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Serious Games For An Active Ageing

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

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But if God got us, then we gon' be alright

Kendrick Lamar

Dedication

In loving memory of my grandmother, who would certainly be proud to see me reaching the finish line.

This document closes what has been a long and joyful journey on both personal and academic levels. It was the longest roller coaster I've been on. If it gave me hard headaches and long sleepless nights facing challenges that, at first sight, looked hard to solve and proved to be quite simple in the end, it also taught me that sometimes it's only a matter of perspective and first sights are not always right. A second look with a fresh mind might help to find hidden paths to the desired goal.

First of all, my parents, who allowed me to be here writing this dedication out of time, without them none of this would happen. Second, my grandparents that were always anxious to see me succeed and many times willing to take exams for me if they could, I hope I made them proud. Third, my uncle, for all those conversations that gave me important insights about different fields of engineering, those were definitely useful hints to keep in mind. Last but not least, the pack, my siblings, and my cousins, for all these years of trash-talking and nonsense conversations that every time ended with great laughs.

A word for my supervisor, Professor Paulo Menezes, my first and last steps in and out of the University, couldn't have been different. Thanks for all the guidance and support in all those moments when the only thing I needed was to keep things simple, those were a lot. To my colleagues in the lab, Bruno, Gustavo, Marta, João, Vishal, Maria Rita, Thibault, Matéo, and Zamayra, Leonie, in some way this work has your fingerprints, it would have been a lot harder without your help and support when I showed up in the lab, thank you for all the different perspectives shared.

My friends, I can't name all of them, but they all know they played a huge role in this journey. To Mário, my right arm in any associative battle I've been in, to Carlos, from freshmen through many arguments and the most important lesson of humility I needed to learn, to Filipa, a second mother

I found during this journey and loyal partner on long bohemian nights, to Pimenta and Leandro (D3), for the moments of stress and joy and for helping me keep my feet on the ground while the thoughts were sometimes far higher, to the remaining of Peladinhas à Terça, fantastic four would look like babies near us, to Raúis, my hometown second family, and last but not least, to the kids I had the delight to meet this last year, it would have been a loner year for sure if they had not shown up.

Acknowledgments

A thankful word to all the participants on the testing moments for their availability and will to help. Those were undoubtedly essential.

This word extends, in a special manner, to Institute of Systems and Robotics (ISR) for providing the necessary resources for the development of this dissertation.

Abstract

The aging process usually enhances several fragilities, both physically and mentally. It is commonly said that what nature gives, nature takes back. With that statement in mind, to retard the natural weakening from the ageing process, people must practice their capabilities.

To maintain these capabilities active, it's essential to keep providing engaging and challenging ways of performing activities, keeping the mind and body defied. If a person feels good doing one task it is possible to see him/her willing to repeat that same task and perform it better than previously.

Aiming to increase motivation and keep people committed to the rehabilitation processes and mentally active, Virtual Reality (VR) and Serious Games (SGs) are helpful tools to reach the desired goal. By creating an immersive game, it is possible to transport the person to a place where he/she feels capable of performing exercises or tasks integrated into rehabilitation protocols and succeed without complaining about pain or the frustrating feeling of not seeing progress in a short time.

Further than the rehabilitation part, the developed solution has been designed for the user to enjoy and feel motivated to return to use it, creating engagement by bringing a sense of entertainment and happiness to the user. These topics have demonstrated to be quite significant in the user recovery process.

User experience questionnaires with 8 participants reported satisfying results in all scales, specially revealing the application felt attractive and stimulating while using.

Keywords: Serious Games, Virtual Reality, Post-Stroke Rehabilitation, Cognitive Stimulation, Active Ageing

Resumo

O processo de envelhecimento geralmente enaltece várias fraquezas, tanto física como mentalmente. Diz-se geralmente que o que a natureza dá, a natureza retira. Com este pensamento presente e querendo retardar o enfraquecimento natural no processo de envelhecimento, as pessoas devem estimular as suas capacidades.

Para manter estas capacidades ativas, é essencial continuar a fornecer formas envolventes e desafiantes de realizar atividades, mantendo a mente e o corpo desafiados.

Tendo como objetivo aumentar a motivação e manter as pessoas comprometidas com os processos de reabilitação e mentalmente ativos, a Realidade Virtual e os Jogos Sérios são ferramentas úteis para atingir o objetivo desejado. Ao criar um jogo imersivo, é possível transportar a pessoa para um local onde se sinta capaz de realizar exercícios ou tarefas integradas em protocolos de reabilitação e ter sucesso sem se queixar da dor ou da sensação frustrante de não ver progressos num curto espaço de tempo.

Para além da componente da reabilitação, a solução desenvolvida foi desenhada para que o utilizador possa desfrutar e sentir-se motivado a voltar a utilizá-la, criando um compromisso para com a reabilitação ao promover uma sensação de entretenimento e felicidade junto do mesmo. Estes tópicos demonstraram-se bastante significativos para processo de recuperação do utilizador. Nos questionários sobre a experiência de utilização, com 8 participantes, foram reportados resultados satisfatórios em todos os parâmetros de avaliação. Especialmente revelou-se que a aplicação era atrativa e estimulante durante a sua utilização.

Palavras-chave: Jogos Sérios, Realidade Virtual, Reabilitação Pós-AVC, Estimulação Cognitiva, Envelhecimento Ativo

Contents

1

Introduction

Human lifespan keeps expanding due to technological improvements, medical advances, and population acknowledgement of the importance of a healthy lifestyle. Ageing is a part of the human cycle that can't be avoided and emphasises symptoms that might reduce life quality. Those symptoms can be physical-motor, for instance illness-related conditions, reduction of mobility, bone density loss, sarcopenia, as well as cognitive, such as mild cognitive impairment (MCI), dementia, or Alzheimer. MCI is usually classified as a pre-clinical stage of dementia, even though the conversion rate to dementia in patients with MCI may vary with the diagnosis criteria. The risk of these two diseases is considered to be the same: ageing, genetic cause, or cardiovascular disease, including stroke [1].

Among illness-related conditions there is the Post-Stroke Affected Upper Limb. Post-stroke rehabilitation process is usually long and complex. After the neural connections collapse, the patients need to train the affected body parts to perform the usual activities previously performed. This process is frustrating as the patient's body does not respond to the brain stimulation as before. This obstacle can lead to the absence of the recovery protocols as the user have the perception that the body is not responding as expected due to the fact the brain mechanism of adapting to the physical condition opting to forget the affected limb and using only the healthy ones, making harder to relearn the basic moves previously executed without difficulty.

This condition leads to mental fragility, which can take the users to depressive states, resigning the rehabilitation and embracing the problem as natural.

Active and healthy lifestyle can prevent both stroke risk and cognitive disease risk[2], even though attention and memory are cognitive functions that naturally decline along the years, in some cases leading to the development of dementia, as this is also connected to mental health aspects that are crucial in elder populations diagnosed with MCI, such as depressions and impaired ability to perform daily activities[3].

In most cases, physical rehabilitation is needed to recover movement and strength. These processes usually consist of repetitive and supervised movements. In many cases, the patients feel difficulty performing the recommended individual therapy exercises, as statistics show that 33% of the patients don't do it [4]. This retards the rehabilitation and can make patients abdicate the recovery. It may have several reasons, such as frustration for not seeing fast results or not having access to the appropriate technological material.

Suppose that people won't perform the exercise by themselves. In that case, the gamification of those exercises, i.e., turning the movement into game controlling commands, can be a powerful weapon to get aged populations active [5] and have them performing their recommended individual therapy. Exercise gamification will make people not only perform a series of movements that will help them improve their condition, but they will also do it while playing a game that will be challenging and joyful.

Virtual Reality (VR) systems have been long proven to be helpful in motor and cognitive rehabilitation [6], directing the patient's attention, with immersive and interactive environments, to the enjoyable way to perform a formerly unpleasant and, sometimes, presumed painful therapy exercise [7]. The exploration of this approach of distracting the user's mind with video games has been collecting interesting therapeutic results. The increased engagement rate with therapies is critical for a shorter recovery journey. This type of interactive video games that have a primary goal beyond entertainment is called serious games. These games are designed to be used for educational, therapeutic, and rehabilitation purposes as they have been seen to be particularly useful in stimulating older populations who are faced with enhanced weaknesses and limitations as they age.

Today's technology allows the user to wear a head-mounted display (HMD) to provide an even more immersive experience to the patients. This immersion combined with virtual elements which the person can focus on helps to distract the user from painful elements, reducing its perception. The adaptability of the virtual reality solutions allows the patients to perform movements in a wider range in the virtual world, with slight movements in the real world giving the perception that the real movement is enough to complete the activities. This adaptability gives patients confidence in the process as they see good results. As the real-world movement range improves, the system can be adjusted to become more challenging to the point that the virtual movement is an authentic representation of the real-world movement range.

1.1 Related Work

Virtual reality for rehabilitation has been a research topic for a long time; Kizony et al. [6] studied the application of virtual reality on a post-stroke patient and a complete spinal cord injury patient that required balance training, using VividGroup's Gesture Xtreme scenarios, adapting them for the therapeutic goal.

Virtual Reality adaptations can assume multiple forms and games belong on that cluster. Games can serve a different purpose primarily besides entertainment, and those have been named Serious Games (SG). SGs, as Stokes[8] describes it, are *games that are designed to entertain players as they educate, train, or change behaviour*. Checa and Bustillo [7] analysis recognised the potential of Immersive Virtual Reality Serious Games as a form to enhance learning and training.

Michael [9] said that *games have the power to teach, to train, to educate*. From this statement is possible to find that turning a day-to-day task into something enjoyable and rewarding, as a game should be, might help the player to learn things that used to be hard to learn traditionally.

Gathering game elements with real-life tasks can provide exciting solutions to improve the engagement rate with the usually recognised as boring activities, as Chatterjee et al.[10] acceptability feedback demonstrates, in the study of recreating daily basic activities, such as cutting bread, counting coins, etc., in a virtual environment for post-stroke rehabilitation.

Control game elements with a certain type of movements prescribed by therapists to the patient, as individual therapy exercises, might be helpful for improve rehabilitation results and may reduce the process time supported by a commitment and motivation increase, since games are often associated with good user engagement, as demonstrated by the studies of Burke et al. [11, 5].

Melconian [12] studied the fall prevention topic and developed an immersive benchmark system, using an HMD and an RGBD camera, to enquire about the sit-to-stand movement accuracy in elderly to help therapists understand the mistakes made by patients performing the exercise and let them watch the comparison of the benchmark avatar, with the patients' performance avatar.

Kern et al. [13] studied the relation between immersive virtual reality gamification and user motivation increase during gait rehabilitation, using a treadmill and a Head-Mounted Display (HMD), reporting greater enjoyment and satisfaction from the participants that were feeling more competent and experienced higher decision freedom.

Ferreira and Menezes [14, 15], have been studying gamification in immersive environments, exploring stroke rehabilitation, and reporting that immersive technologies may be a valuable aid for conventional rehabilitation methods.

Pereira and Menezes [16] studied the gamification of the vestibular system rehabilitation methods on a low-cost headset mobile application that reported the pleasant feeling of the participants on using this rehabilitation method.

Kaminska et al. [17] studied the effectiveness of a VR-based system using Xbox 360 Kinect, evidencing VR can improve postural stability, helping to reduce the risk of falls among elderly participants.

Gamito et al. [18] tried to understand the impact that VR environments based on everyday life tasks for cognitive intervention can have when compared to traditional cognitive stimulation methods. The results displayed were positive on several dimensions, demonstrating that VR-based environments can be a future tool on this kind of therapies.

Oliveira et al. [19] performed a randomised controlled trial based on a non-immersive VR approach of instrumental activities of daily living, such as ordering shoes by colour, selecting pieces of clothes, identifying groceries from the shelves, using neuropsychological instruments for assessing memory, attention and executive functions, demonstrating an improvement in overall cognitive tasks with a particularly interesting effect in global cognition.

1.2 Objectives

This project's goal is to create a set of VR games to serve the purpose of entertaining elder populations while activating them physically, through movements that control game actions, and stimulating them intellectually.

To obtain the desired goal, the solution must to attend several objectives:

- Game components and actions must feel coherent to the player and they must feel comfortable using them;
- Match the limitations typically presented by the target audience;
- Create engagement with the player;

- Stimulate players, physically and mentally;
- Defy the player along the playing time;
- Bring a sense of joy and pleasure to the player;

1.3 Main Contributions

Considering the state of the art, most existing solutions are either non-immersive or non-rewarding solutions.
The developed work creates a VR application using a low-cost HMD to provide an immersive virtual environment to stimulate older people physically and mentally. Stimuli will be delivered through a set of two serious games that promote upper body movement and colour recognition, creating engagement with the user through challenge and reward.
Besides the engagement created with the users, this tool can provide real-time details to therapists. Therapists will be identified by unique codes. Individuals registered as therapists and linked to a user will be able to visualise the sessions' details over time to analyse scores and playtime progress using this tool.

1.4 Dissertation Structure

- **Chapter 1** introduces the theme and its relevance over the work already done that is explained;
- **Chapter 2** describes target conditions' for this study along with previous and current treated options;
- **Chapter 3** reveals the entire structure of the game and the development process;
- **Chapter 4** presents preliminary results collected from tests performed on the application;
- **Chapter 5** presents a discussion of the results;
- **Chapter 6** concludes the dissertations, summing up the work done in this study;
- **Chapter 7** presents future work that can be implemented;

2

Opportunities of Virtual Reality and/for Stimulation

Technological developments from the past years played a vital role in providing consumers with new experiences. One of the experiences is immersing the user in an environment apart from the real world, apart from the perception of the body and possibly from existing limiting conditions, supported by VR devices. These developments allowed people to access this immersive equipment in a lighter and more compact shape more easily with the dissemination of the HMDs. These wearable devices allow the user to be placed inside virtual environments, that can be used for entertainment, learning processes, or rehabilitation. Virtual Reality systems for rehabilitation and stimulation, as mentioned previously, aim to create an endearing environment conducting the user to concentrate all the attention on the ongoing activity and ignoring exterior stimuli.
In the following chapter, several use cases will be explained and application targets will be enlightened.

2.1 Use cases

2.1.1 Affected Upper Limb Post Stroke

A stroke occurs when a blood vessel in the brain ruptures and bleeds or when there's a blockage in the blood supply to the brain [20]. When treating a stroke, the most crucial factor is time. Faster treatment improves the chance of positive results, preventing more brain cell loss. After that, rehabilitation can be long and slow, fig.2.1.

This type of accident usually affects an entire side of the body, paralysing upper or lower limbs if not both in worst case scenarios, demanding the patient to relearn essential motor functions during the rehabilitation process. Recover the affected lower limb has a success rate, 82% of the survivors can expect to walk independently again. Still, the affected upper limb recovery has a poor success rate, as only 50% of the patients are likely to regain some functional use of it. Patients described the upper limb recovery key process as *keeping the door open*, which means that, at the time, it could be a lifelong continuous action, emphasising the importance of not setting a deadline for the recovery [21].

