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VIRTUAL REALITY APPLICATION FOR VESTIBULAR STIMULATION

Dissertation submitted to the Department of Electrical and Computer Engineering of the Faculty of Sciences and Technology of the University of Coimbra in partial fulfilment of the requirements for the Master of Science Degree oriented by Professor Paulo Jorge Carvalho Menezes, PhD.

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Virtual Reality Application For Vestibular Stimulation

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Abstract

One of the primary reasons that elderly individuals visit a doctor is due to symptoms of vertigo and feelings of imbalance. These symptoms can often be attributed to issues within the vestibular system, which plays a crucial role in maintaining posture and balance throughout the body. To help alleviate these symptoms and improve balance, vestibular rehabilitation therapy is often recommended. Vestibular rehabilitation typically involves a series of exercises that are designed to improve the function of the vestibular system. These exercises may include head movements, eye movements, balance training, and coordination exercises. The exercises are tailored to the individual's specific needs and are designed to gradually improve their balance, reduce their symptoms, and increase their overall quality of life. To be truly effective, these exercises should be done multiple times daily, over a period of several months. Since these exercises are designed to be repetitive challenges to vestibular and balance systems, patients will often stop doing them complaining that they are uncomfortable and monotonous. The integration of Serious Games(SGs) and Virtual Reality (VR) in vestibular rehabilitation offers a potential solution to this problem. By creating immersive and interactive environments, patients can perform the same exercises as prescribed but in a more captivating and engaging way. This dissertation proposes the development of three separate game environments, each with its own objectives and goals. All three games aim to direct the patient to perform the head, eye, and body exercises associated with vestibular therapy in a light, joyful, and purposeful way. The therapist can choose to let the patient play the games alone or take an active role in controlling the game's difficulty level and content.

Keywords: Imbalance, Vestibular Rehabilitation, Serious Games, Virtual Reality

Resumo

Uma das principais razões pelas quais os idosos consultam um médico é devido a sintomas de vertigem e sensação de desequilíbrio. Estes sintomas podem muitas vezes ser atribuídos a problemas no sistema vestibular, que desempenha um papel crucial na estabilidade e do equilíbrio de todo o corpo. Para ajudar a aliviar estes sintomas e melhorar o equilíbrio, é frequentemente recomendada uma terapia de reabilitação vestibular. A reabilitação vestibular envolve normalmente uma série de exercícios concebidos para melhorar o funcionamento do sistema vestibular. Estes exercícios podem incluir movimentos da cabeça, movimentos dos olhos, treino do equilíbrio e exercícios de coordenação. Os exercícios são adaptados às necessidades específicas de cada indivíduo e destinam-se a melhorar gradualmente o seu equilíbrio, a reduzir os seus sintomas e a aumentar a sua qualidade de vida global. Para serem verdadeiramente eficazes, estes exercícios devem ser efectuados várias vezes por dia, durante um período de até vários meses. Uma vez que estes exercícios são concebidos para desafiar repetidamente os sistema vestibular, os doentes deixam frequentemente de os fazer, queixando-se de que são desconfortáveis e monótonos. A integração dos Jogos Sérios (SG) e da Realidade Virtual (RV) na reabilitação vestibular oferece uma potencial solução para este problema. Ao criar ambientes imersivos e interactivos, os pacientes podem realizar os mesmos exercícios prescritos, mas de uma forma muito mais cativante e estimulante. Esta dissertação propõe o desenvolvimento de três ambientes de jogo distintos, cada um com os seus próprios objectivos e metas. Todos os três jogos têm como finalidade guiar o paciente para a realização dos exercícios de cabeça, olhos e corpo associados à terapia vestibular de uma forma mais leve, divertida e com propósito. O terapeuta pode optar por deixar o paciente jogar os jogos sozinho ou ter um papel ativo no controlo do nível de dificuldade e do conteúdo do jogo.

Palavras-chave: Desequilíbrio, Reabilitação Vestibular, Jogos Sérios, Realidade Virtual

"Love Yours"

J Cole

Contents

List of Acronyms

VR	Virtual Reality
SG	Serious Games
VRT	Vestibular Rehabilitation Therapy
VOR	Vestibulo-Ocular Reflex
HMD	Head-Mounted Display
BPPV	Benign Paroxysmal Positional Vertigo
VM	Vestibular Migraine
OLED	Organic Light-Emitting Diode
RPC	Remote Procedure Call
DGS	Dedicated Game Servers
COP	Center of Pressure

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1 Introduction

Dizziness, vertigo, and imbalance are not a normal part of aging, but represent the most common complaints that elderly patients bring to their physicians. It is estimated that 2.9% of patients older than 65 years and 3.8% older than 75 years will visit an internist because of dizziness [1].

Contrary to what many people think, vertigo and dizziness is not a disease but can be caused by various reasons. Among these reasons is a dysfunction of the vestibular system, which can be both in the central system, composed of the brainstem and the cerebellum, or in the peripheral system, located in the inner ear and controlled by the vestibular nerve [2].

Vestibular rehabilitation has been proposed to improve the quality of life of individuals experiencing dizzy spells and body imbalance. It is based in a program of exercises for the eyes, head, and body, involving specific physical manoeuvres [3, 4, 5].

Due to the repetitive nature of the exercises, there is a tendency to lose engagement. Besides the time factor, there is the issue that many people don't have a clinic close to their home, which forces them to drive long distances and several times a week. To promote extra enthusiasm and accessibility, gamification of the exercises that are typically recommended have started to be implemented [6].

The gamification of such exercises is often referred to as Serious Games, which are becoming increasingly popular. Even though there is currently no single definition of the concept, most researchers and developers agree that serious games are games used for purposes other than mere entertainment [7].

There has been increasing research interest in the application of virtual reality (VR) technology to rehabilitation [8, 9, 10, 11]. In contrast with traditional rehabilitation procedures, which may be tedious, resource-intensive, and costly, VR provides patients with balance disorders opportunities to engage in meaningful, intensive, enjoyable, and purposeful tasks[12, 13]. With VR the therapist has complete control over the stimulus and its consistency, the ability to vary the stimuli from simple to more complex ones, the ability to readily grade and record the patient's progress, ensuring a safe learning environment and the capacity to offer individualized

treatment[14].

1.1 Related Work

Over the past decade, there has been a notable increase in the use of serious games to improve the health of patients. This has led to the development of a variety of specialized health games, with growing scientific evidence supporting their effectiveness. These games have shown positive results in promoting exercise, aiding physical rehabilitation, providing cognitive training, and assessing different abilities. The availability of these serious games highlights their potential as valuable tools for enhancing the overall health and well-being of patients[15]. This study [16], proposes a VR-based system to motivate individuals with neck pain to perform prescribed exercises through an engaging serious game, resulting in increased interest, engagement, and motivation during the rehabilitation process.

In this study[17], reviewed a total of 42 trials with 1760 participants and found that serious games for stroke rehabilitation led to better improvements compared to conventional therapies, emphasizing the importance of adherence to neurorehabilitation principles[18]. Di Loreto and Gouaich demonstrated that affordable equipment and serious games have the potential to enable home rehabilitation, minimizing drop-out rates and facilitating long-term rehabilitation programs, even for children.

In this study [19] researchers aimed to review and summarize the current literature on the effectiveness of virtual reality-based vestibular rehabilitation, they identified a total of 382 unique articles and 6 randomized controlled trials about the topic and found that the studies reviewed were preliminary evidence to suggest the benefit of virtual reality-based vestibular rehabilitation. However, these studies were limited by their inclusion criteria, heterogeneity, comparator design, and evidence-based clinical outcomes. They concluded that further research should address these limitations. Studies on the subject date back as long as in the late 90's by Viirre [20, 21], where he discussed the use of Virtual Reality (VR) technologies in the rehabilitation of patients with vestibular disorders and found that an appropriately designed VR experience could greatly increase the rate of adaptation in these patients but that further research was necessary to determine if this method could result in persistent vestibular-ocular reflex gain improvements and reduction in symptoms and disability in patients with vestibular disorders. Later in 2002, Virre and Sitarz[22], hypothesized that by placing a vestibulopathic subject with chronic vertigo in front of a computer screen and displayed a moving scene, they could make the scene move slightly faster than what the subject eyes and balance system would be used to. By gradually increasing the speed of the scene, they believed they could help the eyes and balance system

get better at working together and reduce the symptoms of dizziness. They found that this immersive computer environments could improve vestibulo-ocular reflex(VOR) function and reduce vertigo.

Later, in 2006, a group of researchers developed a game that would be primarily controlled by using a specialized platform that measured the movement of a person's center of pressure (COP) to test if it would improve dynamic balance control and to determine whether the motivational and challenging aspects of the video games would increase a subject's desire to perform the exercises and complete the rehabilitation process. They found that the game motivated subjects to increase their practice volume and attention span during training. This in turn improved subjects' dynamic balance control[23].

M Pavlou, in 2012 [24], led a pilot study which compared the responses of sixteen patients with unilateral peripheral vestibular disorder which were randomly allocated to a VR regime incorporating exposure to a static or dynamic VR environment. M Pavlou found that exposure to a dynamic virtual reality environment should be considered as a useful adjunct to vestibular rehabilitation programs for patients with peripheral vestibular disorders.

Et al. Meldrum [25], aimed to compare the effectiveness of virtual reality–based balance exercises to conventional balance exercises during vestibular rehabilitation in patients with unilateral peripheral vestibular loss and although the results showed that virtual reality–based balance exercises performed during vestibular rehabilitation were not superior to conventional balance exercises it was concluded that such exercises may provide a much more enjoyable method of retraining balance after unilateral peripheral vestibular loss.

According to Micarelli et al.[13], using a home-based virtual reality protocol with a head-mounted display (HMD) can be a secure method for enhancing vestibular ocular reflex, postural control, and quality of life in patients with vestibular impairments. This method could prove beneficial for patients whose cognitive decline might impede rehabilitation. In their study, Park et al. [26] demonstrated that incorporating eye trackers and a head-mounted display (HMD) into a virtual reality device can effectively enhance goal-oriented attention and activate specific brain networks during vestibular rehabilitation.

1.2   Main Objectives

The main objective of using Serious Games (SGs) and virtual reality (VR) environments to promote vestibular rehabilitation is to improve the balance and overall functioning of individuals with vestibular disorders using immersive, interactive, and personalized exercises that simulate real-world situations. By leveraging VR technology, healthcare professionals can create cus-

tomized rehabilitation programs that challenge the vestibular system in a controlled and safe environment, allowing patients to gradually build up their balance and coordination skills. The use of Serious Games and VR environments also offers a more engaging and enjoyable experience for patients, leading to better adherence to their rehabilitation regimen and ultimately improving their outcomes.

The proposed system is a serious game that has set of customized interactable VR environments which will promote therapeutic exercises in a fun and engaging way. This system will have two modes: a single player mode, in which the patient can play alone without the presence of a therapist; and a co-op mode, in which the therapist has full control and access to what the patient is seeing. This system will have the following objectives:

- provide a safe and controlled space for patients to challenge their vestibular system.

- a way to do the exercises in calm and relaxing environments.

- gradually improve their ability to maintain balance.

- customizable therapeutic exercises.

1.3   Dissertation Structure

Chapter 1: The first chapter provides a comprehensive introduction to the dissertation, highlighting the related work in the field, stating the main objectives of the research, and outlining the structure of the dissertation for the reader's understanding.

Chapter 2: In this chapter, the fundamental concepts related to vestibular system disorders, therapeutic procedures, and the use of serious games for rehabilitation are explored and discussed. The chapter aims to establish a solid foundation of knowledge and understanding for the subsequent chapters.

Chapter 3: The problem statement is defined in this chapter, followed by the presentation of the proposed solution. The chapter details the description of three specific games and introduces the concept of therapist control, emphasizing how these elements contribute to the proposed application for vestibular rehabilitation therapy.

Chapter 4: This chapter focuses on the practical implementation of the proposed application. It provides an overview of the application as a whole and delves into the specific features

and functionalities of both the singleplayer and multiplayer modes. The chapter outlines the technical details of the application's development process.

Chapter 5: In this chapter, the methodology employed in the study is explained, including data collection methods and analysis techniques. The chapter then presents and discusses the results obtained from the study, specifically addressing patient engagement and therapy outcomes in relation to the implemented application.

Chapter 6: The final chapter of the dissertation summarizes the key findings and conclusions drawn from the research. It provides a concise recap of the main points discussed throughout the dissertation and offers concluding remarks, highlighting the significance of the research and suggesting potential for future work in the field.

2 Fundamentals

2.1 Vestibular System Disorders

The vestibular system is in the inner ear and is composed of two types of vestibular organs, the otolith organs, and semi-circular canals, each one detects different types of acceleration. The utricle and saccule, which are two otolith sensors, sense linear acceleration, while the anterior, posterior, and horizontal canals, which are three semicircular canals, sense rotational movements. The brain needs both signals to comprehend the various physical situations we encounter in a daily basis [27].

