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Emanuel Santos Pereira

A VR-Based Serious Game for Vestibular Rehabilitation

Dissertation submitted to the Department of Electrical and Computer Engineering of the Faculty of Science and Technology of the University of Coimbra in partial fulfillment of the requirements for the Degree of Master of Science

July 2021

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Coimbra, July 2021

This work was developed in collaboration with:

Imagination is more important than knowledge. Knowledge is limited. Imagination encircles the world.

Albert Einstein

Dedication

This dissertation is the result of several years of work and learning at the school and personal level. However, and despite the difficulties encountered that so many headaches gave, it was done next to amazing people that I had the pleasure to meet during my academic career, both students and teachers, and personally with the company and support of friends family. So, although many times they don't even realize the support they gave me, my work is dedicated to them. For my supervisor Paulo Menezes, who has always been willing to help in any difficulty and always guided me in the right direction. For my unofficial co-coordinator, Bruno Ferreira, who started this study and has always been willing to help and spend hours chatting with me on any necessary subject. For my girlfriend, Andreia Carvalho, who always supported me by complaining to me to do things but also for being the best companion someone could ask for. For my friends Mário Teles and Rafael Rebelo, friends who always know when a person needs to go for a drink to refresh their ideas, and João Bondoso, who is ever available for a day fishing without thinking about anything else. To my sister Inês who always supported me and showed me that it is possible to achieve dreams if we fight for them. To my grandparents, who always filled my purse and wallet, but above all, always believed in me and gave me all their support. And above all, to my parents Maria Fernanda and Manuel Antonio, for all their love and affection, for always believing that I was capable of anything and implanting in me their exemplary values, but above all, for the enormous support they were. To them, I dedicate everything.

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Abstract

Gaze and postural control are two essential functions of the human being. The system that controls these senses is the vestibular system, and when some dysfunction is present, vertigo, dizziness, and imbalance can occur. However, there are ways to decrease and control the problem, through vestibular rehabilitation. By repeating exercises that involve moving the head and eyes in various directions, either in the same or opposite directions, it is possible to adapt, habituate, or retrain our brain so that the vestibular functions are restored, and the person can go back to doing basic everyday tasks.

However, the rehabilitation process is long, requiring many repetitions of the same exercises, which makes people lose motivation and interest because they do not see results in a short time. Thus, gamification of exercises has become an increasingly recurrent process in an attempt to stimulate patients. This project focus on developing an immersive virtual reality application to be played on a cell phone to combat this lack of interest and commitment to rehabilitation. The game interaction is through head movements simulating those used in vestibular treatment so that some entertainment is being provided while doing the therapy.

An in house website has been modified to allow the therapist to analyze the patients' progress so that it is possible to see through graphs the evolution over time of each of the patients. Some control tests were also carried out to analyze the performance and effectiveness of the application, resulting in very positive reviews from all involved.

Keywords: Serious games, Virtual Reality, Rehabilitation, Vestibular dysfunction

Resumo

O olhar e o controlo postural são duas funções básicas do ser humano. O sistema que permite controlar estes sentidos é o sistema vestibular que, quando apresenta alguma disfunção, resulta em vertigens, tonturas e desequilibrio. No entanto, há maneiras de diminuir e controlar os sintomas, através de reabilitação vestibular. Recorrendo a exercicios que envolvem mover a cabeça e os olhos em várias direcções, quer seja no mesmo sentido ou em sentidos opostos, é possível adaptar, habituar, ou reensinar o nosso cérebro para que as funções vestibulares sejam repostas e a pessoa possa voltar a fazer tarefas básicas.

O processo da reabilitação é, no entanto, um processo longo e que requer muitas repetições dos mesmos exercicios o que faz com que as pessoas percam a motivação e o interesse por não verem resultados a curto tempo. Assim, a gamificação dos exercicios tem vindo a ser um processo cada vez mais recorrente na tentativa de estimular os pacientes. Este projeto focou-se no desenvolvimento de uma aplicação imersiva de realidade virtual para ser jogada num telemóvel e que tem como objectivo combater esta falta de interesse e compromisso para com a reabilitação. A interação com o jogo é através de movimentos de cabeça iguais aos utilizados no tratamento vestibular pelo que está ser providenciado algum entertenimento ao mesmo tempo que se faz a terapia.

Para permitir ao terapeuta analisar o progresso dos pacientes, um website interno foi modificado de modo a ser possível ver através de gráficos a evolução ao longo do tempo de cada um dos pacientes. Foram ainda realisados alguns testes de controlo que permitiram analisar o desempenho e a eficácia da aplicação resultando em análises bastantes positivas de todos os envolvidos.

Palavras-chave: Jogos sérios, Realidade Virtual, Reabilitação, Disfunção Vestibular

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1

Introduction

Keeping the body in balance and having the ability to orient are two basic and essential aspects of any vertebrate. For these abilities to work, constant control of the trunk and head are needed, emphasizing the control of the head in relation to the trunk. Three sensory systems are crucial to these abilities: vision, proprioception, and vestibular function. The result of this complex sensory integration enables gaze and postural stabilization [1]. Through vestibulo-ocular reflexes (VORs), the vestibular system maintains stable and clear vision during rapid or unintentional head movements by generating an immediate compensation to the eye movements, thus maintaining a stable image on the retina [2].

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[3]. The most commonly reported direct symptoms of peripheral system problems are imbalance, vertigo, dizziness, and oscillopsia. There are, however, also associated indirect symptoms such as depression, loss of concentration, limitation of social life, and a general reduction in quality of life[4]. Therefore, proper treatment and rapid response to the problem are essential for a good and faster recovery.

Statistics show that 33% of the population aged more than 65 years experiences fall, and two-thirds of accident deaths are because of that. Once the vestibular disorder is the main reason for adult instability, balance training is the best method to reduce the falls when the outdoor environment changes [5].

Despite being a complex problem to recover from, our brain comprises the ability to adapt its structure by establishing novel or remapping the existing neural pathways. Hence, a patient can recover from partial to full of the lost capabilities and resume with the daily activities as usual. [6].

Still, even with treatment in rehabilitation clinics, 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, gamification of the exercises that are typically recommended has started to be implemented [7]. Therefore, Virtual Reality (VR) serious games have been introduced to assist the conventional rehabilitation therapies and provide a more enjoyable experience. When treatments become centered on pleasure instead of the usual boring and uncomfortable exercises, they increase patients' engagement and commitment to their recovery process.

Compared to other works that focus a lot on balance training proposals [8], this work consisted of developing a VR-based game that takes the patient-user to perform some of the exercises typically prescribed by physicians for home practice.

1.1 Related Work

To show the current state of the art and how new technologies are increasingly being implemented in rehabilitation, some of the works carried out in recent years are presented below.

The discussion about the use of VR in Vestibular Rehabilitation started at the beginning of the '90s by Viirre [9], [10], and Kramer *et al.* [11]. They suggested that using VR in persons with vestibulo-ocular disorders could improve the success rate of recovery by better adapting the scenarios used in therapy.

At the University of Pittsburgh, in 2002, Whitney *at al.* [12] proposed that exposure to visual experiences and movement is the best way to recover in persons with vestibular disorders. People with vestibulo-ocular disorders can be affected by up to 75% moving the head to the injured side and up to 50% on the opposite. So, instead of having therapy, they usually try to adapt to the problem by moving their body where they want to look instead of turning their head as they are supposed to because it causes discomfort. However, it is a weak way of achieving long-term recovery compared to those on therapy who demonstrate less disability. Two years after, the relationship between motion sickness and VR was studied by the same team [13]. Was mentioned that people with vestibular disorders complain of visual vertigo (e.g., fear of heights) and space and motion discomfort that it's felt, for example, in supermarkets, car/train movements, and long visual distances. Using a VR simulator, people with vestibular disorders went exposed gradually to symptom-provoking situations in a controlled environment and was proved that the first uses of this system could proportionate a high level of nausea and discomfort. However, the outcome was that, the more often it is used, the less the indisposition will be.

Also Meldrum *et al.* [14] studied the effects of gait impairment, balance, dizziness, vertigo, and dynamic visual acuity to compare the effectiveness of conventional therapy versus VR in vestibular rehabilitation. They also quantified the patients' satisfaction and adherence. Participants with unilateral vestibular disorder and without any other neurological problem were randomly distributed by the two therapy methods to perform the tests. An intermediary analysis was made at eight weeks, and the final one was after six months [15]. In both cases, the primary outcome analyzed was the gait speed followed for the rest of the impairments. The conclusion was that there were no significant differences between the two methods for Vestibular Rehabilitation in patients with unilateral peripheral vestibular loss. However, with VR-based exercises, the experience was a much more enjoyable and less challenging method of balance retraining.

Another example that uses VR in vestibular rehabilitation is Ménière's disease. To verify the effects of VR stimuli in a balance body program in this disease, VR goggles produce 3D situations that trigger dizziness or vertigo and a balance rehabilitation unit to evaluate the patient's position. The sessions were performed twice a week for six weeks and comparing the case and control groups, it was verified that the case group had a significant quality of life increased, proving that VR is an efficient method also in Ménières's disease rehabilitation [16]..

More focused in this project proposal, Micarrelli *et al.* [17] has been developing applications and testing them using Head-Mounted Displays (HMD). In 2017, using a mobile application that simulated a race and where the person had to tilt his head to control the game, was concluded that the use of these systems had a promising future for maximizing the effects of vestibular rehabilitation. In 2019 the long-term results of the article mentioned above were published. After one year of use, it was possible to conclude that using a hybrid system between VR and traditional therapy can bring better results than traditional rehabilitation alone [18].

Taking into consideration stories of attacks experienced by patients suffering from vestibular disorders, Lubetszky *et al.* [19], were developed four scenarios that simulate everyday spaces that people tend to be afraid to walk through because of a large number of people causing confusion and discomfort. Using a VR headset that tracks people's walking in space , even though it is in a limited zone, and simulating the same route in the scenario, was also concluded from initial analysis that this type of system produces good results in recovery.

Delgado *et al.* [20] recently conducted a general analysis of where things stood regarding the use of VR using HMDs. The conclusion was that, at the time of publication, there are not enough articles proving whether the use of these systems is adequate. However, with the few reports available, it is possible to say that using this technology can bring reliable results regarding balance recovery and gait.

After reviewing these and other articles, it was concluded that there are not many works developed in this area, especially when it comes to mobile applications for VR devices that people can use anywhere. However, it was possible to verify the potential of this type of implementation to aid in the recovery of people affected with vestibular disorders. Also, the time spent in virtual training is critical for a good and rapid rehabilitation.

1.2 Main Contributions

Considering the above state of the art, the project presented here aims to provide people who are undergoing vestibular rehabilitation with a tool to help them in the recovery process. The work described focuses on developing a Virtual Reality cell phone application that focuses on therapeutic exercises and provides fun and excitement while performing the exercises.

Furthermore, the game information is stored so that the therapist can monitor the development of each patient for a better adjustment of therapy.

1.3 Dissertation Structure

This dissertation has the following organization:

- **Chapter 1** is where the importance of this study and the advantages over the work done so far is explained.
- **Chapter 2** describes how treatments are currently performed and how they can be adapted for VR.
- **Chapter 3** shows the entire structure of the games and everything that is integrated, and how they were developed. Finally, the graphical interface that is available on the therapists backoffice is shown.
- **Chapter 4** presents the preliminary results obtained from some tests performed on the application.
- **Chapter 5** discusses the results and the evaluation of a specialist therapist in the area.
- **Chapter 6** is the conclusion of the dissertation, summarizing all the work done.
- **Chapter 7** presents some of the future work relevant to the field that could be implemented.

2

Fundamentals

2.1 Patient Condition

Vestibular system disorders are affecting a very significant number of people with consequences in their lives [8]. The vestibular system is located in the inner ear and composed of a structure including three semicircular canals responsible for sensing rotational movements and the otoliths sensitive to linear accelerations. Together with the eyes, it provides the necessary information for the brain to control the muscles to keep the body stable. When problems occur with these sensing mechanisms, is common feel dizziness and nausea, and balance can be affected [21]. However, most people try to accept the problem in their lives, assuming it as a simple dizziness instead of seeking professional help. Thus, temporary damages become permanent as time goes by since proper rehabilitation procedures are not carried out and it can provoke psychological and physical problems.

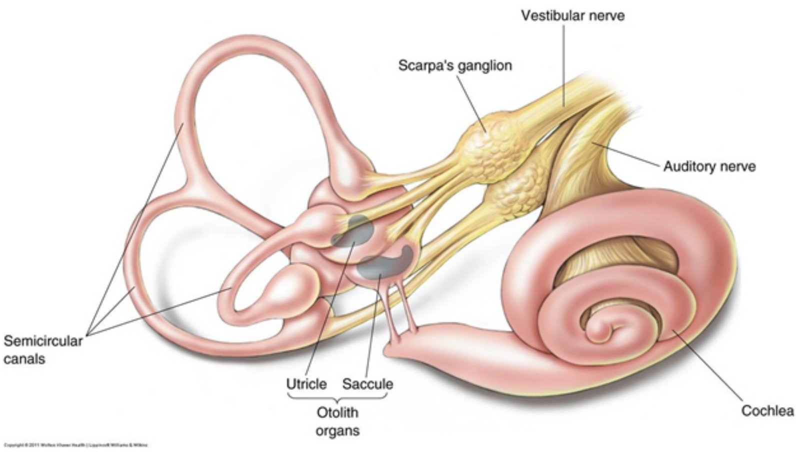


Figure 2.1: Vestibular System [22]

Benign Paroxysmal Positional Vertigo (BPPV) is the most prevalent vestibular disorder, accounting for around one-third of all cases. Approximately 35 percent of United States of America individuals aged 40 and up had symptoms of balance impairment, according to statistics from 2001 to 2004. This number rises with age, reaching 85 percent of those in their eighties. [23]. This pathology has vertigo as its main symptom and is caused by erroneous signals sent through the semicircular canal that create an illusion of movement. BPPV can appear in any of the three channels, but between 80-90% of cases are found in the superior channel because it is the part in the vestibular labyrinth that is most gravity-dependent [24]. Consequently, when the head moves with respect to gravity, it can provoke an episode of vertigo that usually lasts less than a minute [25].

Another common case is identified as Ménière’s disease and is described as a disorder of the inner year characterized by intense vertigo, intermittent hearing loss, feeling of ear filling (ear pressure feeling), and tinnitus (ringing noise in the ear). Each outbreak can take from 20 minutes to 24 hours, and the time between episodes varies in days, weeks, and even years [16].

2.2 Vestibular Rehabilitation Principles

Rehabilitation is a necessary process to allow those who suffer from vestibular injuries to return to everyday life. As mentioned in Chapter 1, it is a slow process that must begin as soon as possible to achieve the desired results. The main goals of vestibular physical therapy are to improve gaze stabilization and postural control, reduce vertigo episodes, and increase the overall quality of life.

Three mechanisms are essential in recovery [25]:

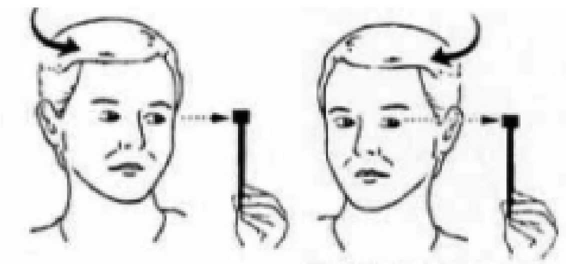
- **Adaptation:** focused on head movements to stimulate the remaining vestibular systems. It aims to increase gaze stability, reduce dizziness, and thus improve balance. For patients with VOR, vertical and horizontal head movements are used with gaze fixation at a given point.