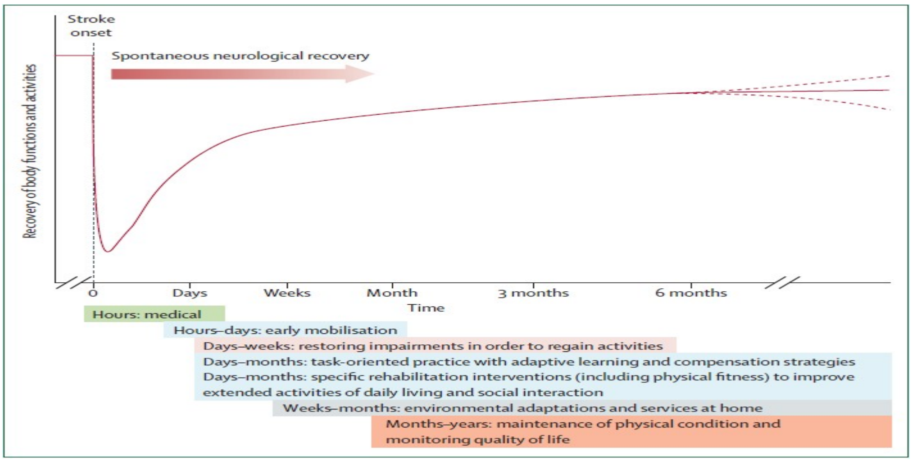


Figure 2.1: Hypothetical pattern of recovery after stroke [22]

This kind of accident are usually devastating for the survivors mental state, specially to the ones affected on the upper limbs which might face a great challenging in two ways, physically to retrain the body to relearn previously known essential movements, as well as, mentally by dealing with the frustration of a slow paced recovery process that can lead to a depressive state of mind and withdrawal from recovery therapies.

2.1.1.1 Recovery Methods

Methods and technologies have evolved significantly over the past decades. Treatments have become more innovative, specially on this study's object, the Arm Medial Lateral Rotation (AMRL). The recovery aims to replace the natural function of the arm to rotate on the elbow, as displayed in fig. 2.2.

Figure 2.2: Affected upper limb rehabilitation

Post-stroke rehabilitation has evolved significantly, allowing technological additions to conventional physiotherapy methods. The offer is long, using Brain-computer interfaces and robotic arms, fig. 2.3, in an *assist-as-needed* control approach, where the robot arm assists when the patient fails to follow the commanded trajectory by his/her capabilities [23], or reproducing day-to-day activities in immersive virtual environments, fig. 2.4, for the brain to regain old habits in a closed and controlled environment, so the patient can evolve at its own pace [5, 10, 14].

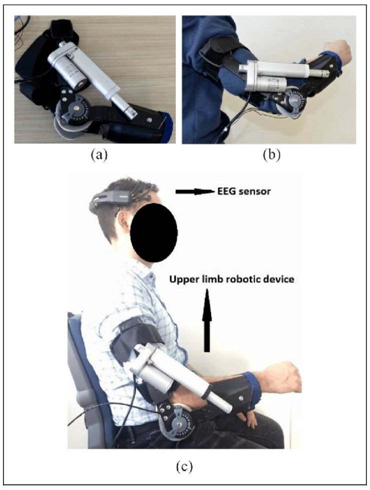


Figure 2.3: Upper Limb Robotic Arm

Figure 2.4: Daily activities represented in a virtual environment

AMRL can be easily pictured as a controller for a game, allowing clinical treatments to be even more efficient, by creating engagement in the patient, motivating him/her to practice more often, and taking more seriously the therapist-recommended individual therapy exercises at home.

2.1.2 Mild Cognitive Impairment

MCI is a transitional state between cognitive decline for normal ageing and early dementia and often Alzheimer's disease, in which mental degradation is greater than expected[24, 25]. The most common cognitive deterioration proof regards memory loss over the life span.

Mild Cognitive Impairment can be classified into two sub-types: amnestic and non-amnestic. Amnestic MCI (aMCI) is a significant memory impairment that is still not strong enough to be considered dementia. Patients are typically more prone to increased forgetfulness. Although memory has been affected over the years, other cognitive functions, such as executive function, use of language, and visuospatial skills, are still preserved. On the other side, Nonamnesic MCI (naMCI) patients show a slight decline in memory-related functions, affecting attention, use of language, and visuospatial skills. This second sub-type is less common than the first one.

Petersen estimates the prevalence of MCI ranges between 10% and 20% in individuals older than 65 years, yet referring that in *Mayo Clinic Study of Ageing* a population-based study with participants without dementia between 70 and 89 years old, the prevalence of aMCI was 11,1%, and naMCI was 4,9%.

According to several studies, cognitive and motor ageing plays a critical role in the motor decline in MCI patients [26, 27]. Cognitive capabilities indirectly have influence in motor behaviour as the schematic in fig.2.5 illustrates. Compared to healthy older adults, MCI patients showed additional motor deficits and greater cognitive decline.

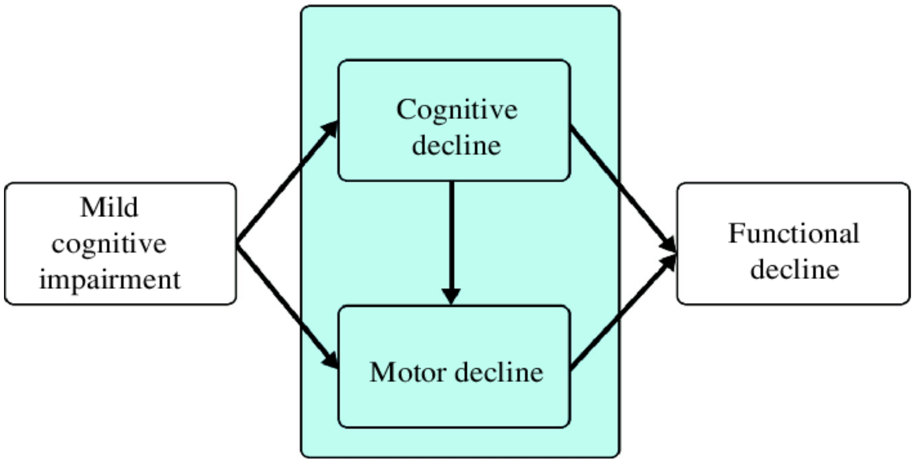


Figure 2.5: Effects of MCI on declining motor performance and learning. Taken from [2]

Chan et al. [2] also say that physical activity helps prevent functional and cognitive decline, relating regular exercise with better cognitive abilities, among them reasoning, working memory, and reaction time.

2.1.2.1 Recovery Methods

A healthy routine with regular exercise, is not only preventive, but also therapeutic and related to the better cognitive function [2]. According to the previously mentioned Chan's article, "*aerobic exercise for 6 months increase older adults' brain volume, including grey and white matter*". Further than physical activity, adding cognitive stimulation, e.g., training in mnemonic techniques, can help improve patients' cognition.

Modern studies look to stimulate patients in VR environments, where patients have to perform daily activities, such as morning hygiene, selecting clothes from the wardrobe, and grocery shopping, among others, so the patients don't forget the basics 2.6.

In fact, any mind-stimulating exercise or game[28] can be helpful in MCI recovery. Keeping the brain active and mentally challenged helps to rebuild normal cognition. Those exercises can be, for example, memory card games, fig.2.7, puzzles, fig.2.8.

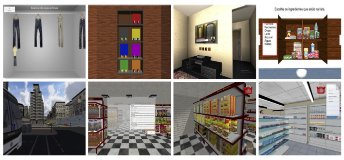


Figure 2.6: Daily activities

Figure 2.7: Memory Card Game

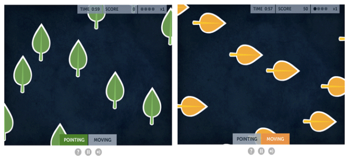


Figure 2.8: Brain puzzles

Games involving reaction speed to objects and sounds can also help cognitive function improve, by demanding attention from the patient to concentrate and focus on distinguishing the things that might be destructed, or the ones that should stay in place.

2.2 Use Advantages

Considering the methods' evolution and the actual practices - more conservative or innovative - it is safe to say that Virtual Reality can represent an added value to an active ageing process based on the generated stimuli on people. While wearing a HMD people will get immersed in virtual environments where the real world gets out of sight. With real world out of sight, people lose direct visual contact with disabilities, which means an open new world of opportunities to explore without thinking of being unable to succeed in a proposed task or exercise due to overthinking about actual difficulties.

Following the expansion of technologies in more accessible forms, it was visible that video games' popularity have increased in all age groups showing that it is possible for them to serve different purposes other than pure entertainment. This blend of a pedagogical/therapeutic aspects with the entertaining and competitive components of a regular video game, peaking in the trendy concept of serious game, can be attained by promoting the *gamification* of the typical monotonous and sometimes frustrating exercises.

This combination of purpose and entertainment has already ability to attract the person attention creating the necessary engagement that regular therapies and stimulating solutions often lack. But when all this is build to run in a VR device it gains a significant extra advantage because of the above mentioned immersion of the user into the virtual environment hiding the conditions and difficulties.

3

Proposal

3.1 Problem

Stroke survivors often face a number of challenges in their journey towards recovery, including frustration over the lack of immediate results. This frustration can be compounded by a weakened mental state, leading to feelings of depression and a tendency to withdraw from therapy and rehabilitation processes. The combination of these factors can lead to an accelerated decline in cognitive function, resulting in Mild Cognitive Impairment.

The absence of engaging and stimulating solutions for stroke survivors can contribute to this decline in cognitive function, as the brain needs stimulation in order to continue to develop and grow. This lack of engaging stimuli is a major concern for stroke survivors, as it can lead to boredom, frustration, and a decrease in motivation to participate in therapy and rehabilitation processes.

3.2 Motivation

Concerned about the sensitivity of these questions and the fact that the target population are elders with enhanced weaknesses and often limitations, the idea of using video-games emerged. These are well known for generating engagement amid the ones who play them, and the lack of engagement is the bottleneck of the actual therapies. Serious games, as previously mentioned, have been seen to be particularly useful in stimulating older populations who are faced with enhanced weaknesses and limitations as they age. In an effort to combat the sedentary lifestyle associated with advanced age, serious games designed for an active ageing have emerged as an ideal solution. The use of virtual reality in these games adds an extra dimension of immersion and engagement, as it allows players to be transported to a different space, detached from their surroundings and any impairments. This can provide a stimulating and rehabilitative experience, promoting physical and mental activity among the older population. Serious Games For An Active Ageing can be designed to target specific physical or mental challenges, such as balance, coordination, memory, or cognitive function. They can also be tailored to the individual needs and abilities of each player, ensuring that the experience is both challenging and achievable. By using VR technology, the games can create an immersive environment that engages the player and encourages them to be more physically active.

3.3 Proposed Solution

Serious Games For An Active Ageing is an application that intends to stimulate and encourage elders to keep physically and mentally active, through a set of games. Concerned about the possible fragilities and disabilities, natural from advanced ages, and to preserve the safety and the comfort of the user, the games have been developed for the person to play them seated. While seated, the player is able to interact with the game elements using the upper body, more specifically the arms. To promote the desired stimuli among the older populations the application has two games.

The first game, Spheres Popping (explored later), aims the cognitive stimulation of those who play the game. To succeed in this game the person must pay attention to the position of the new objects appearing on the scene and destroy only the rewarding ones. This reward will be distinguished by a semaphore colour code, fig. 3.1, to award persons' faster interactions with the objects with the intention to stimulate the reaction speed.

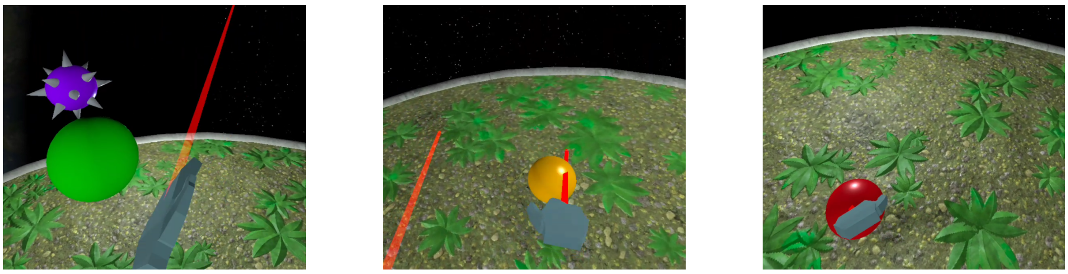


Figure 3.1: Semaphore colour coded spheres

The perception of the newly created objects will be assisted by the sounds each type make which allow to identify the type of sphere created and estimate the position based on the distance to the sound source, stimulating the spatial notion and awareness of the player. Moreover this game also stimulates the person's upper body since the core action to play this game is to reach the objects to destroy them, promoting and activation of trunk and the upper limbs. This body parts' activation through intentionally arbitrary movements and can be split in two parts. In a first moment it will happen a rotation of the head and the trunk to figure where a new sphere has been created, after the object detection begins the second moment when the person has to reach the sphere to destroy by slightly leaning and/or rotating the trunk and open the arms to touch and destroy the spheres to receive the reward point(s), fig. 3.4.

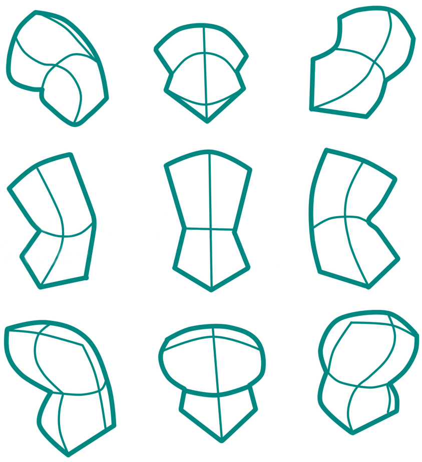


Figure 3.2: Trunk movements representation

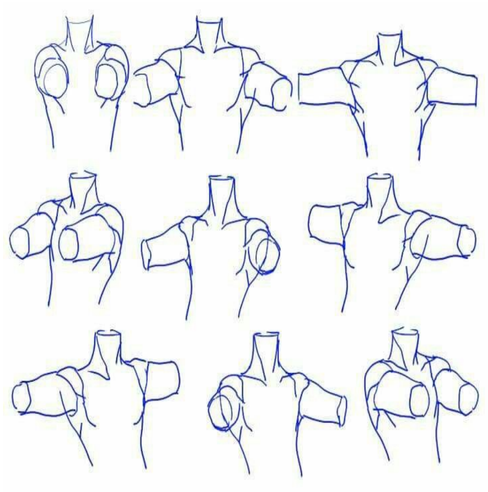


Figure 3.3: Arms movements representation

Figure 3.4: Spheres Popping interaction moves

The second game, Box Placing (explored later), is focused on recreate in VR the AMLR movement, typically seen in post-stroke affected upper limb rehabilitation protocols. This type of movement movement can assume a wide variety of ways to perform, as far as fig. 3.9 can illustrate, to retrain the brain and work on regaining the rotation movements of both elbow and shoulder. The user can performs this exercises both alone using lightweight objects to help strengthening the affected muscles by applying light resistance to improve movement control.