Disorders of the vestibular system, often give rise to the sensory illusion of rotation, vertigo, disequilibrium, or imbalance[28, 29]. In certain instances, vestibular dysfunction may result in a severe fall that is linked to significant injury and limited mobility. Falls, which are one of the primary causes of death among older people, can be a catastrophic outcome of vestibular dysfunction [30, 31, 32].
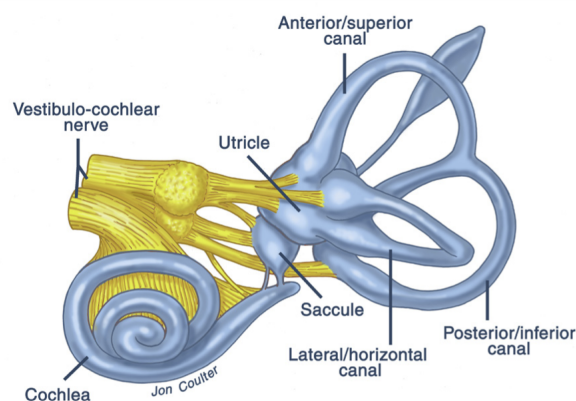
Figure 2.1: Vestibular system.

The most prevalent vestibular diagnoses encountered in the dizziness clinic include benign paroxysmal positional vertigo (BPPV), vestibular migraine and Ménière's disease[33].

BPPV is the most common vestibular disorder and may account for up to one-third of vertigo presentations to dizziness clinics[34]. According to a survey conducted on a population of 1003 individuals, the prevalence of BPPV was 2.4%. Furthermore, the 1-year prevalence of BPPV increased with age, with those aged 60 years and older experiencing it at a rate seven times higher than those aged 18-39 years[4]. BPPV may affect the posterior, horizontal, or anterior semi-circular canal, and in some cases, it may even involve more than one canal at a time. The gravity-dependent position of the semi-circular canal makes the posterior canal the most frequently affected one in BPPV cases, accounting for approximately 85 to 90% of them. As a result, when not specified otherwise, BPPV typically refers to the posterior canal form of the disorder[35].

Vestibular migraine is considered the second most common cause of vertigo and the most common cause of spontaneous episodic vertigo. The duration of attacks varies from seconds to days, usually lasting minutes to hours[2, 36]. VM is diagnosed when migraines accompany vestibular symptoms in at least half of the attacks[37].

Meniere's is another common disease associated with a vestibular disorder which affects a substantial number of patients every year worldwide. The disease is characterized by intermittent episodes of vertigo lasting from minutes to hours, with fluctuating sensorineural hearing loss, tinnitus(ringing noises in one or both ears), and aural pressure (clogging sensation of the ear)[38, 39, 40, 41].

2.2   Therapeutic Procedures

Vestibular rehabilitation therapy (VRT) is an exercise-based treatment program designed to promote vestibular adaptation and substitution. The goals of VRT are to enhance gaze stability, to enhance postural stability, reducing vertigo symptoms and improving overall ability to perform daily activities[42].

The first proposed vestibular rehabilitation therapy exercises can be linked back to the Cawthorne-Cooksey exercises, which were developed by Cawthorne and Cooksey as a treatment for labyrinth injury resulting from surgery or head injury. These exercises involve a combination of head, eye, and body movements, and have since become the standard of care for all forms of peripheral vestibular disorders due to their proven effectiveness in improving balance, reducing dizziness, and enhancing overall quality of life for patients[43, 44].

Several studies have proven that Cawthorne and Cooksey exercises were able to promote significant improvement in patients suffering from balance disorders[45, 46, 47, 48].

The Cawthorne and Cooksey exercises although revolutionary in their foresight and still in

use today, can't be applied to every patient in the same exact manner[49].

The pathophysiology of vestibular disorders is diverse, and thus, it is impractical to have a standardized vestibular rehabilitation (VR) protocol that is effective for all patients. The sensory and behavioral strategies used for recovery vary considerably among patients, rendering a standardized protocol ineffective. The process of vestibular compensation, which involves the recovery of balance control in static and dynamic conditions as well as the recovery of gaze stabilization, is unique to each patient, and is characterized by idiosyncratic differences. Therefore, it is essential to tailor VR interventions to the specific needs of each patient to optimize their recovery from vestibular loss-induced problems[50].

2.3 Serious Games for Rehabilitation

Conventional functional rehabilitation costs time, money and effort for the patients and for the medical staff. As an alternative approach, serious games have emerged to enhance performance and potentially reduce future medical costs in cognitive rehabilitation and body balance control[51].

Serious games represent a remarkable fusion of entertainment and healthcare. They are specially designed digital applications that leverage the principles of gameplay to engage patients in various therapeutic activities. By blending fun and engaging gameplay with targeted exercises, serious games are a powerful tool to support rehabilitation across a wide range of conditions, from physical injuries and disabilities to neurological disorders and cognitive impairments[52, 53].

The appeal of serious games lies in their ability to motivate and captivate patients, turning what might otherwise be perceived as monotonous or repetitive therapy into an enjoyable and immersive experience[54].

Through interactive interfaces, motion tracking technologies, and virtual environments, these games offer patients a unique way to actively participate in their recovery process. By setting goals, providing feedback, and adapting to individual progress, serious games empower patients with a sense of purpose and direction in their rehabilitation journey[55].

Serious games also extend rehabilitation beyond the clinic, allowing patients to continue their exercises at home and maintain long-term commitment to their treatment[56].

The applications of serious games in rehabilitation are incredibly diverse. They can aid in improving motor skills, balance, and coordination through virtual simulations of everyday activities or specialized exercises[57].

3 Proposal

3.1 Problem

Patients who undergo vestibular rehabilitation therapy (VRT) often find that it can be very time-consuming and require a significant commitment. Depending on the severity of the patient's condition, VRT may require multiple sessions per week for several weeks or even months. This can be challenging for patients who have busy schedules or who live far from the therapy location. Additionally, the exercises themselves can be repetitive and boring, which can make it difficult for patients to stay motivated and engaged. The lack of engagement and the frustration over the lack of immediate results leads to patients not following the recommended exercises which causes a slower recovery or even no recovery at all, which is why that giving incentive to a patient to commit to their therapy by creating more engaging and accessible alternatives is key to achieve optimal outcomes and improve the patient's quality of life.

3.2 Proposal

Our proposed solution is an application which include a set of games that all promote certain eye/head exercises that closely resemble the exercises typically prescribed in vestibular rehabilitation therapy. The games are designed so that they can be played seated or standing since exercises prescribed are to be done in both positions. The system will have single player and multiplayer capabilities, which means that the patient can play alone at home or choose to play with the assistance of a therapist who will be put in control of the difficulty of the games as well as some additional parameters to make the games more customized to each patient. The therapist can take control of a patient game from anywhere in the world which facilitates therapy both for the patient and the therapist. The application is very easy to use and includes calm ambience and music to give the patient a relaxing and safe environment to do therapy and give maximum chances of recovery.

3.2.1 Horizontal semi-circular canal stimulation

In the first game the stimulation of the horizontal(lateral) semi-circular canal is promoted by making the patient look left and right in a successive manner while attempting to catch random fish that spawn on the player sides.
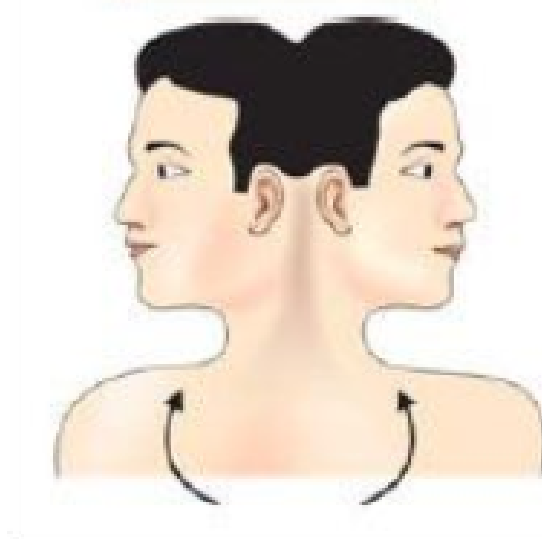
Figure 3.1: Game 1 proposed exercise.

It is called "Catch the fish" and as the name implies, involves the activity of fishing. The patient is put in the middle of the ocean in a boat and is given the challenge to catch fishes that jump out of the water around the boat using only head/eye coordination. The fishes always spawn either at the right or the left of the boat, actively making the patients have to turn their head either to the left or right respectively to try to catch any fish that is jumping out of the water.

(a) Player looking to the left   (b) Player looking forward   (c) Player looking to the right

Figure 3.2: Patient Field of View while capturing fish

This game allows the user to choose from three predefined difficulties which vary the fish speed and size.

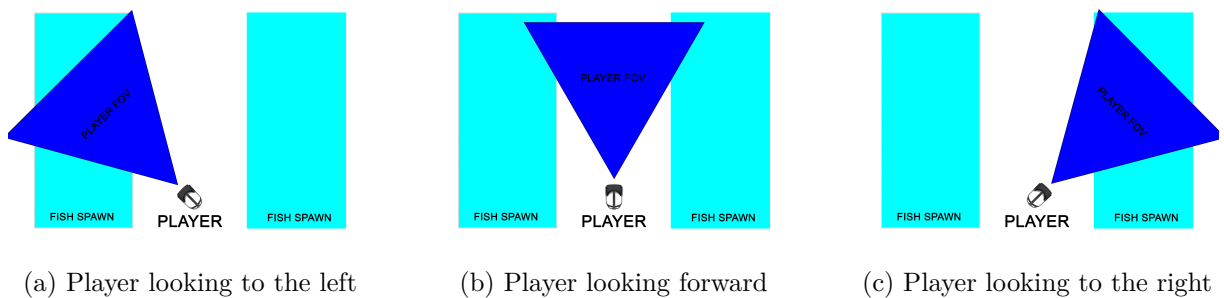### 3.2.2 Superior semi-circular canal stimulation

In this game, like the first game, the stimulation of the horizontal(lateral) is encouraged semi-circular canal but also the superior(vertical) semi-circular canal. We achieve this by having the patient follow with their eyes a balloon which has three different movement directions: left, right and up.

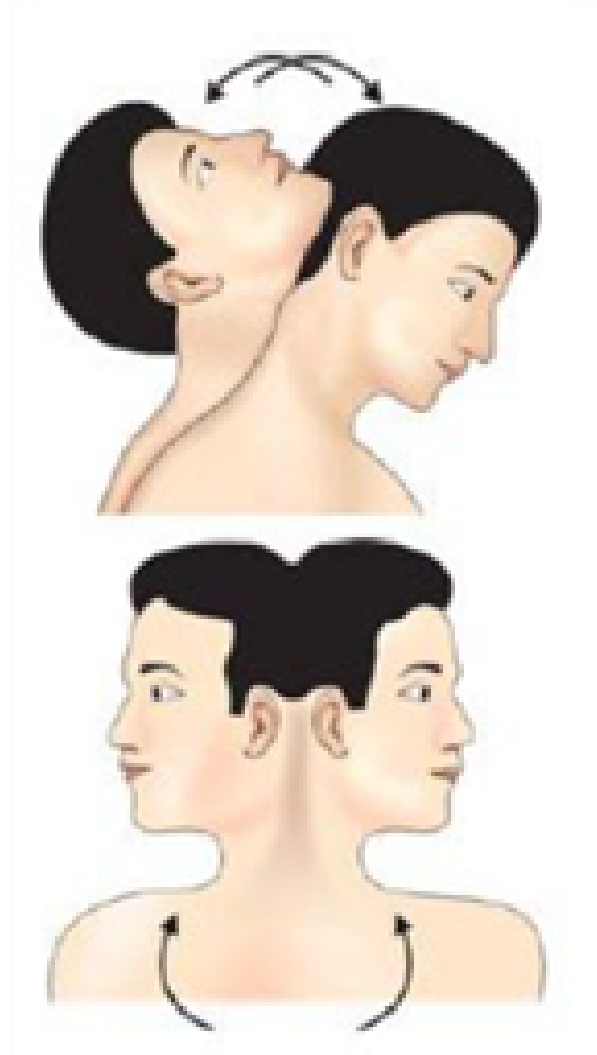Figure 3.3: Game 2 proposed exercise.

