By creating a simple yet confusing word play, it forces the player to swap over the word and colour association in their head as fast as they can. Additionally, having the

players put their answer near their mouth associates the action with eating, allowing the older adults to associate the game with an important daily activity.

Fruit Game

Figure 16: Screenshot of Fruit Game

Similarly, Fruit Game is a minigame under the 'Processing' category. The goal of Fruit Game is to read the given prompt and process it by swapping the colour and the word around as well, but the word is a fruit instead. An example would be 'Lemon' (Red coloured) means that the player needs to find a Yellow (colour of the fruit of the prompt) Tomato (colour of the prompt). The player will then have to place the item near their mouth. Fruit Game will slowly increase in difficulty by increasing the number of prompts in the pool of possible prompts based on the number of correct answers the player has given so far.

The aim of Fruit Game is towards the processing capabilities of the cognitive function. Even though Fruit Game has the same mechanics as Word Game, having a fruit instead of a colour as the prompt requires more processing by the player. For Word Game, it is a single association for the word, where given 'Yellow', the player finds a yellow fruit. But for Fruit Game, there is an extra association for the word, where given 'Lemon', they need to process 'Lemon' to 'Yellow', before finding a yellow fruit. This

increases the required processing by Fruit Game by a notch as compared to Word Game.

8.2   Game Modes

Free Play Mode

Free Play Mode is the default game mode. When the player launches the game, they will be loaded into Free Play Mode. The aim of Free Play Mode is to allow the players to take their time and practice the different minigames. Since there is not time limit, players will not be pressured and can leisurely train their cognitive function. Free Play Mode also allow the players to push their limits, trying to achieve the highest difficulty per minigame.