Figure 3.5: Open arm movement rehabilitation exercise. Taken from [29]

Figure 3.6: Pushing movement rehabilitation exercise. Taken from [29]

Figure 3.7: Neofect Smart Board to assist rehabilitation movement. Taken from [30]

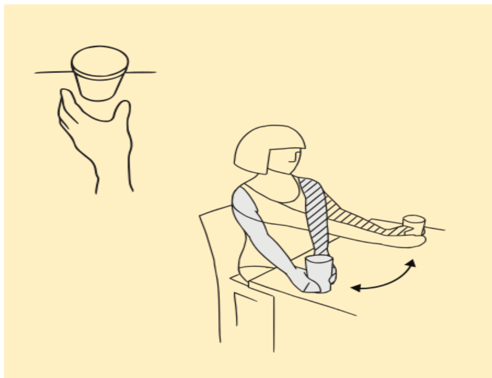


Figure 3.8: Arm Rehabilitation exercise. Taken from [31]

Figure 3.9: Arm Rotation Recovery Methods

To turn these movements into something appealing to the one performing, Box Placing game consists of an aleatory sequence of objects, with different colours, moving from a far point towards the person that must be placed in the corresponding container. To play this game the person will perform movements similar to the above illustrated, as the containers are placed and the left and right sides, so the one can perform the *Open Arm Movement*, fig 3.5, to place the cube on the same side container, focusing the movement on the elbow, or it is also possible to grab the cube and taking it to the opposite side container performing a movement similar to the one illustrated on fig. 3.8, using a shoulder rotation instead of the elbow one.

Beyond the intended physical component natural from the recreation of the rehabilitation rotation movement, the game can also targets the cognitive side of the player by stimulating the attention and memory when it comes to place the cubes on the corresponding containers. To avoid the game to become monotonous for the player, Box Placing has a particularity that every time the person hears the sound of a bell one of the hand representations will be randomly disabled for a short amount of time, forcing the user to be concentrated to not waste points and stimulating the weaker hand that might been spared due to the fragility, during this period of the game the punctuation will be doubled to award the person performance with this restriction.

Figure 3.10: Arm rehabilitation exercise. Virtual Reality recreation

4

Implementation

Following the proposal concept description it is important to highlight that the intended solution needs to meet the cornerstones of serious games. Those are:

- **Entertainment:** to make it easier to catch user empathy for the therapy, the game must be entertaining, earning the attention of the player and promoting a return from the user to play the game again.
- **Purpose:** this part is the great concern of an SG, add something to the solution delivered to the user rather than just entertainment, this type of game is really useful and helpful to learn, the user is performing a pleasing activity. In this case, the purpose is related to rehabilitation.
- **Competitiveness:** a game becomes engaging when the player feels challenged and wants to play again, to beat the previous result of an opponent result. This feeling will conduct the user to be more diligent with the individual therapy.
- **Happiness:** the feeling awakened by the satisfaction of performing a pleasing activity, it is important to deliver an appealing environment and an easy-to-use platform to absorb the user to the experience, stimulating the joy of using the application.

4.1 Requirements

Every system must attend to several guidelines to attain the purposed goal. Designing a VR-based application, a VR-based game, is mandatory to obey one topic: coherence. Aware of this, the game must feel fluid, mainly when the system includes VR technology using an HMD. It must feel natural to the human brain, as the player's vision has been temporarily blinded. With realwold perception loss, if the game is not coherent for the user's brain, it can result in discomfort or cybersickness for the user, which is not the desired outcome of this experience.

Concerning about this matter, developing a VR-based game for the elders' cognitive and motor rehabilitation needs to attend several restrictions.

Those restrictions are presented in the following tables:

Requirement	**Description**
1	The application must be suitable for clinical and domestic use
2	The application should have a friendly user interface
3	The experiment should not cause any harm to the player
3.1	The player has to be able to play seated
4	The games must be appealing to keep the user engaged
5	Users may be able to select the starting difficulty

Table 4.1: Game Non-Functional Requirements

To respond to the needs revealed by the non-functional requirements of the app, there are several functional requirements to fulfil in order to achieve the intended result. Those requirements are displayed in the table bellow.

Requirement	**Description**
1	**User Management**
1.1	Users may be able to register new accounts and login
1.2	Users may be able to log in to existing accounts
2	**Settings**
2.1	Users may be able to choose game language
2.2	Users may be able to select the starting difficulty
2.3	Users may be able to adjust the volume of the application music
2.4	Users may be able to adjust the volume of the application sound effects
2.5	Users may be able to add or modify the therapist's code
3	**Games**
3.1	Users may be able to select the desired game
3.2	Users may be able to visualise playing time and score while playing
3.3	Games' difficulty must be progressive
3.3.1	The game parameters must dynamically increase/decrease
3.3.2	The difficulty level must last ten clock cycles
3.4	User may be able to pause the game
3.5	User may be able to quit the game
4	**Personal Data**
4.1	User may be able to visualise personal data and games' own top scores
4.2	User may be able to visualise games' global ranking

Table 4.2: Game Functional Requirements

4.2 Interaction

The game development was carried out in Unity, a 3D game engine developed by Unity Technologies. It is the world's most used cross-platform for game development. Unity allows multiplatform deployment, using the same code and assets, without significant changes to each one[32]. Beyond the variety of deploy platforms, the fact Unity is already a stable game engine was one reason that led to its choice. The editor has a user-friendly drag-and-drop interface, allowing the developer to design the graphic environment without programming the geometry and shading that every 3D graphic element demands, making game development much simpler than OpenGL. Since this engine works with objects, after creating them, it is possible to use them in every project after turning them into a prefab. After that it is possible to add them to the project scene. The game behavior is scripted in C#, a simple, modern, and object-oriented language based in C and C++ [33].

Regarding the applications' target audience, interaction is a core concern and it has to be easy for the user to interact with the system. It has to be intuitive. Thus, the measures of the system were carefully thought, due to the immersion of the user, to be as realistic as possible. Unity helped with it, since a 3D cube freshly created on the project is 1m x 1m x 1m, by default, and taking advantage of Unity's scaling feature, several dimensions were tested until they reached the perfect size for the objects and scenarios.

Considering the immersion desired for the project and the interactivity while using the application, the lower cost option found to deploy the application was *Oculus Quest*, fig.4.1, a *"full 6 degrees of freedom (6DOF) headset with inside-out tracking allowing high performance wireless room-scale experience"* [34], that also brings controllers allowing the user to use the hands to interact with the application, either with several buttons, fig 4.3, or just with motion tracked by the device.

Figure 4.1: Oculus Quest

The trigger button is for the user to interact with game interface buttons, for instance, application navigation, select input fields, pause the games, and interact with the menus.
When the keyboard is open, fig.4.2, the left controller interacts with it through the ”PrimaryThumbstick”, which allows the user to navigate through the characters’ panel and choose the desired character to type, button one, ”**A**”, allows the user to navigate between lower case characters, upper case characters, as well as numbers and special characters.

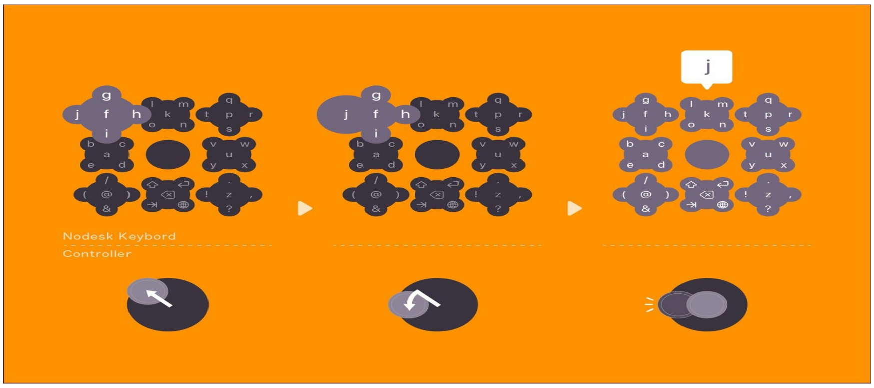


Figure 4.2: Keyboard usage explanation

For actions to succeed in both games, the user will need to do different things with the controllers. Interaction inside the spheres’ game consists in moving the hands towards the sphere to destroy, making the hand model hit the intended object. On the other side, to interact with the cubes’ game, the user needs to move the hands towards the cube and, when the hand model reaches one cube - the user will feel the haptic feedback vibration -, the player has to hold the trigger button to keep the object in his/her hands and release it to drop the object in the desired place.

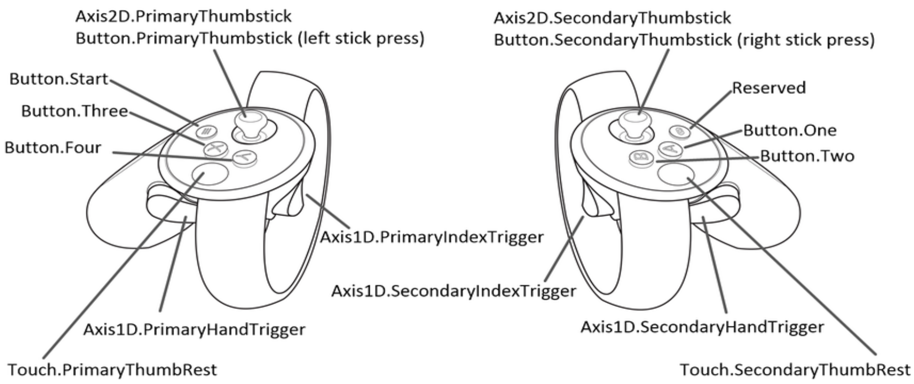


Figure 4.3: Oculus Quest Controllers

On the right hand remote, there's a button *Oculus Button* that beyond letting user exit the application with a click, if instead of clicking the user holds it until the white circle completely fills the application will recenter.

4.3 Game Development

4.3.1 Application Tour Guide

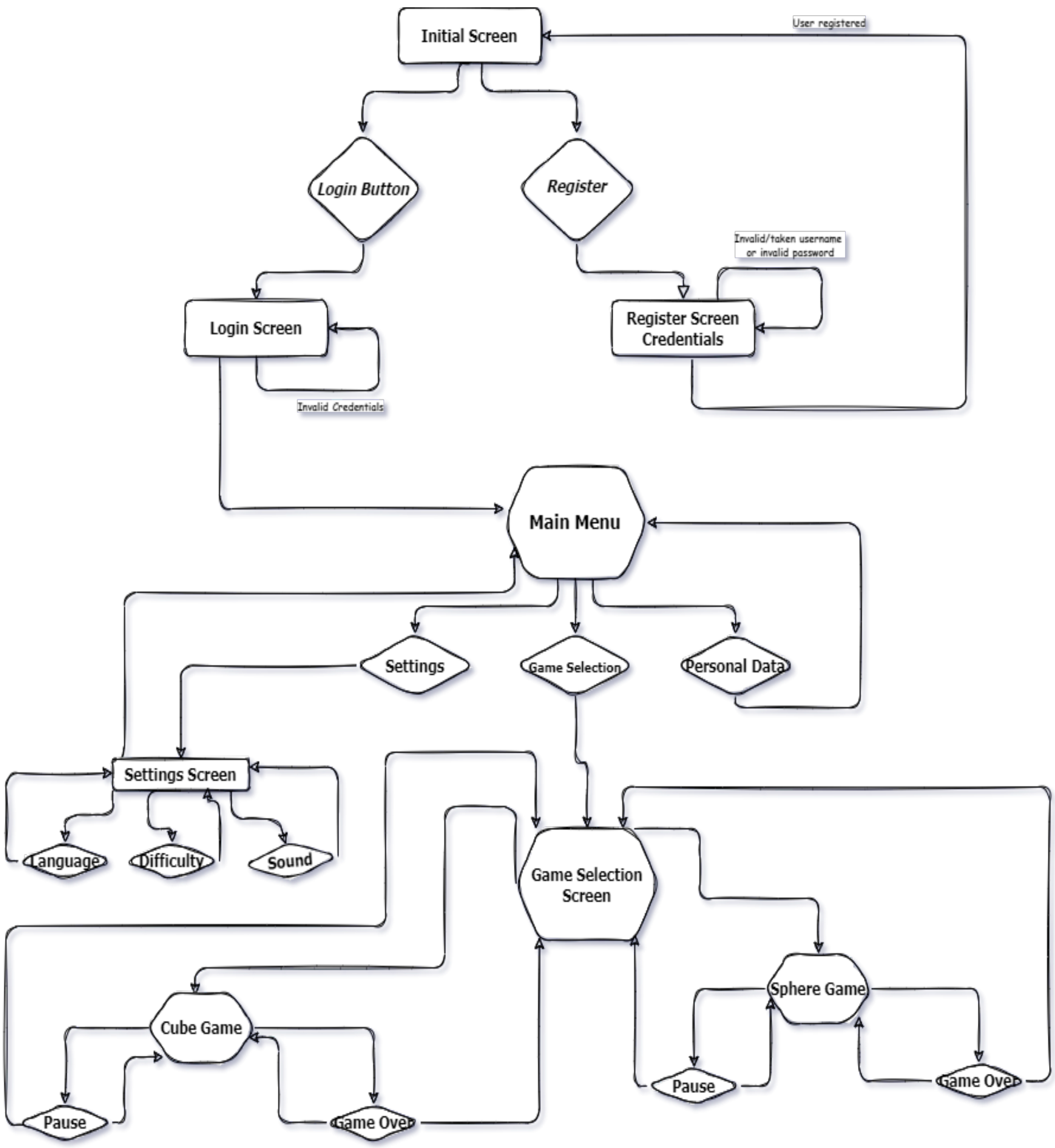


Figure 4.4: Game Plan Flowchart

The application follows the map on fig.4.4. It is composed of five scenes, divided in two groups:

- **Menus:** this group includes three scenes, the LogIn scene, where the user will be able to access his/her account, the Register scene, where the user can create his/her account to enter the application and play the games, and the Main Menu, the scene where the user can access personal data, game rankings, choose the application settings and select the game to play.
- **Games:** this group is composed by the two VR games.

The first scene is the initial lobby, fig.4.5, where the user can select the application language from a drop-down near the title on the big screen, between the five options available: English, Portuguese, Spanish, Italian, and French. By default, if the user has not picked any language yet, the system will boot in English. After selecting the language and moving forward, this can only be changed on the settings screen in Main Menu.
On the little screen, the user has three buttons: LogIn, Register, and About Us.

Figure 4.5: Application Start Lobby

The LogIn button will open the login screen, fig. 4.6, where the user is invited to introduce the previously registered credentials to access the account and play the games.
The Register button will take the user to the Register scene, fig. 4.7, where the user must introduce personal data such as name, gender, date of birth, email, username and password - mandatory - and the therapist's code - optional -, to create a new account to play the games and has the values saved and allowing progress to be analysed. After completing the register, the player will be moved again to the LogIn scene to access the account and start playing.
The About Us button opens a panel, fig.4.8 containing information about the developer's team and the institutions that supported the development, as well as a button with a link that will open the

website of the main institution.

All institutions' logos are visible on the main screen and across all the application.