This game is called "Balloon Sunset" and its objective is to pop balloons which are flying in the sky by staring at them for a extended period of time. A balloon is spawned in the middle of the scenario and then proceeds to move in one of the three directions described above, left, right or up. The balloon will explode if the patient looks directly at it long enough.
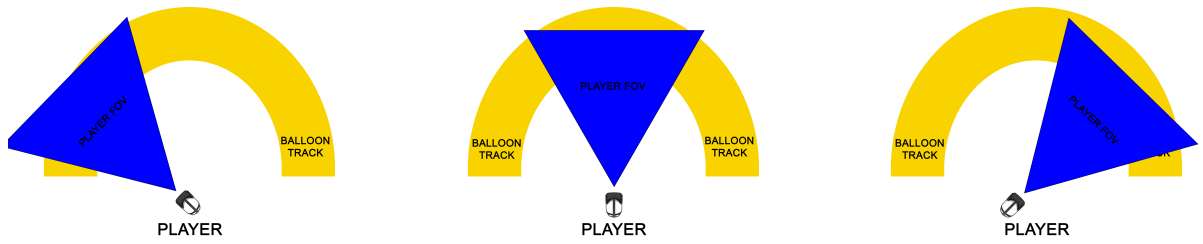
(a) Patient looking to the left   (b) Patient looking forward   (c) Patient looking to the right

Figure 3.4: Patient Field of View while looking at a balloon travelling to the right or left
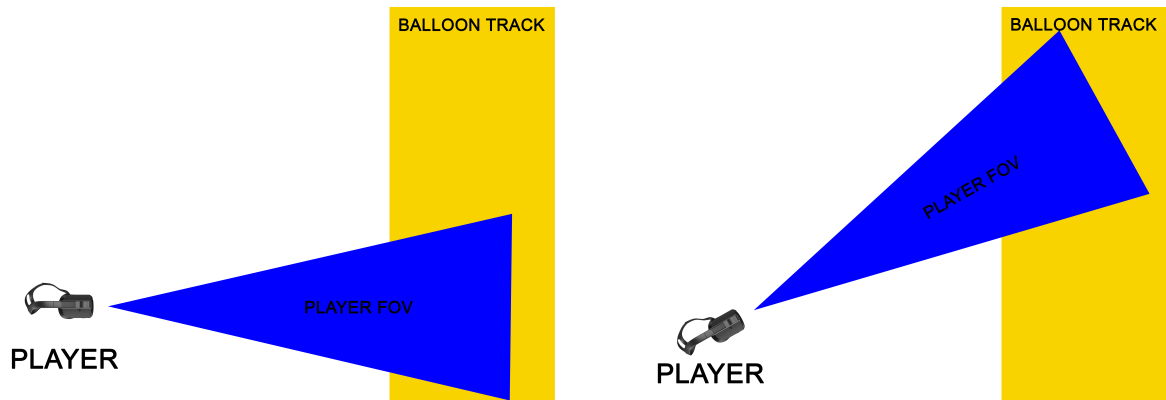
(a) Patient looking forward   (b) Patient looking up

Figure 3.5: Patient Field of View while looking at a balloon travelling up

This game allows the user to choose from three pre-defined difficulties which vary the balloon speed.

3.2.3 Posterior semi-circular canal stimulation

This game encourages the stimulation of the vertical and horizontal semi-circular canals but also the posterior semi-circular canal via lateral movement of the head since the patient needs to bend his back down to reach the objects at his feet.

Figure 3.6: Game 3 proposed exercise.

This game is called "Sort the Tomatoes" and its main goal is to sort between "good" and "rotten" tomatoes that are all mixed up in boxes in the floor and put them in the correct box in top of the table. This game allows the user to choose from three predefined time limits.

3.2.4 Therapist Control

One of the system's key features is the ability to customize the experience for each patient, ensuring that the exercises are better suited to their specific needs.

Each game in the system offers a range of parameters that can be adjusted to cater to the individual patient's requirements. These parameters encompass various aspects of the game, such as movement speed, visual complexity, and range of movement. By fine-tuning these parameters, therapists can create personalized exercise routines that challenge and engage patients at their own pace.

The system allows therapists to actively participate in the therapy sessions by joining the patient's game. This enables the therapist to assume an active role in controlling and manipulating various game mechanics during the session. By doing so, they can dynamically adjust the speed, range of movement and difficulty of each game so that it meets the patient's specific needs. This real-time involvement enhances the therapist's ability to provide targeted guidance and intervention, maximizing the therapeutic benefits for the patient.

To facilitate the therapist's control and monitoring, each game environment provides a dedicated control panel. This intuitive interface displays all available options and parameters clearly, empowering the therapist to make informed adjustments as necessary. With this control panel,

the therapist can seamlessly adapt the game mechanics to align with the patient's progress, ensuring a customized and effective therapeutic experience.

3.3 Development Materials

This solution requires the use of a Head Mounted Display (HMD) for both singleplayer and multiplayer mode, and a computer when using the multiplayer mode.

3.3.1 Oculus Quest

The Oculus Quest was chosen as the cost-effective option for deploying the application since it created the level of immersity required aswell as the interaction options of the controllers. The Oculus Quest is a standalone virtual reality (VR) headset released by Facebook's Oculus division in May 2019. It is a wireless, all-in-one device that doesn't require a PC or any external sensors, making it incredibly easy to set up and use. Inside the headset is an OLED display using custom-designed lenses with 1440 x 1600 pixels per eye and a 72 Hz refresh rate for smooth, seamless gaming interactions.

Figure 3.7: Oculus Quest 1.

3.3.2 Unity

For the game development it was used Unity, a 3D game engine developed by Unity Technologies, it is the world's most used cross-platform for game development. Unity is easy to use and helps developers create games quickly, especially on mobile devices. It has a simple export process and its component architecture is easy to understand. Scripting in C# is also fast and efficient.

Unity has a big community with helpful forums that make it easier to fix problems. Additionally, there's an asset store where developers can find useful assets at affordable prices.

4 Implementation

4.1 Overview of the application

In order to understand the need of each component and the full scope of the application we must first talk about the structure of the application. As referred before the application has two methods of playing: singleplayer or multiplayer. Both have the same exact games but they differ in who's control. In the singleplayer game the difficulty is set by the user before the start of each game while in the multiplayer game the therapist is in complete control and can change the game's difficulty and even certain game objects as needed in real-time. With this in mind we will next detail the implementation of each gamemode, starting with the singleplayer mode.

4.2 Singleplayer Mode

The singleplayer mode follows the map in the figure below, in which the user has to select from the three different VR games that all promote different head/eyes coordination exercises. For the first two games the player has to select, before the game, from three different pre-defined difficulties. For the last game the player has to select a time limit for the game.
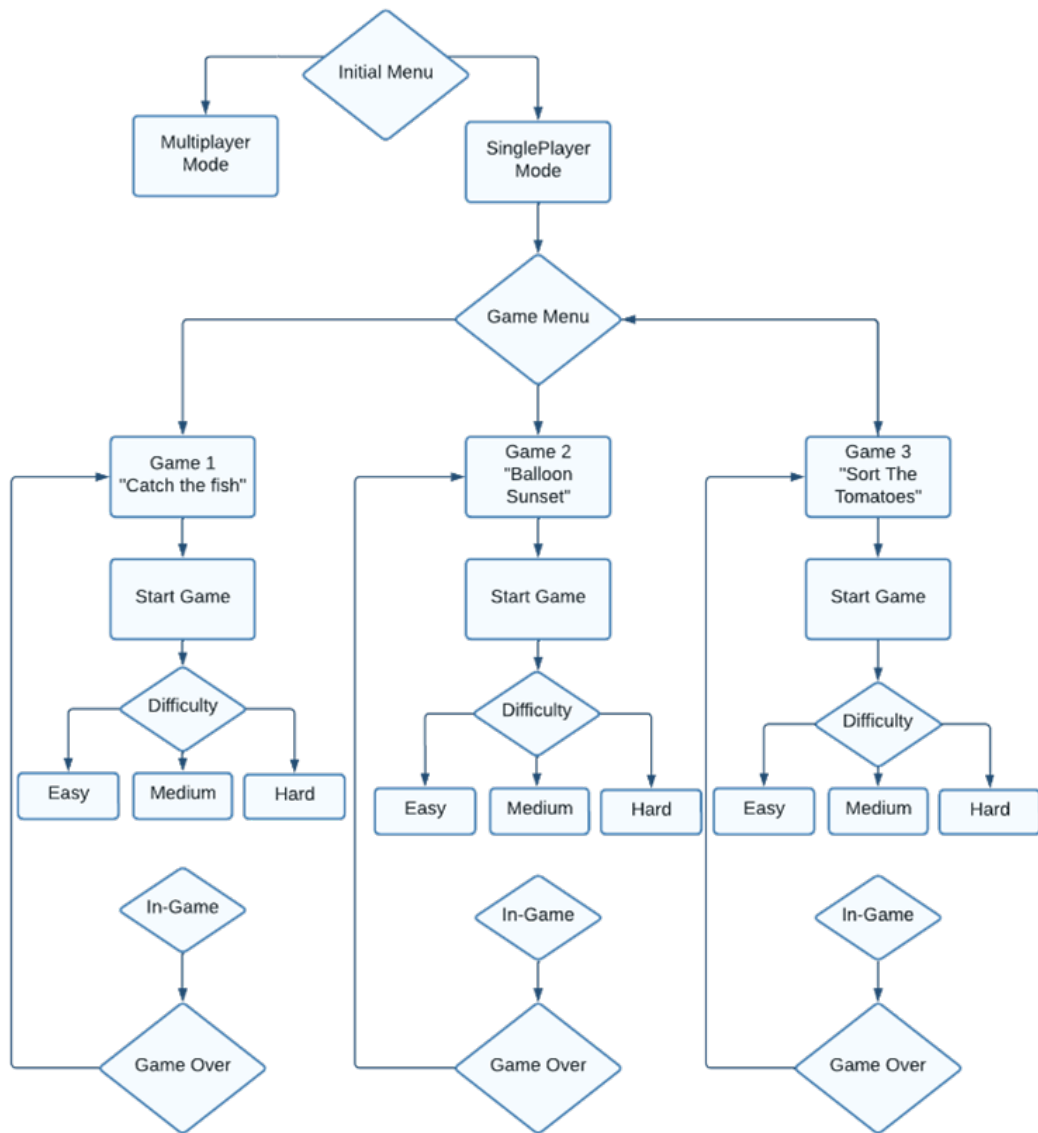
Figure 4.1: Singleplayer Mode Overview.

4.2.1 Menus

4.2.1.1 Initial Menu
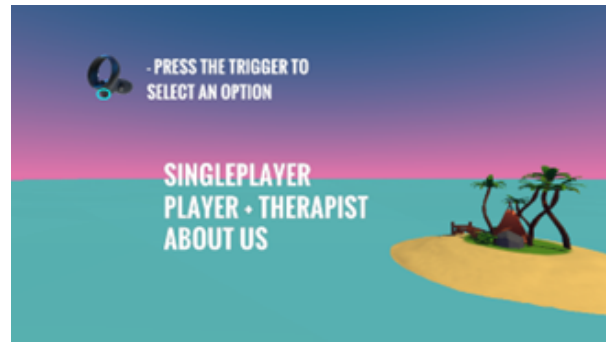
Figure 4.2: Initial Menu.

This menu is the first scene that loads when starting up the game, it has three different buttons:

- Singleplayer.

- Player+Therapist.

- About Us.

The first button, like the name suggests, takes the user to the menu of the singleplayer mode; the second button, takes the user to the multiplayer lobby system which will be detailed later; the third and final button, shows the user a new panel that contains information about the developer and the team, aswell as the institutions that supported and enabled the production of this application.

4.2.1.2 Singleplayer Menu

Figure 4.3: Singleplayer Menu.

After clicking the singleplayer button the user will be directed to this scene which offers the user the possibility to choose between the set of three games or to go back to the initial menu, for this purpose it has 4 buttons:

- Catch the fish

- Balloon Sunset

- Sort the Tomatoes

- Back to Menu

By selecting one of the three first buttons: "Catch the Fish", "Balloon Sunset" and "Sort the tomatoes", the user will be taken to the scenes in which the game selected takes place. By selecting the last button, "Back to Menu", the user will be taken back to the initial menu.

4.2.2 Games

All three games were designed to promote different vestibular rehabilitation therapy exercises. All games stimulate the cognitive system of the patient while encouraging the head/eye/torso movements that are typically associated with this type of therapy. The games are simple and very easy to understand for maximum adhesion by all patients from all age groups and to discourage frustration while playing. They all include calm ambience and music to give the patient a relaxing and safe environment to do therapy and give maximum chances of recovery.

4.2.2.1 Catch the fish

The first game takes place on the middle of the ocean on a small boat, the patient is located at the bow of the boat and its objective is to catch the fish that are continuously jumping from the water around the boat.
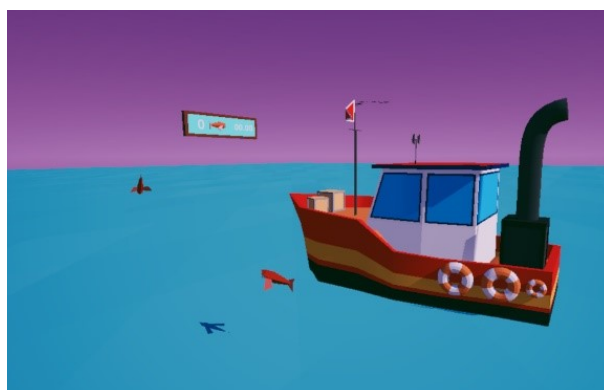

Figure 4.4: Game 1 scenario.