Tutorial Mode

Tutorial Mode can be loaded from the menu panel under 'Tutorial'. The aim of Tutorial Mode is to allow the player to learn the minigames by providing them with step-by-step instructions. Tutorial Mode will include the instructions of each step that the player is required to do, as well as providing them with floating arrows pointing at what they need to interact with. For the Fruit and Word Game, the answers are given on a panel to allow the players to familiarize with the minigame. Similar to Free Play Mode, there is no time limit as well and the player can try the tutorial as long as they like.
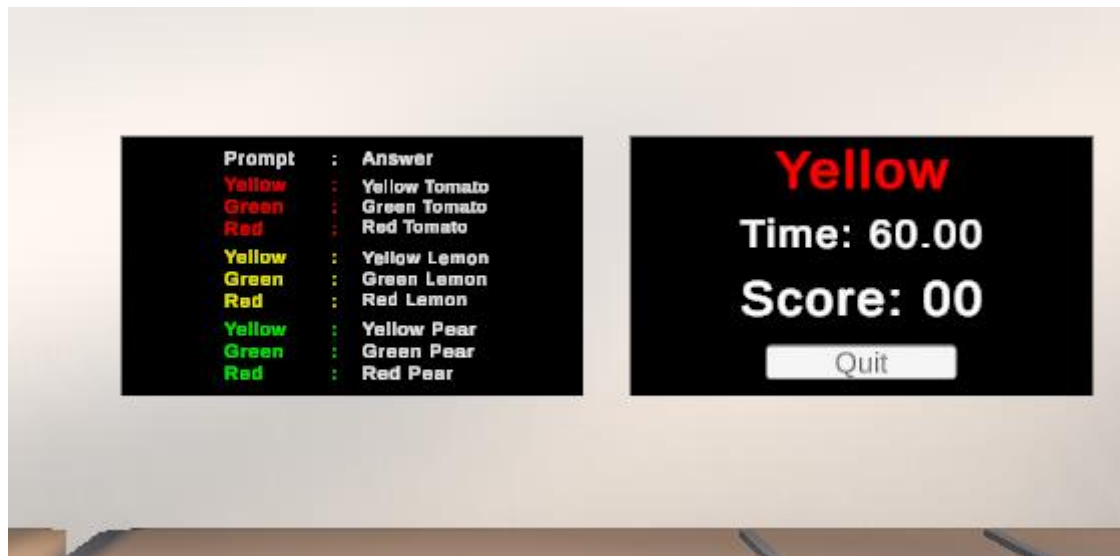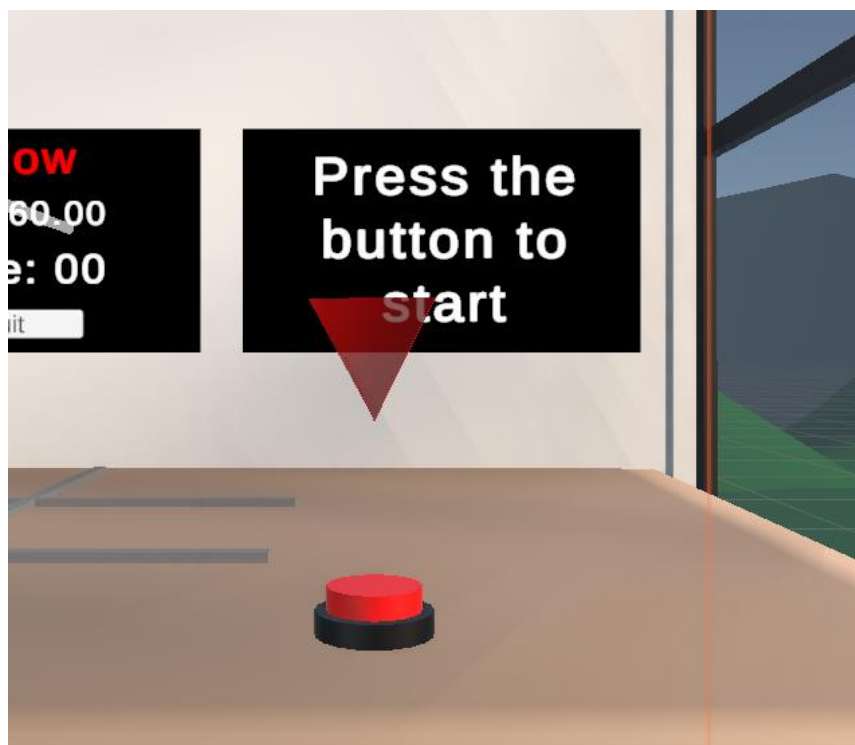
Figure 18:Screenshot of Answers for Word Game

Figure 17:Screenshot of Floating Arrow in Tutorial

Challenge Mode

Challenge Mode can be loaded from the menu panel under 'Challenge. The aim of Challenge Mode is to allow the player to train their cognitive function by requiring them to get as many correct answers as possible given a time limit of 1 minute. Challenge Mode promotes friendly competition to motivate players to push their own limits and

achieve higher scores. At the end of Challenge Mode, a summary panel will be shown, displaying the player's current score, high score and the minigame's leaderboard.