- **Habituation:** exposing patients to scenarios that cause discomfort. The purpose is to reduce the effects caused by provoking stimulus situations through repeated exposure. It is one of the most recommended exercises to do at home.

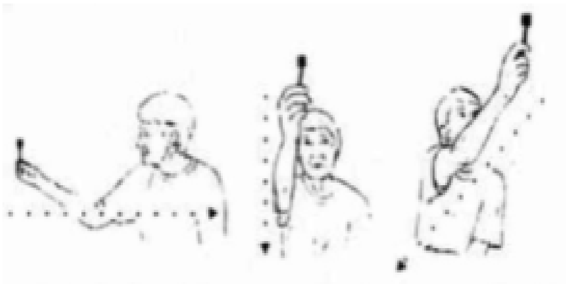
- **Replacement:** retraining the vestibular system. It allows patients to increase postural control by using other sensory systems to prevent, for example, falls. Visual or somatosensory signals can thus replace vestibular functions.

2.3 Therapeutic Procedures

Gaze instability is one of the problems that can occur due to the decreased gain of the vestibular response to head movements. Therefore, the best stimuli for recovering it into normal conditions is performing a visual process called retinal slip. Retinal slip is defined as the image motion on the retina during head movements and can be induced by horizontal/vertical head movements while maintaining visual fixation on a target [26] as can seen in figure below. In addition to these two exercises, it is also recommended to tilt the body, while sitting, in order to touch the floor on both sides (diagonal moves).



(a)



(b)

(c)

Figure 2.2: Head movements examples for vestibular rehabilitation: a) move head with eyes fixed on a target, b) moving object with head and eyes following in the same direction, c) moving object with head and eyes following in the opposite direction

Gait and balance rehabilitation requires motor learning. Therefore, practice and feedback are two critical factors to the patients, and in the conventional therapy that is not available [14].

Rehabilitation itself is a long process that is divided into several steps: evaluation of the patient, setting objectives to improvement, assistance to reach the purposes, and re-evaluation to confirm if the goals have been achieved [27]. It is a time-consuming process that frustrates most people, especially if the detection and rehabilitation process is done too late. [28].

Although being a lengthy process, people who start rehabilitation as soon as possible, and with the right motivation, can show better results [28]. However, when most of the work is done at home, the biggest problem is that people tend to lose interest quite fast, resulting in a slower recovery process and, consequently, delaying the return to the execution of ordinary activities.

One device that has been used in recent years is the DizzyFix^{TM} (Clearwater Clinical Ltd; Canada). This device is shaped like a semicircular canal and its objective is to give the person the autonomy to perform Epley's maneuver at home. This maneuver is an exercise widely used in the vestibular treatment that consists of rotating the head while lying down to stimulate the semicircular canal [29].

Figure 2.3: DyzzyFix device [29]

The recommended gaze stability exercises, according to Herdman *et al.* [30], should be done four to five times daily for a total of twenty to forty minutes per day, in addition to twenty minutes of balance and gait exercises.

From several works presented in the past, every single one states that home exercises are critical to a better outcome. Without that "homework", healing can be sluggish and, in some cases, incomplete, resulting in long-term consequences.

3

Approach

Up to this chapter, we have presented the work developed by other researchers and how the therapeutic process of vestibular rehabilitation is carried out. In this section, the project development and the entire process will be presented.

As described in the previous section, several types of exercises can be performed for vestibular rehabilitation. In a first approach three exercises were selected to be adapted for serious gaming: horizontal, vertical, and diagonal movements, with head and eyes following the same direction.

Serious games have the purpose of teaching or (re)teaching some skill to those who play them, but always keeping in mind the competitive and fun part that a game has [31]. To make serious games, some factors must be considerate:

- **Entertainment:** the game has to stimulate users to don't lose interest and stay excited while in the virtual world.
- **Serious part:** being games with a purpose, this has to be the main factor to consider because the final result needs to have effects that help in the patient's recovery.
- **Variety of scenarios:** it is essential to have a change in the designs throughout the game; if the environment is the same from beginning to end, people tend to lose interest
- **Happiness:** this point is linked to the previous one; when making the variety of scenarios, it is necessary that these are designed with happy colors and good light to stimulate the joy of the use.

- **Competitiveness:** like any game, people need the motivation to want to play and do their best. It was thinking about this point that the ranking system was implemented, thus triggering the humans' competitive part.

3.1 Requirements definition

Systems requirements are the base of any project and must be carefully defined; they are divided into functional, that should explain the system's behavior, and non-functional requirements, which specify how the system should do it without affecting the functionality. Two specialists were contacted to obtain the maximum information possible for a better job and an even better final result; the first was a specialist in vestibular dysfunction, and the second in post-stroke rehabilitation. The obtained requirements tables will be presented next.

Requirement	Description
1	User Management
1.1	Login
1.2	Register new user
2	Settings
2.1	Change game language
2.2	Select starting difficulty
2.3	Select playing mode, i.e., user's point of view and representation (object)
2.4	Add or modify provided therapist's code
3	Games
3.1	Select the desired game
3.2	Visualize high-scores
3.3	Dynamic Level Adaption
3.3.1	Generate the trajectory of the objects according to the user's selection among the available games and starting level difficulty
3.3.2	Increase difficulty after a desired time slot (45 seconds)
3.4	Stop playing
3.5	Show playing time and user's score

Table 3.1: Game functional requirements

Requirement	Description
1	Clean and friendly user interface.
2	The experiment should not cause any harm to the player.
3	The game should be enjoyable, giving a sense of entertainment and fun.
4	Small size application.
5	Reduced computational requirements for making it adequate for a smartphone.

Table 3.2: Games Non-Functional requirements

The therapist's graphic interface also needs to meet some requirements. The following tables will present these requirements.

Requirement	Description
1	Initial Page
1.1	Login
1.2	Register new therapist
2	Therapist page
2.1	List all patients
2.2	Search patient
2.3	Confirm selection
3	Patient page
3.1	Change patient information
3.2	Select game to analysis
3.3	Change time interval
3.4	Visualize graphs in compressed or uncompressed format
3.5	General information about each user game session
3.6	Visualize graphs with score and time played by day

Table 3.3: Website Functional requirements

Requirement	Description
1	Good performance and response time.
2	Must be available all the time.
3	Clean and friendly interface.
4	Easy access to all functions.
5	Detailed charts for better analysis.

Table 3.4: Website Non-Functional requirements

3.2 Interaction

The game development was carefully thought out, and one of the aspects taken into account was the interaction that the user will have while playing. This section will explain how this happens and why it is the way it is.

The development was performed in Unity, which is the world's most used cross-platform game engine, created by Unity Technologies. The main reason to choose that platform is the ease of use and the possibility to export for multiple platforms without significant development changes. Once this platform works with objects that can be used by drag and drop after being created, it was possible to make two projects almost simultaneously using some of the same objects in both of them. The game dynamics are scripted in C#, a fast and efficient object-oriented language based in C++ [32].

Considering the application's target audience, the interaction has to be easy, intuitive, and easily accessible. Therefore, the buttons were one of the first things created. The size was an essential factor analyzed to allow an easy selection and can't be too small to be challenging to select, nor too big to be too close together. Taking advantage of Unity, which allows scaling any object very quickly, it was possible to test various dimensions until a size considered ideal. This is useful in the initial menus, where the iteration is done in a 2D mode that uses screen touches.

When this changes to a 3D scenario, the mobile Inertial Measurement Unit provides the information needed to control the camera motion.Then, since no external cell phone controllers are used, with the help of a reticle point (a red spot) located in the center of the screen, the user gets a better orientation inside the game. The only requirement is to own Virtual Reality glasses, like Google Cardboard (Figure 3.1), a cheap device that proportionate a VR experience using the smartphone's screen.

Figure 3.1: Google Cardboard

Through head movements and the point mentioned above, the selection dispenses buttons and is made by fixing the gaze on a specific object that reacts to the interaction. An example is shown in the images sequence present in figure 3.2 and shows how the game selection is performed. Identified with a circle that fills up over time, the player is pulled into the game to start after two seconds. A frame is also shown around the selected object, so it is easier to identify the game that is being chosen, and it also identifies the selectable area that has a good margin to make it easier to center the point in the desired location.

Figure 3.2: Game selection interaction

3.3 Game Developed: RehabSeriousGames

3.3.1 Game Scenarios

The game is divided into scenarios in which one has a different purpose. Therefore, this game has two major divisions:

- **Initial menus:** constituted by the main menu, where is choose the player that will perform the game and the game difficulty, the login/register menu, where the login is made, or the creation of an account to play, the settings menu, where it is possible to choose the game settings, and a warning page to inform about the VR safety recommendations.
- **VR games:** formed by the games menu, place to choose the game to play, and the games themselves.

When the transition between these two parts is made, a message informing to insert the smartphone in the headset is shown, and the player has ten seconds to perform that action before the first 3D scene loads. Once the opposite can also happen, the same message appears, but informing to remove the mobile phone.

3.3.1.1 Main Menu

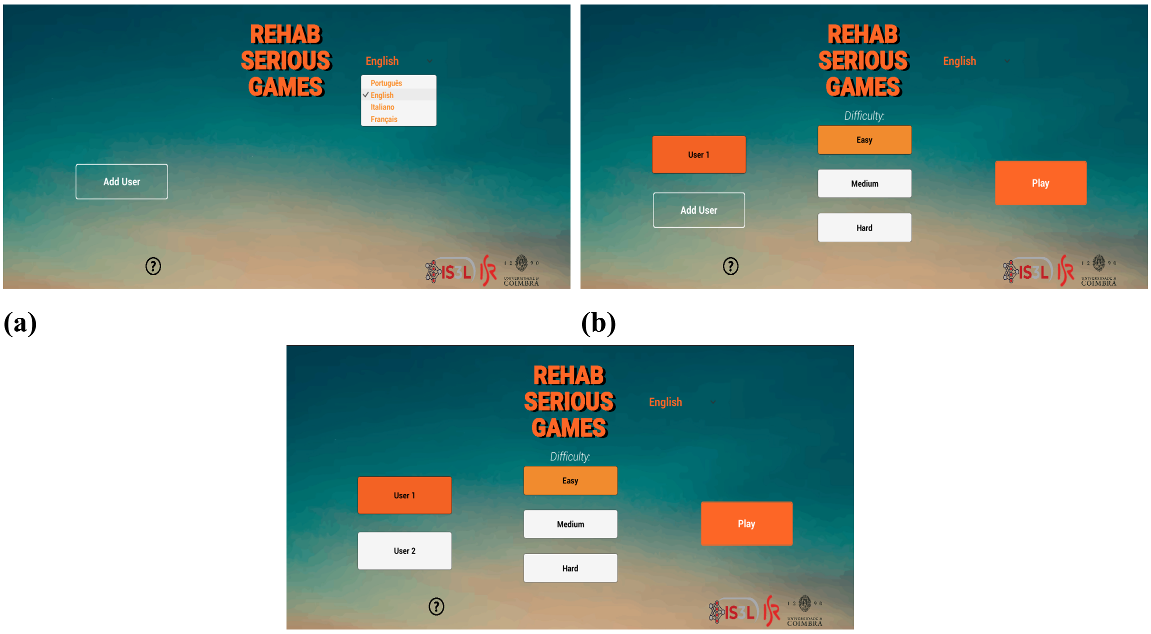
The main menu is the first scenario that is shown.

The first thing that is possible to do is select the game language between the four available: Portuguese, English, Italian, and French. By default, the pre-selected is the one default for on the cell phone. The one chosen in this menu is the one that will be present in the rest of the game and only can be changed if the player returns to this menu. The language can be selected in a dropdown, and the selected one stays visible to the user.

This page’s primary purpose is to allow the users to select their account, to enable them to play with their data, and choose the game starts difficulty. Furthermore, any device can have two users’ accounts simultaneously, considering that one of the game objectives is to promote entertainment while the therapy is done, the possibility of the healthy family members also have an account to encourage the diseased member to perform the exercises is a great advantage.

Choose starting difficulty is also essential for people in a more advanced stage of recovery. This is a game without an end so the run begins with a low speed that increments at each level, which can be boring for people who want to start in a more advanced stage. That way, it is possible to choose between three different start levels to increase the initial speed: easy (level 1), medium (level 3), and hard (level 5).

To add a user to the game, when are less than two players logged in, a button is visible on the left of the screen to redirect to the page where the login is made; the page and process will be explained ahead. Once the device already has two users connected, the button to add more disappears because it has reached the maximum allowed.



(a) **(b)** **(c)**

Figure 3.3: Main menu screens: a) without users, b) with one user, c) with two users

Information about the developers' team and where the game went created is also possible to check by click on the interrogation icon located in the bottom left. The message that the users see is presented in figure 3.4. All the logos of the institutions involved in this project are also visible on the primary screen bottom.

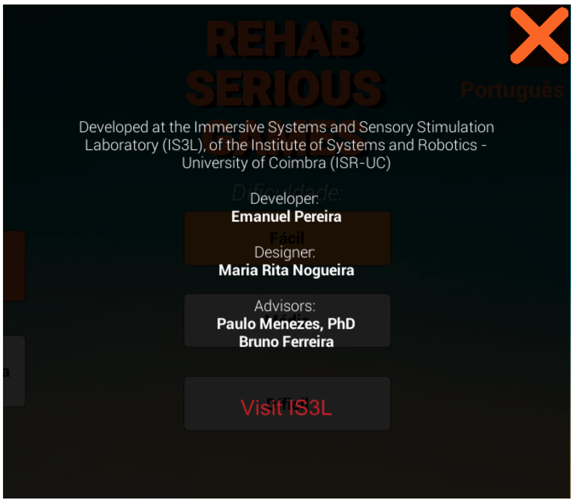


Figure 3.4: Game developers team and information shown in the game

3.3.1.2 Login and Register

All the users need an account to perform the game. This chapter will explain all processes, including the database integration and how the information is stored.

As the name implies, the login page allows the user to log in to his account with a username/email and a password registered. After introducing the personal account identification, only needs to press the *Login* button that is below the input fields, and a search is made to find the account. If the username or email is not found or doesn't match with the password, a message saying ”Username or password incorrect” is shown. All this part of the game is protected against mistakes with simple informative texts that inform that something is wrong. Another example is when the player presses the confirmation button with some of the parameters empty; a message saying ”Empty field” appears on the screen. The same happens when the user tries to log in with the same account that already is logged in; he is informed that ”User already logged in”.

Considering that all the fields are correctly completed, the game return to the main menu with the player name attributed to one of the two buttons available to play. Simultaneously, a local JSON is created with the user information loaded from the database. That way is possible to keep associating the sessions to each player. When it has an internet connection, the data is continuously uploaded to the database with a correct link between session and player.

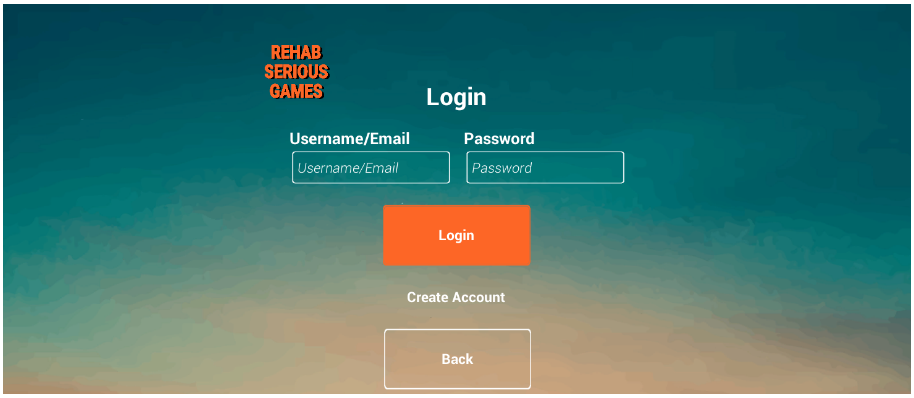


Figure 3.5: Login menu

None of this last part makes sense without a register. For that, the user can register in the game by pressing the button *Create Account* located under the login confirmation.