To catch the fish the user as to align the middle of the screen, where a small blue dot is located, with the incoming fish. This small blue dot in the middle of the screen is called a crosshair and it is important that the user understands that for moving the crosshair he must move his head from side to side with a certain degree of precision to align the crosshair directly on top of the fish.
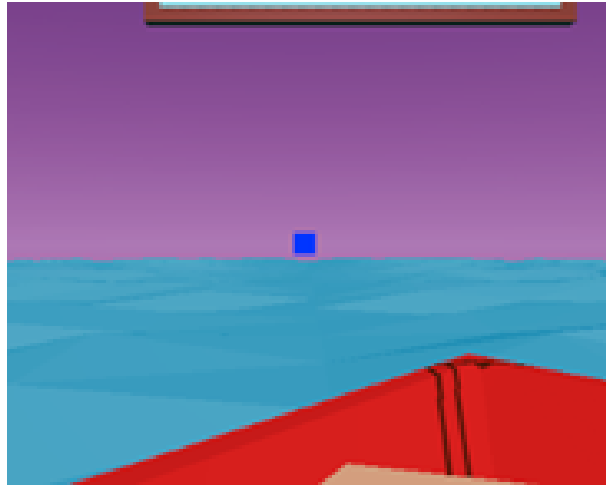
Figure 4.5: Game 1 crosshair.

To add cognitive function and stimulation fishes can have two colors, orange and black, when capturing an orange fish, a rewarding sound will play and the fish will be counted as captured, incrementing the score; when capturing a black fish an explosive sound will play and the score will be decremented.

(a) Orange fish

(b) Black fish

Figure 4.6: Preview of the different types of fish

The score and time system is presented to the player by a board that is located in front of the boat. Capturing a orange fish adds one point to the score while capturing a black fish removes one point from the score, the game score can be negative. All the games have a duration of 30 seconds.
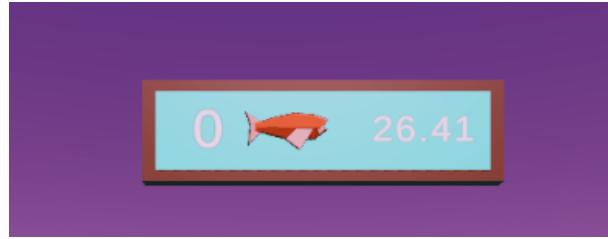
Figure 4.7: Game 1 timer and score board.

All fish make a splash sound when jumping out of the water that helps the user in knowing if the fish is at the right or left of the boat. To add a visual help as well, a arrow beneath the scoreboard also indicates where the last fish was spawned, left or right.
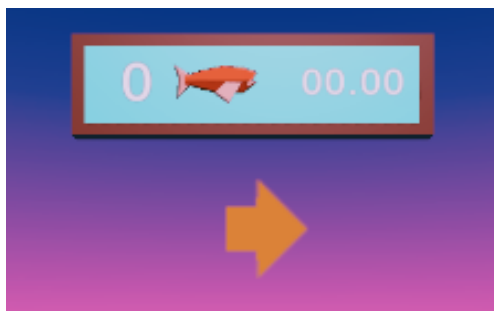
(a) Left arrow
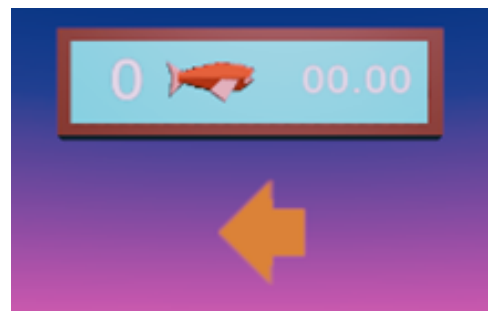
(b) Right arrow

Figure 4.8: Arrows indicating where the fish is

When entering the game the player will have two options, starting a game or going back to the menu. By clicking the option Main Menu the user will be taken back to the singleplayer menu where he can select a game to play. By selecting the option Start Game the user will be then shown from one of three pre-defined difficulties: easy, medium and hard. After selecting the difficulty the game will start, the timer will countdown from 30 seconds and fish will start to jump around the boat.

Figure 4.9: Game 1 starting options.
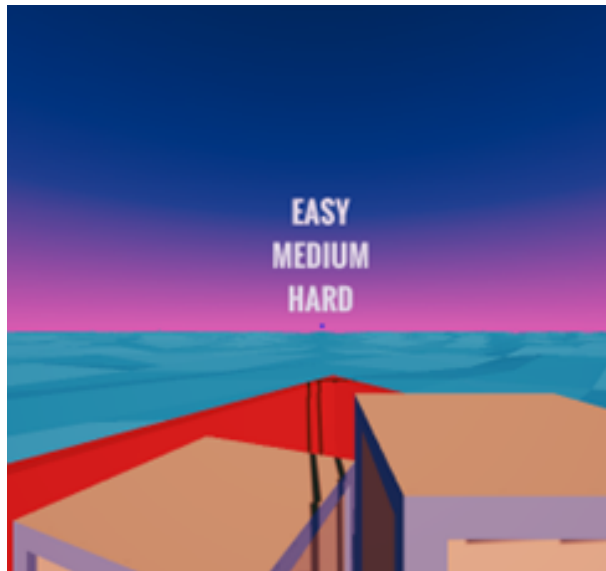
Figure 4.10: Game 1 difficulty options.

The game difficulties change the speed and size of the fish:

Table 4.1: Fish speed and size by difficulty

	Easy	Medium	Hard
Fish Speed	1,5	2,5	3,5
Fish size	4	3	2

4.2.2.2 Balloon Sunset

The second game takes place in the middle of the desert, the patient is located on the ground and its objective to pop balloons that are flying around in the air.

Figure 4.11: Game 2 scenario.

Similarly to the first game the user has to use the crosshair located at the middle of the screen but now to aim to the balloons, with a small but big difference, the patient will now have to hold the crosshair and balloon alignment in order to successfully pop a balloon.

Figure 4.12: Crosshair aligned with a balloon.

While the crosshair is aligned with the balloon the balloon will play an inflate sound and will grow, passing between three states before popping. The balloon starts green in color and after growing enough size will turn to orange and red before popping. Every state change the balloon will play an explosive sound as well as display explosion particles. Only one balloon is in the scene at any given time, when a balloon is successfully popped another one spawns immediately after.
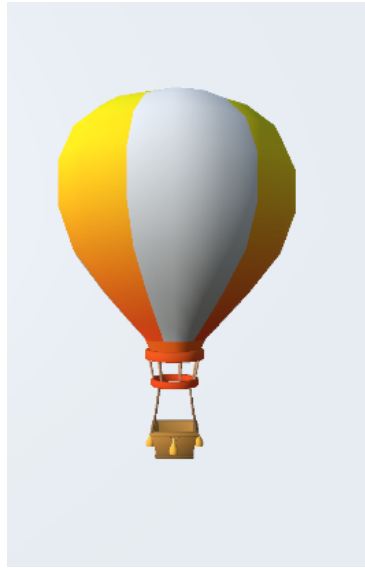
(a) Green Balloon   (b) Yellow balloon   (c) Red Balloon

Figure 4.13: Different balloon colors

Balloons always start their movement in the middle of the screen and will go back and forth between the middle position and one of three target positions: one target to the right of the player, one target to the left of the player and one target above the starting middle position. The game has two possible game modes, horizontal and vertical, the horizontal game mode only spawns balloons that travel or to the right or to the left, the vertical option spawns balloons that travel up and down.

When entering the game the player will have two options, starting a game or going back to the menu. By clicking the option Main Menu the user will be taken back to the singleplayer menu where he can select a game to play. By selecting the option Start Game the user will be shown two options, Vertical and Horizontal, which select the gamemode of the game which was explained earlier. After selecting the game mode the user will be then shown from one of three pre-defined difficulties: easy, medium and hard. After selecting the difficulty the game will start, the timer will countdown from 60 seconds and balloons will start spawning vertically or horizontally depending on the gamemode selected before.

(a) Game 2 starting options.
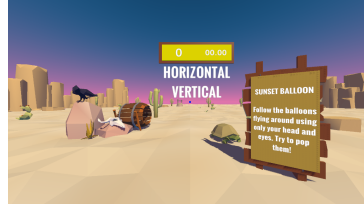
(b) Game 2 horizontal or vertical mode.

(c) Game 2 difficulty options

Figure 4.14: Game 2 Menu options.

The game difficulties change the speed of the balloons according the table below:

Table 4.2: Balloon speed by difficulty

	Easy	Medium	Hard
Balloon Speed	0.16	0.23	0,3

4.2.2.3 Sort the Tomatoes

The third and final game takes place in the middle of a farm, the patient is in the middle of two tomato plantations and its objective is to sort good and rotten tomatoes into separate boxes.

Figure 4.15: Game 3 scenario.

In this game the patient will, like the two previous games, make use of head/eye coordination but now also use both hands to pick up the tomatoes. The patient will see both hands represented in-game by white hand models. They can have two states: neutral and grabbing. In the neutral state the hand is just a visual representation of the hands and does not have any influence in the world. In the grabbing state if the hand model is touching any tomato, it will attach it to itself and only let go if changes to the neutral state. The hands and in the neutral state and change to the grabbing state by pressing the trigger on the side of the oculus controller.

(a) Open hand model   (b) Closed hand model

Figure 4.16: Hand models

There are two types of tomatoes: good and rotten. These tomatoes are designed to mimic their real-life counterparts, where the distinction between the two is typically intuitive based on their coloration. In this game, the good tomato is represented by a bright red color, while the rotten tomato is depicted as brown.

The choice to make the coloration of the tomatoes resemble their real-life counterparts serves two purposes. Firstly, it adds a level of realism to the game, making the virtual environment feel more familiar and relatable to players. By associating the bright red color with a good tomato and the brown color with a rotten one, players can rely on their natural instincts and prior knowledge to differentiate between the two types of tomatoes.
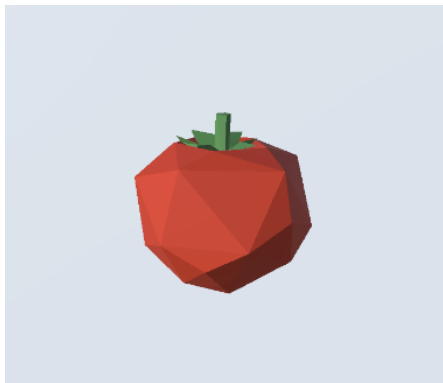
(a) Good tomato   (b) Rotten tomato

Figure 4.17: Types of tomato

The patient will be placed by a table with two empty boxes in front of him, both labeled with a good tomato and a rotten tomato, respectively. On the ground, to the right and left of the player, there are two boxes full of unsorted tomatoes. The user will have to bend over to the side and using the oculus controllers pick up the tomatoes and put them in the correct box

in the table.
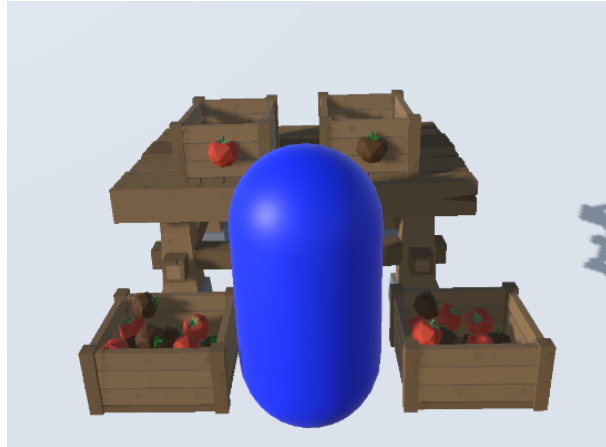
Figure 4.18: Table and both boxes with a player dummy(blue).

4.3 Multiplayer Mode

One great benefit of this application for VRT is that the games can be tailored to the specific needs and abilities of each patient. Therapists can adjust the difficulty level, speed, and duration of each VR game to match the patient's individual rehabilitation goals and progress. This customization can help to maximize the effectiveness of the therapy and improve patient outcomes. To achieve this, we implemented a multiplayer feature which allows the therapist to remotely join a session and control many different aspects of each game. The game has two different versions, the VR and PC version, the VR version runs on the oculus quest and will be the server, and the PC version runs on Windows 10 or above and will act as a client. The patient will use the VR server build and the therapist will use the PC client build.
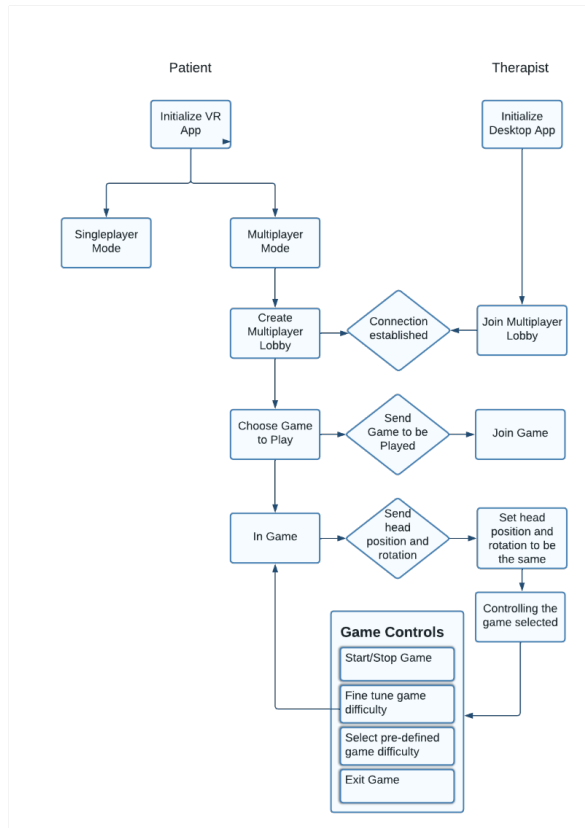
Figure 4.19: Multiplayer Overview.