*Figure 19: Screenshot of Challenge Mode Timer and Score*

Figure 20: Screenshot of Summary Panel

8.3 Extras
Hand Physics

The most important unique feature of Virtual Reality compared to traditional platform is the interactivity. Therefore, having realistic hand physics is important in achieving high levels of interactivity. Firstly, cylinder colliders are used for every section of the hands, including each finger and its respective sections.
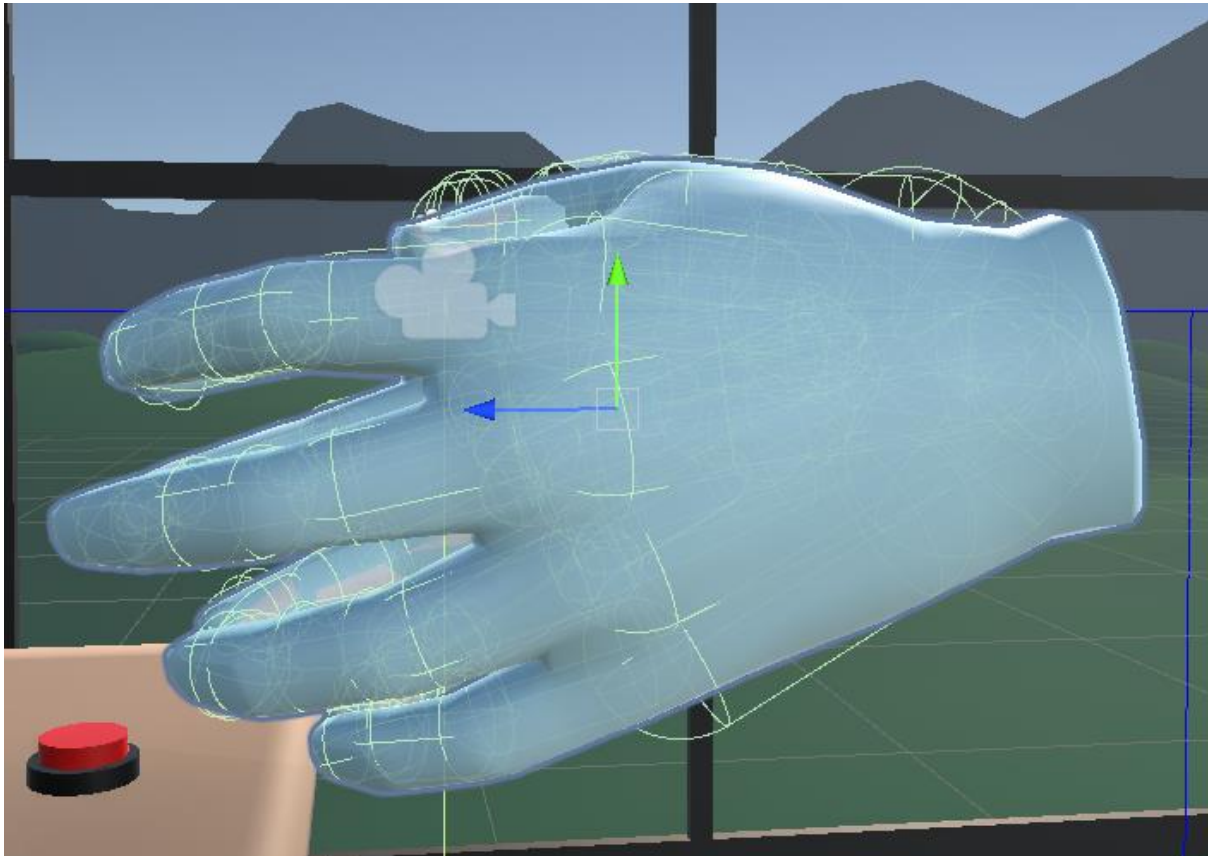
Figure 21:Screenshot of Hand Colliders