To create an account has some general information parameters that can be mandatory and others that are asked to be used only in this game. The required fields are:

- **Name:** player's identification name;
- **Username:** unique parameter that identifies the user, which means that no one can create an account with the same username as an existing one;
- **Email:** personal email to contact if needed, also unique;
- **Password:** to secure the users account, it is shown by asterisks for privacy and encrypted when saved;
- **Repeat password:** prevent users from writing something wrong on the first try and can't remember later, also represented by asterisks.

As optional is:

- **Birthday date:** Users birthday date to show his age;
- **Gender:** only informative, selectable by toggle buttons to an easy interaction;
- **Therapist's code:** Code associated with a single therapist to a later session analysis by the rehabilitation responsible.

As in login, all these fields are protected against mistakes. If any mandatory field is empty, a message with ”Empty field” is shown; if the email or the username isn’t unique or the passwords didn’t match, the user is also informed about it.

Completing all the fields, the user presses the button *Create Account* located at the base, and all the information is stored in the database to allow the login and then play games with his data.

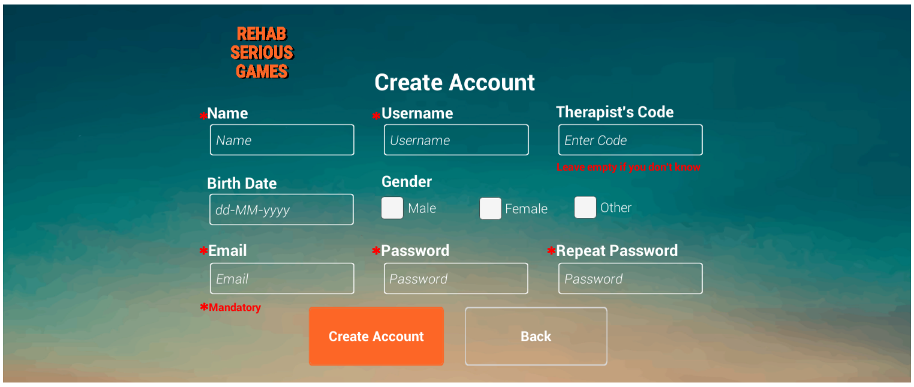


Figure 3.6: Register menu

3.3.1.3 Settings Menu

Keeping the user entertained is one of the main goals when developing a game, whether serious or not. One of the ways to do this is by using different interactions so that it doesn’t become repetitive and, consequently, boring so that the person stops feeling interested in playing.

To oppose these issues, the game was developed with two different interaction modes:

- **First-person view:** where the user moves through the game without anything appearing in front of them, except the objects in the game. Only a red dot is visible, indicating the center of the screen for better orientation.

- **Third-person view:** a player controls a dummy that appears in front of him, and it is with this dummy that he has to collect the points. In this game, two controllable objects have been added:

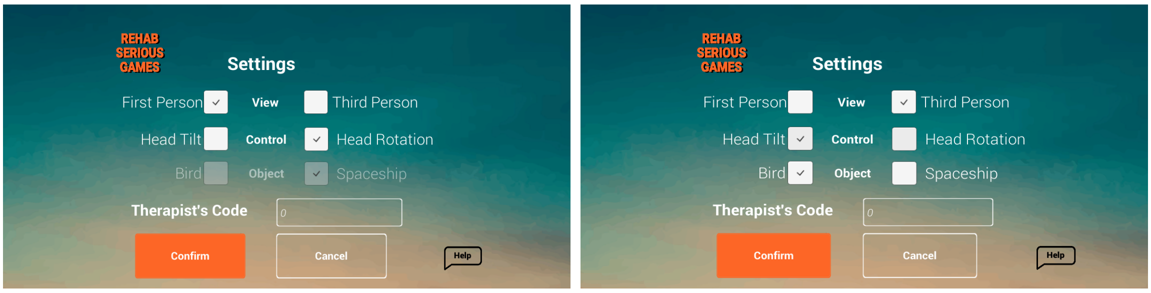
  - **Bird:** is a bird in constant flapping motion that simulates a funny death when the user loses.

– **Spaceship:** aims to present another option for the user to vary. In this case, it does not have any animation.

Regarding the entertainment part of the games, these are the options developed to allow the application to be used in different ways, even though the games themselves are the same. Changing some detail makes the human brain automatically gain another excitement, and this is what was tried to take advantage of for the choice of game modes.

Another aspect to consider is the therapeutic methods applied in conventional therapy. As mentioned earlier, some of the various exercises performed are through rotation or tilting of the head. Thus, there is also the option of choosing between control the game by rotating the head around the vertical axis or around the forward axis

It is then in this settings menu that all this is selectable using checkboxes. In the case of interactions, if is selected to play in the first-person view, the object selection options are disabled. However, if the third-person perspective is selected, they are enabled, allowing the user to choose between the two options provided. Likewise, the choice for the way the game is controlled is independent, so it is always available to be chosen.



(a) **(b)**

Figure 3.7: Settings Menu: a) with First Person View, b) with Third Person View

The code that associates a patient with a therapist is essential when the player is followed by one. That way, it is possible for the therapist to monitor the patients' improvements, mainly at-home exercises, thru the study of the many sessions performed. To analyze these sessions, the therapist has access to a web interface explained in section 3.4.

So, this point is essential to everyone that is making some recovery. Once the therapist can know if the patient is improving, it is possible to give some feedback to achieve better therapy results. However, as said before, this point isn't mandatory when the registry is performed to allow other people to play the game.

Another thing that can happen is the user forgets the number that must insert. To prevent that and don't stop them from continuing playing, even without any therapist association, it is possible to add this code later. In the settings menu bottom, if has an internet connection, otherwise the input will not be interactable, it is possible to change/add the code that associates him to a therapist. Doing that, even the sessions that already went performed can be checked by the therapist.

If a code is inserted and matches some existing therapist, a message with the therapist's name associated with the number entered is displayed to ensure that the person doesn't enter the wrong number. After confirming, it is uploaded to the user's data in the database, and the local JSON file is also updated.

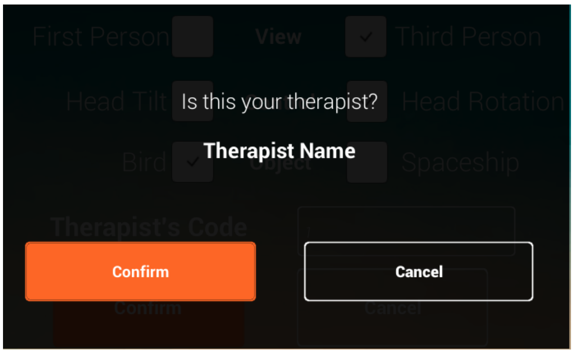


Figure 3.8: Check therapist name

3.3.1.4 Surveys

The next page that can appear is the surveys one. The developers must regularly follow an application, mainly one with therapeutic purposes. One way to do that is by asking the users how they feel and what they think can be changed through System Usability Scales, for example, forms to analyze the system functionality given the players' opinion. This page only is displayed if it has any form in the database that the players meet the minimum requirements to perform that. That way is possible to manage which surveys appear to the users complete. As some forms must need some experience using the app, the minimum sessions are the number of sessions that each user must complete before asking a specific formulary.

If all the requirements are accomplished, the page is then loaded and is asked the user to fill the currently available form. At this point, three options are given: answer now, ask later, and don't answer at all.

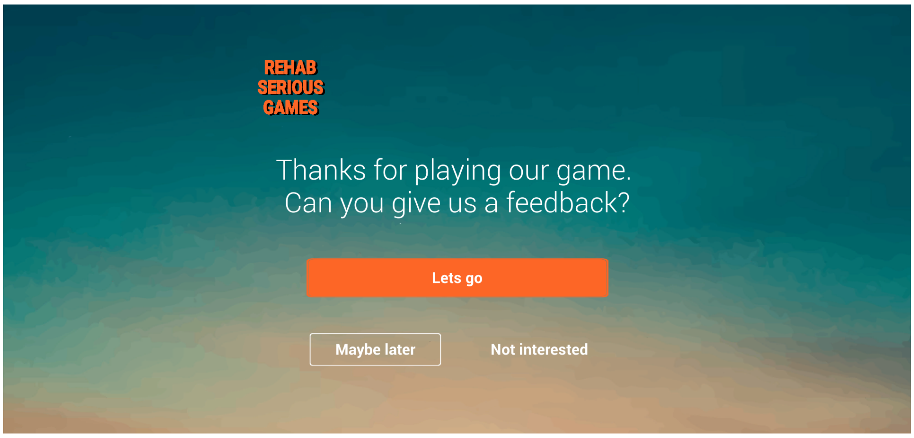


Figure 3.9: Survey menu

If the user chooses to answer, the link is loaded, and a browser page is open with the form to fill. After completion, only is needed to return to the game, where a button to say that already completed is now available. Was considered that no one will lie and say that already answered when didn't, even because has a button to say that won't answer. In both cases, the form should not reappear, what is possible to do by sending to the database the username of everyone that responded and that doesn't want. The username will be attached automatically to the respective form in an array created for that purpose and that is queried every time the game starts to see if it has something to a specific player.

If the player chooses to answer later, the game doesn't do anything and moves to the game itself. That way, it has no registry, and the formulary will be available next time the game starts.

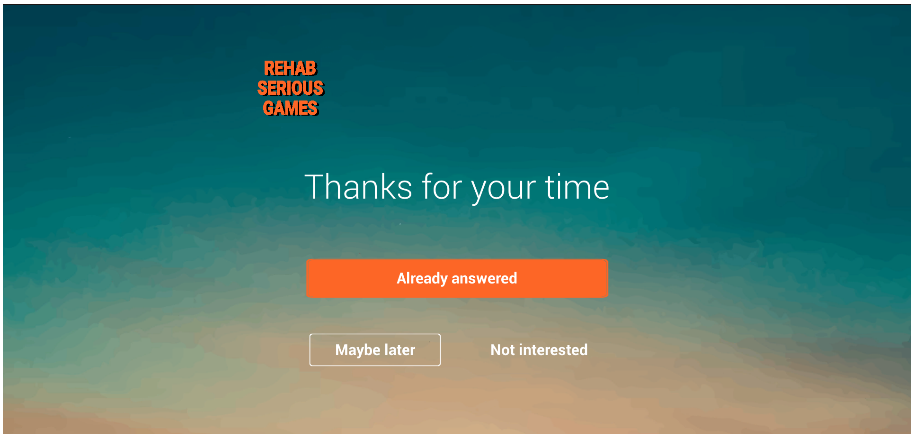


Figure 3.10: Survey confirmation menu

3.3.1.5 Games Menu

Virtual reality starts from here. After all the previous menus, the player is instructed to insert the smartphone in the VR glasses to start an immersive experience and rehabilitation. However, before using virtual reality, a window warning of the risks and precautions to take when using an immersive system is shown and only goes forward after the user confirms.

After the user place the glasses on his head, a small video tutorial shows how this menu works. Thus, the developing plan was carefully considered to look like some comfortable place with natural objects, preventing nausea as much as possible.

Initially, this scenario was made to a neuroscience project simultaneously developed with this work. The referred project is in the appendix and used HTC Vive VR glasses, and was a good start point for designs. Another significant advantage was that the project was followed nearby by the neuroscience specialist, who gave good feedback by not feeling any sickness, which is a good indicator once we want to avoid it.

Even using the scenario, the purpose is different, so it was needed to change the objects to adapt to the required interaction. To a most uncomplicated perception of what is possible to do, the interactable items are placed on the table in front of the player; that way, it is possible to select all the options available without significant head moves.

Figure 3.11: Game selection menu

As shown in figure 3.11, the scenario comprises three screens, a tablet, and a notepad. In the notepad, a gear icon was used as a settings button and, by selecting this, the user returns to the first menu.

Lying down on the table also is a tablet saying ”Ranking” that, as the name indicates, allows the user to see a ranking system with the best player and respective score to each one of the games. To visualize this, the user only needs to look inside the tablet with the reticle point, and the ranking screen appears. When he looks to another place and the reticle leaves the tablet, the ranking will disappear automatically. However, if there is no internet connection, the ranking window is displayed without any information, only showing a symbol that indicates this lack of connection.

The algorithm that shows the ranking starts for searching in the database the nine highest scores of all games already filtered to be sorted from the highest to lowest. When the list is made, it stores the score and the player’s username who achieved those points.

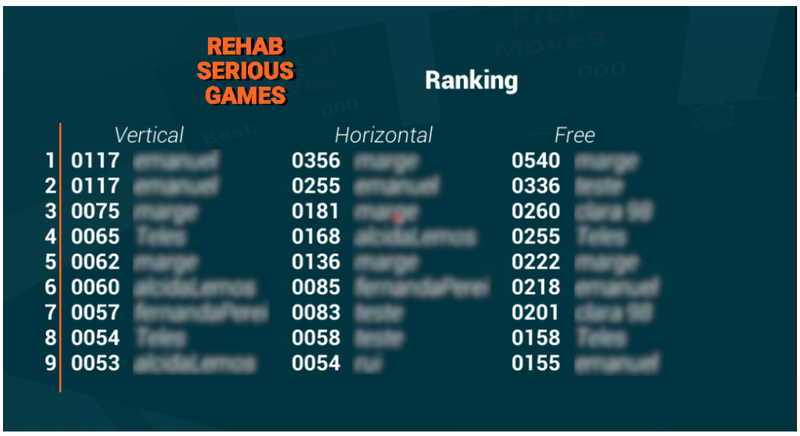


Figure 3.12: Ranking system

Besides all this, it is in this menu that the games are selected to start the therapy itself. As is possible to see in figure 3.11, three screens stand out to redirect to the three games available at this moment. As already mentioned, the three exercises that were gamified were vertical, horizontal, and diagonal moves. That way, the games were developed to simulate the same actions, always taking care of the sensation.

3.3.1.6 Games

So, the games are divided into three, and each one of them has its therapeutic purpose.

The games were developed with a scoring and time system associated with each game to allow the therapist to analyze each of the movements that each type of game requires. When a session ends, the information about the user who played it, the day and time they were performed, the game name, the time, and the score achieved are saved to the database. These values can give information about each user's development, as the game's difficulty increases each 45 seconds. Thus, if a person manages to increase the time of the game or the score, it means that he has good results and that the game is helping in recovery.

In terms of game mechanics, it was necessary to consider that it is an application developed for cell phones and cannot be too demanding in terms of resource consumption to be used on any device, thus requiring careful management of simultaneous objects in the scene. Because of this, Low Poly objects were used. This type of item represents an object but with much fewer polygons, which frees up the graphic memory to increase performance and reduce lag. Another way to avoid this system overload was to put the world moving in the direction of the camera instead of being the camera moving in the world. The player only controls the camera on the x and y axes. However, the moves need to have a limitation; somehow, the player could go to the infinite what makes no sense, for that, a *clamp* function was used so the player only can go until the limits of the road that is represented. The objects are being created a little ahead of the player's position and destroyed shortly after passing through it. Comparing the performances with when the world's whole creation is initially made, the fluidity sensation was instantaneous in the mode with this described and implemented method.