The multiplayer mode follows the map in the figure above, the patient launches the game in the oculus quest and the therapist launches the game from a PC. After establishing a connection using a lobby system the patient view will be replicated in the therapist side, which allows the therapist to see the games from the patient perspective in real-time, at the same time the therapist has a panel of options in which different features of each game can be affected.

4.3.1 Multiplatform communication

To achieve the desired communication between the Oculus Quest and the therapist computer we made use of some Unity libraries which facilitate the implementation of a working multiplayer game. For establishing a remote connection, we created a lobby system using Unity Lobby Service, for multiplayer communication we used Unity Multiplayer Networking and for hosting the game we used Unity Relay.

4.3.1.1 Unity Multiplayer Networking

Netcode for GameObjects (Netcode) is a high-level networking library built for Unity for abstracting networking logic. It makes possible to send GameObjects and world data across a

networking session to many players at once. Using Netcode we can focus on building the game instead of low-level protocols and networking frameworks. Some of the features of this library used in this application include the creation of network objects that replicate their behavior across the network, network variables which synchronize across the network and remote procedure calls(RPC) that let the client and server call one another.

4.3.1.2 Unity Lobby Service

The Lobby service facilitates grouping players and configuration settings before game sessions. In this application we used this to group both the therapist and the patient in a lobby before launching the game server.

4.3.1.3 Unity Relay

Unity Relay offers a way to securely provide increased connectivity between players by using a join code style workflow without needing to invest in a third-party solution, maintain dedicated game servers (DGS), or worry about the network complexities of a peer-to-peer game. Instead of using DGS, the Relay service provides connectivity through a universal Relay server acting as a proxy. Relay enabled us to create a multiplayer solution that acts globally and with the minimum amount of delay.

4.3.2 Server and Client Communication

One of the requirements of this project was that the therapist could see and control what the patient was doing in real-time in order to be able to customize each patient experience to their current needs and capacities. To achieve this it was required an architecture that allowed the server(patient) and client(therapist) to communicate back and forth seamlessly. The created solution was to use Remote Procedure Calls (RPC) and network variables. A remote Procedure Call(RPC) is a software communication protocol that one program can use to request a service from a program located in another computer on a network without having to understand the network's details. The library Unity Networking described previously had two types of RPC: a Client-RPC, in which the server would be able to invoke a method client-side; and a Server-RPC, in which the client would be able to request the server to execute a method server-side. A network variable is, at a high level, a way to synchronize a property ("variable") between a server and client(s) without having to use custom messages or RPCs.
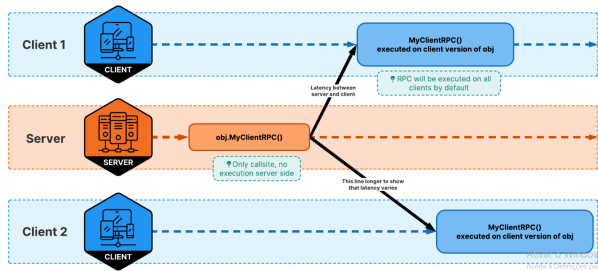
(a) Diagram of a Client RPC
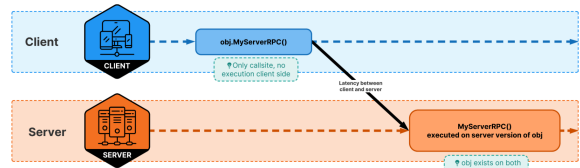
(b) Diagram of a Server RPC

Figure 4.20: Differences between a Client and Server RPC

4.3.2.1 Estabilishing the same point of view

To help the therapist capture and understand the ability and capacity of each patient, it was crucial that the therapist could actually see what the patient was doing in real-time. To achieve this the server (patient) continuously (60 times per second) sends its camera position (x,y,z) and camera rotation (rx,ry,rz) to the client(therapist) making use of network variables and the client(therapist) reads these values and sets them to their camera. This allows the therapist to actively see what the patient is doing in "almost" real-time.

4.3.2.2 Controlling the patient environment

In each game environment the therapist is shown a lateral panel which contains different controls depending on the game, these controls are sent to the server (patient) via a server-RPC, which means each control will be invoked by the client(therapist) and performed on the server-side(patient).

4.3.3 Menus

Some menus vary slightly in the Oculus and desktop versions, so the patient sometimes has different options than the therapist in the same menu, for each menu it will be explained the patient view, what the patient sees, and the therapist view, what the therapist sees.

4.3.3.1 Initial Menu

After launching the game both the patient and therapist will load the initial menu. The patient view and button options were already described in section 4.2.1.1 and figure lalal but the therapist view varies slightly, it only displays two buttons instead of three buttons like the Oculus version. This is because, the PC version doesn't have a single player mode.

- Start

- About us

The first button, will open the lobby menu; the second button, shows the user the about us panel that was also described in a earlier section, 4.2.1.2 and figure lalal
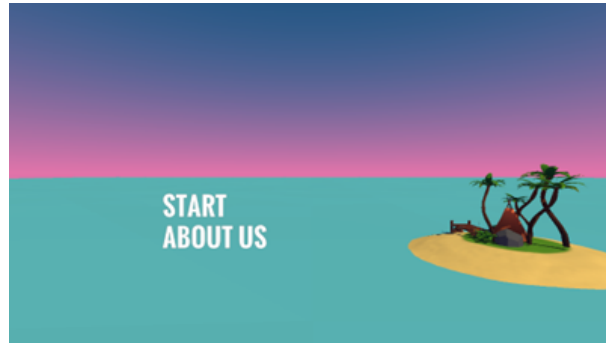
Figure 4.21: Patient view of the Initial Menu.

4.3.3.2 Lobby Menu

Since that in this menu the patient and therapist vary quite a bit, each of the views will be detailed separately starting with the patient's view.

The patient is tasked with the creation of the lobby and starting the game after the therapist joined the lobby. The therapist only has to join the already created lobby and wait for the patient to start the game. Now we will detail the patient view of the lobby menu as well as the different options shown to the user in each part of the system.
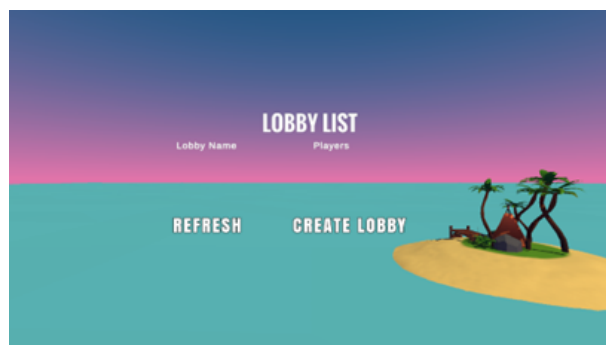
Figure 4.22: Lobby list - patient view.

After clicking the Player+Therapist option of the Initial Menu the player will be shown an empty lobby list with two buttons:

- Refresh

- Create Lobby

The refresh button updates the lobby list and lists all the available lobbies in which the user can join. The create lobby button creates a lobby which other players can see and enables the in-lobby view.

(a) In-Lobby one player   (b) In-lobby two players
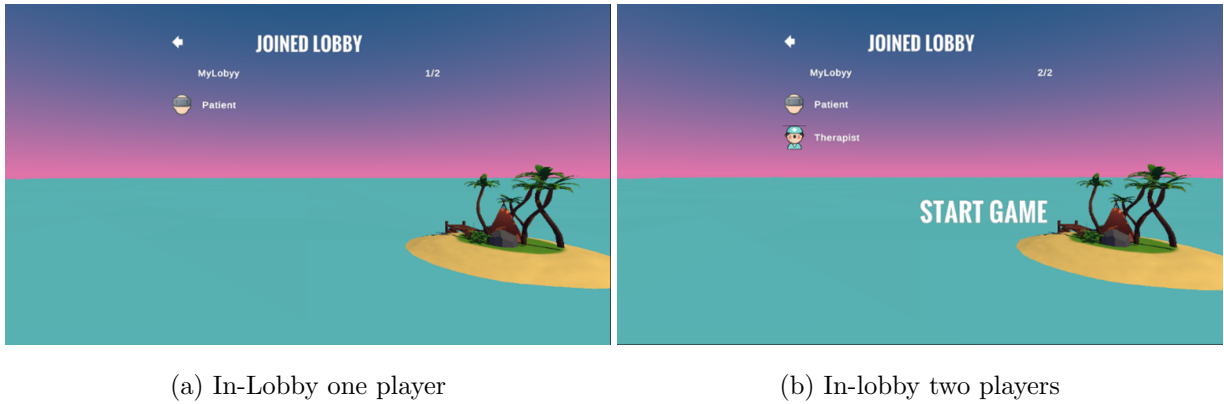
Figure 4.23: In-lobby - patient view

After creating a lobby, the patient is shown the in-lobby view, which details the lobby name, lobby player count and lists the players inside the lobby. After creating the lobby, the patient is the only player inside the lobby and is shown only one option that is to click the arrow on the top left corner which returns the patient to the lobby lists and deletes the lobby. After the therapist successfully joins the lobby, the patient is given another button which is the start game option which if clicked starts the game and sends both the patient and therapist to the multiplayer menu. We will now detail the therapist view of the lobby system.

(a) No lobbies exist   (b) One lobby exists and is displayed
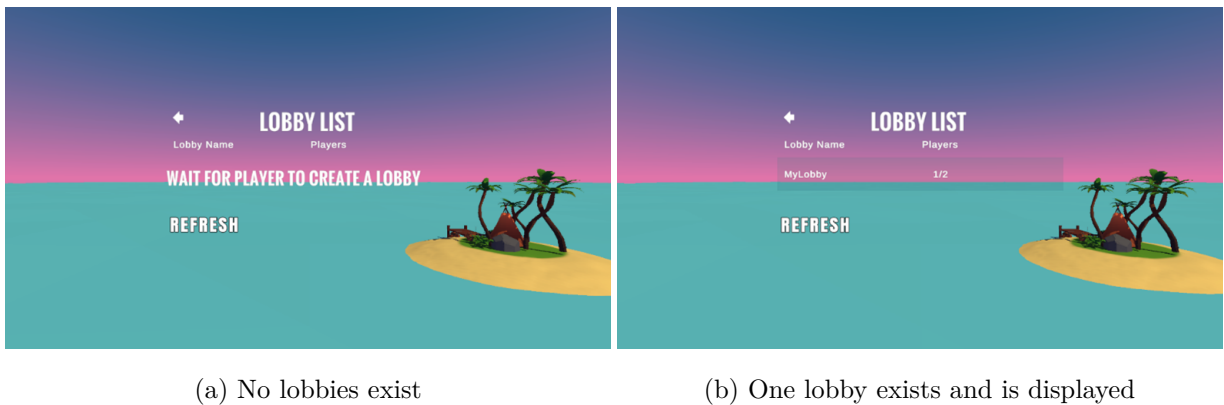
Figure 4.24: Lobby list - therapist view

After clicking the Start option in the Initial Menu the therapist is shown the menu in the figures above which have two buttons:

- Refresh

- Arrow button

Like mentioned before the refresh button updates the lobby list and if it finds any lobby it will list it. The arrow button returns the user to the Initial Menu. By clicking the lobby listed the therapist will be taken to the in-lobby screen.
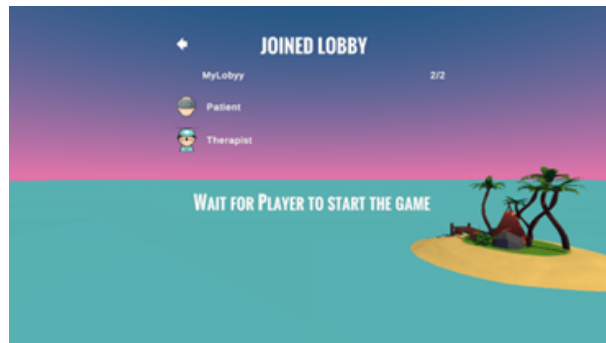
Figure 4.25: In-lobby - therapist view.

In the in-lobby screen the therapist is shown the current players in lobby, the player count, and a message to wait for the patient to start the game. The therapist has the option of leaving the lobby and returning to the lobby list by clicking the arrow on the top left corner of the screen.