A non-physics hand (translucent blue) was added for clarity. If the physics hand (opaque white) is stuck on a object or surface, the player can still see their hands on the non-physics hand. This reduces the confusion that the player might have by allowing the player to know where their exact hand positions are even if the physics hand are stuck.
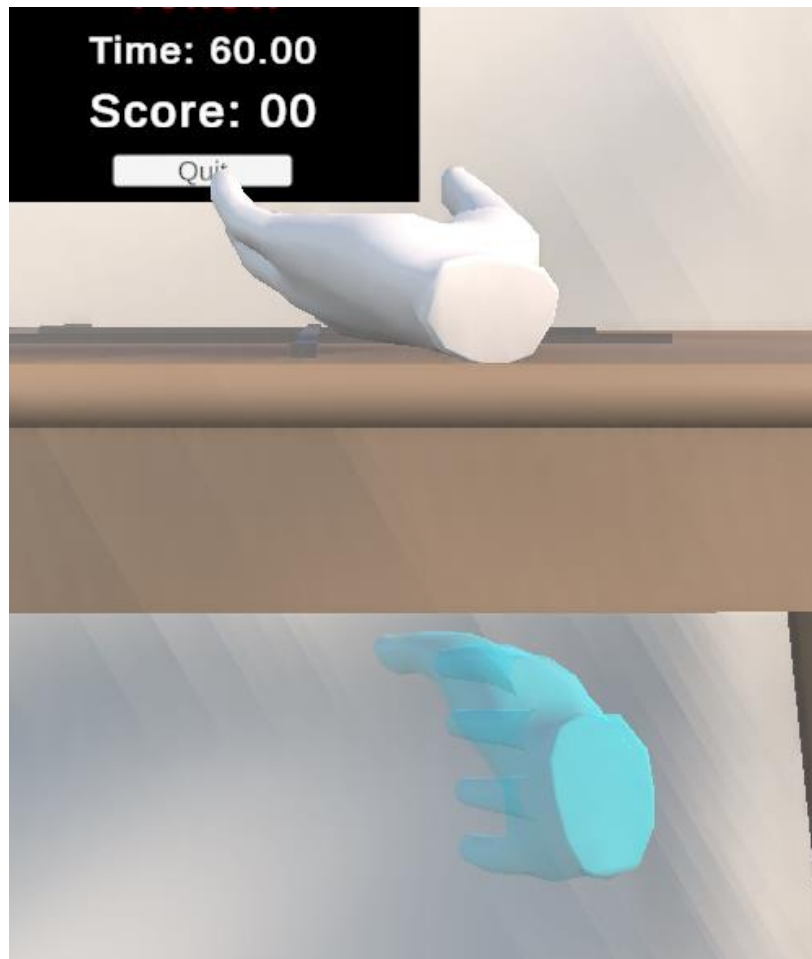
Figure 22: Screenshot of Physics and Non-Physics Hands

The following script is used to combine the physics and non-physics hand into a model. This only displays the non-physics hand when the physics hand gets stuck.

```
void Update()
{
    float distance = Vector3.Distance(transform.position, controller.position);

    if (distance > showNonPhysicalHandDistance)
        nonPhysicalHand.enabled = true;
    else
        nonPhysicalHand.enabled = false;
}

// Unity Message | 0 references
void FixedUpdate()
{
    rigidBody.velocity = (controller.position - transform.position) / Time.fixedDeltaTime;
    Quaternion rotationDiff = controller.rotation * Quaternion.Inverse(transform.rotation);
    rotationDiff.ToAngleAxis(out float angleDegree, out Vector3 rotationAxis);
    Vector3 rotationDiffDegree = angleDegree * rotationAxis;
    if(rotationDiffDegree.x == Mathf.Infinity || rotationDiffDegree.x == Mathf.NegativeInfinity)
        rigidBody.angularVelocity = new Vector3(0, 0, 0);
    else
        rigidBody.angularVelocity = (rotationDiffDegree * Mathf.Deg2Rad / Time.fixedDeltaTime);
}
```

Figure 23: Screenshot of Hand Physics Script

Locomotion

Teleportation locomotion and snap turning is used since this helps reduce the possibility of the player getting motion sickness. To implement teleportation locomotion, the XR interactor is used with a 'Floor' layer mask to prevent he player from teleporting on any other surface.
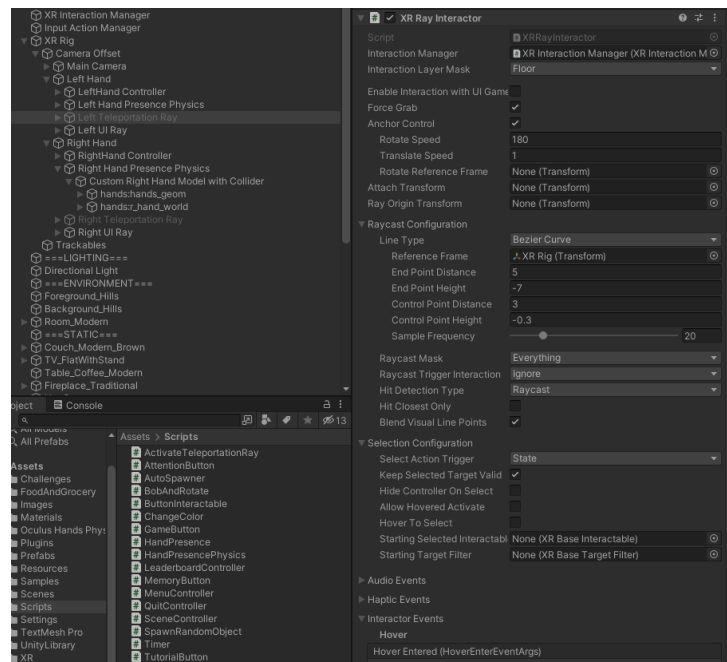