However, putting the objects to be created in front of the user gave a less natural feeling than intended. To get around this problem, a system that Unity has integrated was used, which is the possibility of placing a fog around the user to disguise what is more distant. Another advantage of this tool is the feeling of infinity that is perceptible and difficult to counter without a strange sensation; this way, we have a more authentic sense because it is a relatively natural element.

About the games themselves, and taking into account all said so far, two scenarios have been developed that are used in all three games. Keeping the commitment to entertainment, joy, and variety, the two views created were a park and a city shown in Figures 3.13 and 3.14, respectively.

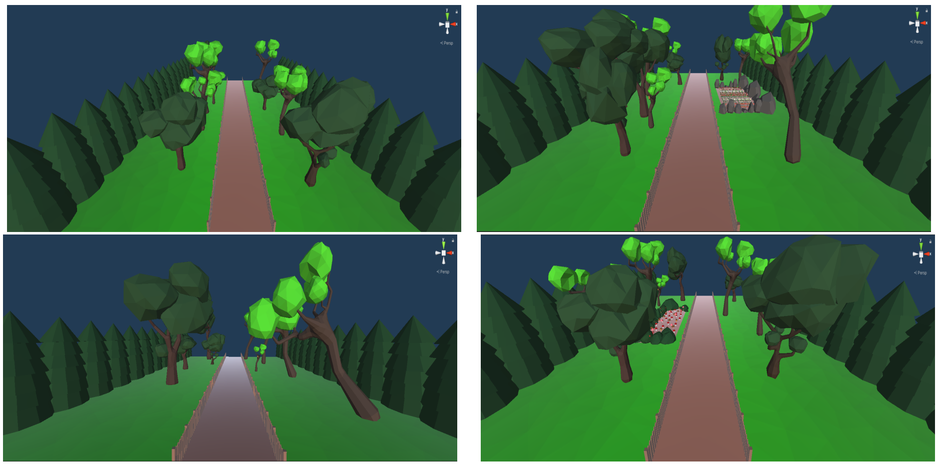


Figure 3.13: Park scenarios

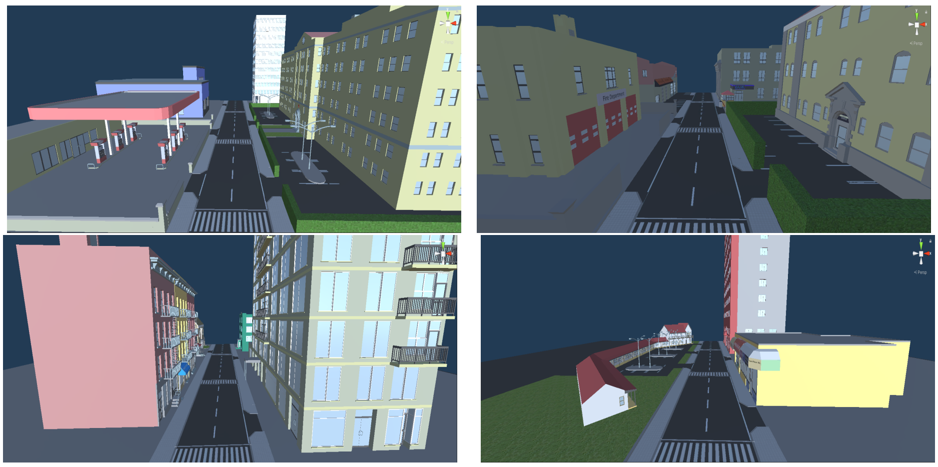


Figure 3.14: City scenarios

As is possible to see from the images, each scenario comprises four mini-scenes randomly called to build the whole world. For this to happen, when each of the games begins, is randomly generated the value zero or one and if the generated number is zero, the city will be shown first, and in the opposite case is the park. At the beginning of each level, the environment goes thru the same system and can change or stays the same.

To orient immediately to the desired type of movement, the point system is made to work as a reward system. Objects have been placed simulating diamonds, that usually indicate a reward right away, and it is by going against these diamonds that the score increases. Here comes the question of competitiveness. Everyone wants to do better than others and give their best. For this to happen, is mandatory to follow the path traced by the rewards for each game and thus perform the recommended exercises while earning points. To help/force following the score objects, tubes have been placed in the middle of the path, making the user lose against them.

One of Unity's tools is colliders, which allow objects to interact with each other, either as an obstacle or a trigger. For the intended use, only the box collider was used, which creates a box around the object that is intended to execute an action. The characters available, bird and spaceship, the camera, the pipes, and the diamonds have these colliders. In addition, the diamonds and pipes are classified with tags that identify them as scorable and deadly, respectively, so that it is possible to identify which objects have collided. When there is a collision between one of these objects and the controlled character, or the camera, in the case of the first-person view, the object tag with which it collided is analyzed. If it is the scoring object, it is destroyed, and a value is added to the score, on the other size, if it is the tubes, the game stops, and the player loses.

The first game, is focused on vertical movements. To make the player follow this path, the points have been placed between two obstacles, and the user has to pass between them to score. These obstacles are generated with random heights, between two measures that can be reached without increasing the speed so that it is not uncomfortable to use. Moreover, it is necessary to avoid the big jumps between two obstacles in a row so, thinking about this, a limit has been imposed on the maximum jump that can be reached. For example, the limit is between -15 and 15 and the maximum of the jump is 5, if one obstacle is at zero, the next one can only go to a value between -5 and 5. Thus, it forms the wave that the user has to follow with vertical movements. These values, even the limit as the maximum jump allowed, increase as the game level increases.

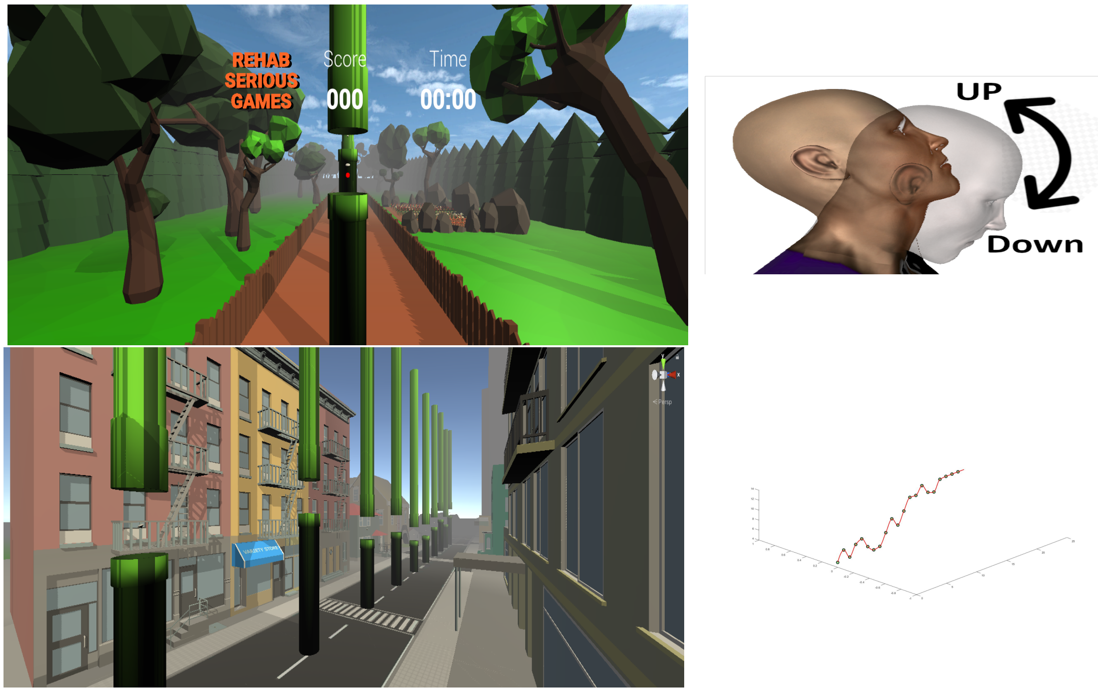


Figure 3.15: Vertical game with the therapeutic exercise and a wave simulation in which each point represents a scoring point

The second game is focused on horizontal movements. To perform this level, it was necessary to put the rewards to make a flat sinusoidal wave so that the person playing makes lateral moves to both sides. Here the tubes have the function of making the player walk around them without touching, for this were removed the holes that had in the first game to become a single pillar.

The formula that distributes the points in the world has the following form:

$$x = cos(time * \frac{2\pi}{period}) * amplitude - 1.2 \tag{3.1}$$

Where time is the time since the game begins and, to align the wave with the new speeds, period and amplitude will provide the frequency and amplitude of the wave. The decremented value 1.2 is just an adjustment that was considered necessary.

As in the previous game, the player loses if he hits one of the tubes, and all the information referred to the session is saved for future analysis.

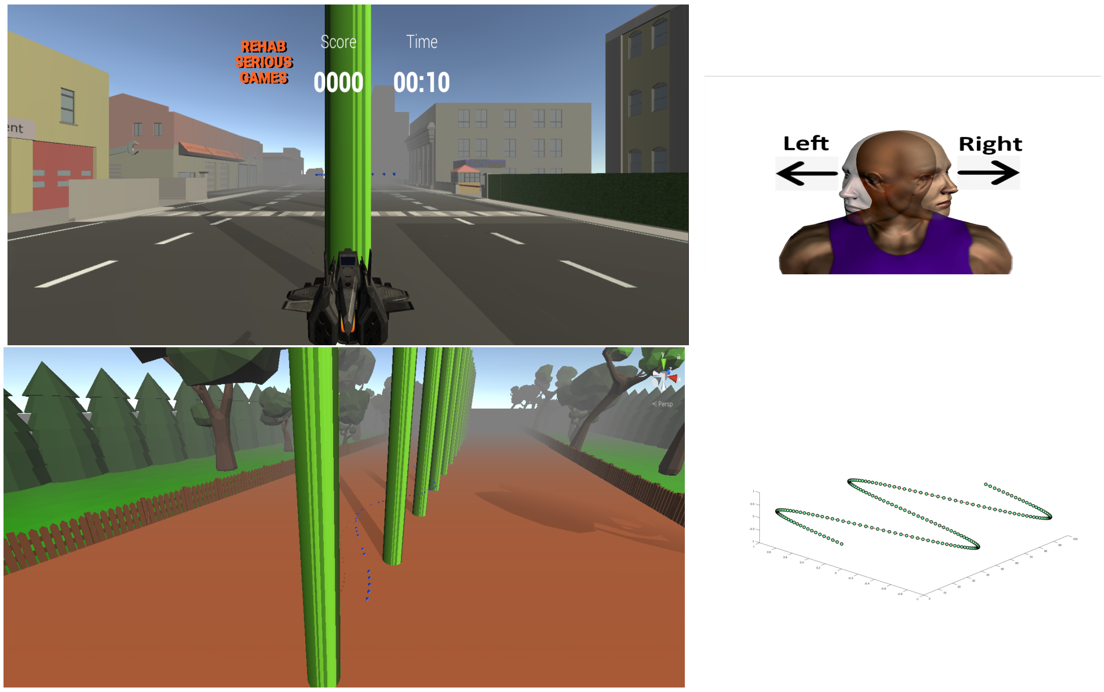


Figure 3.16: Horizontal game with the therapeutic exercise and a wave simulation in which each point represents a scoring point

The third and final game is a combination of the two above. To make a game with diagonal (free) moves without all the points being randomly scattered, it was necessary to think of a path that could be followed that included the vertical and horizontal movements. The solution to this problem was solved by making diagonal sinusoidal waves that can change direction randomly when the level starts.

Here, the wave is generated by applying to the diamond coordinates from the wave represented in equation (3.1) to the x-axis and then using the following one to the y-axis to give it the height that makes it sinusoidal:

$$y = cos(time * \frac{2\pi}{period}) * \frac{amplitude}{2} + 5; \tag{3.2}$$

The values mean the same, but the amplitude is cut to half to not became too high and difficult to reach, and five units are added to the wave to do not touch the ground when it is being drawn at the bottom of the path.

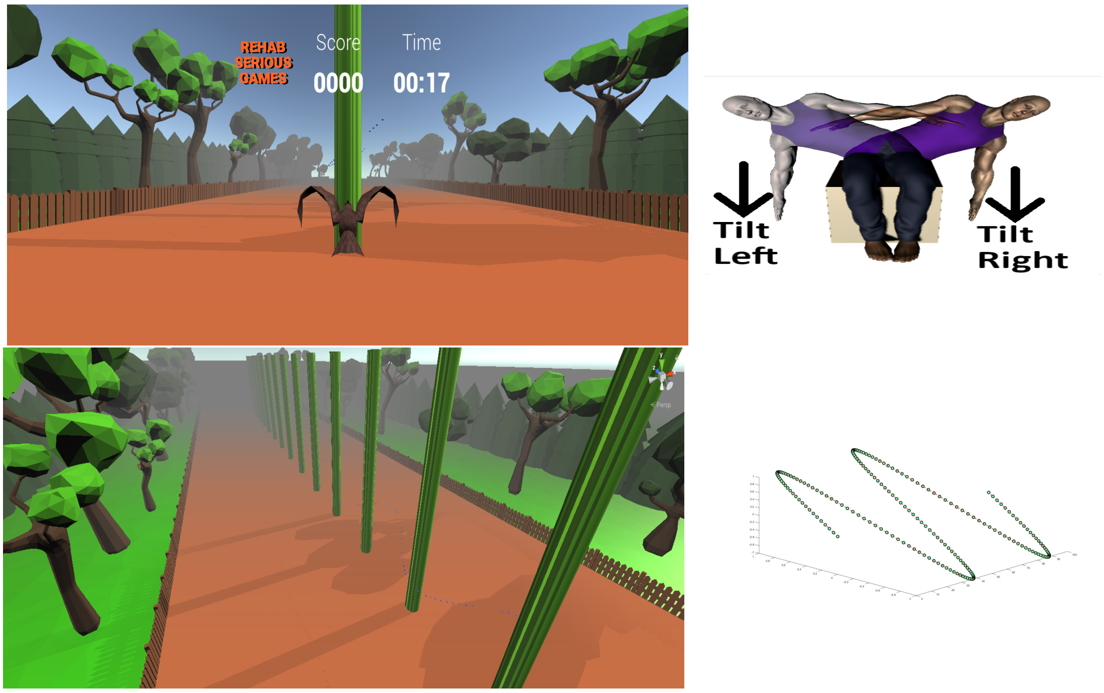


Figure 3.17: Free game with the therapeutic exercise and a wave simulation in which each point represents a scoring point

3.3.2 Level Management

Despite the initially chosen difficulty, after 45 seconds of play, the level ends, and it is possible to advance to the next one. The playing time is shown in a decreasing time from 45 to 0 seconds, and when the time is up, the player stops at the exact spot where he is and a window is shown with the score he has achieved. In the window shown there is the possibility to advance to the next level or to stop there and go back to the games menu. To increase the difficulty, the wave speeds and parameters are affected gradually. However, the level is the only common factor in all parameters, so all the object generations in the game are controlled by formulas that are level dependents, as can be analyzed in the following list.