4.3.3.3   Multiplayer Menu
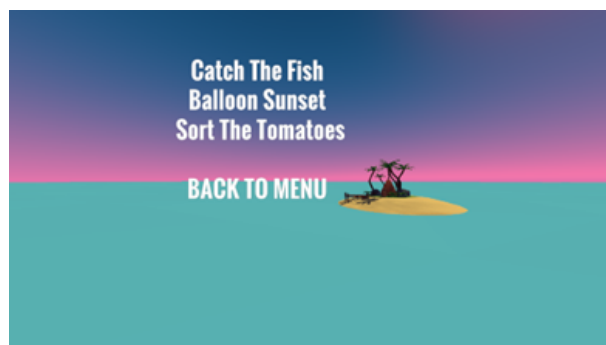
Figure 4.26: Multiplayer Menu.

After the patient clicks the start button both the user and the therapist will be directed to this scene which offers the user and the therapist the possibility to choose between the set of three games or to go back to the initial menu, for this purpose it has 4 buttons:

- Catch the fish

- Balloon Sunset

- Sort the Tomatoes

- Back to Menu

By selecting one of the three first buttons: "Catch the Fish", "Balloon Sunset" and "Sort the tomatoes", the user and therapist will be taken to the scenes in which the game selected takes place. By selecting the last button, "Back to Menu", the user and the therapist will be taken back to the initial menu.

4.3.4 Games

All the multiplayer games are the same as the singleplayer mode with the only difference being that the therapist has an additional panel which has the controls to start and end the games as well as individually changing or spawning different elements in each game which will be further specified in the next sections. Since the games are the same from the patients point of view only the therapist side will be shown next, by therapist side it is meant the desktop version of the game.

4.3.4.1 Catch the fish

When selecting the Catch the Fish game both players will be sent to the game 1 scene where the therapist will have access to the panel shown below.

Figure 4.27: Game 1 Therapist panel.

The panel offers two main buttons which contain the two sections of the panel:

- Play Game (Play game section)

- Manual Mode (Manual Mode section)

Play game is the main and default section which is open by default when loading up the game, from this section the therapist can start a custom game. Manual mode is the secondary section in which the therapist can customize fish attributes and manually spawn in fish without having to start a 30 second game.

In the play game section it is presented to the user a slider to change the fish speed which inherently changes the difficulty, faster fishes are harder to catch and promote much faster movements and reactions from the patients. To assist the therapist in selecting an appropriate speed there is, above the slider, an indicator which changes based on the current speed selected given that:

Table 4.3: Difficulty shown by fish speed

Fish Speed	Difficulty Shown
0,1 to 1,66	Easy
1,67 to 3,22	Medium
3,22 to 5	Hard

| (a) Fish speed in easy difficulty range | (b) Fish speed in medium difficulty range | (c) Fish speed in hard difficulty range |

Figure 4.28: Difficulties based on fish speed

After selecting an appropriate speed the therapist can click the button below the slider, "Start game", this will reset the score, start a countdown 30 second timer and spawn fishes around the boat with the speed which was previously selected using the slider. It will also update the therapist panel to give the option of stopping the game early by pressing the button "Stop the game".

Figure 4.29: Game in Progress Panel

By selecting the "Manual mode" button, the therapist can see the manual mode section

which contains a button, a toggle and two sliders:

- Spawn Fish(button)

- Automatic Mode(toggle)

- Fish Speed (slider)

- Fish Size (slider)

The therapist can use the sliders to customize the attributes of the fishes according to the table below and can spawn individually a fish by pressing the "Spawn Fish" button.

Table 4.4: Minimum and maximum fish speed and size

	Minimum	Maximum
Fish speed	0,1	5
Fish size	1	5
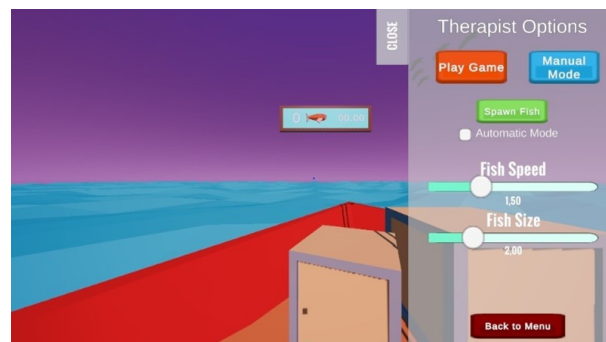
Figure 4.30: Manual Mode section - automatic untoggled

By enabling the toggle "Automatic Mode" the user is presented a new slider "Total Fish" and the "Spawn Fish" button is disabled. In this mode the fishes are automatically spawned given that the number of fishes concurrently active at the same time is defined by this new slider. The therapist can have one, two or three fishes active at the same time. A fish is active from the time it is spawned to either when the user catches it or it reaches the water again, then it becomes inactive and does not count towards the total fish active in the scene.
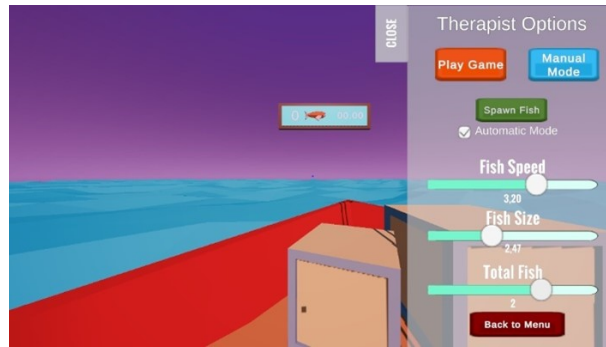
Figure 4.31: Manual Mode section - automatic toggled

4.3.4.2 Balloon Sunset

When selecting the Balloon Sunset game both players will be sent to the game 2 scene where the therapist will have acess to the panel shown below.

Figure 4.32: Game 2 Therapist Panel.

The panel, much like game 1, offers two main buttons which cointain the two sections of the panel:

- Play Game (Play game section)

- Manual Mode (Manual Mode section)

Play game is the main and default section which is open by default when loading up the game, from this section the therapist can start a custom game. Manual mode is the secondary section in which the therapist can customize the balloon attributes and manually spawn in balloons without having to start a 60 second game.

In the play game section it is presented to the user a slider to change the balloon speed which inherently changes the difficulty, faster balloons are harder to follow and promote much faster movements by the patients. To assist the therapist in selecting an appropriate speed there is, above the slider, an indicator which changes based on the current speed selected given that:

Table 4.5: Difficulty shown by balloon speed

Balloon Speed	Difficulty Shown
0,05 to 0,16	Easy
0,17 to 0,32	Medium
0,33 to 0,5	Hard

(a) Balloon speed in easy difficulty range

(b) Balloon speed in medium difficulty range
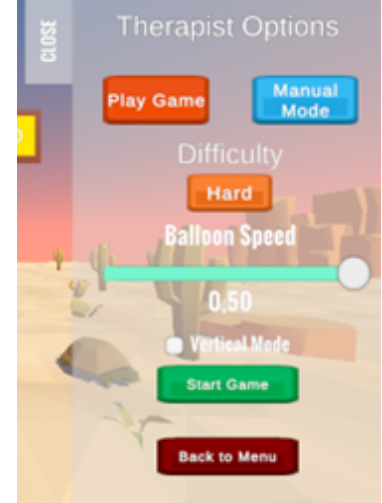
(c) Balloon speed in hard difficulty range

Figure 4.33: Difficulties based on balloon speed

After selecting an appropriate speed the therapist can click the button below the slider, "Start game", this will reset the score, start a countdown 60 second timer and spawn a balloon with the speed which was previously selected using the slider. It will also update the therapist panel to give the option of stopping the game early by pressing the button "Stop the game". If the vertical mode toggle is selected the gamemode will be vertical, if it is not selected, a horizontal gamemode will be played.
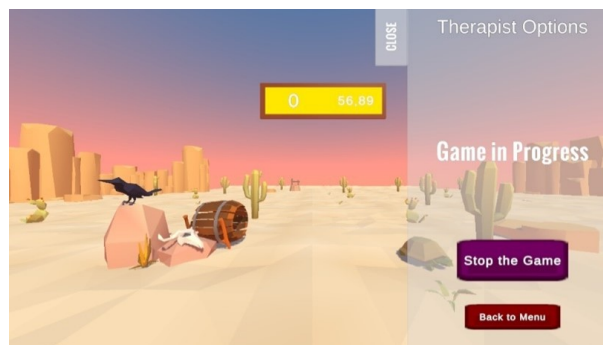
Figure 4.34: Game in Progress Panel

By selecting the "Manual mode" button, the therapist can see the manual mode section which contains two buttons, three toggles and a slider:

- Spawn Balloon(button)

- Destroy All Balloons(button)

- Left(toggle)

- Vertical(toggle)

- Right(toggle)

- Balloon Speed (slider)

The therapist can use the slider to customize the speed of the balloon and can spawn a balloon individually by pressing the "Spawn Balloon" button or destroy all the balloons on the scene by pressing the "Destroy all Balloons" button. The three toggles function as toggle group, which means that only one is active at a given time, and their purpose is to give the therapist the option to either spawn a balloon that flies horizontally right, horizontally left or vertically.
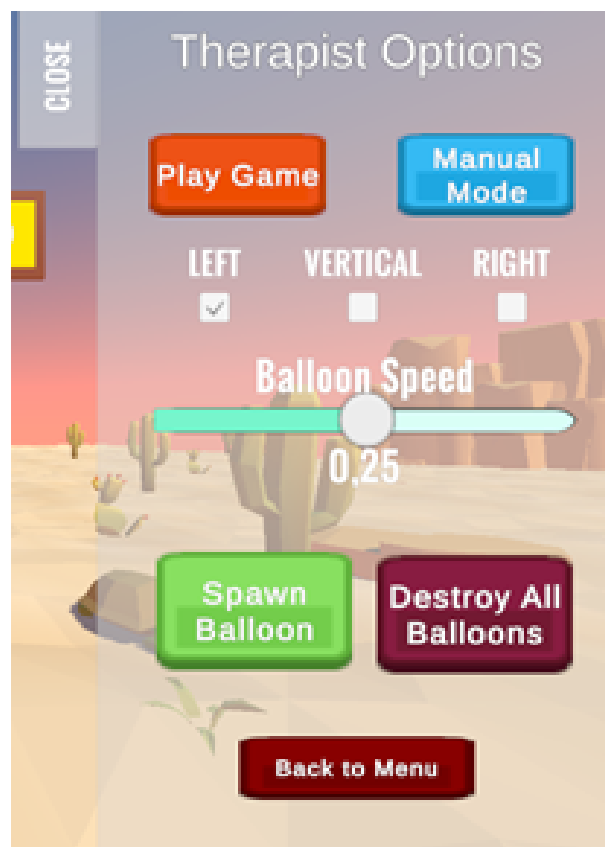
Figure 4.35: Manual Mode section

4.3.4.3   Sort the tomatoes

When selecting the Sort the Tomatoes game both players will be sent to the game 3 scene where the therapist will have access to the panel shown below.

Figure 4.36: Game 3 Therapist Panel.

The panel is a bit different than the previous two games it also offers two main buttons which contain the two sections of the panel, but instead of a manual mode we have a adjustments section:

- Play Game (Play game section)

- Adjustments (Adjustments section)

Play game is the main and default section which is open by default when loading up the game, from this section the therapist can start a custom game. Adjustments section is where the therapist can calibrate the location of the player, table, and boxes of tomatoes.

In the play game section it is presented to the user three toggles that function as toggle group, which means that only one is active at a given time, and their purpose is to give the therapist the option to set the game length to one of three predefined time limits.
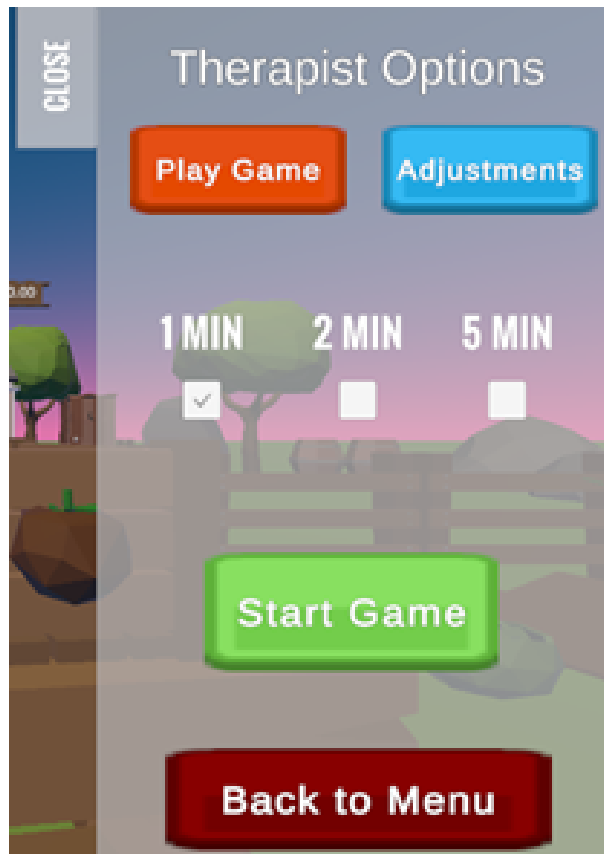
Figure 4.37: Game 3 Therapist Panel.