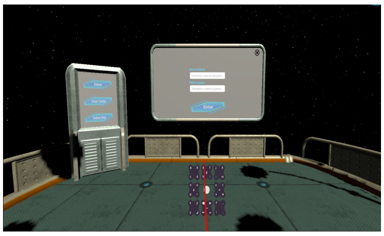


Figure 4.6: Log In Screen

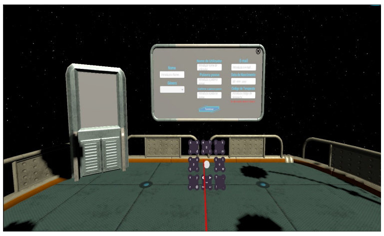


Figure 4.7: Register Screen

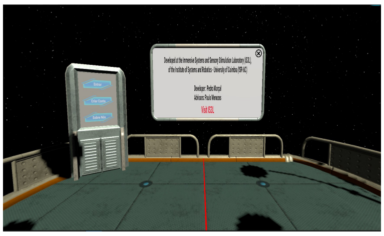


Figure 4.8: About Us Screen

Already logged in, the application will change the scene to the Main Menu scene, fig.4.9. In this scene, the user will be presented with two buttons on the big screen the start game or the settings button.

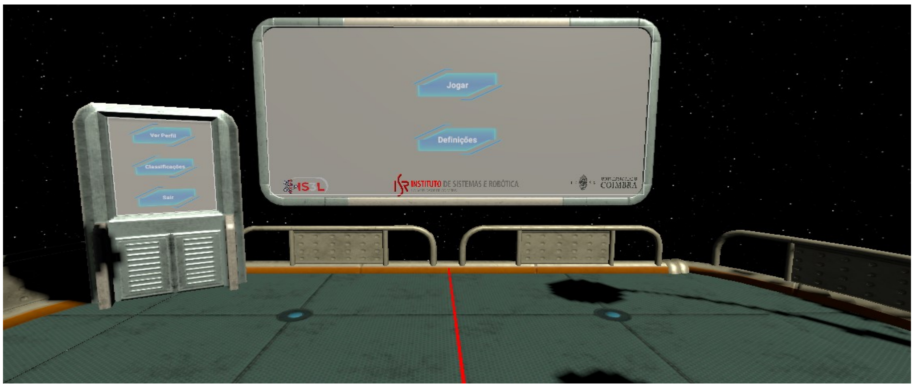


Figure 4.9: Main Menu Lobby

Clicking on the start game button, the user will be presented with three other buttons, the button to select the spheres' game, the button for the cubes' game, and a return button for the user to get back to the main lobby, fig. 4.10.

Clicking on the settings button, the user will have at his/her disposal the settings to customise the experience, controlling the difficulty of the levels, the application sound, the application language and introducing or modifying the therapist code, in case it has not been introduced at the register moment or if it needs to be changed later, fig.4.11.

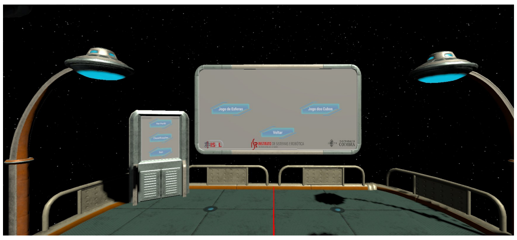


Figure 4.10: Game Selection Screen

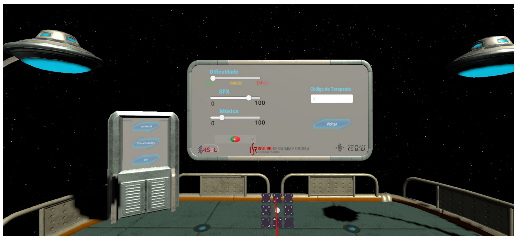


Figure 4.11: Settings Screen

In the little screen, the player will find three more buttons. The first one will open the user details' screen, fig.4.12, where the user can see personal details as well as the higher scores obtained playing the games. The second button opens the ranking screen, fig.4.13, where user can visualise other five players' top score. The last button allows the user to quit the application.

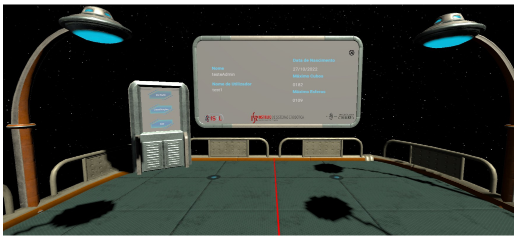


Figure 4.12: User Details Screen

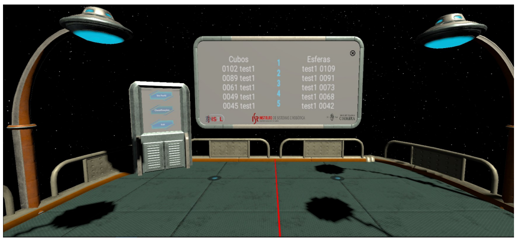


Figure 4.13: Rankings Screen

4.3.2 LogIn and Register

Every user that intends to use Serious Games For An Activation needs an account to play the games. In this section will be explained the processes along with the database integration and how the information is stored.

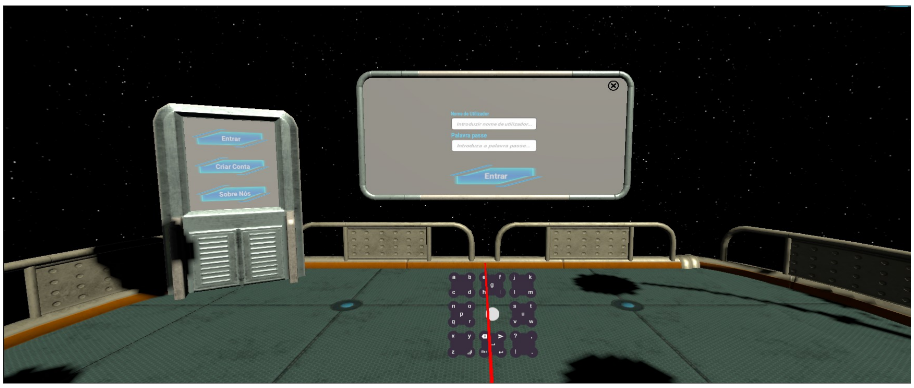
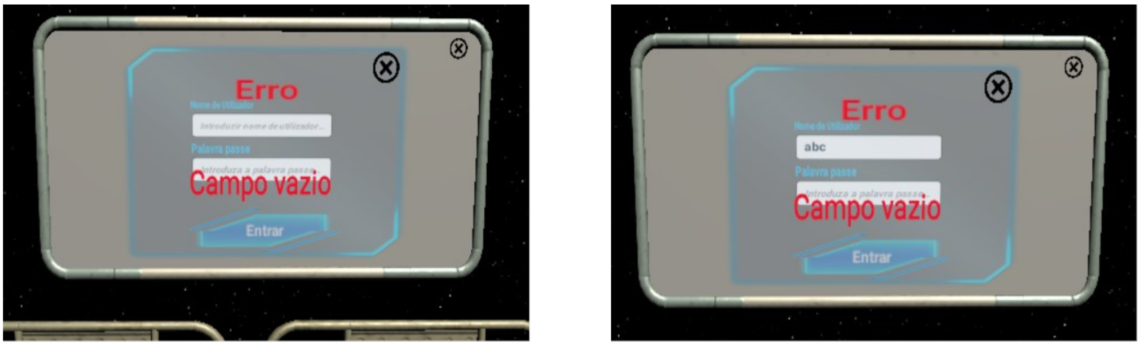


Figure 4.14: LogIn Screen

The LogIn screen, fig.4.14, is the space where the user will introduce the identification credentials to proceed and access the game. To enter, the user must provide a previously registered username and password. Presented the identification credentials and clicked the *SignIn* button, it takes place a quick search for the matching account. If the username is not found or does not match the provided password, an error screen emerges, displaying the message *"Invalid Credentials!"*, fig.4.15 ***a)***. Also, if the user clicks the *SignIn* button missing to fill an input, the error screen will emerge showing the message *"Empty field"*, fig.4.15 ***b)***.



a) b)

Figure 4.15: Login Errors: a) Invalid Credentials, b) Empty Field

Otherwise, the user successfully enters the game, if this search result returns positive. As the result from the database (DB) returns positive, a JSON file is created locally with the user details that have been loaded from the DB. Local files allow the user to play offline and, as soon as the device reconnects to the internet, the data stored locally will be uploaded to the database, assigning the session to the respective user correctly.

Logging in can't happen without having registered the credentials. To create an account, the user must press the *Register* button.

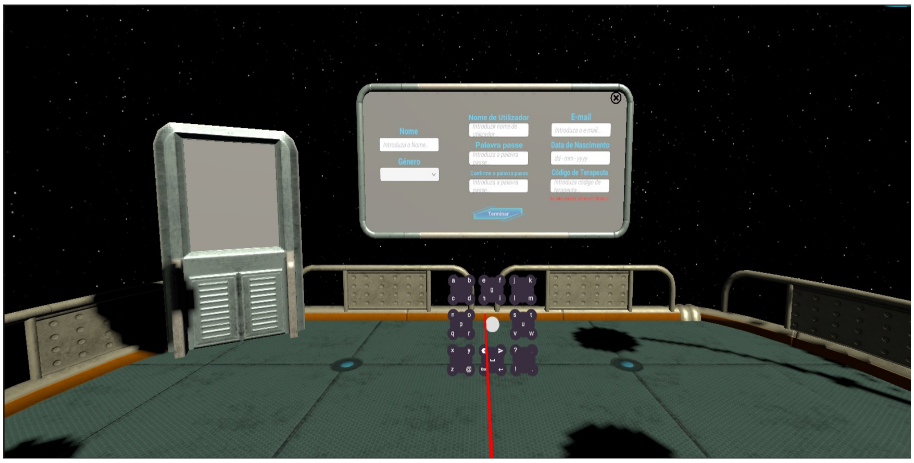


Figure 4.16: Register Screen

Register screen, fig.4.16 requires the user to provide mandatorily a few general information and others needed, and this will only be used in this game.
The required information is:

- **Username:** the name chosen to represent the user before the system. This parameter is individual, and no other user can take a username already introduced on the system.
- **Password:** is the key that will keep the account safe, displayed with asterisks for user privacy, and is encrypted when saved. The user is asked to type this parameter twice for precaution, helping the user avoid typing mistakes when introducing the individual access key.
- **Name:** player's name.
- **Email:** personal email is needed for contact effects if needed. Similarly, with the username, only one user is allowed to register on the email address.

Optionally the user is invited to share the following information:

- **Date of Birth:** user's date of birth to display user's age.
- **Gender:** only informative.
- **Therapist's code:** is the number that identifies a registered therapist for future session data analysis by a responsible professional.

In the same way as login, during the register process the user is also protected from committing mistakes. In case of any mandatory input field is left to fill, the error screen will display the "Empty field" message, fig.4.17 ***a)***, if the username or email have been taken before the error screen will display *"Username already in use"*, fig. 4.17 ***b)***, and *"Email already in use"*, fig.4.17 ***c)***, respectively. If the passwords don't match the user will see the *"Passwords don't match"*, fig.4.17 ***d)***.

a) b) c) d)

Figure 4.17: Register Errors: a) Empty Field, b) Existing Username, c) Existing Email, d) Passwords Unmatch

Suppose the user introduces the mandatory data correctly. In that case, when clicking the *Finish* button at the bottom of the screen, the provided information will be stored in the DB, so the user starts to be able to log into the application and thereafter play the games.

4.3.3 Main Menu

Passed the initial door of register and login, the user is taken to the main lobby, the centre of the application.

In this scene, the user can take several actions, such as selecting the game to play and start it, managing game settings, visualising user details, looking at game rankings, or even closing the app if he/she pleads. On the big screen the user will find:

- **Start Game;**
- **Settings;**

On the little screen the user will find:

- **User Details;**
- **Rankings;**
- **Quit;**

These actions previously mentioned can be selected on both the big and little screens, where the user will find the respective buttons.

If the ***Quit*** button is clicked, it allows the user to leave the application, as the name suggests.

If the ***Rankings*** button is clicked, the application opens the rankings screen, fig.4.12. At the same time, the system will quickly search on the DB for the users' performance on games' data tables, searching for each game name. Filtered the data, the system sorts it in descending order by score. Sorted the filtered data, the system delivers the first five elements from each table, corresponding to the five users with the five highest game scores. The rankings can only be displayed if the device is connected to the internet.

If the ***User Details*** button is clicked, the application opens the user data screen, fig.4.12. Concurrently the system searches on the JSON file of the logged user delivering the information requested to display on the screen, the user's name, the user username, the user date of birth, and the user's top scores in each game.

If the ***Settings*** button is clicked, the application opens the settings screen, fig.4.11. In this screen, the user will have the possibility to adjust several application details such as game difficulty, game language, background music and sound effects volume.

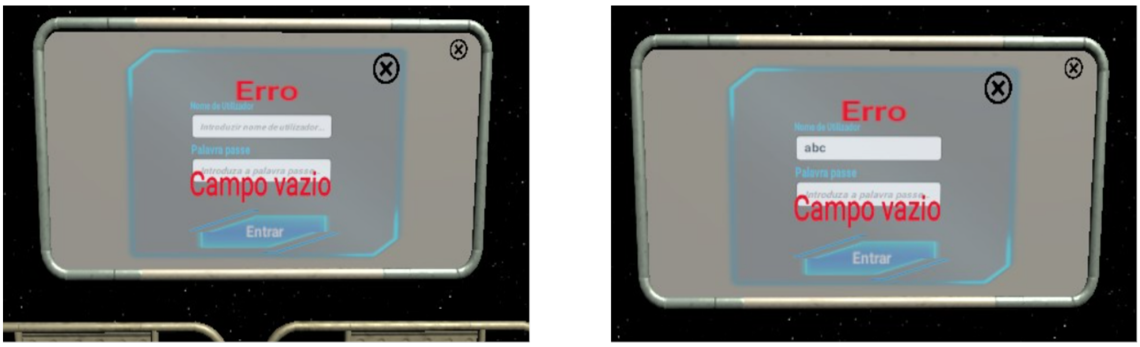
The difficulty can be adjusted between the three values available corresponding to *easy*, *medium*, and *hard*. These modifications take direct action in games, as the difficulty value controls the starting values for the game progression parameters. By default the value for difficulty is medium.

The user can also control the volume of the application sounds, the volume values go from *0* to *100* and the default values are *20* for background music and *80* for sound effects, giving priority to the sound effects as these take an important role during the playing experience.

Game language can be manipulated in this screen as well, using a drop-down box, in case the player forgets to adjust this parameter on the initial screen of the application. This application supports five languages - English, French, Italian, Portuguese and Spanish - and this feature is possible using an internationalisation and localisation framework.

These changes are all stored locally as *PlayerPrefs*, a class in Unity that stores user preferences between game sessions.