- Increasing the player's speed horizontally and vertically (axes allowed for movement) and the world's speed (that moves in the negative forward axis), both with the same values.

$$\text{Vertical: } Speed = Level + 4; \tag{3.3}$$

$$\text{Horizontal/Free: } Speed = \frac{Level + 9}{2} + Level; \tag{3.4}$$

- Decrease the rate at which obstacles are generated

$$\text{Vertical: } SpawnRate = 5.8 - \frac{Level}{2}; \tag{3.5}$$

$$\text{Horizontal/Free: } SpawnRate = \frac{13 - Level}{2}; \tag{3.6}$$

- Addition of the amplitude and period of the point wave (horizontal and free play)

$$Amplitude = Speed * 2 - 2; \tag{3.7}$$

$$Period = \frac{60}{Speed}; \tag{3.8}$$

- Expansion of the maximum height and the possible difference between scoreable spaces (vertical game)

$$Maximum\ Height = 14 + Level; \tag{3.9}$$

$$Maximum\ Difference = 6 + Level; \tag{3.10}$$

All these values and formulas were calculated considering the scale with which the application was developed in Unity. When changing scales, the values will have to be recalculated.

3.4 Therapists interface

An online back-end, developed by the student Bruno Ferreira during his master's thesis, was adapted to visualize this project's data. In addition, the whole structure was modified so that any student working with serious games who enters his data into the same database can view it without having to make any changes. To do this, only have to follow the data structure of the database that is also prepared for this.

The main objective of this platform is for therapists to consult the progress made by their patients and thus be able to adapt in-person treatments and recommend those to be done at home more effectively. This page is available at `https://is3l.isr.uc.pt/SeriousGamesBO/`.

On the home page, it is possible to register and then log in to access the therapists' page, where all patients from the logged in user will be listed. This is possible due to a code assigned to each therapist when the register is performed, and is guarantee that there are no repeated numbers. This number can then be given to the patients who, by inserting it in the game, are automatically linked to the therapist who has access to all the information about their sessions. During registration, one of the fields to choose is the work area. In this way, it is possible to make the platform more generic but at the same time selective in the sense that each therapist can only see the games that are developed for the respective field of work.

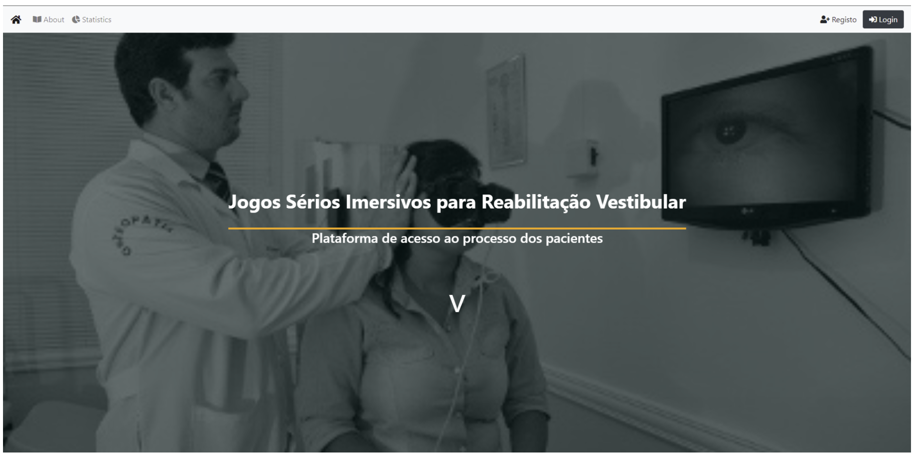


Figure 3.18: Home page

On the therapist's page, all the patients that a given therapist follows are listed, and is allowed to scroll through the list or do a search to select the person from who is intended to view the information.

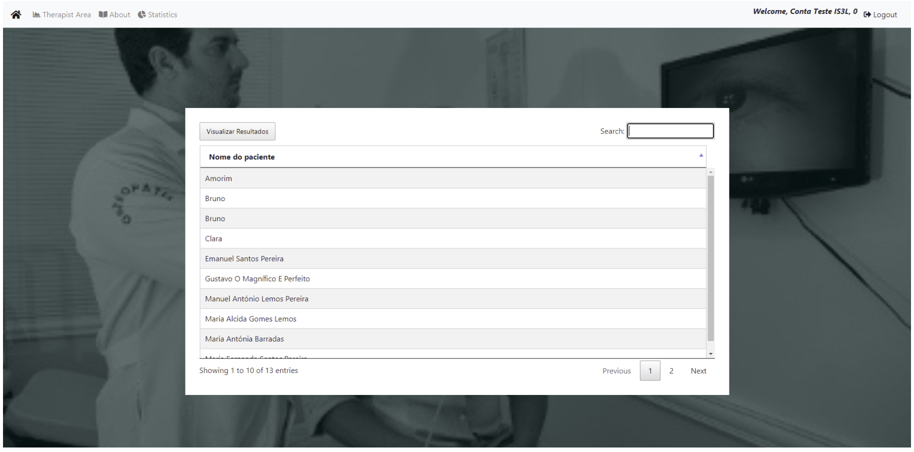


Figure 3.19: Therapist page

After confirming the selected name, the website redirect to the page where the person's information is located. Here is shown the name and age, if the person entered their date of birth when they registered in the game, and some notes that the specialist can write. These fields are editable thru a button underneath this information, allowing to add/change the date of birth and notes.

At the top, under the menu bar, there is a dropdown where it is possible to change the game to analyze, so it is possible to see the patient's development in each type of movement. Clicking on the pretended game, the page will automatically reload with the newly selected game data.

In addition to this, it is often necessary to analyze the data over a specific time period to better understand it. With this in mind, a system has been implemented where the therapist can select a start and end date so that the data shown on the graphs are only those comprised in that time period. There is also available a checkbox that allows to view the charts in a compacted or decompressed way. If is intended to analyze the sessions one by one and draw graphs in which each bar corresponds to each session, the checkbox must be deselected so that the data appear this way. On the other hand, if is required to see the scores and daily times added up, where each bar corresponds to the totality of each day, check the checkbox, and then pressing the validation button the page is loaded with the new request.

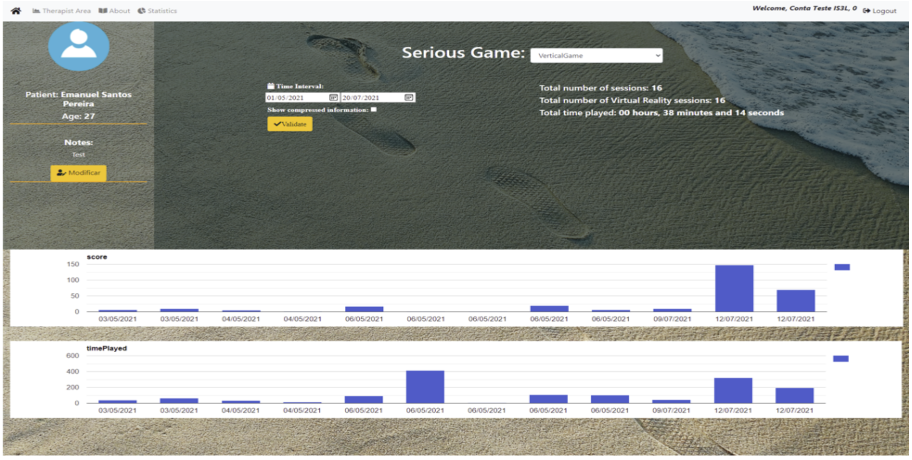


Figure 3.20: Patient page with decompressed data.

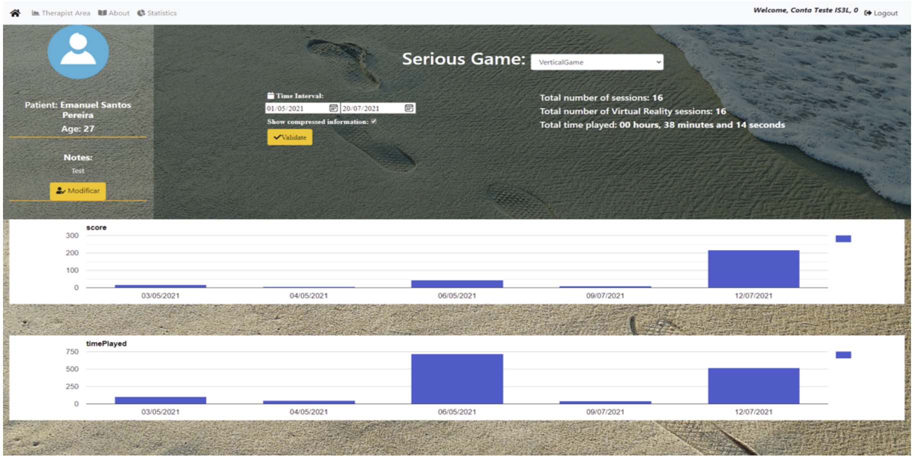


Figure 3.21: Patient page with compacted data.

The site is also prepared to show compressed and uncompressed data simultaneously, meaning that if there are values that need to be shown but don't make sense to be compressed, these parameters can be quickly changed in a part of the PHP code of the page that is prepared for the effect.

3.5 Database

The database is one of the essential parts of the system; that way, it is possible to save the progress made by each of the users and connect them to the therapist's graphical interface for a later evaluation.

To simplify all this process was used a MongoDB NoSQL database that is allocated in

Institute of Systems and Robotics servers. In contrast to SQL databases with relational tables with a fixed size of columns and rows, NoSQL is a non-relational database that stores information in JSON files that can receive more or fewer parameters without compromising the data structure. However, it is also possible to store relation data, but in a different way, because it isn't split into tables. In fact, it can be stored in the same data structure.

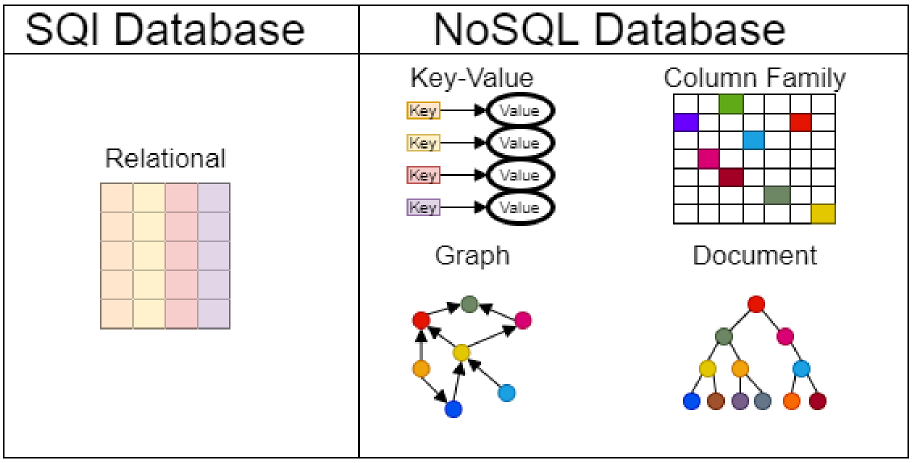


Figure 3.22: SQL vs. NoSQL

MongoDB stores those documents in collections. Is possible to create several in the same database and save all the different kind of records in the respective group to a better organization. At this moment, five collections went created:

- **Users:** where all the users' personal information is stored.
- **Therapists:** saves the therapists' login information.
- **Sessions:** stores all the session information that can be analyzed later.
- **Surveys:** keeps the form links, the users that already answered, and the minimum requirements to reply to each one of them.
- **Game Parameters:** stores the game names and the parameters that each one of them will have. Created to support the website and will be explained later.

NoSQL has four databases types: document databases, key-value databases, wide-column stores, and graph databases. Once we use MongoDB and save information locally, the chosen one was the document database, where the data is stored in BSON (Binary JSON) and convert from BSON to JSON is an easy process that allows keeps the information in a local file.

The files saved in each one of the collections have the following configuration:

- **Users documents:** Name, email, username, password (encrypted), birthday date, gender, and therapist code (to associate to a therapist).
- **Therapist documents:** Name, username, email, password, personal code (generated automatically in the registry), and field of work.
- **Session documents:** Username (relation with user), session day and hour, name of the played game, time played, score, and others parameters required.
- **Surveys documents:** Surveys links to each language available, form name, minimum sessions to answer, priority, and the users that already completed in an array.
- **Games Parameters documents:** Game name, game purpose, parameters in the game (in this case, five parameters, score and four amplitudes measures).

Unlike SQL, NoSQL has no names nor constraints to model a diagram because it has no tables relationships rules. However, an illustrative one is always helpful to understand what we are doing. The one that represents this project is the following:

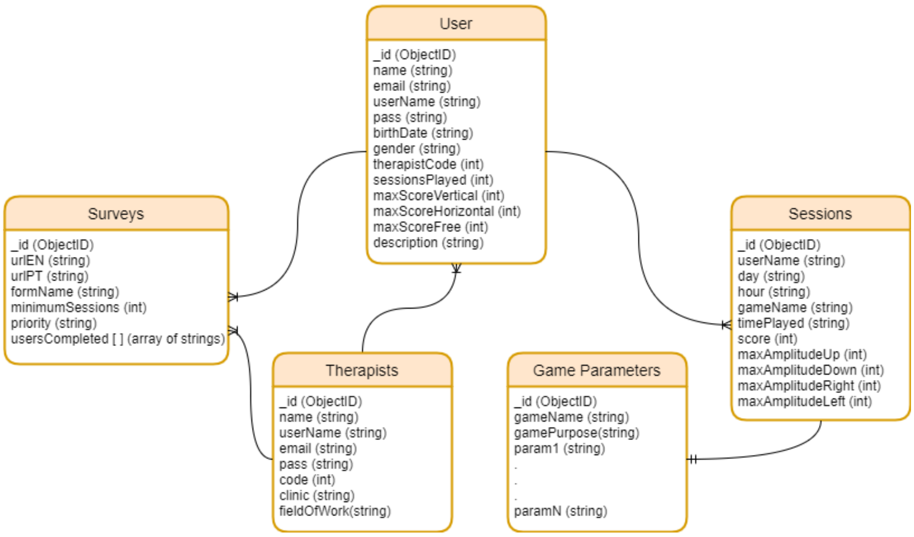


Figure 3.23: Database diagram

3.6 System Behavior

As has been emphasized several times, communication between patient and therapist is an essential part of this work. That way, the game comprises three fundamental elements: the game, the database, and the online therapists' application. So, the system's outline is shown in the following figure.

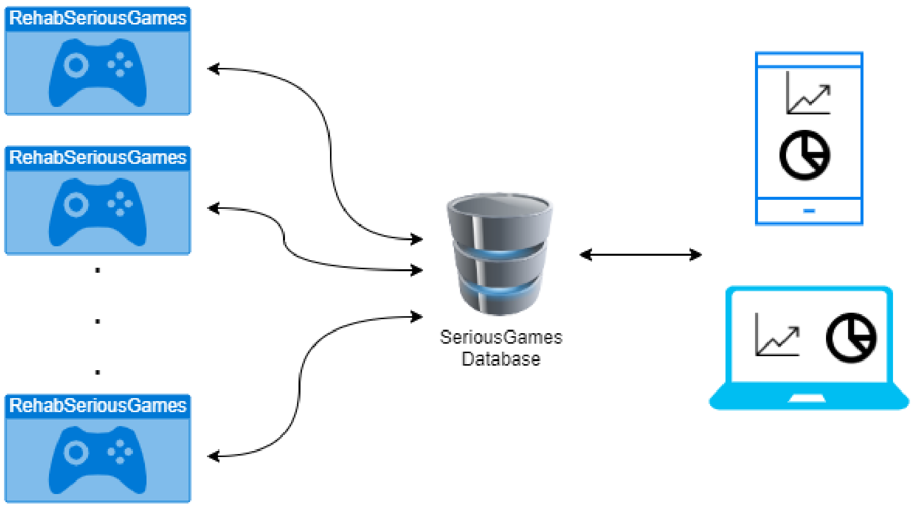


Figure 3.24: System Design

Because a password is needed, was implemented SHA256 cryptography to protect the users' privacy. SHA256 (Secure Hash Algorithm with 256-bit) is an encrypting protocol designed by NSA that runs a mathematical operation to store data in a fixed size hash. Depending on the data, it can be one-way encryption, only being comparable with another hash [33].