After selecting a time limit the therapist can click the button below the toggle group, "Start game", this will reset the score, start a countdown with the time limit selected and spawn the two boxes of tomatoes by the user. It will also update the therapist panel to give the option of stopping the game early by pressing the button "Stop the game".

Figure 4.38: Game in Progress.

By selecting the "Adjustments" button, the therapist can see the adjustments section which contains the objects that can be calibrated and custom controls for each of the objects.

Figure 4.39: Adjustments section.

There are four objects that we can move:

- Table

- Player

- Box right

- Box left

They are presented in the panel as they are placed in the world and by clicking in one object, custom controls appear for each object.
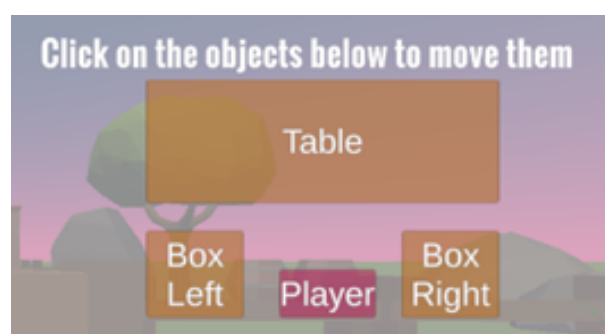
Figure 4.40: Movable objects panel.

By clicking the table panel we see the controls for the the table object, the table can only be moved up or down, decreasing or increasing in height (move on Y axis).The table object is composed by a table and the two boxes on top of it.

(a) Table object.
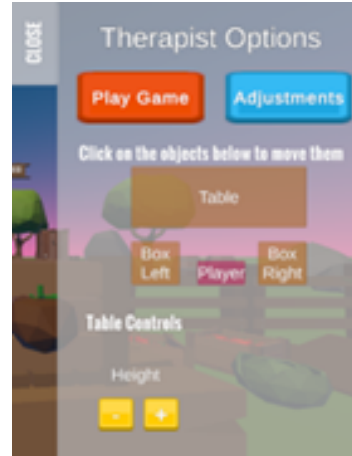
(b) Table custom controls.

Figure 4.41: Table object and controls.

By clicking the box right or box left panel we see the controls for the the respective box object, both boxes can be moved right, left, forward and back but their height can't be changed(both move in the X and Z axis). The two boxes initially start at the patient feet, one to the right and one to the left.

(a) Left box custom controls.

(b) Box left and right objects.
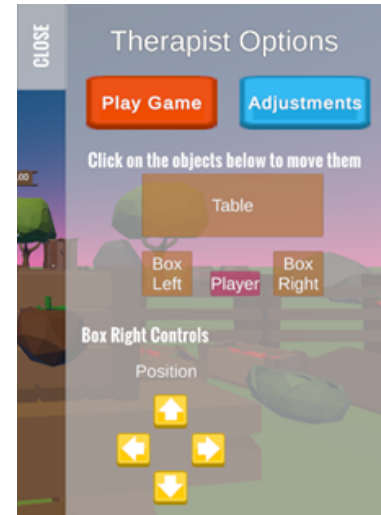
(c) Right box custom controls.

Figure 4.42: Box objects and controls

By clicking the player panel we see the controls for the the player object which is the position of the patient in the world, the therapist can move the player camera to the right, left, forward,

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back, up and down (move on the X, Y and Z axis).
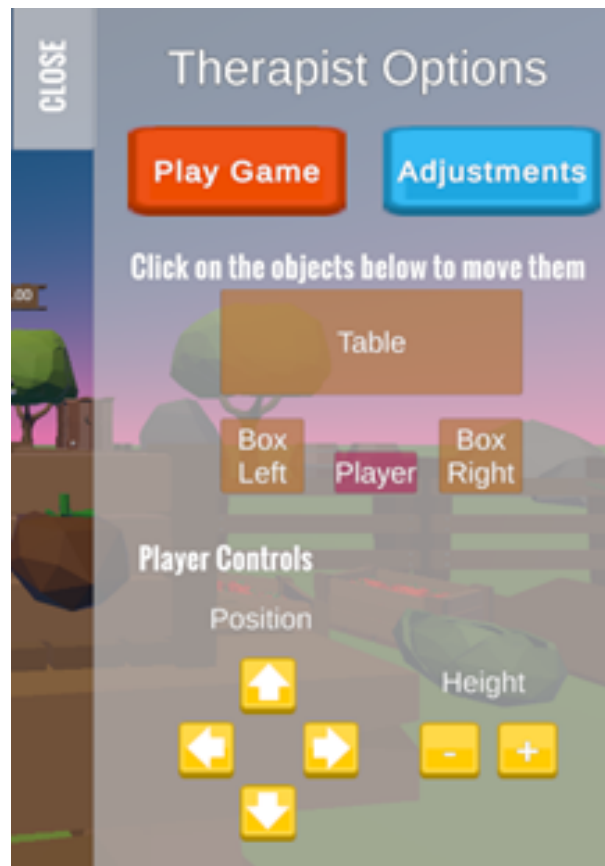
Figure 4.43: Player custom controls.

All the objects move in the real-world by clicking on the custom controls but to give some visual aid to the therapist, they also move in the adjustments panel, for example by clicking the boxes controls the therapist could put both boxes in front of the patient as opposed to the sides.
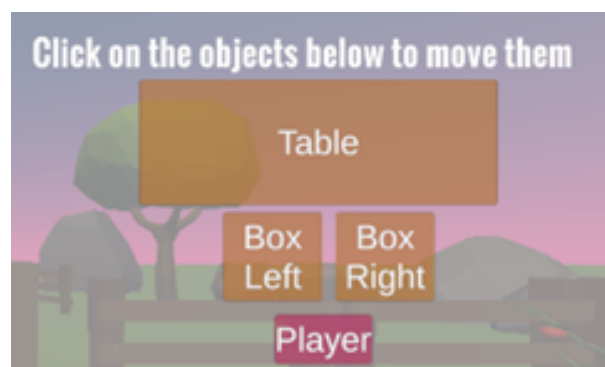
Figure 4.44: Player custom controls.

After the therapist is satisfied with the position of each object in the scene the game can be started by going back to the Play game section and pressing the Start Game button.

5 Results

In this chapter, we present the results of the implementation of the proposed application for vestibular rehabilitation therapy (VRT). We describe the features and functionalities of the application and discuss its potential impact on patient engagement and therapy outcomes based on the implemented system.

5.1 Methodology

The implementation followed a systematic approach to design and develop the VR games for vestibular rehabilitation. The process involved several stages, including requirement analysis which was done with the help of a therapist, game design, programming, integration of multiplayer functionality, and user testing with the help of fellow colleagues. Unity3D was used as the primary game development platform, while Oculus Quest served as the VR headset.

5.2 Application Features

The implemented application includes a set of games that promote eye/head exercises similar to those prescribed in traditional VRT. These games are designed to be played either seated or standing, accommodating the different positions required for therapy. The application provides a user-friendly interface that allows patients to navigate through the games easily.

The system offers both single-player and multiplayer capabilities. Patients can choose to play alone at home or play with the assistance of a therapist who can control the difficulty of the games and customize additional parameters based on the patient's needs. The multiplayer feature allows therapists to remotely guide and monitor the patient's progress from anywhere in the world, making therapy more accessible and convenient.

The application creates a calming and relaxing environment by incorporating ambient background music and visuals. This environment aims to provide a safe and enjoyable experience for patients during their therapy sessions.

5.3   Patient Engagement and Therapy Outcomes

Although no formal experiments were conducted, the implementation of the application provides insights into its potential impact on patient engagement and therapy outcomes.

The inclusion of gamified exercises in the application offers a more engaging alternative to the repetitive and potentially monotonous exercises prescribed in traditional VRT. By integrating games into the therapy process, the application may help to maintain patient motivation and interest, which are important factors for therapy adherence.

The application's user-friendly interface and customizable features provide patients with a sense of control and personalization over their therapy sessions. This empowerment may contribute to increased patient engagement and a greater commitment to their prescribed exercises.

Furthermore, the ability for therapists to remotely guide and monitor patients through the multiplayer feature can enhance the therapeutic relationship and facilitate ongoing support. This remote access may also reduce barriers to therapy, such as travel time and distance, enabling patients to receive consistent and timely guidance from their therapists.

While the specific therapeutic outcomes cannot be directly measured without conducting formal experiments or clinical trials, the implementation of the application suggests its potential to improve therapy adherence and patient satisfaction. These factors are known to have a positive influence on the overall effectiveness of VRT.

5.4   Validation

Additionally, at the conclusion of the implementation, the entire project was presented to a physical therapist who specializes in vestibular rehabilitation. The therapist was given an opportunity to interact with the application, explore its features, and provide feedback.

The therapist expressed excitement and enthusiasm about the potential of the application to revolutionize the field of vestibular rehabilitation. They appreciated the gamified approach, noting that it could greatly enhance patient engagement and motivation during therapy sessions. The therapist also recognized the value of the application's remote therapy capabilities, emphasizing the convenience and accessibility it offers to both patients and therapists.

Furthermore, the therapist commended the application's user-friendly interface, calm ambiance, and relaxing environment. They highlighted the importance of creating a safe and enjoyable space for patients to undergo therapy, as it can contribute to a positive therapeutic experience and ultimately improve patient outcomes.

The therapist acknowledged the potential of the implemented application as a valuable tool in

supporting and augmenting traditional vestibular rehabilitation therapy. They expressed enthusiasm about future developments, emphasizing the need for continued research and collaboration to further refine and optimize the application for clinical use.

The therapist's approval and excitement about the implemented application serve as a validation of its potential and reinforce the significance of incorporating technology in the field of vestibular rehabilitation. Their input will guide and inspire further advancements in the application, ensuring its alignment with the needs and expectations of both patients and healthcare professionals in the future.

6 Conclusion

The implementation of the proposed application for vestibular rehabilitation therapy presents a promising opportunity to enhance patient engagement and improve therapy outcomes. By incorporating gamified exercises, customizable features, and remote therapy capabilities, the application offers a novel and accessible alternative to traditional VRT approaches.

The gamified exercises within the application provide an interactive and engaging platform for patients to perform their therapy. By transforming the exercises into games, the application creates a more enjoyable and immersive experience, making it easier for patients to stay motivated and committed to their therapy regimen. The element of gamification introduces elements of challenge, reward, and progression, which can enhance patient engagement and contribute to a more positive therapy experience.

Furthermore, the application's customizable features empower both patients and therapists to tailor the therapy experience to individual needs and goals. Patients can adjust the difficulty levels of the games to match their capabilities and gradually increase the challenge as they progress. Therapists, on the other hand, can remotely control certain parameters of the games, allowing them to fine-tune the exercises to suit each patient's specific requirements. This customization aspect ensures that the therapy remains personalized and targeted towards the individual patient's condition, maximizing its effectiveness.

The inclusion of remote therapy capabilities in the application brings added convenience and accessibility to patients and therapists alike. Patients no longer need to travel to a specific location for their therapy sessions, as they can engage in the exercises from the comfort of their own homes. This eliminates barriers such as geographical distance and time constraints, enabling patients to adhere to their therapy schedule more consistently. Additionally, therapists can remotely monitor patients' progress and provide real-time guidance and adjustments, fostering a sense of support and continuity in the therapy process.

However, while the initial implementation of the application shows promise, it is essential to conduct further research and experimentation to validate its effectiveness in a clinical setting. A

rigorous evaluation of the application's impact on patient recovery rates, quality of life, and long-term outcomes is necessary to determine its true efficacy. This can involve conducting controlled studies with larger sample sizes and comparing the outcomes of patients using the application to those receiving traditional VRT. By objectively measuring the application's effectiveness, researchers can gain valuable insights into its potential benefits and areas for improvement.

In addition to quantitative measurements, gathering user feedback and conducting usability studies will be crucial in refining and enhancing the application. By actively involving patients and therapists in the development process, the application can be tailored to better meet their needs and preferences. User feedback can provide valuable insights into usability issues, user experience, and any potential shortcomings of the application, guiding future iterations and updates.

Overall, the implementation of this application holds significant promise for the field of vestibular rehabilitation therapy. By offering engaging and accessible alternatives to traditional VRT, it has the potential to positively impact patient experiences and treatment outcomes. Continued research, user feedback, and improvement efforts will contribute to the evolution of this application and further advance the delivery of vestibular rehabilitation therapy, ultimately improving the quality of life for patients with vestibular disorders.

Bibliography

[1] S. J. Herdman, *Vestibular Rehabilitation.* 4 ed., 2007.

[2] M. Strupp, J. Dlugaiczyk, B. B. Ertl-Wagner, D. Rujescu, M. Westhofen, and M. Dieterich, *Vestibular Disorders*, vol. 117. 2020.

[3] S. Doriasala, A. S. Rao, S. Joshi, S. Mehta, B. Yadav, S. Rajeswari, and R. Nayar, "Virtual reality (vr) for vestibular rehabilitation: A pilot study comparing vr with conventional rehabilitation with conventional rehabilitation alone," 2020.