Beyond managing application parameters and keeping in mind that therapist supervision has a critical role in user's recovery, and since this is not a mandatory parameter to insert during registration, because the player might forget the number, the player can add or modify the therapists' code in this screen. If the user introduces a code that does not match the codes on the database, the application displays an error screen with the message *"Empty or invalid field"*, fig.4.18 ***a)***; In case of success, the application shows a screen displaying the message *"Is this your therapist?"*, 4.18 ***b)***, asking the user to confirm if the therapist name associated with the inserted code corresponds to the one supervising the rehabilitation.



a) b)

Figure 4.18: Settings Confirmation Messages: a) Therapist Code Error, b) Therapist Code Confirmation

If the ***Start Game*** button is clicked, the application opens the game selection screen, fig.4.10. In this screen the user will be presented with three options, enter the spheres' game, enter the cubes' game or return to the main menu. Selecting the spheres' game the user will be transported to the game platform where the spheres' will take place, selecting the cubes' game the user will be transported to the game platform where the cubes' will take place. After this decision the therapeutic exercises *gamified* commence.

4.3.4 Games

To this point, there have already been presented and described almost all the application features, login and registration, settings management and user details, and ranking consulting. This topic will explain the application's primary purpose, the games.

This application, as previously mentioned, consists of two games for different rehabilitation purposes and can complement each other. The spheres' game aims to stimulate player cognitive functions as reaction speed to sounds and objects that appear on the scene. The cubes' game intends to replicate a movement typically performed on the affected upper limb recovery process as the actuator of the game.

The games' design aimed to take the user out of the conventional comfort zone, placing him/her on a round platform in outer space with stars in front and the earth and the moon in sight. The concept was chosen to absorb the user from any real-world element, so the user is only thinking about the game elements and performing well, achieving the best score possible.

Games were developed with scoring and time systems associated, collecting information about the user performance in each game. At the end of each session, either due to the deduction of all lives or the player's will, data about the person who played will be saved to the database, including the date and time of the performance, game name, time played, and score.

Games were developed adopting the concept of endless run, the time will be increasing as the player keeps performing, and the game's specific parameters will increase every *45* seconds. Users' progress can be measuring the sessions' duration and the score obtained per session. If these values increase over time, it means that the player is improving and the game is being helpful to the rehabilitation.

Both games will start after an initial 5 seconds countdown and during the game the user can have perception of the parameters' update time by looking at the clock. The timer interface has a coloured circle around that will be unfilled every second for 45 seconds and at the end will be refilled for the next cycle. During the playtime if the user progresses to the next difficulty the clock will change colour, giving the user the awareness about the difficulty level at the moment. The clock colours follow the same colour code as the labels on the settings menu; Green for easy, yellow for medium and red for hard.

Figure 4.19: Easy mode clock color

Figure 4.20: Medium mode clock color

Figure 4.21: Hard mode clock color

4.3.4.1 Sphere Popping

Sphere Popping game intends to combine cognitive stimulation through spatial sounds and different types of spheres, instantiating every at a predefined frequency, and physical movements with the upper body as the user must look around to find the spheres and touch them to destroy them, earning the desired points.

The game starts with the player placed at the centre of the platform - coordinates (0, 0.57, 0) - after the starting countdown, the spheres will begin to be instantiated at a predefined frequency, assuming the default settings the initial frequency for instantiating a new object is $\frac{1}{3\ seconds}$.

Figure 4.22: Spheres Popping Game

The instantiated spheres will be randomly positioned in a restricted range, so the user can play on the centre position without needing to travel around the scene either walking, without perception of real-world motion, or using a motion controller, avoiding any uncomfortable sensation during or after the game session. Inside that area, the spawning objects will be generated following the rules of an occupancy grid. This occupancy grid consists of a three-dimensional array, a 2x3x3 matrix, initially set as empty, 4.23. The only exception is the player position, the centre column of the last matrix row is considered reserved space and is set as -1. Taking advantage of the fact that every object in a Unity scene possesses an ID, the first step is to generate grid coordinates randomly while the generated position is filled, i.e. the value on that grid position is other than 0. When the grid position is empty, those coordinates are converted to spatial coordinates proceeding to the instantiation of the new object. After the object instantiation, its ID is stored on the corresponding grid position, marking it as unavailable.

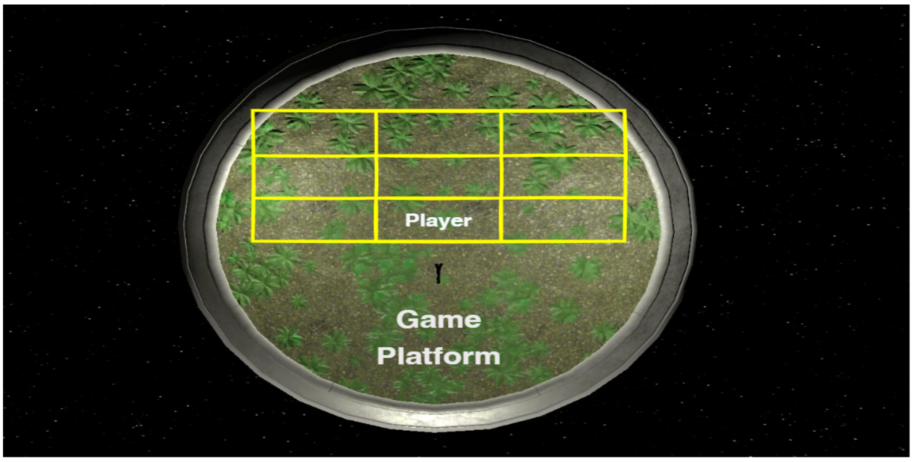


Figure 4.23: Occupancy Grid - planar representation

An occupied position returns to an empty state either if the player destroys the previously generated object or when the object's lifespan reaches the end without being destroyed. This method is used concerning the user experience, avoiding creating new objects on the player position, improving the reward attribution accuracy and the player comfort while enjoying the game.

The previously mentioned lifespan intends to prevent the screen from getting overcrowded. This parameter can also be used to turn the game more challenging and motivating by rewarding faster movements from the player destroying the spheres. Initially, considering the default app values for difficulty and assuming the user starts the game on level *11*, this parameter value is *6.0*, corre-

sponding to six seconds. Finished that period, the spheres are set to self-destroy if the user doesn't reach them. This time value allows the introduction of a colour transition rewarding system, so the user can see his movements rewarded for getting faster.
To earn points, the player must destroy the plain colored spheres because, in case of beating a spiked sphere, one life will be deducted from the life rack.
This scoring system is:

- **Green sphere** - 3 points;
- **Yellow sphere** - 2 points;
- **Red sphere** - 1 point;

The colour transition occurs at defined periods dynamically adapted along the game. Having the default situation as a reference, with seven seconds lifespan for each type of sphere, the plain coloured ones will change from green to yellow after two seconds on the screen and later turn red after two and a half seconds more. At the end of the remaining two and a half seconds where spheres' are red, they will self-destroy.

4.3.4.2 Box Placing

Box Placing game reproduces in a virtual environment one movement that is common in the affected limb post-stroke rehabilitation process. The previously mentioned movement is the AMLR (internal and external) movement, fig.4.24, that consists of a forearm rotation around the elbow inside and outside. This rotation will be the action that controls the gameplay.

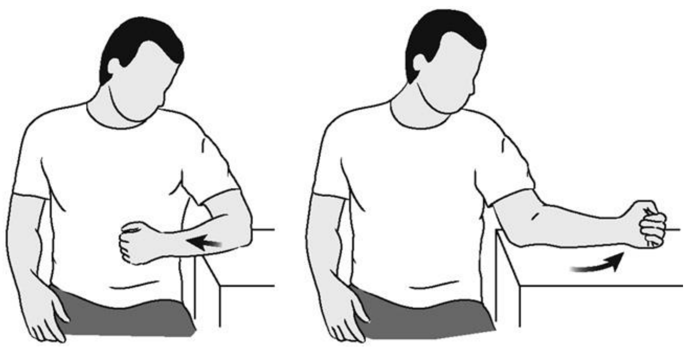


Figure 4.24: Arm Medial Lateral Rotation

After the starting countdown, cubes of different colours will be instantiated on the furthest point of

the table at a predefined frequency, assuming easy mode as default settings for the initial frequency for instantiating a new object is $\frac{1}{4\ seconds}$. The cubes slide over the table towards the user at a predefined speed of *0.365 m/s*. When the cube reaches the first lighter circle, the speed will decrease to 65% of the original value, making it easier for the player to prepare the pick-up. Moving at a reduced speed, the cube will reach the second circle stopping the movement so the user can grab and place it into the respective container.
Similarly, as in the spheres game, there is also a mechanism implemented in this game to prevent the scene from becoming overcrowded. In contrast to the lifespan mechanism for the spheres, which self-destruct after a determined period, here, the preventive method is based on the colliders. When one cube reaches the pick-up point, the player has 2 seconds to grab it and place it on the crate. After that time, the cube will disappear. And if the cube is not placed correctly on the container and ends up falling to the ground, it will be automatically destroyed.

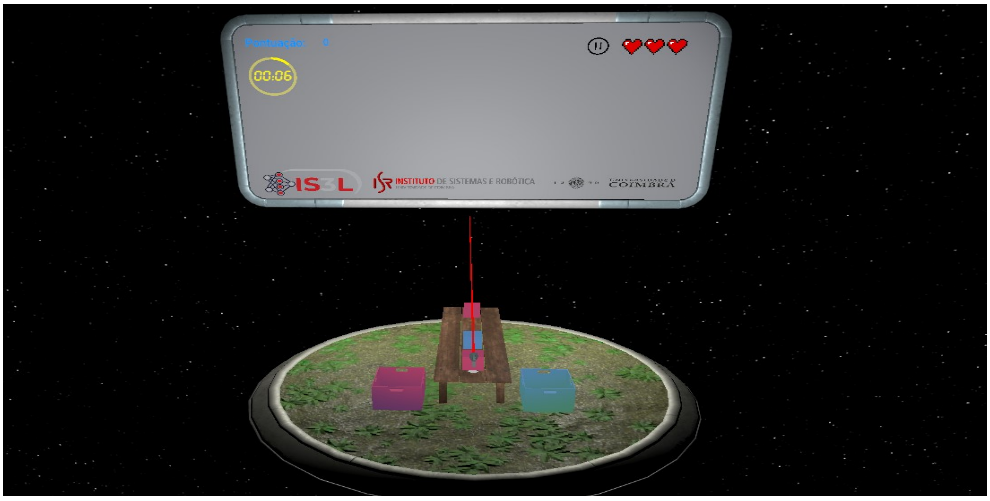


Figure 4.25: Box Placing Game

To interact with the cubes and place them inside the correspondent containers, the user will be performing the movements displayed in fig.4.24, bringing the hand towards the object, feeling a vibration when it's reached, holding the trigger button on the controller, fig.4.3, to grab the cube, and then rotate the arm in the direction of the respective crate holding the button to keep the cube in hand and finally release the button to drop the object and collect the reward point. One life is deducted every time a cube is released on the opposite colour container. The game will end when all the lives have been removed from the rack.

Beyond the entertaining component of the game, in advanced stages of post-stroke recovery, Box Placing game can help improving the user's upper limb motion range, focusing on muscular re-activation by performing rehabilitation movements to interact with the game objects and placing them on the corresponding containers.

A game-changer condition has been added in addition to the colour separation stimuli to make the game more attractive and challenging. At a certain point while playing, the player will hear a bell ring, and ahead of the sound, one of the controllers will become disabled, so to succeed in the game, the player will be conditioned to use only the hand on which the model remains visible. Even with the model hidden from the player's sight, the red ray remains active, so the user can still interact with the panel in front to pause the game with both hands. This constraint will last for 15 seconds. The player will hear a second bell ring indicating the end of the restriction, and the previously disabled controller will be active again. During this restrictive cycle, all the positive rewards will count as double.

The implementation of the restriction can be illustrated by the state machine displayed in fig. 4.26 and described as follows; Finished the first clock cycle, considered a game adaptation period, two values will be generated. One value between 16 and 35 determines the moment of the clock cycle for the bell to ring, leaving 10 seconds in the beginning and reserving at least the last second of the cycle to return to the main state of the game. The second value is generated between 1 and 2 to define the next state when the bell rings. State 1 disables the left-hand controller, and state 2 disables the right-hand controller.

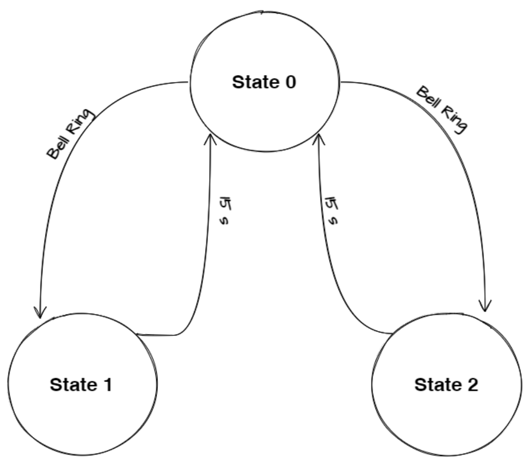


Figure 4.26: Game changer state machine

Introduced this restriction, a warning on the panel has been added during the initial countdown for the player to be aware of what will happen after the sound, fig.4.27.

Figure 4.27: Game changer warning

4.3.5 Game Progression

A game to be successful among the users have to keep them engaged and willing to play continuously. The user need feel motivated to perform at that game. There is no room for monotony when the goal is keep users interested in return to play, specially speaking of SGs when keeping the user committed with the game might influence the results.

To keep the player entertained the game must flow naturally, as well as the challenge and stimuli might be correctly balanced, otherwise, the player can get tired, bored, or frustrated, ending up quitting. For that, the games might evolve over time, with slight difficulty increments each clock cycle. This progression along the way will helps the player feel the game becoming more challenging as time passes.

Inspecting the game, several parameters can be easily perceived as active agents of these games. After playing a while in each game there is a clear awareness that time has a direct influence on the game. As time passes the objects in both games will be generated faster, cubes will move faster, positive rewarding spheres will last shorter and colour transitions will happen faster, contrarily negative rewarding spheres will last longer.

Games have three difficulty levels and the individual parameters are set to be dynamically updated along time. The user receive informations about the difficulty transitions through the clock shown on the panel. The difficulty levels are divided in 10 cycles of 45 seconds each. Through the game clock the user can notice how much time is left until the next difficulty increment, by looking to the fulfilment of the clock's outer circle. The first two levels last ten cycles, i.e. $45 \times 10 = 450\ seconds \Rightarrow \frac{450}{60} = 7.5\ minutes$, on the other hand the hard level is the last stage and lasts as longer as the player keeps playing. This difficulty level transition can be noticed by the colour presented by this feature.

Figure 4.28: Semaphore colour coded spheres

The method to implement the progression during playtime consists of separating the transitions odd and even. This even and odd grouping method helps to alternately manage the parameters, keeping the changes slight but noticeable as the game advances.
Considering ten clock cycles per difficulty level, there are at least thirty. Since that is an even level and the number of level transitions $n-1$, twenty-nine for this case, there will be no parity between the two groups of levels. There will be one more transition to even cycles than to odd cycles, fifteen to fourteen, respectively. If the next cycle is even, the modified parameter will be the instantiation interval between new objects. Despite this parameter being common to both games, it is managed differently for each. For odd cycles the adjusted parameters are specific to the objects and the way they behave in each game.