The players performances are being stored for later analysis by their therapist at the end of each session. The data is stored directly in the database with information about the playing user. However, if there is no internet connection, the same information is stored in a local file, uploaded to the database, and deleted from the storage, once the game is open with some connection.

4

Results

This section aims to present the results obtained with the tests performed after the development of the platform. Due to the current pandemic situation, the SARS-COV-2 virus, it was impossible to carry out the case study because access to clinics by people outside the service is prohibited. However, it was possible to carry out control tests with friends and family who were willing to evaluate the application developed.

4.1 Quantitative Evaluation

As mentioned above, the tests performed were not the best due to the current situation, and as such only control tests were possible. When tests are carried out on a new development in the medical field, it is necessary to carry out tests that validate the latest findings. The best way to do these tests is to use two different groups and compare the results, the case and the control groups. The control groups are people without any disturbance concerning what the research is about. If they only have a low-impact disorder or in a practically treated state, they can also be valid; on the other hand, the case study is the study with people who have the problem with the various stages that come from it. In both cases, when possible, the variety of ages is of great importance to analyze how the system works and its impact on the age group.

In this study, only the control test was possible. For this to be possible with as little contact as possible, the solution arranged was to ask relatives and close friends and ask known people with virtual reality goggles to test. Thus, it was impossible to carry out the desired tests and with the number of people wanted.

However, it was possible to carry out the tests with a reasonably good variety of people, as can be seen in the graphic below:

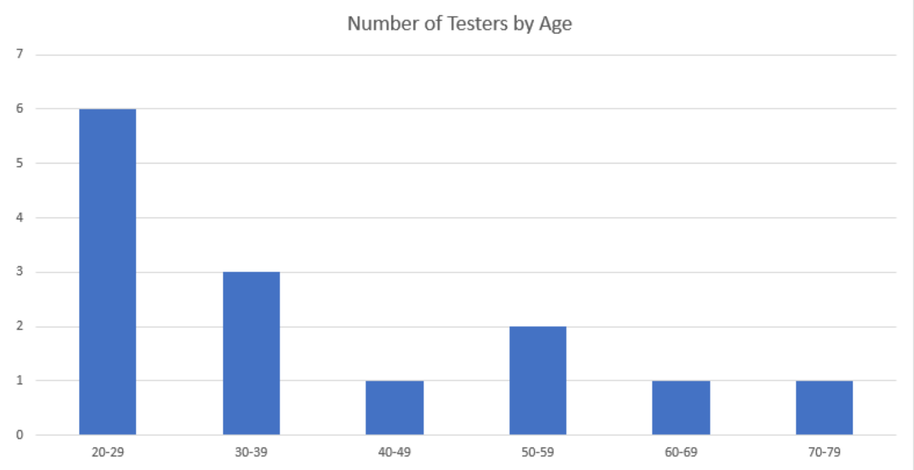


Figure 4.1: Number of users that testes the application divided by age.

The procedure to perform the tests was the following:

1. Give a brief introduction about the objective of the study and how to play.
2. Asking people to interact from an early stage to make it possible to check if the menus are intuitive to login and register.
3. Give a little help to put the smartphone in the glasses. People tend to ask for help at an early stage for fear of spoiling.
4. Check and constantly warn to remove the glasses immediately in case of any nausea or unbalance. The first few times this type of system is used, people tend to get weird and feel bad.
5. Ask the person to perform several tests in the various games available if they feel comfortable and willing to continue.
6. In the end, they were asked to answer a questionnaire about the System Usability Scale (SUS).

Regarding the initial menu, it was possible to verify that these were easy to interact with and quite intuitive for people not to have great doubts. Only the more senior people had difficulties, and it was necessary to handle this process for them; this was also because they do not have a smartphone and do not know how to interact. It was possible to conclude that the 2D part of the system was easy to use and thus fulfilled the requirements.

In the case of the 3D environment, which includes games, the biggest concern was nausea and discomfort, especially in older people. However, of the various tests performed, there was no significant warning. As expected, there was a minor strangeness at a very early stage that was quickly overcome with a little use; however, the overall feeling was considered quite pleasant. Another aspect that was verified, which was against the intended one for competitiveness, was that familiar people, in this case, a couple, always wanted to play a little more to try to make a better score than the spouse.

In general, it was possible to conclude that the game is pleasant and in agreement with the requirements initially stipulated.

4.2 Qualitative Evaluation

The qualitative evaluation allowed us to assess the behavior and complexity of the application from the user's point of view. As mentioned above, there was a scene in the game that allowed redirection to a survey, and, at this initial stage, the questionnaire available was the System Usability Scale (SUS). To answer it, people only had to have performed two sessions, which is not much, but since these are tests, we did not want to exaggerate the minimum number that had to be completed. The questions that make up this form are as follows:

1. I think that I would like to use this system frequently.
2. I found the system unnecessarily complex.
3. I thought the system was easy to use.
4. I think that I would need the support of a technical person to be able to use this system.
5. I found the various functions in this system were well integrated.
6. I thought there was too much inconsistency in this system.

7. I would imagine that most people would learn to use this system very quickly.
8. I found the system very cumbersome to use.
9. I felt very confident using the system.
10. I needed to learn a lot of things before I could get going with this system.

Relative to the answers, the participants were asked to respond on a scale of one to five, where one corresponds to strongly disagree, and five corresponds to strongly agree. Of the several people who were asked to test, only seven completed the questionnaire. However, it was the most important seven because some of the tests were performed in the work group, and the people who responded were the external ones. It was important because it was a small group that covered higher age groups, 40-75, and even one person diagnosed with Ménière's disease and another recovering from a stroke. The answers given to each question, in percentage, are present in the chart below.

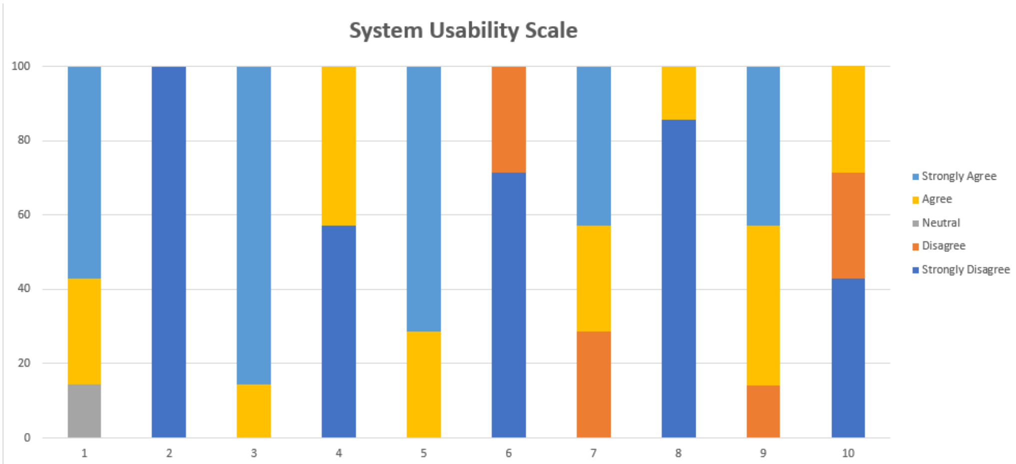


Figure 4.2: System Usability Scale answers

Even though it is possible to get conclusions from the answers given, this questionnaire has a scoring system that allows us to obtain a percentage rating for each of those filled out and calculate an average rating. To figure this, we have to take into account that for the odd questions, the best answers are the Completely Agree, and the opposite for the par ones [34]. Since Google Forms was used, it is possible to immediately export all the answers to an Excel file and calculate these percentages that can be seen in the following graph.

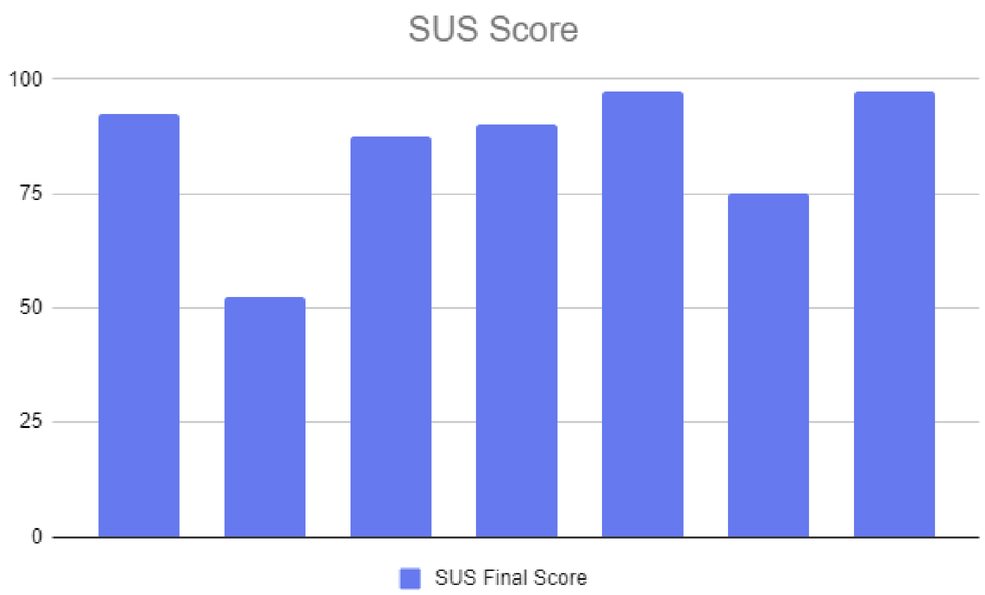


Figure 4.3: System Usability Scale final scores per answer

Calculating the average, the value 84.64 (out of 100) was obtained, which is between the range 84.1-100 that is considered the highest in this type of evaluation.

We can thus conclude that, despite the difficulties of some users in interacting with the application, the result is quite good and demonstrates the easy interaction that the game provides.

At the end of the internal testings, the medical specialist was contacted and performed an analysis of the game classifying it very positively, and proposing to take it to the next level, a clinical validation with real patients. For that purpose the procedure will be subject to validation by an ethical committee.

5

Discussion

During the test execution, it was possible to conduct sessions with one person suffering from Ménière's disease and another who suffered a stroke. Regarding the person with Ménière's disease, he had never tried any system like the one presented in this project, so he had some initial difficulties adapting to the virtual environment. However, after a few attempts, he was already becoming comfortable, confirming that regular use will increase his comfort during use. On the other hand, the person recovering from a stroke had no difficulty in adapting to Virtual Reality, but it was more difficult to reach the objects on the affected side. Besides the lack of mobility present on that side of the body, which makes it difficult to move the neck, the vestibular system can also be affected when someone suffers this type of incident, so the tests ended up being more focused on one side. This shows one of the concepts mentioned that one of the improvements to be made that is to adjust the game to force the patient to focus more on the affected side.

In the first meeting with the expert regarding the game, one of the observations was the difficulty in understanding the available options in the settings menu. Therefore, a button was then implemented that redirects to a webpage where a short description of the game and the instructions in Portuguese and English are described. This website can be visited through the link `https://is3l.isr.uc.pt/index.php/research/software/vr-vestibular-rehab`.

An Italian therapist who heard about the project through a video also contacted Prof. Paulo Menezes showing interest in trying the game and suggesting some things that could be implemented. However, the suggestions mentioned are impossible to realize with a cell phone since they are focused on eye-tracking, and extra hardware is needed that is only present in the most advanced glasses. The intended meeting has not yet been held because the priority has been given to those who initially followed the project, but the game is already prepared for Italian, and contact will soon be made.

The website is available for use, and therapists can start tracking their patients. Some visual aspects are still being worked on, so the layout of the information is not the most correct. However, the information that is supposed to be analyzed is all shown, and the necessary changes will not affect the intended analysis. The only problem at this point, but which is unrelated to us, is that the application only works with WiFi due to the drive that connects to the database, so it may limit sending the information to people who only use mobile data. Nevertheless, as the recovery process will not leave aside conventional therapy, it is possible to use the internet of the clinics to upload the data by simply opening the application in the initial menu that everything is done automatically.

6

Conclusion

This paper presented the development of a mobile application for vestibular rehabilitation that aims to provide some excitement to those who suffer from this dAysfunction. Using low-cost devices and exploring VR as an alternative treatment, it is possible to perform therapy while having some entertainment provided by the game. The developed games were presented and explained and the therapeutic purpose of each one, and all the visual aspects involved. It was also demonstrated how the level system works so that it is possible to reach people in various stages of therapy.

The website used by therapists to check on their patients' progress was also presented here. The feedback received was that it is a tool that can be useful, although, as with the game, testing is needed to conclude if any other aspects can be implemented.

A paper was submitted and accepted at the conference *13th International Conference on Disability, Virtual Reality Associated Technologies (ICDVRAT 2020)* and will be presented in September 2021 if there are no changes to the date. It was the article that started this project and can be found in the appendices of this document.

Finally, an otorhinolaryngologist specialist performed an evaluation, who provided very positive feedback regarding all the work developed.

As previously mentioned the developed game is currently available for android smartphones, and can be freely accessed through the following address `https://play.google.com/store/apps/details?id=com.IS3L.RehabSeriousGames`.

7

Future Work

As future work, we intend to carry out clinical tests with patients in therapy and further develop the game by creating more scenarios and adapting the game to each type of dysfunction that the patient may have to adjust in a more personalized way.

The system can also be adapted for post-stroke therapy since there are many similarities between the two therapeutic methods. Using an Arduino mounted as a wristband, it is possible to play the same games using the movements of the upper limbs. It is only necessary to adapt the whole game for a non-VR view to avoid motion sickness and bad mood. This was an initial idea of the project that ended up not being developed due to the complexity required and lack of time for its realization.

It is also possible to apply this application to more advanced devices, such as the Oculus Quest, and thus have a device with better quality that can be used in clinics or at home if the person wants to buy one.

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Appendix

- ICDVRAT2020 - Poster paper
- Proactive neuroscience project - Design Specification Document

Virtual Reality-based Visual Training for Vestibular Rehabilitation

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ABSTRACT

Vestibular rehabilitation therapy helps individuals deal with many vestibular-related disorders, such as vertigo, visual disturbances, gaze instability, or even nausea. It consists of an exercise-oriented program that is carefully outlined by specialty-trained vestibular physical therapists and should be followed rigorously to ensure natural vestibular compensation and substitution mechanisms. With the successful proliferation of games among all ages, one can think about turning these exercises more pleasing and motivating for patients while focusing on the game, instead of the task they are performing. In opposition to the current trendy research for patients' balance training, we have driven our attention to the visual and gaze related issues. Therefore, we propose a virtual reality-based therapeutic tool that encourages patients to perform the recommended exercises for their recovery plan while simultaneously stimulating their vestibular system through both visual and auditory modalities. Moreover, explores game principles to make the user perform a suggested set of both head and ocular movements, which are translated as a way of interaction with the developed serious games. Similar to the current approaches for gamifying activities, the user's progress can be naturally encoded by a scoring system that may be stored and made accessible to the doctor or therapist for later evaluation. A preliminary evaluation was carried out with expert appraisal, which provided crucial insights for guiding the following steps on the work and future conduction of a pilot study.