Figure 24: Screenshot of Teleportation Locomotion

To make the controls feel more polished and look better, the teleportation line is only shown when the player wants to teleport. Otherwise the teleportation line should be deactivated.

```
void Update()
{
    leftTeleportation.SetActive(leftActivate.action.ReadValue<Vector2>() != Vector2.zero);
    rightTeleportation.SetActive(rightActivate.action.ReadValue<Vector2>() != Vector2.zero);
}
```

Figure 25: Screenshot of Teleportation Script

Database

Since many online databases require some form of payment, SQLite was used. Even though SQLite is a local database, it is used in this project as a form of a simulated online database. This can easily be imported to an online SQL Server if required for a database to store the leaderboard data.

43

9. Evaluations

In order to evaluate the effectiveness of the game on cognitive function, evaluations must be done. 4 players, who are older adults aged 50 – 70, will be training their cognitive function through the game, each player will play 1 minigame 5 times a day, for 7 days. Player 1 (P1) will be playing Hat Game, Player 2 (P2) will be playing Book Game, Player 3 (P3) will be playing Word Game, Player 4 (P4) will be playing Fruit Game. The following 3 different metrics will then be used to assess the effectiveness of the game.

9.1   Game Statistics

Game statistics refers to the current scores and high scores of the players in game. Using game statistics is a quick and simple way to judge whether if the players are improving in the minigames through practice.
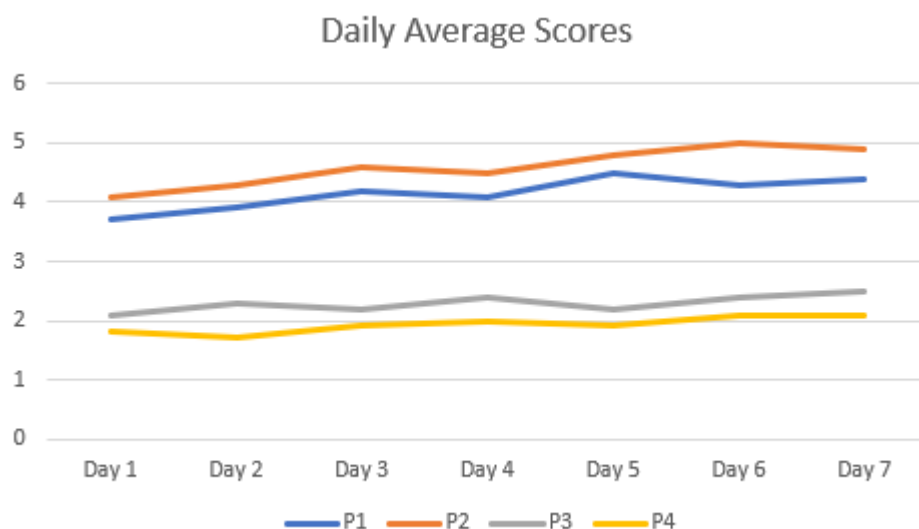

Figure 26: Graph of Daily Average Scores

Based on the Daily Average Scores as shown in Figure 26, there is a very slight but noticeable upward trend on the scores achieved by the players. This shows promising results as it seems that the game is effective in improving the cognitive function of the players.