4.3.5.1 Sphere Popping

In spheres' game case, starting on easy mode, the creation rate is 4 seconds. Considering that easy and medium difficulty modes last for ten cycles, the last mode behaviour will be divided in two moments. Until the end of the tenth clock cycle of the hard mode the creation rate will gradually fall until 1 second. This 3 seconds interval will be split through the fifteen transitions, meaning that every even transition reduces 0.2 seconds to the instantiation rate.

$$spawnTime_{spheres} = \frac{Interval}{NumberOfTransitions} \Leftrightarrow spawnTime_{spheres} = \frac{3}{15} = 0.2\,\frac{seconds}{transition}$$

Finished the tenth hard mode game cycle, if the player keeps playing, this rate will decay at a pace of 0.05 seconds per transition until the minimum of 0.5 seconds per new unit.

Apart from the spawning frequency another parameter will face changes: the lifespan of both plain and spiky spheres. Lifespan splits into two parameters it will follow opposite roads for each kind of sphere, plain spheres' lifespan will decrease 0.2 seconds every time and the spiky spheres will have their lifespan increased by 0.1 seconds, half of the plain spheres' decrements.

Plain spheres' have a specification that needs to be adapted as the time passes. These spheres display a colour transition during their lifespan. Assuming easy mode values for the calculations, i.e. 7 seconds of lifespan, the spheres will be green during the first 2 seconds; when the lifespan reaches five seconds, the colour is set to yellow for the next 2.5 seconds, and after getting this last milestone, the sphere enters the final stage assuming a red colour for the remaining time before the destruction.

To apply this transition correctly along the levels, avoiding jitter and spheres getting destructed without passing for every stage of the transition, the milestones percentage compared to the initial time was calculated by the following rule:

$$\frac{7}{5} = \frac{100}{x} \Leftrightarrow x = \frac{5 \, * \, 100}{7} \Leftrightarrow x = \frac{500}{7} \Leftrightarrow x = 71.43\%$$

$$\frac{7}{2.5} = \frac{100}{x} \Leftrightarrow x = \frac{2.5 \, * \, 100}{7} \Leftrightarrow x = \frac{250}{7} \Leftrightarrow x = 35.71\%$$

$$\frac{7}{1} = \frac{100}{x} \Leftrightarrow x = \frac{1 \, * \, 100}{7} \Leftrightarrow x = \frac{100}{7} \Leftrightarrow x = 14.29\%$$

It was possible to determine that the first checkpoint corresponds to 71.43% of the initial time, the second corresponds to 35.71%, and the last represents 14.29% of the initial time. These values are significant for the development, allowing for a dynamic adaptation of the transition, defining the time limits as a percentage of the initial lifespan that is updated at every transition to an even level.

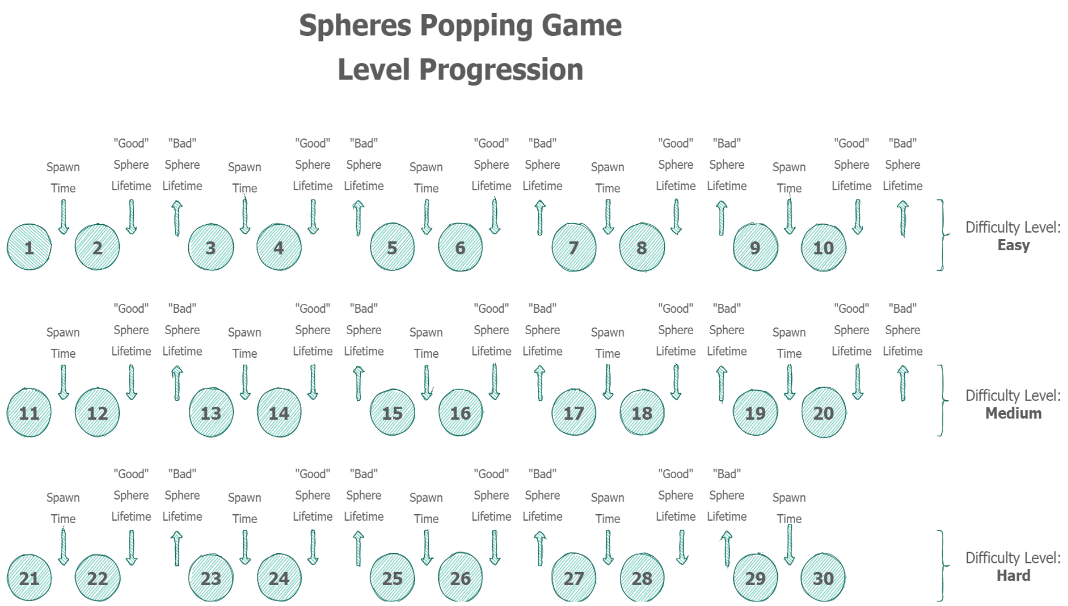


Figure 4.29: Sphere game level progression

4.3.5.2 Box Placing

For the cubes' game case, starting on easy mode, the creation rate is the same as the spheres', the difference stands on the evolution. Spawn rate has to be combined with cubes' speed moving towards the player. If the object's moving pace is too slow, player gets bored waiting for them, if it is too fast, player will not have time to interact with all the cubes, losing opportunities to score points.

Prior to defining cube's game progression the most important part is understanding initial conditions. Previously were presented the starting values for easy mode, these were defined taking in account the time one cube takes to travel from the generation point to the slow down point, the time travelling to the pick-up point. Concerning of the initial values, the user must expect that a cube during easy mode first clock cycle reach the pick-up point in 6 seconds. The progression is oriented by the time one cube spends travelling from initial point to pick up point, for that reason the generation frequency was the secondary parameter and it was managed to keep the game with a comfortable pace for the player. The objective is, after thirty clock cycles, having new cubes reaching the pick-up point approximately 1 second from the instantiation.

To attend the desired goal cubes' collider once again proven to be useful tools as they allowed to measure the moment when a cube makes contact with the white marks on the table. Using them was possible to adjust the speed that matches the intended time. Standard speed values for the reaming modes are *0.365 m/s* for easy making the cube reach the pick-up position in 6 seconds, *0.46 m/s* for medium making the cube reach the pick-up position in 4.78 seconds and *0.7 m/s* for hard making the cube reach the pick-up position in 3.13 seconds.

Defined the speed for each mode, the progression definition was simple and defined by the following rule:

$$speedIncrement = \frac{speedInterval}{NumberOfTransitions}$$

Speed will be incremented five times per mode, applying the formula the increments are:

$$speedIncrement_{easy} = \frac{0.46 - 0.365}{5} \Leftrightarrow speedIncrement_{easy} = 0.019$$

$$speedIncrement_{medium} = \frac{0.7 - 0.46}{5} \Leftrightarrow speedIncrement_{medium} = 0.048$$

The hard mode increment needed some extra calculations and experiments to predict the suitable speed for the tenth cycle of hard difficulty level. The selected speed value was *1.3 m/s* which deliver a cube to pick-up point each 1.58 seconds.

$$speedIncrement_{hard} = \frac{1.3 - 0.7}{5} \Leftrightarrow speedIncrement_{hard} = 0.12$$

Generation rate will be progressive the same way as speed, i.e. each difficulty mode will have its own increment to keep the game comfortable to the user, adapted to the speed instead of a uniform increment. Starting in easy mode the default time is 4 seconds to instantiate a new cube, with the defined speed, the player will have three cubes over the table at the moment the first one reaches the pick-up spot. To keep the rhythm of the game the fluid the progression on the instantiation interval was adjusted to keep delivering at least three cubes on the table and increasing this rate over time to create a challenging atmosphere. These values were defined using the same method as the speed values, defining the initial amount for each difficulty mode and the thirtieth clock cycle. For the easy mode the interval for a new object is *4 seconds*, for the medium mode is *2.5 seconds* and for the hard mode the period is *1.5 seconds*. Having this values defined for a comfortable and challenging experience to the player the increment will follow the same rule:

$$spawnTime_{cubes} = \frac{Interval}{NumberOfTransitions}$$

With twenty nine transitions and knowing that speed will have 15 transitions, the generation rate will have fourteen, divided in three groups, five, five and four.

$$spawnTime_{easy} = \frac{4 - 2.5}{5} \Leftrightarrow spawnTime_{easy} = \frac{1.5}{5} = 0.3\ seconds$$

$$spawnTime_{medium} = \frac{2.5 - 1.5}{5} \Leftrightarrow spawnTime_{medium} = \frac{1}{5} = 0.2\ seconds$$

To determine the evolution of the generation time for the hard mode was set an objective of creating a new cube every second on the thirtieth cycle since the cubes take approximately 1.6 seconds to be on the pick-up point.

$$spawnTime_{hard} = \frac{1.5 - 1}{5} \Leftrightarrow spawnTime_{hard} = \frac{0.5}{4} = 0.125\ seconds$$

Similarly to the spheres' game, this game also has a mechanism to prevent the cubes to be generated at an excessive rate, when the generation time reach the 0.5 seconds the this value will decrease by 0.05 seconds every next instantiation rate update.

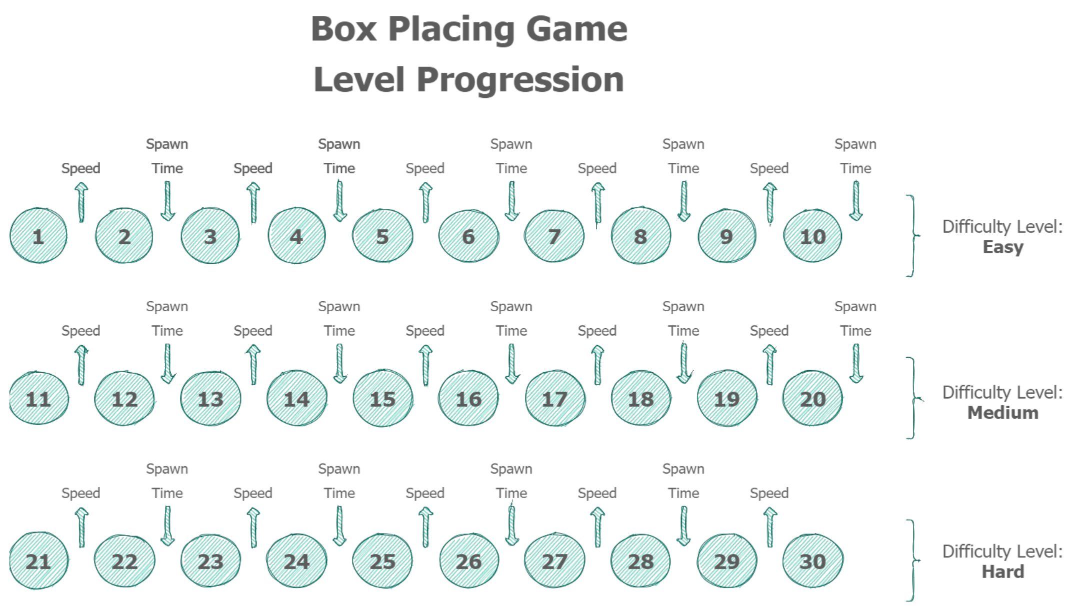


Figure 4.30: Cube game level progression

4.4 Database

The database is a fundamental element of the application. Without a database, it would never be possible to save the players' sessions or any users' progress made while playing, nor retrieve the collected data for the therapists to analyse and evaluate the users' evolution.

To store all this information, it was used a local database. Instead of a traditional SQL database that needs to attend several restrictions, the option went for a MongoDB NoSQL database allocated on Institute of Systems and Robotics (ISR) servers previously created to host Serious Games. Compared with conventional SQL databases with a specific data structure to respect and relational tables with a fixed size of columns and rows, MongoDB is a non-relational NoSQL database that does not follow the table-based structure of relational databases. It can be document based and store the information in JSON, as it was used in this application, giving the possibility to add more or fewer parameters without compromising the data structure. Featuring dynamic schema, it allows the developer to build the application without a prior definition of the database schema, making future changes to data structure more flexible and less expensive than with relational SQL databases. Nonetheless, is it still possible to store related data differently since it won't be split into tables.

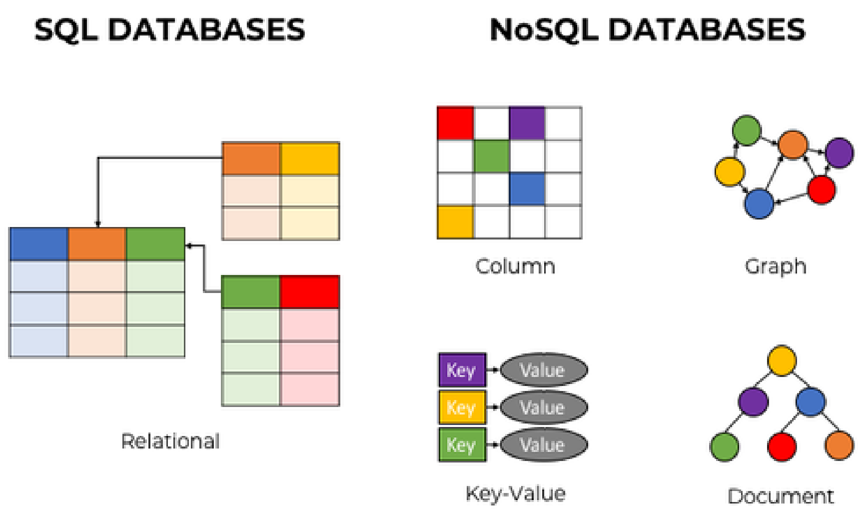


Figure 4.31: SQL vs. NoSQL

MongoDB stores the documents in collections, groups of information documents, that are the equivalent to tables in relational databases. There can be more than one collection per database to save different types of information and group them in the more appropriate way for a cleaner organisation. For this application were used three collections:

- **Users:** the collection where all user's information is stored.
- **Sessions:** the collection that stores every sessions information to be later analysed by the therapist.
- **Therapists:** the collection where the therapists' login data is stored.

Other than SQL databases, NoSQL databases have no table relationship rules, avoiding the constraints modelling the diagram. The following diagram is a representation of the project database.

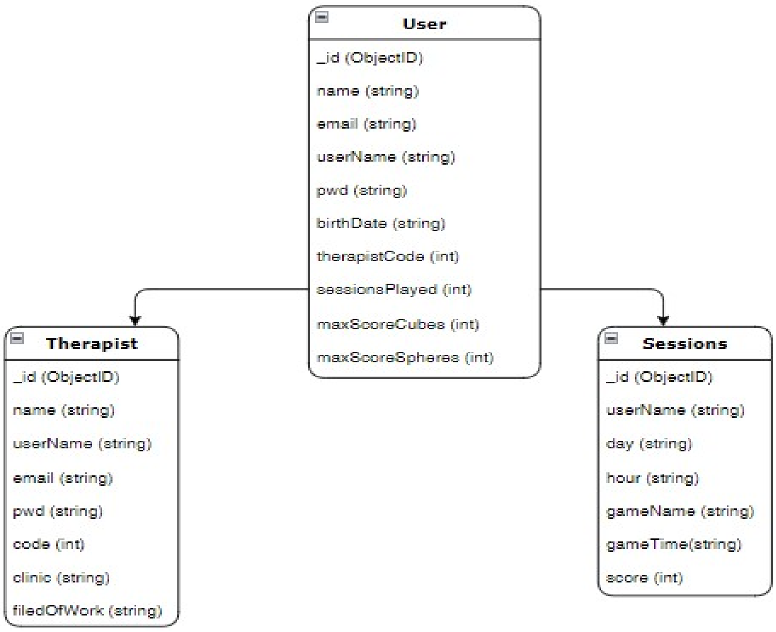


Figure 4.32: Database Structure

4.5 System Behavior

Patient-therapist communication is a nuclear foundation for rehabilitation, as emphasised before, so it is for this project. This communication is fundamental for the recovery process as it is convenient the therapist having real-time access to the patient's latest results to analyse the evolution across sessions. For this, three elements are essential: the game, the database, and the therapists' platform, as displayed in fig.4.33.