1. INTRODUCTION

Spatial orientation, coordinating motion with balance, and maintaining the upright posture are some of the examples that are supervised by visual and proprioceptive senses, but also by our vestibular system [Agrawal, 2013]. The vestibular system's main components are located in the inner part of the ear, consisting of a labyrinth of semi-circular canals and otolith end organs that are continuous with cochlea [Khan, 2013]. The semi-circular canals are essentially three ring-shaped structures filled with endolymph while being situated in each plane that our head can rotate. Therefore, when individuals rotate their heads along a specific plane, it causes this liquid to shift within that specific semi-circular canal, allowing our brain to perceive the rotation performed. On the other hand, the otolith end organs provide information concerning gravitational forces and horizontal/vertical movements in space.

Evidence shows that people who had suffered from diseases or traumatic incidents in these areas are often known for experiencing vestibular-related disorders, such as vertigo, dizziness, gaze instability or balance issues [Burzynski, 2017]. When focusing on the existing visual problems, peripheral vestibular lesions cause a deficient vestibular-ocular reflex (VOR), which leads to the inability to fixate the desired visual targets during head movements. For instance, normal visual processing demands that the observed visual targets should be fixated on the fovea. The process of foveation or gaze stabilization during head motion is achieved by voluntary saccadic eye movements and reflexive controls, such as the VOR and optokinetic reflex, regardless of the execution velocity [Barnes, 2008]. Under normal conditions, both the VOR and optokinetic reflex can accurately elicit compensatory eye movements to match the performed head motion. Given that it can significantly tackle individuals' quality of life by imposing changes in different aspects of their daily living, people suffering from vestibular disorders are commonly encouraged to undergo Vestibular Rehabilitation Therapy (VRT) programs.

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VRT is commonly based on an exercise-oriented plan carefully designed to alleviate the previously mentioned problems while stimulating compensation mechanisms to retrieve back some functionalities. For instance, despite having lost certain abilities, the brain learns to use other senses to replace the lacking vestibular system [Chen, 2019]. Moreover, this program typically comprises three different modalities that are promptly advised for patients depending on their disabilities, such as habituation, gaze stabilization, and balance training.

In contrast to other past works that were solely focused on balance training [Meldrum, 2015], this proposal aims to address the visual training by employing playful Virtual Reality (VR) games that follow the same conventional therapeutic principles. Therefore, a low-cost mobile VR application with different mini-games that focus on different therapeutic purposes is presented to complement the patient's therapy sessions.

2. DEVELOPING SERIOUS GAMES FOR VESTIBULAR REHABILITATION

Literature states that gaze instability is due to the decreased gain of the vestibular response to head movements [Han, 2011]. The best stimuli for recovering it into normal conditions is by performing a visual process called retinal slip. Retinal slip is defined as the image motion on the retina during head motion, and can be induced by horizontal/vertical head movements while maintaining visual fixation on a target. Therefore, patients are frequently encouraged to perform exercises that reinforce these head movements, given that repeated periods of retinal slip are known for inducing vestibular adaptation [Lotfi, 2016]. Other approaches to tackle this diminished component of the VOR include performing the same head movements while blinking throughout the motion. This process leads patients to perform corrective saccades that properly generate the necessary drift to match the head motion, or in other cases, to rectify the excessive drift that may occur in the opposite direction.

According to Herdman et al. in [Herdman, 2007], the recommended gaze stability training should be performed four to five times daily for a total of twenty to forty minutes/day, in addition to twenty minutes of balance and gait exercises. By carefully following these instructions over time, patients are able to improve gaze and postural stability, but also to reduce vertigo sensation. As a matter of fact, the main objective is to improve their quality of life, by leading them to recover some of the lost abilities to perform simple to complex daily living activities. However, individuals with vestibular-related disorders are frequently diagnosed with depression and anxiety, as a result of the amount of time that is needed for their recovery. Together with the fact that the recommended tasks are boring to perform, they often show a lack of commitment and interest to the proposed recovery plan by their therapists. Therefore, one may think of gamifying the previously mentioned exercises by providing an alternative that seeks to follow the same principles, but intends to increase the patient enthusiasm.

VR is a path worth exploring, given its freedom of design to produce interactive environments and its more established usefulness in therapies. It provides safe and customizable training that can be tailored to each patient's abilities/difficulties and comprehend the different variations that the exercises should comprise [Ferreira, 2020]. For instance, varying the amplitude of the previously mentioned retinal slip, or inducing a wide range of required frequencies of head movements to fulfill the game's purpose. Nevertheless, a study carried out by Bergeron et al. in [Bergeron, 2015] suggested a relationship between the duration of the VR sessions and the magnitude of its therapeutic effects, where results suggest that 150 minutes as a minimum accumulated time of exposure leads to positive and quantifiable outcomes for the patient.

The challenge remains on how to ensure that patients are performing the supposed head and ocular movements. One may think about using eye-trackers to monitor the player's gaze throughout the game, but this comes with additional costs, which turns this idea not suitable for home deployment. Therefore, other alternatives can be explored to evaluate if patients are performing those movements, such as developing scenarios with game elements that require constant interaction (e.g., fixating them for long periods) to increase the game's score. Besides, it can be combined with the user's head pose information obtained from the smartphone's gyroscope, and thus a low-cost solution can be developed for home use.

3. IMPLEMENTATION

From the above, the proposed work relies on the development of a low-cost system that consists of two immersive VR-based mini-games for the most common mobile platforms[1]. The games were developed on the

[1] Demo: http://orion.isr.uc.pt/demovideos/VRTgames.mp4

Unity Engine following the previously mentioned requirements, and they can be played using a regular smartphone and a cheap headset.

The first game is called “LightWorks” and its main purpose is to stimulate horizontal ocular and head movements while maintaining fixation on a visual target. Players are part of the quality control of a light bulbs factory, where they must observe a certain number of lamps that pass in front of them on a conveyor belt, as illustrated in Figure 1. They must fixate the lamps during their whole trajectory while pressing a button that powers the conveyor belt. When it reaches the final destination (the left or right extremity of the conveyor belt), a poll asks either the number of times it has lit or the emitted sequence of colors. The game implementation can have different variations, such as the frequency of appearance of lamps, speed of movement, or the trajectories made to stimulate player's attention.

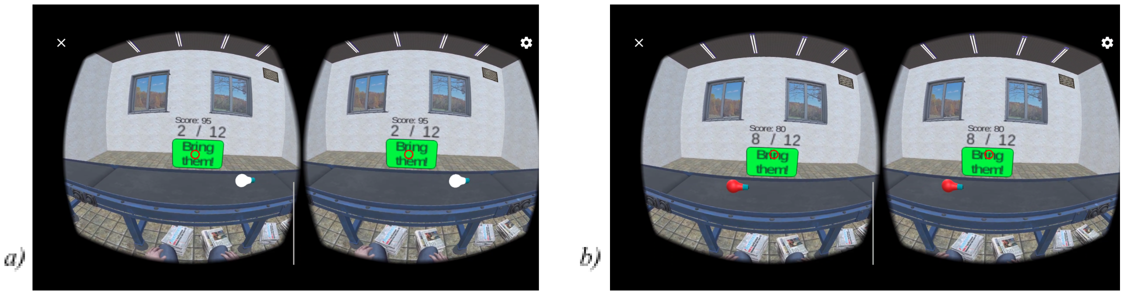

Figure 1. *Gameplay of “LightWorks”: a) Lamp has lit; b) Lamp is displaying a sequence of colors.*

The second proposal is called “Labyrinth” where the main objective is to guide the player himself through a mined path until the end of the circuit. This game tries to stimulate both vertical and horizontal movements and lead the user to explore the whole visual field. As the mines are hidden, several instructions appear in the middle of the screen over time. Without losing them from view, they must turn their head accordingly to change the move direction and follow a safe road while either increasing or decreasing their score (e.g., when stepping a bomb). The game has three rounds of difficulty to ease the player’s learning curve, but also to enable patients at different stages of recovery to play. Moreover, the game can be adjusted to demand quicker head movements, or to insist more on the affected side on earlier stages.

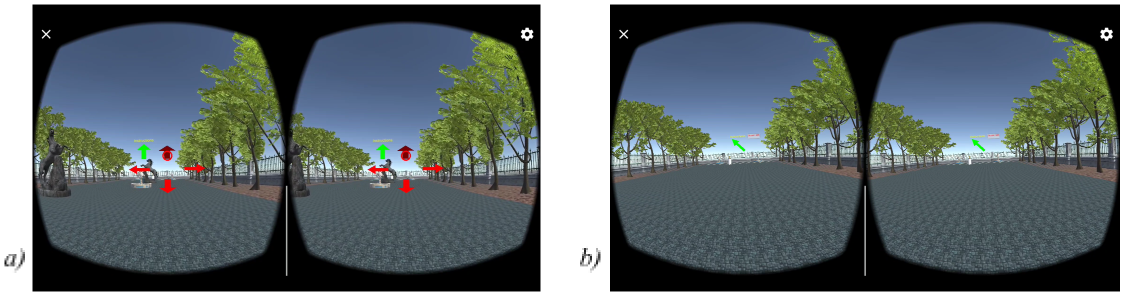

Figure 2. *Gameplay of “Labyrinth”: a) Intermediate level: instructions and navigation arrows are shown; b) Advanced level: only the instructions are shown and head controls navigation.*

4. PRELIMINARY EVALUATION

A preliminary evaluation was carried under the supervision of an expert to assess the validity and usability of both created games. The feedback received was positive and validated the previously mentioned requirements, specifically for the second game, as it demands quicker and more complex head movements while maintaining the fixation on a visual target. However, it was suggested that these types of games should focus more on the affected side, while continuously varying the game elements to demand faster/slower ocular and head motions. Such behavior allows patients with acute impairments on their vestibular system to regain or compensate the lost abilities within an expected shorter time. Aside from the games' validated purposes, the specialist referred that patients are indeed typically depressed and tend not to perform the recommended exercises between sessions at home, which has a significant impact on their recovery. Therefore, such a mobile VR application was considered to be interesting, given that it can certainly be used in the clinical space. Still, most importantly, it enables patients to perform their therapy at home.

5. CONCLUSION

This paper presented the development of games that seek to support the conventional procedures of the vestibular rehabilitation, specifically for the gaze training. Under this scope, the different requirements for promoting visual training and how immersive systems can be used to address patients' commitment issues were explored. Two games under a low-cost mobile VR application were presented, and their therapeutic purposes discussed. A preliminary evaluation of these games was performed under the supervision of an expert, confirming the expected interest and validity in both clinical and home scenarios. Therefore, future work on the topic encompasses the development of different games that exploit other recommended exercises and the conduction of a pilot study in a local clinic to evaluate its usability in the recovery of patients with vestibular-related impairments.

Acknowledgments: We would like to sincerely thank Dr. Ana Margarida Amorim of Centro Hospitalar Universitário de Coimbra (CHUC) for all the significant suggestions and enlightenment about the procedures involved in vestibular rehabilitation therapies that were integrated in the design of the presented games.

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Design Specification Document

V.2.0

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1 Introduction

1.1 Purpose

The present document accompanies the developed Virtual Reality software program developed at the Immersive Systems and Sensory Stimulation Laboratory - IS3L of the Institute of Systems and Robotics under a collaboration with the Proaction Lab - Perception and Recognition of Objects and Actions Laboratory of the Faculty of Psychology and Educational Sciences of the University of Coimbra. This work was initiated by Achraf Bouguerra and completed by Emanuel Pereira, both under the supervision of Prof. Dr. Paulo Menezes to fullfill the established requirements of Dr. Artur Pilacinscy.

The purpose of this software is to support experimentation in the field of neurosciences, in particular connected with the subject of brain mapping.

1.2 Experiment Definition

The following project aims to solve a specific problem that exists within the field of neuroscience.

The problem is addressed with an artistic touch, combined under the strict engineering rules, offering a unique approach represented in a Unity simulation that will be designed very similar to a real environment. Subjects will be going through a virtual experience that offers them easy challenges: avoid obstacles to pushing a particular button or copying the lines from a shown image, both using hand motion.

Subjects, under a specified timing, will take the preselected challenge. Different variety of data will be analyzed afterward:

- The path taken by subjects to reach the goal.
- The precise kind of activity is represented within the subjects' human posterior parietal and dorsal premotor cortex.
- The timing passed by each subject to reach the goal and to finish the given tasks.

→It yields a final goal of understanding the human brain's behavior when it comes to trajectory and path planning within a virtual environment.

1.3 Definitions, Acronyms, and Abbreviations

DSD: Design Specification Document.
Unity: Unity is a cross-platform game engine developed by Unity Technologies, first announced and released in June 2005 at Apple Inc.'s Worldwide Developers Conference as a Mac OS X-exclusive game engine. As of 2018, the engine had been extended to support more than 25 platforms.
Blender: Blender is a free and open-source 3D computer graphics software toolset used for creating animated films, visual effects, art, 3D printed models, motion graphics, interactive 3D applications, and computer games.
ID: Identifier.
GUI: Graphical User Interface.
CSV: Comma Separated Values.
FR: Functional Requirements.
NFR: Non-Functional Requirements.

Scene: An instance of the game that can be compiled as part of a game build. Games must have at least one scene, but can have many (i.e. different Scenes for each level, start screen and game over screens, etc.)
GameObject: Base class for entities in Unity scenes.
Prefab: A GameObject that is saved in Unity with set properties so that it may be duplicated in the scene as needed.
Script: Code that is attached to game objects to trigger events and set their attributes.
Subject: A research participant, also called a human subject or an experiment, trial, or study participant or subject, is a person who participates in human subject research by being the target of observation by researchers.
UI: User Interface.
PC: Personal Computer.
HMD: Head-Mounted Display.

1.4 The Use

1.4.1 Intended Audience

The whole project is intended to offer a precise package of visual and immersive experimental environment in which professionals in the field will use to test theories, discover and answer unknown questions related to a particular or general brain activity within a virtual environment.

Professionals: This considers neuroscientists, psychologists, engineers, or/and enthusiasts who are welling to reach out and understand whats going on within the human brain while an interaction is happening within a virtual environment.

1.4.2 Intended Use

This project aims mainly to add a significant stamp in the already vast community of scientific research.

Aiming to contribute and to ease any kind of contribution that any professional can add.

It tackles a precise research area, trying to reveal specific questions that evolve around the human brain's behavior.

2 Requirements Definition

2.1 Functional Requirements

One of this document's purposes is to explain the system requirements; they will then be explained next. These requirements went identified by the developers with the neuroscientist responsible approval. To better understand, they are divided by the several types of requirements needed for a better implementation.

2.2 General

The table below shows the general functional requirements of the developed game.

General Functional Requirements	
REQUIREMENTS	DESCRIPTION
G01	The Admin interface and the game should be displayed in two different screens (PC and HMD).
G02	All system functionalities should be accessible through individual buttons and input fields.

Table 1: General Functional Requirements

2.3 Player

The next table represents the direct functional requirements of the player/subject that are going to be directly enjoying the experience of the developed game.

Player Functional Requirements	
REQUIREMENTS	DESCRIPTION
P01	The player should visualize the scenes using a VR headset (HTC Vive Pro Eye, in this case).
P02	The player should get a realistic feeling and an immersive sensation throughout all the present scenes.
P03	The player should be able to interact with almost every present GameObject in the scenes using joysticks(HTC Vive Controllers in our case).