9.2 Test Statistics

After each daily practice, the players will be given an external test. P1 and P2 who played the minigames under the 'Memory' category will be using the Number Memory Test by Human Benchmark [11] to assess how effective the game was at improving their memory. P3 and P4 who played the minigames under the 'Processing' category will be using the Click The Colour by b3ta [12] to assess how effective the game was at improving their processing speed.
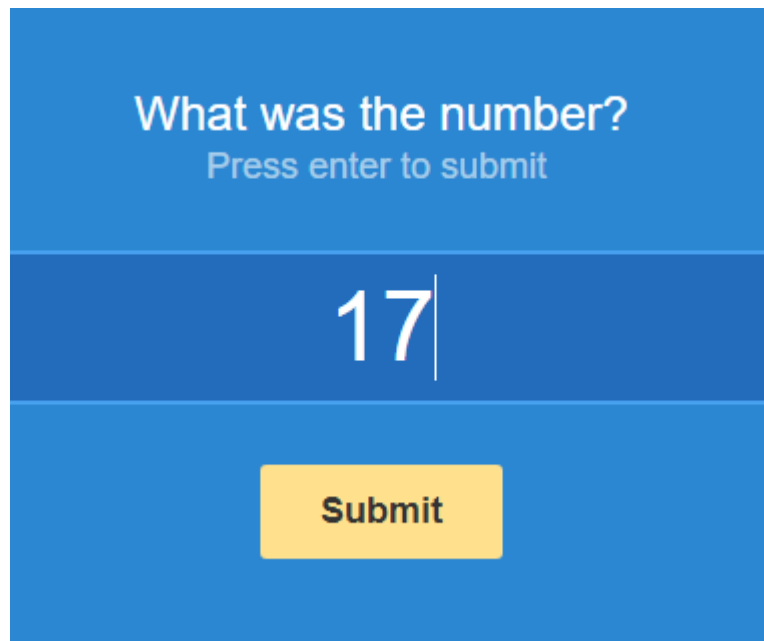

Figure 27: Screenshot of Number Memory Test

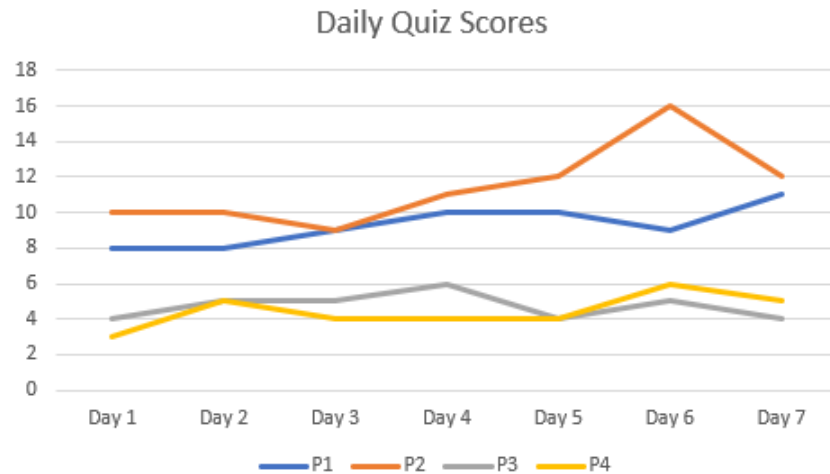*Figure 28: Screenshot of Click The Colour*

Figure 29: Graph of Daily Quiz Scores

Based on the Daily Quiz Scores as shown in Figure 29, there is a slightly significant upward trend on the scores achieved by the 'Memory' category players. However, for the 'Processing' category, P3 did not have any noticeable improvements while P4 have a minor improvement. This shows that even though the players are improving their scores in game, it does not necessarily mean improvement out of game. This is expected as players tend to improve faster in cognitive games as compared to out of game due to repetition memory in game. The slight improvements out of game do still show that the game can be effective in training cognitive function if given more time.