[4] H. S. Cohen, "New epidemiological findings on benign paroxysmal positional vertigo," *Journal of Neurology, Neurosurgery Psychiatry*, vol. 78, pp. 663–663, 12 2006.

[5] N. A. Ricci, M. C. Aratani, H. Caovilla, and F. F. Ganança, "Effects of vestibular rehabilitation on balance control in older people with chronic dizziness: A randomized clinical trial," *American Journal of Physical Medicine Rehabilitation*, vol. 95, pp. 256–269, 4 2016.

[6] B. Ferreira and P. Menezes, "Gamifying motor rehabilitation therapies: Challenges and opportunities of immersive technologies," *Information*, vol. 11, p. 88, 2020.

[7] S. Deterding, D. Dixon, R. Khaled, and L. Nacke, "From game design elements to gamefulness," pp. 9–15, ACM, 9 2011.

[8] S. Cao, "Virtual reality applications in rehabilitation," 2016.

[9] A. Heffernan, M. Abdelmalek, and D. A. Nunez, "Virtual and augmented reality in the vestibular rehabilitation of peripheral vestibular disorders: systematic review and meta-analysis," 2021.

[10] J.-J. Song, "Virtual reality for vestibular rehabilitation," *Clinical and Experimental Otorhinolaryngology*, vol. 12, pp. 329–330, 10 2019.

[11] A. P. Garcia, M. M. Ganança, F. S. Cusin, A. Tomaz, F. F. Ganança, and H. H. Caovilla, "Vestibular rehabilitation with virtual reality in ménière's disease," *Brazilian Journal of Otorhinolaryngology*, vol. 79, pp. 366–374, 5 2013.

[12] R. Teasell, M. J. Meyer, A. McClure, C. Pan, M. Murie-Fernandez, N. Foley, and K. Salter, "Stroke rehabilitation: an international perspective," *Topics in Stroke Rehabilitation*, vol. 16, pp. 44–56, 2009.

[13] A. Micarelli, A. Viziano, B. Micarelli, I. Augimeri, and M. Alessandrini, "Vestibular rehabilitation in older adults with and without mild cognitive impairment: Effects of virtual reality using a head-mounted display," *Archives of gerontology and geriatrics*, vol. 83, pp. 246–256, 8 2019.

[14] M. T. Schultheis and A. A. Rizzo, "The application of virtual reality technology in rehabilitation," *Rehabilitation Psychology*, vol. 46, pp. 296–311, 2001.

[15] J. E. Muñoz, M. F. Montoya, and J. Boger, *From exergames to immersive virtual reality systems: serious games for supporting older adults.* Elsevier, 2022.

[16] Z. Mihajlovic, S. Popovic, K. Brkic, and K. Cosic, "A system for head-neck rehabilitation exercises based on serious gaming and virtual reality," *Multimedia Tools and Applications*, vol. 77, pp. 19113–19137, 8 2018.

[17] D. L. Ines and G. Abdelkader, "Mixed reality serious games: The therapist perspective," pp. 1–10, IEEE, 11 2011.

[18] I. Doumas, G. Everard, S. Dehem, and T. Lejeune, "Serious games for upper limb rehabilitation after stroke: a meta-analysis," *Journal of NeuroEngineering and Rehabilitation*, vol. 18, p. 100, 12 2021.

[19] M. Xie, K. Zhou, N. Patro, T. Chan, M. Levin, M. K. Gupta, and J. Archibald, "Virtual reality for vestibular rehabilitation: A systematic review," *Otology Neurotology*, vol. 42, pp. 967–977, 8 2021.

[20] E. Viirre, "Vestibular telemedicine and rehabilitation. applications for virtual reality," *Studies in health technology and informatics*, vol. 29, pp. 299–305, 1996.

[21] E. Viirre, C. Draper, C. Gailey, D. Miller, and T. Furness, "Adaptation of the vor in patients with low vor gains," *Journal of vestibular research: equilibrium orientation*, vol. 8, pp. 331–354, 8 1998.

[22] E. Viirre and R. Sitarz, "Vestibular rehabilitation using visual displays: preliminary study," *The Laryngoscope*, vol. 112, pp. 500–543, 3 2002.

[23] A. L. Betker, T. Szturm, Z. K. Moussavi, and C. Nett, "Video game–based exercises for balance rehabilitation: A single-subject design," *Archives of Physical Medicine and Rehabilitation*, vol. 87, pp. 1141–1149, 8 2006.

[24] M. Pavlou, R. G. Kanegaonkar, D. Swapp, D. E. Bamiou, M. Slater, and L. M. Luxon, "The effect of virtual reality on visual vertigo symptoms in patients with peripheral vestibular dysfunction: a pilot study," *Journal of vestibular research: equilibrium orientation*, vol. 22, pp. 81–273, 2012.

[25] D. Meldrum, S. Herdman, R. Vance, D. Murray, K. Malone, D. Duffy, A. Glennon, and R. McConn-Walsh, "Effectiveness of conventional versus virtual reality–based balance exercises in vestibular rehabilitation for unilateral peripheral vestibular loss: Results of a randomized controlled trial," *Archives of Physical Medicine and Rehabilitation*, vol. 96, pp. 1319–1328.e1, 7 2015.

[26] J. H. Park, H. J. Jeon, E.-C. Lim, J.-W. Koo, H.-J. Lee, H.-J. Kim, J. S. Lee, C.-G. Song, and S. K. Hong, "Feasibility of eye tracking assisted vestibular rehabilitation strategy using immersive virtual reality," *Clinical and Experimental Otorhinolaryngoly*, vol. 12, pp. 376–384, 11 2019.

[27] B. L. Day and R. C. Fitzpatrick, "The vestibular system," *Current Biology*, vol. 15, pp. R583–R586, 8 2005.

[28] M. Fetter, *Vestibular System Disorders*. Wiley, 9 2010.

[29] Y. Agrawal, J. P. Carey, C. C. D. Santina, M. C. Schubert, and L. B. Minor, "Disorders of balance and vestibular function in us adults," *Archives of Internal Medicine*, vol. 169, p. 938, 5 2009.

[30] S. J. Herdman, P. Blatt, M. C. Schubert, and R. J., "Falls in patients with vestibular deficits," *The American Journal of Otology*, vol. 21, pp. 847–851, 11 2020.

[31] M. E. Tinetti, "Preventing falls in elderly persons," *New England Journal of Medicine*, vol. 348, pp. 42–49, 1 2003.

[32] M. E. Tinetti, D. I. Baker, M. King, M. Gottschalk, T. E. Murphy, D. Acampora, B. P. Carlin, L. Leo-Summers, and H. G. Allore, "Effect of dissemination of evidence in reducing injuries from falls," *New England Journal of Medicine*, vol. 359, pp. 252–261, 7 2008.

[33] R. T. Zhu, V. V. Rompaey, B. K. Ward, R. V. de Berg, P. V. de Heyning, and J. D. Sharon, "The interrelations between different causes of dizziness: A conceptual framework for understanding vestibular disorders," *Annals of Otology, Rhinology Laryngology*, vol. 128, pp. 869–878, 9 2019.

[34] H. Neuhauser, M. Leopold, M. von Brevern, G. Arnold, and T. Lempert, "The interrelations of migraine, vertigo, and migrainous vertigo," *Neurology*, vol. 56, pp. 436–441, 2 2001.

[35] T. Fife, "Benign paroxysmal positional vertigo," *Seminars in Neurology*, vol. 29, pp. 500–508, 11 2009.

[36] A. R. Bisdorff, "Management of vestibular migraine," *Therapeutic Advances in Neurological Disorders*, vol. 4, pp. 183–191, 5 2011.

[37] C. G. Lauritsen and M. J. Marmura, "Current treatment options: Vestibular migraine," *Current Treatment Options in Neurology*, vol. 19, p. 38, 11 2017.

[38] T. Nakashima, I. Pyykkö, M. A. Arroll, M. L. Casselbrant, C. A. Foster, N. F. Manzoor, C. A. Megerian, S. Naganawa, and Y.-H. Young, "Meniere's disease," *Nature Reviews Disease Primers*, vol. 2, p. 16028, 5 2016.

[39] J. Harcourt, K. Barraclough, and A. M. Bronstein, "Meniere's disease," *BMJ*, vol. 349, pp. g6544–g6544, 11 2014.

[40] H. Sajjadi and M. M. Paparella, "Meniere's disease," *The Lancet*, vol. 372, pp. 406–414, 8 2008.

[41] R. F. MOGAN and C. J. BAUMGARTNER, "Meniere's disease," *Archives of Otolaryngology - Head and Neck Surgery*, vol. 41, pp. 113–116, 2 1945.

[42] B. I. Han, H. S. Song, and J. S. Kim, "Vestibular rehabilitation therapy: Review of indications, mechanisms, and key exercises," *Journal of Clinical Neurology*, vol. 7, p. 184, 2011.

[43] F. S. Cooksey, "Rehabilitation in vestibular injuries," 1946.

[44] T. Cawthorne, "Vestibular injuries," 1946.

[45] A. dos Santos Bersot Ribeiro and J. S. Pereira, "Balance improvement and reduction of likelihood of falls in older women after cawthorne and cooksey exercises," *Brazilian Journal of Otorhinolaryngology*, vol. 71, pp. 38–46, 1 2005.

[46] H. Rasteh, G. Olyaei, M. Abdolvahab, M. Jalili, and S. Jalaei, "Efficacy of cawthorne amp; cooksey exercise on balance improvement in elderly persons in mashhad," *Journal of Modern Rehabilitation*, vol. 3, pp. 49–53, 2009.

[47] S. Corna, A. Nardone, A. Prestinari, M. Galante, M. Grasso, and M. Schieppati, "Comparison of cawthorne-cooksey exercises and sinusoidal support surface translations to improve balance in patients with unilateral vestibular deficit.," *Archives of Physical Medicine and Rehabilitation*, vol. 84, pp. 1173–1184, 8 2003.

[48] A. F. Abarghuei, M. Fadavi-Ghaffari, S. Tousi, M. Amini, and A. R. Salehi, "Effect of cawthorne and cooksey exercises on balance and quality of life of 60 to 80 year- old individuals in shiraz: A randomized clinical trial," *Medical Journal of The Islamic Republic of Iran*, vol. 32, pp. 429–433, 10 2018.

[49] M. C. Schubert and S. L. Whitney, "From cawthorne-cooksey to biotechnology: Where we have been and where we are headed in vestibular rehabilitation?," *Journal of Neurologic Physical Therapy*, vol. 34, pp. 62–63, 6 2010.

[50] M. Lacour and L. Bernard-Demanze, "Interaction between vestibular compensation mechanisms and vestibular rehabilitation therapy: 10 recommendations for optimal functional recovery," *Frontiers in Neurology*, vol. 5, 1 2015.

[51] H. Tannous, D. Istrate, M. H. B. Tho, and T. Dao, "Feasibility study of a serious game based on kinect system for functional rehabilitation of the lower limbs," *European Research in Telemedicine / La Recherche Européenne en Télémédecine*, vol. 5, pp. 97–104, 9 2016.

[52] E. Biddiss and J. Irwin, "Active video games to promote physical activity in children and youth," *Archives of Pediatrics Adolescent Medicine*, vol. 164, 7 2010.

[53] T. Baranowski, R. Buday, D. I. Thompson, and J. Baranowski, "Playing for real," *American Journal of Preventive Medicine*, vol. 34, pp. 74–82.e10, 1 2008.

[54] E. A. Boyle, T. M. Connolly, T. Hainey, and J. M. Boyle, "Engagement in digital entertainment games: A systematic review," *Computers in Human Behavior*, vol. 28, pp. 771–780, 5 2012.

[55] M. van Diest, C. J. Lamoth, J. Stegenga, G. J. Verkerke, and K. Postema, "Exergaming for balance training of elderly: state of the art and future developments," *Journal of NeuroEngineering and Rehabilitation*, vol. 10, p. 101, 2013.

[56] S. Arnab, P. Petridis, I. Dunwell, and S. de Freitas, *Enhancing Learning in Distributed Virtual Worlds through Touch: A Browser-based Architecture for Haptic Interaction.* Springer London, 2011.

[57] A. Fleet, S. J. Page, M. MacKay-Lyons, and S. G. Boe, "Modified constraint-induced movement therapy for upper extremity recovery post stroke: What is the evidence?," *Topics in Stroke Rehabilitation*, vol. 21, pp. 319–331, 7 2014.

Appendix A

Clinical Opinion

Declaração

O mestrando André Gameiro Marques revelou uma notável capacidade de realização do projeto pretendido, conseguindo através de simples ideias chegar a um produto final totalmente capaz de vir a ser utilizado na área da reabilitação vestibular de pacientes com queixas de vertigem e tonturas.
Penso que se trata de um excelente aluno/ profissional que cumpriu com dedicação, interesse, rigor e competência a tarefa a que se tinha proposto.
O enriquecimento que trouxe para esta área é de extrema importância e como clínica penso que pode vir a ajudar muitos pacientes.

Coimbra, 29 de abril, 2023

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