Table 2: Player Functional Requirements

2.4 Games

2.4.1 Main Menu

Table 3 presents the direct functional requirements that should be present in the developed game. The game must have a main menu at first that includes:

Main Menu Functional Requirements	
REQUIREMENTS	DESCRIPTION
M01	The logo/name of the game.
M02	A simple design.
M03	A place to insert the subject name.
M04	A button to load the CSV file with the game parameters.
M05	A button to select where it is to save the data acquired during the session
M06	A start button to each game.
M07	A exit button.

Table 3: Main Menu Functional Requirements

2.4.2 Reaching Tasks Game

The functional requirements of the Reaching Tasks game are present in the following table:

Reaching Tasks Functional Requirements	
REQUIREMENTS	DESCRIPTION
RT01	**Whiteboard:** The whiteboard is the only element that will be showing text to the player.
RT02	**Timing:** The one trial will take a decreasing period pre-selected by the admin in the CSV file, in which the trial will finish with the time reaching 00seconds. The time only appears to the user if the admin select that in the same file.
RT03	**The Experiment:** It must consist of a present button to be pushed by the player and having an obstacle hiding that button.
RT04	**Obstacle:** The goal out of the obstacle is to see how subjects will be following a specific trajectory to push the button, so modifications in the size, shape, look, location of the obstacle are acceptable. The obstacle appears after some time to allow the player sees where the button is.
RT05	**Push-buttons:** The buttons will take the shape of a floating wooden box and is considered clicked when it is wholly pushed down.
RT06	**Player's view:** The player must have a clear view of the whole scene, with the main focus and the original position facing the whiteboard.
RT07	**Coordinates file:** The game can get the space coordinates of the trajectory made by the subject. For that, only press the controller trigger (back button) while doing the intended path. If the trigger is not being pushed, the game does not save anything.
RT08	**Recenter:** The HMD system has real movements measure. Considering that the user can stay in different positions in the space, a shortcut thru the *r* keyboard button was inserted to recenter the world in front of the user's view.
RT09	**Start session:** Since the player needs to adapt to the virtual world, the pretended session only starts after the admin presses the keyboard's *Space* button.
RT10	**Exit:** If *ESC* in the keyboard is pressed with each new scene, the game returns to the main menu.

Table 4: Reaching Tasks Functional Requirements

2.4.3 Drawing Tasks Game

The functional requirements of the Drawing Tasks game are present in the following table:

Drawing Tasks Functional Requirements	
REQUIREMENTS	DESCRIPTION
DT01	**Whiteboard:** The whiteboard is the only element that will be showing images to the player.
DT02	**The Experiment:** It must consist of an image showed on the whiteboard that can disappear after some time, and that the user must repeat the outline with the controllers.
DT03	**Feedback line:** It is possible, by the CSV file, to enable a line that will appear in front of the user to give feedback of the trajectory made.
DT04	**Player's view:** The player must have a clear view of the whole scene, with the main focus and the original position facing the whiteboard.
DT05	**Coordinates file:** The game can get the space coordinates of the trajectory made by the subject. For that, only press the controller trigger (back button) while doing the intended path. If the trigger is not being pushed, the game does not save anything.
DT06	**Recenter:** The HMD system has real movements measure. Considering that the user can stay in different positions in the space, a shortcut thru the *r* keyboard button was inserted to recenter the world in front of the user's view.
DR07	**Start session:** Since the player needs to adapt to the virtual world, the pretended session only starts after the admin presses the keyboard's *Space* button.
DT08	**Exit:** If *ESC* in the keyboard is pressed with each new scene, the game returns to the main menu.

Table 5: Drawing Tasks Functional Requirements

2.5 Non-Functional Requirements

When it comes to the security, used protocols, and architectural point of view, they are all handled automatically by the Unity Gaming Engine.

The following table present briefly most of the Non-Functional Requirements.

General Non-Functional Requirements	
REQUIREMENTS	DESCRIPTION
NFR01	**Hybrid Interface:** The interface should be clean and visible in the computer monitor and the HMD.
NFR02	**UI Control:** UI in the games must be controlled through the Vive controllers.
NFR03	**Safety:** The experiment, and the whole setting, should not cause any harm to the playing subject or the admin.
NFR04	**Performance:** The game's performance must be quick, responsive, and the lowest energy consumption for the hardware as possible.
NFR05	**Ambient:** The game should be enjoyable, giving a sense of entertainment and fun.
NFR06	**Quality:** All present objects should be in a 3D dimension.
NFR07	**Interaction Sounds:** While interacting with objects, each interaction must have a specific sound.

Table 6: General Non-Functional Requirements

3 Developed Application

3.1 Overall Description

The intended to build application is an independent system, not related to another system, and not considered a larger system component.

This application has two different kind of users:

- **Professionals:** The main kind of users that will use the application are professional users, in which they are the only ones with access to control the platform.
  - The platform will provide multiple types of variables that can be plotted, changed, deleted, modified, saved, copied, and pasted.
  - The platform will include a control panel to start, pause, stop, interrupt, or modify the experiment whenever needed.
- **Normal Users/subjects:** There is no specific type of users intended here, in which a more diverse list of subjects can result in better outcomes to these experiments.
  - The whole experience is immersive, fun, and interactive, meaning that any subject who enjoys these experiences is a welcomed user.

3.2 Hardware Interface

The application was built using the Unity Gaming Engine.

The engine offers the possibility to build and run the created applications on Windows, iOS, and Android devices.

The present application requires a Head-Mounted Display (HMD). In this case, the project was developed to work with HTC Vive Pro Eye that uses SteamVR software. With this VR headset, two controllers come included, and are these two controllers that are used to interact with the game environment.

Considering the HMD used, the minimum requirements for running this software are Intel® Core™ i5-4590 or AMD FX™ 8350, NVIDIA® GeForce® GTX 970 or AMD Radeon™ R9 290, 4 GB RAM, DisplayPort 1.2, and 1x USB 3.0[1].

4 Usage Instructions

4.1 Main Menu

The initial menu is where is loaded all the information regarding the game. The admin is the only one who sees this menu since when the user places the VR Glasses, he only sees an image with the information that the game data are being selected. To start, the current session user's name can be entered. This field is optional, but it can help to identify better who performs the session since the file that will be created to save the moves made by him has the following name format: *UserName_trackingCoords_YYYmmDD_HHmm*, being *YYYYmmDD* the date and *HHmm* the time, both entered automatically considering the computer clock.

Next we have a button to load the CSV file that will contain the information for each game. A Windows window is displayed to choose the location where the file is saved and load the data contained in it by selecting this option. The format of this file will be explained later.

Similarly, another window is shown so that it is possible to choose the folder where the coordinates obtained from the controllers' movement will be saved. This file will have the name mentioned above.

Once this process has been carried out, the admin chooses which game will be played according to the chosen file. If he chooses the game that does not meet the selected CSV, it will not load as it should because each file has its organization. Considering that this can happen, an option to return to the main menu was added, only needs to press the ESC button on the keyboard and thus choose the right parameters or start with the previous data, but in the right game.

When this menu appears after a game finish or a forced exit, all the fields will be empty. However, all the previous session data are saved in the memory. If the intention is to repeat the same session, it only needs to insert the user name and play the same game again. The coordinates file will be saved in the previous folder if no other was chosen.

If the session is over or pretend to close the game page, there is the *Exit* button which will perform this operation.

Figure 1: Main Menu scene

4.2 Reaching Tasks Game

After pressing the "start" button in the main menu, the game will load to the scene where this game is designed.

The scene is mainly composed by:

- A room with some furniture that gives a sense of realism.
- A table/desk, in which all experiment will be held on
- A chair just in front of the desk, where the player will see all the game.
- An avatar is seated in the chair to give a sense of presence.
- A whiteboard on the wall located in front of the player, in which information will show.
- Two realistic hands, controlled by the Vive Controllers, will interact with the different present objects.

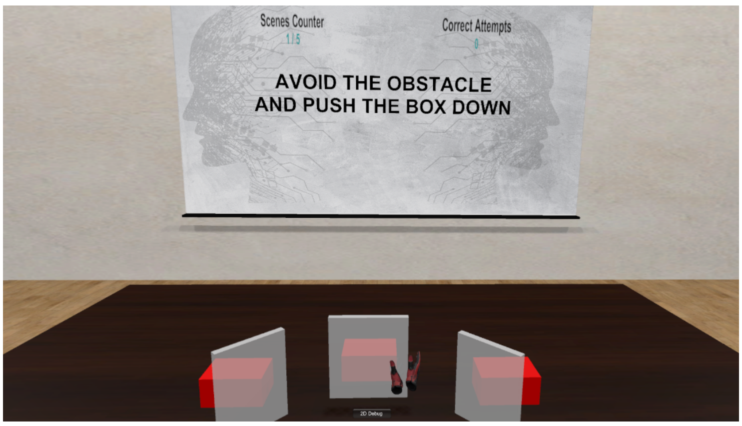

Figure 2: Reaching Tasks scene

The CSV that controls the scene has the next format:

```
Transparency,0,5
ObstacleTime,8
FinishTime,10
TimeShow,y
Button,Obstacle1,Obstacle2,Obstacle3,Hand
1,O,,,Both
3,,,t,Left
2,,O,,Both
1,t,,,Right
2,,O,,Left
```

Figure 3: Reaching Tasks CSV

Where Transparency indicates the transparency that the obstacles will have; this value is between zero and one where zero is transparent, and one is opaque. Then, ObstacleTime indicates the time after which the obstacle appears, so the user is allowed to view the button before the obstacle appears. FinishTime is the time that indicates after how many seconds each scene ends, and TimeShow, which can take any value or be empty if not to use, is to show to the user the time he still has to complete the challenge. The fourth line is merely informative and indicates the order in which the following values will be found.

The game has three buttons available, of which only one will be activated. To choose which one, it is necessary to put a value between one and three in the first parameter, each corresponding to a button from left to right. As we have three buttons, there are also three obstacles being available in front of the respective button. The following three parameters control these obstacles' appearance, which may or may not appear, and if they do, have transparency or are opaque. If the purpose is to appear an obstacle with transparency, must insert the letter t or T in the respective space so that they will have the transparency defined at the beginning of the file; if the objective is appearing an opaque, insert the o or O. On the other side, if the space is left blank, that obstacle will not be shown. Finally, it is possible to select which hand will appear in the game to press the buttons. Writing Right appears the right hand, Left for the left hand, and Both for both hands. These parameters are case sensitive.

After the scene loads, the admin can reset the camera position by pressing *R* on the keyboard, and after the user is well-positioned, the game will start by pressing *Space*. However, if the admin needs to cancel this experience and start again, he can use the *ESC* button to return to Main Menu.

4.3 Drawing Tasks Game

The second game is loaded by pressing the right scene button, redirecting to the Reaching Task game.

This scene is composed of the same furniture present in the previous one, but this time without the table. On the whiteboard will appear the image that the subject needs to copy. Instead of realistic hands, an image of the controller appears to give a better sense to interact in the scene.

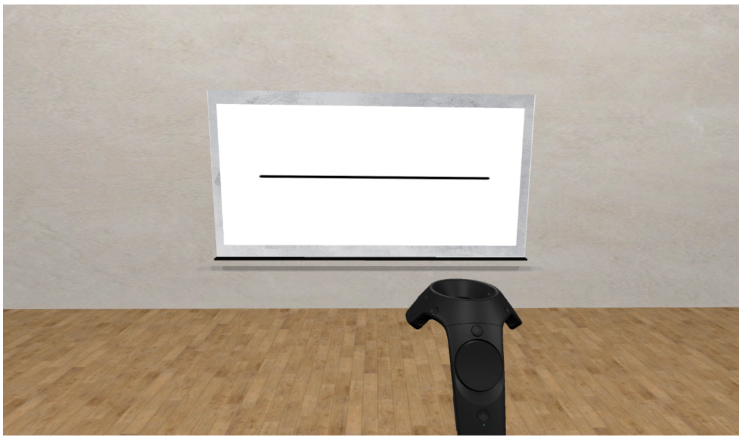

Figure 4: Drawing Tasks scene

As previously mentioned, all the game dynamics will be controlled by a CSV file previously filled in and then selected in the initial menu.

The CSV that controls the scene has the next format:

```
SceneTime,10
Path,C:\Users\PM\Documents\NeuroscienceProject\Images
FileDirectory,ImageONTimer,ShowPath
img1.jpg,2,
img2.png,,y
img3.jpg,,Y
img2.png,5,
```

Figure 5: Drawing Tasks CSV

Where SceneTime;10 corresponds to the time each scene will be active before moving on to the next, in this case, as an example, 10 seconds. Path refers to the directory where all the images to be used during each session are stored. To obtain this info, open the folder where the images are and click on the window's top bar where the path leads to this location. An address equivalent to the one shown in the image will appear and should be copied and pasted to replace this one.

The third line is only informative about the following parameters and should not be deleted to avoid errors. However, it is possible to change what is write in there. Finally, the subsequent lines are where each scene in the game is configured and can have as many scenes as wished, as long as there are no blank lines, and the structure is maintained. Thus, to control the game, the first parameter is the image's name to be shown in the frame; this can have any extension once the program processes it to be displayed. Then, how much time the image will be visible is entered; after this time, the image disappears from the frame. Please note that the entered value must be a value between zero and the one inserted in the scene's time; otherwise, it will be the same as leaving the field blank, and the image will always be on. The last parameter is to indicate if the line shown on the second image above should be shown; for that, it should be indicated with "y" or "Y" in this field. It is imperative always to keep this scheme, even if it is not to fill some field, must put the semicolon separators.

As indicated, the spatial coordinates of the controller will be saved in a file for analysis. For this to happen, the user has to press the trigger, which is on the controller's back. When this happens, the data is saved, thus avoiding that coordinates are stored when are not making any movement of interest, for example, when resting waiting for the next scene. To be easy to analyze, the file is organized to save in the first column when the data was acquired, in-game time, and the following ones are the X, Y, and Z coordinates, respectively. Every time a new scene is loaded, time is reset in the file; each scene is previously identified with the name of the shown image.

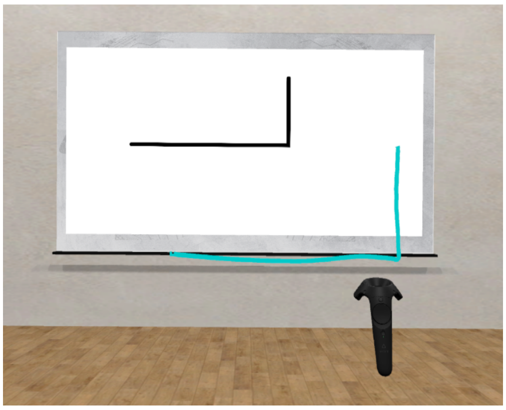

Figure 6: Draw example with feedback line

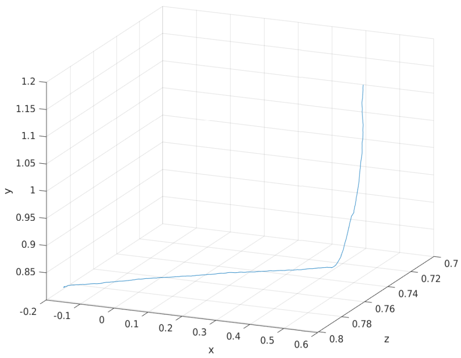

Figure 7: Example of the coordinates in a plot

After the scene loads, the admin can reset the camera position by pressing R on the keyboard, and after the user is well-positioned, the game will start by pressing Space. However, if the admin needs to cancel this experience and start again, he can use the ESC button to return to Main Menu.

References

[1] "Vive pro eye specs | vive™." https://www.vive.com/eu/product/vive-pro-eye/specs/.