9.3   Player Feedback

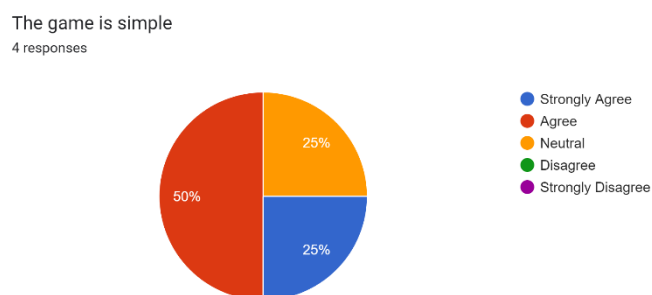Lastly, all 4 players are given a questionnaire at the end of Day 7 to ask for their feedbacks.

Figure 30: Response of Q1
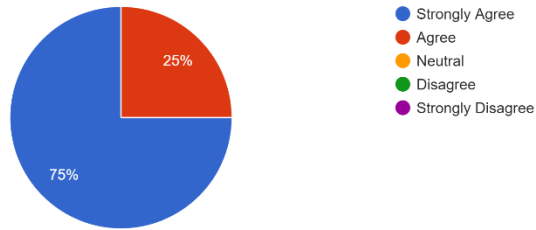
The game is fun
4 responses

Strongly Agree
Agree
Neutral
Disagree
Strongly Disagree

25%

75%

Figure 31: Response of Q2

The game is challenging
4 responses

Strongly Agree
Agree
Neutral
Disagree
Strongly Disagree

75%

25%
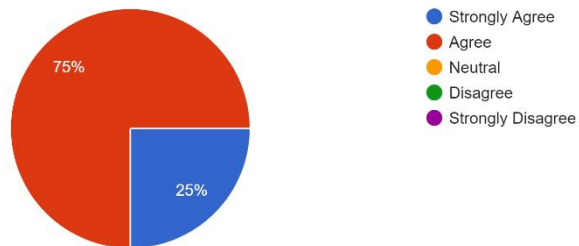
Figure 32: Response of Q3

The game helped you with your day-to-day activities
4 responses

Strongly Agree
Agree
Neutral
Disagree
Strongly Disagree

25%

50%

25%
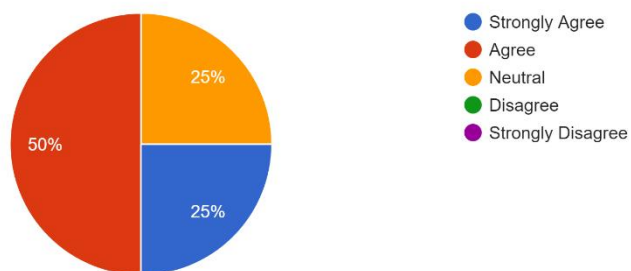
Figure 33: Response of Q4

The leaderboard motivates you to play better
4 responses

- ● Strongly Agree
- ● Agree
- ● Neutral
- ● Disagree
- ● Strongly Disagree
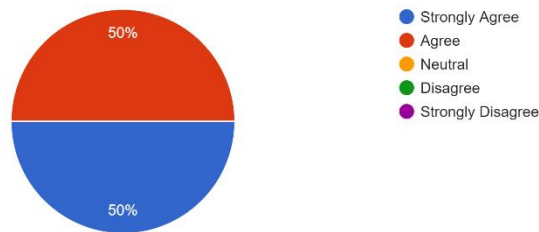
Figure 34: Response of Q5

Based on the results of the questionnaire shown in Figure 30 -34, the game seems to be well received by the players. On average, majority of the players felt that the minigames were simple yet challenging and engaging. The friendly competition introduced by the leaderboard also motivated them to do better. Majority of the players felt that the game helped them in their day-to-day activities due to the improvement in their cognitive function.

10. Conclusion

In conclusion, Brainworks, a successful Virtual Reality game prototype was designed and developed. The target players of the game are mainly older adults (50 years old and above). The game aims to improve their cognitive function and to reduce cognitive declination, which ultimately helps them to live better lives.