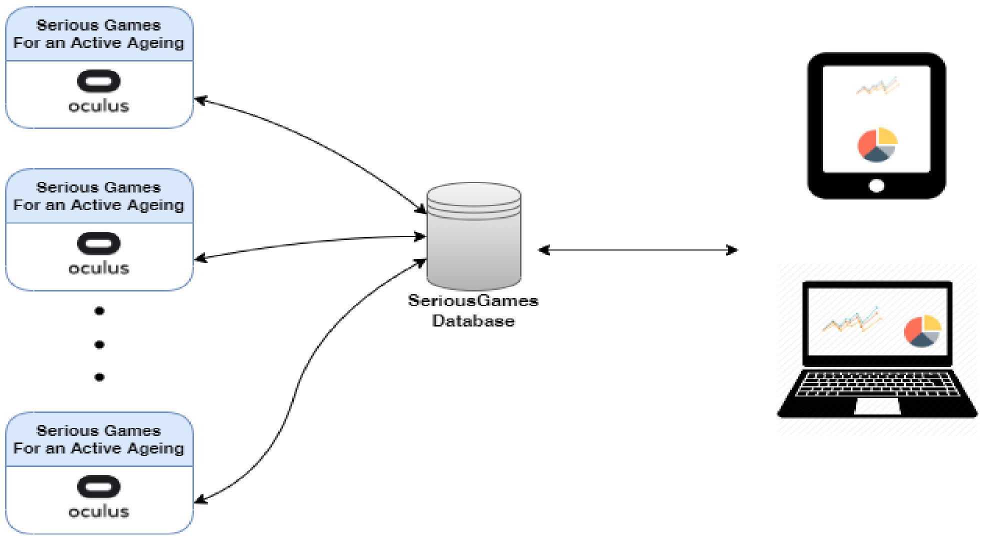


Figure 4.33: System Model

Aware of the application's password request it was implemented the Secure Hash Algorithm 256 (SHA256) cryptography system was implemented to protect the user's privacy. The SHA256 is an encrypting protocol developed by the United States National Security Agency (NSA) that runs a hashing algorithm, a mathematical function that compresses data to a fixed hash size.

Players' performances are stored at the end of each session for later analysis. After the *Game Over* screen emerges, or after the player clicks the *Quit* button on the pause menu, the data from the session, username, game name, time played, score, date, and time, is directly stored on the database. If the device is not connected to the internet, the session data will not be lost. That information will be kept in local files that will be uploaded to the DB as soon as the user connects the device to the network, being deleted from local storage right after the upload.

5

Results

This chapter aims to present the obtained results from the experiment to be later discussed in the following chapter of this dissertation. The user experience evaluation was based on two moments: the questionnaires' answers, allowing a quantitative evaluation, and the participants' feedback allowing a qualitative evaluation. To produce the results, the participants in this study performed two gaming sessions, corresponding to playing each game one time. After playing the two sessions, the participant is presented with a questionnaire to provide quantitative feedback about several parameters of the experience. Beyond the parametric insights collected from the questionnaires, the participants were invited to give personal feedback about the activity. That personal feedback resulted in the qualitative evaluation of the application developed for this study.

5.1 Quantitative Evaluation

Quantitative evaluation is a method of producing numerical indices collected from formal methods (questionnaires) to analyse later and understand the participants' feedback from the experienced activities.

In this study participated, individuals from young age groups, fig. 5.1, building a control group to later produce validation tests with actual to understand the possibility of using Serious Games For An Active Ageing as a therapeutic solution. Without medical validation, younger groups helped with usability testing and providing feedback on how suitable this application might be for the desired purpose.

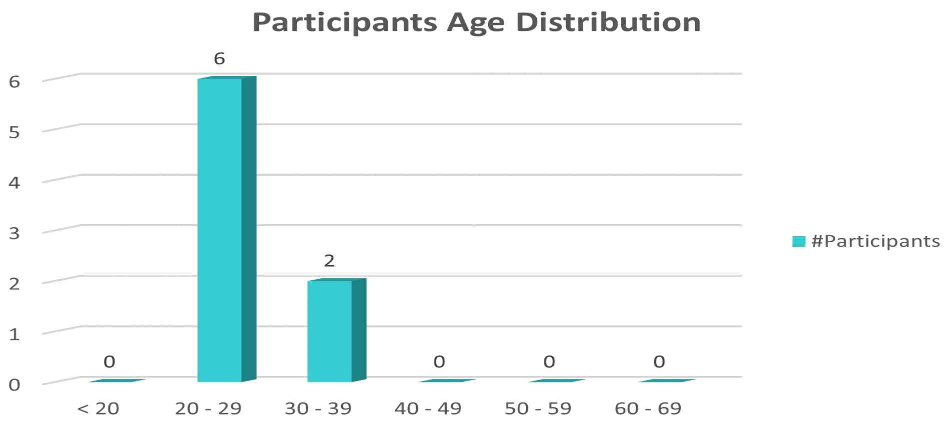


Figure 5.1: Participants Age Distribution: November 2022

For this evaluation, the preferred method was the User Experience Questionnaire [UEQ] developed by Schrepp et al. [35], a questionnaire to evaluate several topics of the experiment such as attractiveness, perspicuity, efficiency, dependability, stimulation and novelty. In the UEQ Handbook [36], it is possible to understand the meaning of these topics of analysis that is:

- **Attractiveness:** Overall impression of the product. Do users like or dislike the product?
- **Perspicuity:** Is it easy to get familiar with the product? Is it easy to learn how to use the product?
- **Efficiency:** Can users solve their tasks without unnecessary effort?
- **Dependability:** Does the user feel in control of the interaction?
- **Stimulation:** Is it exciting and motivating to use the product?
- **Novelty:** Is the product innovative and creative? Does the product catch the interest of users?

To analyse these topics, each participant answered the 26 questions survey, where the answers used a seven-stage scale to reduce central tendency bias. These were measured from -3 to +3, with 0 as the neutral answer. Half of the questions start with a positive term, and the other half start with a negative term.

The procedures to realise the tests were the following,

1. Brief introduction to the application and use of the typing system;
2. Asking people to enable the option for a screencast on the device;
3. Inviting the participants to explore the application and adjust the setting accordingly;
4. Brief explanation of each game before starting, including helping the user to sit and recenter the application before the cubes' game;
5. Monitoring the participant performance through the screencast on the Oculus application and advice when needed;
6. Ask the participant to fill in the survey after finishing the second game session;

Analysing the participants' surveys with the analysis tool provided by the UEQ authors, it was possible to obtain the mean per item, fig. 5.2. Observing this chart is possible to understand the opinions were positive overall. Even the "slow/fast" topic displays positive feedback with a mean near zero. In this case, the perfect result would be the neutral answer that could be interpreted as "just right".

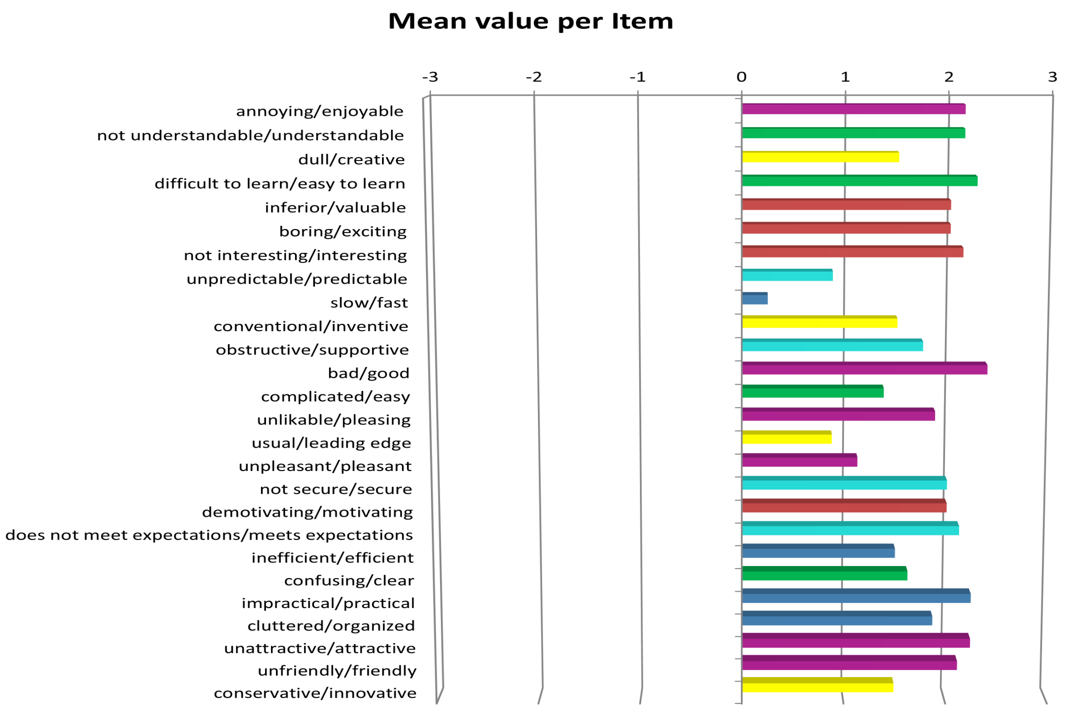


Figure 5.2: Mean Per Item: November 2022

Items are identified with colours corresponding to each of the topics of analysis above-mentioned. The chart on the fig. 5.3 helps to understand the participants found the application stimulating and attractive above the remaining topics. All the scales have shown positive results and even efficiency, affected by the *"slow/fast"* tending to the neutral answer desired for the occasion, displays a positive result. So it is possible to understand that the overall evaluation from the participants was positive.

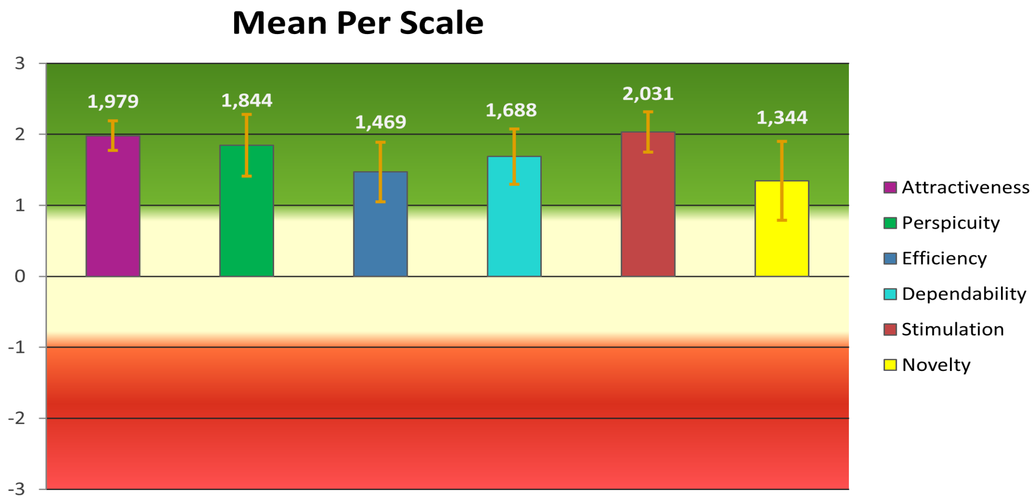


Figure 5.3: Mean Per Scale: November 2022

The UEQ analysis tool provides a benchmark that compares the participants' responses to UEQ for this study with the answers to the same survey related, for instance, the general benchmark, to 452 other products. According to the handbook [36], this benchmark classifies the product scales into five grades

1. Excellent: when the scale results stand between the 10% best results;
2. Good: when 10% of the benchmark results better and 75% are worse than scale results;
3. Above Average: when 75% of the benchmark results better and 50% are worse than scale results;
4. Below Average: when 50% of the benchmark results better and 25% are worse than scale results;
5. Bad: when scale results stand between the 25% worst results;

From the chart in fig. 5.4 it is possible to realise that all the Serious Games For An Active Ageing evaluation scales' are *Above Average*, with Efficiency as the only scale standing on the edge between that grade and *Good* and the Attractiveness and Stimulation are classified as *Excellent*.

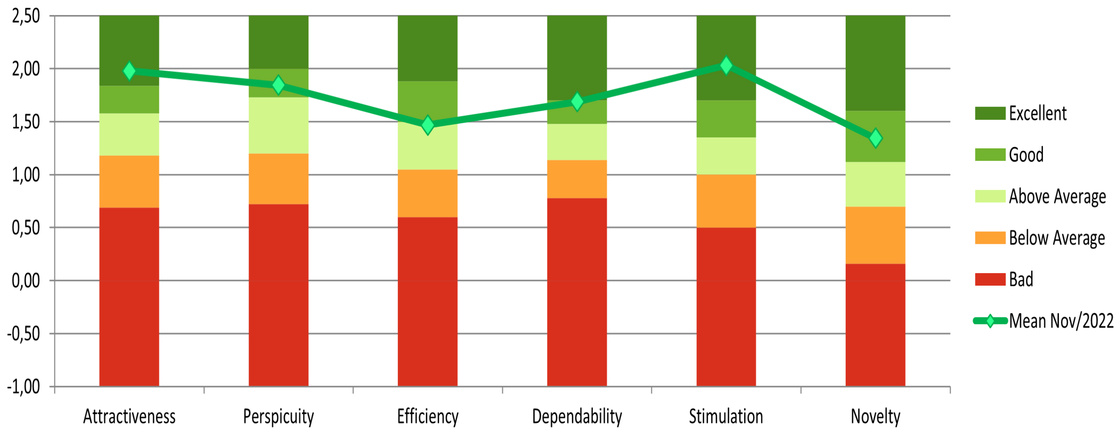


Figure 5.4: Benchmark November 2022

5.2 Qualitative Evaluation

Qualitative evaluation is a method regarding narratives gathered from unstructured methods of data collection, such as natural observation, typically associated with goal-free evaluation other than goal-based evaluation.

This type of evaluation is not metric. It is mostly based on participants' opinions after using the application. The only component capable of being measured in this section is satisfaction while using the app; once all the participants were questioned about the sensation of experimenting virtual reality and if there was any nausea or discomfort during the usage. The response to that was linear. All of the participants reported feeling good after the gaming session.