In order to achieve this objective, multiple minigames of different categories were implemented. Each category of minigames is designed to target a specific cognitive function. The minigames are created in a way such that they mimic real life activities, such as placing books on a shelf, taking hats off a hook and eating. This takes advantage of the interactivity provided in a Virtual Reality environment where other platforms are not able to. The interactivity may also help older adults work out a little as well as form stronger association to these actions which may help with reducing cognitive declination. An example would be the action of placing books on the bookshelf in Book Game.

Lastly, through the use of SQLite database, which is used to simulate an online database, a leaderboard was also added. This promotes healthy competition between the players which will motivate them to try harder in the minigames, allowing them to reach higher difficulties, thus increasing the effectiveness of the game at improving cognitive function.

11. Future Works

There is much more room for enhancements that would improve the effectiveness of the game on cognitive function.

More Minigames

At the moment, the game only consists of a total of 4 minigames in 2 categories as a prototype. More categories of games can be implemented such as, 'Reasoning' and 'Attention'. This will provide a more holistic cognitive training for the player.

Graphical Improvements

Currently, the game uses royalty free assets found online. The graphics of such free assets are usually simple and not as realistic. With an budget or time, more realistic assets could be bought or designed. This will improve the player experience and provide a more immersive experience. Better graphical hardware could help with the immersion as well as by increasing the quality of the graphics and the frames per second.

Artificial Intelligence

An artificial intelligence (AI) can be added where the players' scores and progression are processed, and then generate a personal curated training program. The AI can help find the weaknesses and strengths of the players' cognitive function and recommend different minigames with adjusted difficulty to help increase the effectiveness of the cognitive training.

References

[1]   G. G. Fisher, M. Chacon, and D. S. Chaffee, 'Chapter 2 - Theories of Cognitive Aging and Work', Work Across the Lifespan, B. B. Baltes, C. W. Rudolph, and H. Zacher, Publisher: Academic Press, 2019, Pages 17–45.

[2]   T. A. Salthouse, 'When does age-related cognitive decline begin?', Neurobiology of Aging, Volume 30, Issue 4, Pages 507–514, 2009.

[3]   A. Wimo, B. Winblad, H. Aguero-Torres, and E. von Strauss, 'The Magnitude of Dementia Occurrence in the World', Alzheimer Disease & Associated Disorders, Volume 17, Issue 2, 2003.

[4]   E. Tam, A. Au, D. Fok, and T. Kwok, 'EFFECT OF USING COMPUTERIZED GAMES FOR EPOSIDIC MEMORY TRAINING IN ELDERY'.

[5]   T. Alsop, "VR headset unit sales by device worldwide 2020," Statista, 10-Feb-2022. [Online]. Available: https://www.statista.com/statistics/987701/vr-unit-sales-brand/. [Accessed: 03-Sep-2022].

[6]   Dementia SingHealth. Available at: https://www.singhealth.com.sg/patient-care/conditions-treatments/dementia (Accessed: March 18, 2023).

[7]   Create with VR Unity Learn. Available at: https://learn.unity.com/course/create-with-vr?uv=2020.3 (Accessed: January 19, 2023).

[8]   Improve brain health with VR, Virtuleap. Available at: https://virtuleap.com/ (Accessed: March 11, 2023).

[9]   Brain dots - apps on Google Play. Google. Available at: https://play.google.com/store/apps/details?id=jp.co.translimit.braindots&hl=en (Accessed: March 11, 2023).

[10]   Games designed to Train your brain Lumosity. Available at: https://www.lumosity.com/app/v4/games (Accessed: January 19, 2023).

[11] Human benchmark. Available at: https://humanbenchmark.com/tests/number-memory (Accessed: March 17, 2023).

[12] Click the colour (and not the word) by Rob Manuel [b3ta : We love the web]. Available at: https://www2.b3ta.com/clickthecolour/ (Accessed: March 17, 2023).