Several other opinions were provided and helped improving the application, such as:

1. Lateral and frontal position generation range of spheres should be decreased to make all the objects accessible to the player;

2. Adjust the speed of the cubes on easy mode to avoid the user to waste grabbing only two or three objects;

3. Provide information about the game-changing condition on the initial screen. Without it, the

game might feel confusing to the player;

4. The environment is clean and simple, and it provides a comfortable experience;

Beyond the insights mentioned above, the participants' feedback was consistent with the quantitative evaluation. Participants reported that the games felt challenging enough after testing them in different difficulty modes and also felt excited and motivated to keep playing and increasing their scores.

6

Discussion

During the Serious Games For An Active Ageing development, there were two testing moments. The first one, during the summer, provided a set of results of how users felt about the application, which helped to understand what was being done well and what might need to be improved. The second one was presented above as the final tests made after finishing the development.
In this chapter, these results will be put side by side to compare both stages, analyse the evolution over this period, and explore the modifications and additions made to the application.
The sample dimension was similar between the two moments, varying from 10 participants, during the first test period, to 8 participants, during the second.

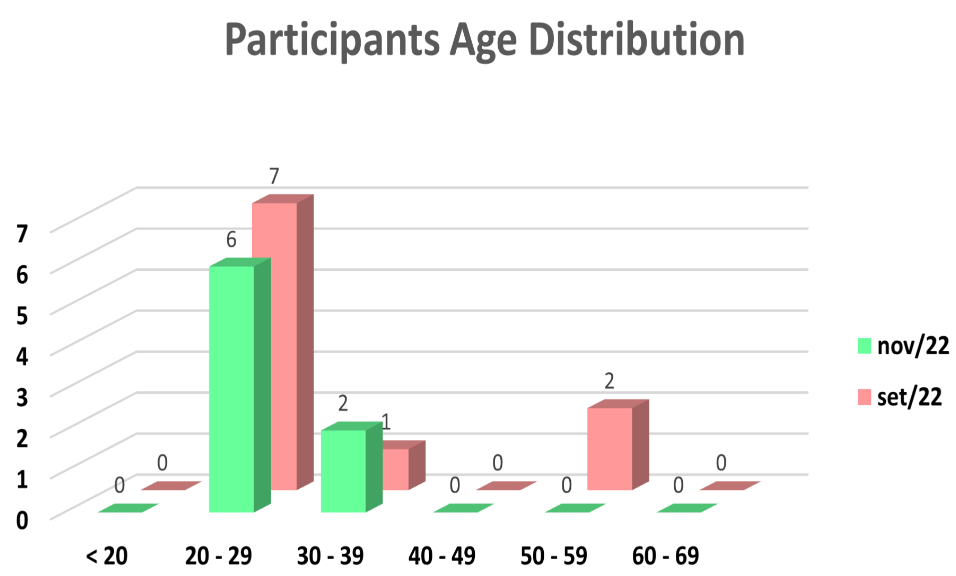


Figure 6.1: Participants Age Distribution: September compared to November 2022

During the first moments of testing, it was possible to collect feedback from two older participants, which was very interesting since they had never experienced VR before. They felt comfortable with the device and were excited while playing the games.

The procedure to collect participants' feedback during the summer was the same as the one mentioned in the previous chapter. Placing the results side to side, it is possible to notice relevant differences between the tests. The most eye-catching difference is on the *"slow/fast"* item of the questionnaire. In September, the answers mean reported that participants felt the application was slightly slow, while in November, the same item turned slightly fast.

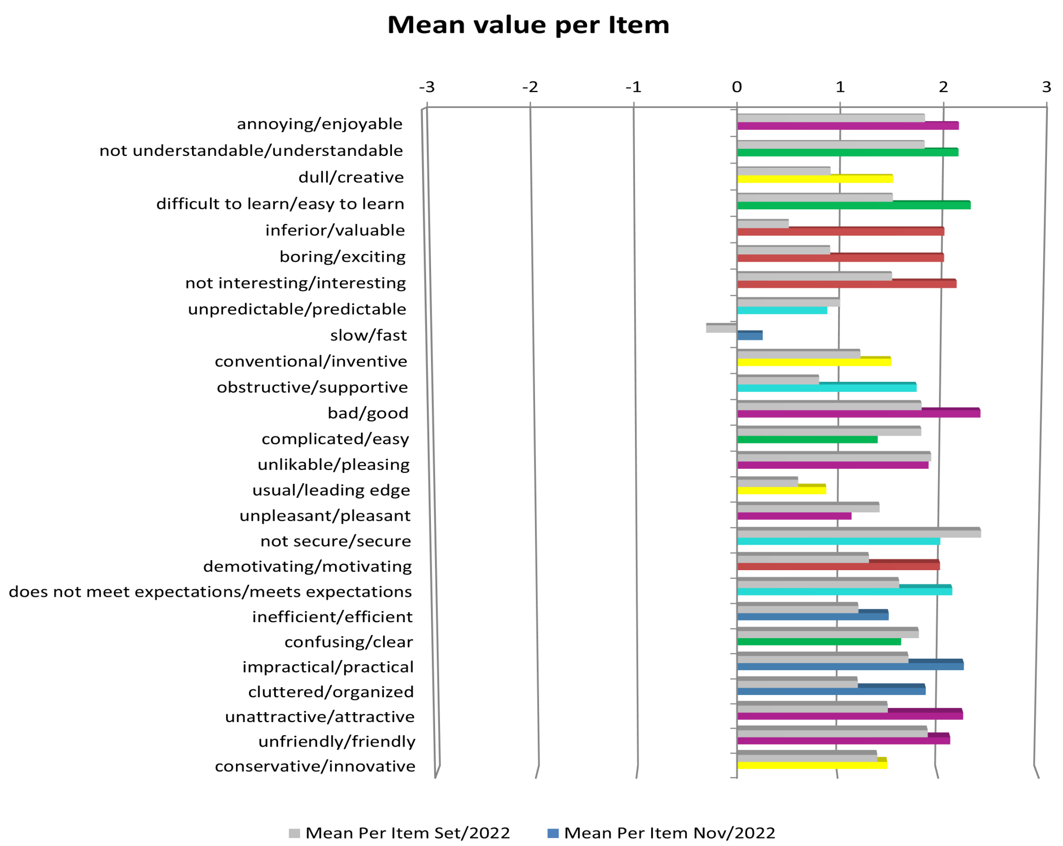


Figure 6.2: Mean per Item: September compared to November 2022

This change of mind comes from a different approach to the games and an upside-down turn on the conceptual side. The first approach to this project was to create games following a 45 seconds per level mechanism, considering the possibility of therapeutic usage and user fatigue while playing. Implemented that method, it was possible to understand that the application was fluid. Still, the game-play was slow and not appealing to the user due to excessive device memory usage that led to black screens and application freezing. With that in mind and looking at the code, it was easy to understand what was causing that problem, incorrect use of a method that was requested once per frame and the excessive object rendering led to that situation. It was to correct this mistake that the games began to operate as state machines that moved from state to state after predefined amounts of time; for instance, the colour transition on the spheres' game was rendered once per frame. After that, it started to be operated as a state machine that changed its state based on time. Finished this implementation, it was noticeable that the game flowed much more smoothly, but the stops every 45 seconds kept breaking the rhythm of the game when the player started to concentrate on the task. In addition, the loading of the next level was not immediate, which led to several participants clicking the *"Next Level"* button on the screen, fig. 6.3, and repeated action caused timer and scoring systems conflicts.

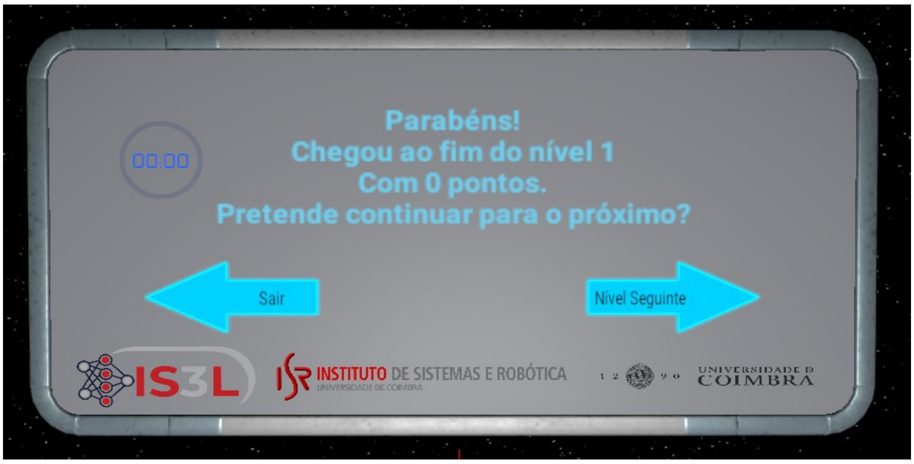


Figure 6.3: Next level Screen

Another strategy was adopted to fix those conflicts and make the games more fluid and appealing. That new strategy turned a game of timed levels of 45 seconds each into an endless run. The clock system changed from a timer to a stopwatch to obtain that goal, and the level breaks and the *Level Finished Screen* were removed. With these changes, it was possible to get a smooth and fluid game that keeps running until the player intends to leave or wastes all his/her lives.

Aside from the corrections and strategic modifications, the previously explained game-changing condition was implemented in the cubes' game to avoid the possibility of the game becoming monotonous to the one playing it. That addition was well accepted by the test users, revealing that it made the game slightly more challenging and motivating.

After implementing these modifications to the initial approach, it was visible that all the UEQ scales improved, fig. 6.4, and the stimulation was clearly the most positively affected scale by the modifications.

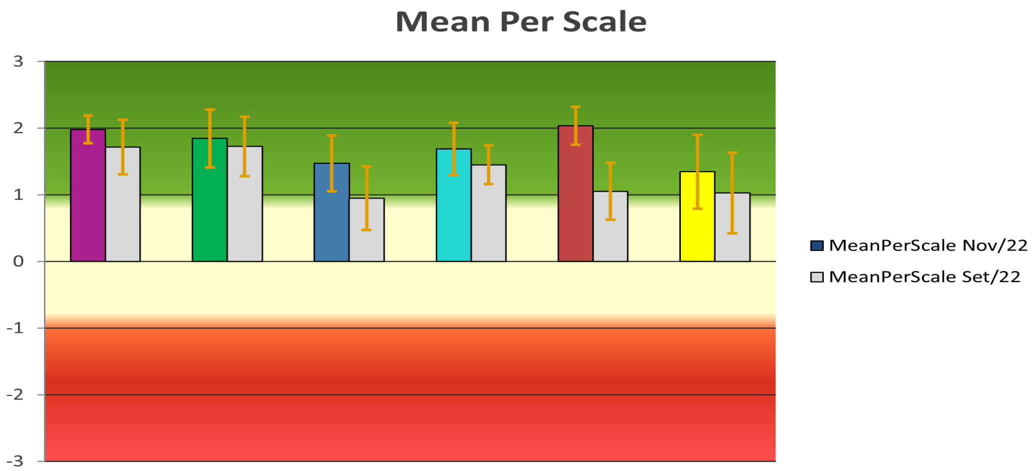


Figure 6.4: Mean Per Scale: September compared to November 2022

The benchmark testing comes to the improvement in every scale of the questionnaire, reinforcing what is shown by the comparison of mean per scale between the tests. Stimulation grew from being close to *Below Average* to *Excellent*, and the Efficiency grew from a negative evaluation of *Bellow Average* to the meeting point of *Above Average* with *Good*.

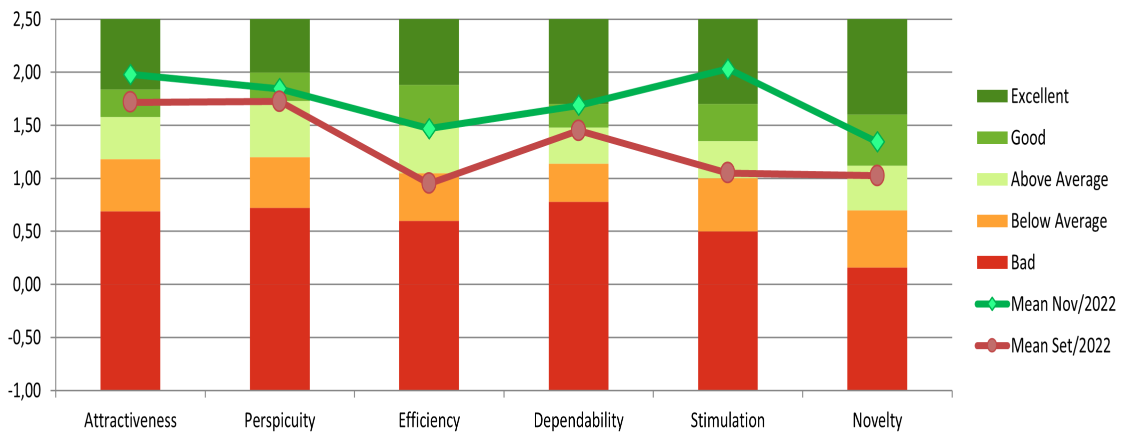


Figure 6.5: Benchmark: September compared to November 2022

The analysis of the participants' answers allowed concluding that the changes promoted generated a positive impact among the application users.

7

Conclusion

This dissertation presented the development of an application combining two games to stimulate people to stay physically and mentally active during the ageing process. With the commitment to improving engagement in elder populations, this application is destined to be deployed in a mid-range cost VR device to immerse the user into an appealing virtual environment, exploring a different technique to captivate the attention. The target device, other than low-cost VR goggles, provides the use of the hands to interact with the game through the device controllers.

The application was presented, all of its features were explained, and the decision-making process was later discussed to demonstrate the option for an endless run instead of timed levels. Also, this game can be helpful for users that have gone through stroke rehabilitation on the upper limb. Even though it has not been clinically tested and validated, one of the presented games aims to reproduce one of the movements performed during this type of rehabilitation which can be helpful in advanced stages of the recovery to rebuild and reinforce movement routines.

The user experience feedback provided good indications of how useful this kind of tool might become. It demonstrated that the test users well accepted the games and that VR-based solutions are an interesting and motivating alternative to traditional methods. If this research field continues to be explored for rehabilitation and the dissemination of VR equipment and the consequent price decrease, this type of serious game can conquer its space as an effective therapy.

8

Future Work

In the future, the objective is to test the applications in a clinical environment with patients going over the recovery process and validate Serious Games For An Active Ageing as a therapy. From the feedback received from them, the application might be adjusted to meet the needs. Those adaptations can be the creation of new scenarios that users find more comfortable or adjusting the game to different conditions that patients may suffer, enlarging the rehabilitation offer and providing a wider variety of treatments for other dysfunctions that patients might exhibit.

After the patients' feedback and the therapist's approval of the application, several features can be discussed to add to the application, such as a minimum score value at a determined clock time to allow the user to advance or adding bonus lives if the user obtained a certain score in a limited time. This addition concerns user engagement and the quality of the performance.

Beyond the additions that can be done to the games, and in case of validation of the therapy, one of the next steps might be the creation of a therapist web application that will allow the therapist to visualise the data stored on the existing database and analyse the user progress over time, as well as in a clinical environment watch in real-time the player in-game actions.

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