DEPARTMENT OF
COMPUTER SCIENCE

DIOGO FILIPE MATOS PINTO
Bachelor in Science and Computer Engineering

ENHANCING MOTIVATION IN PHYSIOTHERAPY FOR PEOPLE WITH PARKINSON'S DISEASE: AN EXPLORATION OF SERIOUS GAMES AND VIRTUAL REALITY

DISSERTATION SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTER IN COMPUTER SCIENCE

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Abstract

Parkinson's Disease (PD) is a degenerative disorder of the central nervous system that mainly affects the motor system. There is currently no cure for PD, although it is possible to slow down its progression and control its symptoms with medication, surgery and physiotherapy. Physical exercise is an essential component of the treatment, helping patients to stay active, maintain physical performance and stimulate cognitive function. One of the main problems is that patients are more vulnerable to apathy and lack of motivation, which affects their willingness to follow an exercises plan and maintain their quality of life. Therefore, the necessity to develop an effective tool that persuades and actively engages patients becomes evident.

Persuasive Technology is defined as any interactive computing system designed to change a person's attitudes or behaviors. Gamification has demonstrated successful results in healthcare by increasing physical activity levels. Moreover, treatment can take advantage of Serious Games by combining the physical exercise component with cognitive function stimulation. If well aligned with therapy these can be used as Persuasive Technology. Therefore, this dissertation aimed to tackle this challenge by studying a motivational approach to persuade People with PD to practice even more therapy exercises. The proposed solution is based on the exploration of Serious Games and Virtual Reality (VR), mainly to study and discover the best natural user interfaces that could be used.

A collection of Serious Games was implemented under a preliminary study to determine which devices were more suited to use in the implementation of the motivational strategy. Afterwards, the solution was based on the development of two VR-based Serious Games, one using Kinect V2 and the other fully immersive with Oculus Quest 2. A human factors study was then designed, showing very positive results in the first evaluation phase before moving on to the final assessment with patients. The research produced conclusions about the devices to use, but also about the design process of these solutions, from non to fully immersive VR.

Keywords: Parkinson's Disease, Physical Exercise, Persuasive Technology, Gamification, Serious Games, Virtual Reality.

Resumo

A Doença de Parkinson é uma doença degenerativa do sistema nervoso central que afecta principalmente o sistema motor. Actualmente, não existe cura para a doença, embora seja possível abrandar a sua progressão e controlar os seus sintomas com medicação, cirurgia e fisioterapia. O exercício físico é um componente essencial do tratamento, que ajuda os doentes a manterem-se ativos, a manter o desempenho físico e a estimular a função cognitiva. Um dos principais problemas é que os doentes são mais vulneráveis à apatia e à falta de motivação, o que afeta a sua vontade de seguir um plano de exercícios e de manter a sua qualidade de vida. Por conseguinte, torna-se evidente a necessidade de desenvolver uma ferramenta eficaz que persuada e envolva ativamente os doentes.

A Tecnologia Persuasiva é definida como qualquer sistema informático interativo concebido para alterar as atitudes ou os comportamentos de uma pessoa. A Gamificação demonstrou resultados de sucesso nos cuidados de saúde, aumentando os níveis de atividade física. Além disso, o tratamento pode tirar partido de Jogos Sérios, combinando a componente de exercício físico com a estimulação da função cognitiva. Se bem alinhados com a terapia, podem ser usados como Tecnologia Persuasiva. Assim, esta dissertação teve como objetivo enfrentar este desafio, estudando uma abordagem motivacional para persuadir as pessoas com a Doença de Parkinson a praticar ainda mais exercícios terapêuticos. A solução proposta baseia-se na exploração de Jogos Sérios e Realidade Virtual, principalmente para estudar e desenvolver as melhores interfaces de utilizador naturais que podem ser utilizadas.

Foi implementada uma coleção de Jogos Sérios num estudo preliminar para determinar quais os dispositivos mais adequados para utilizar na implementação da estratégia motivacional. Posteriormente, a solução baseou-se no desenvolvimento de dois Jogos Sérios baseados em Realidade Virtual, um utilizando o Kinect V2 e o outro totalmente imersivo com o Oculus Quest 2. Foi então concebido um estudo de fatores humanos, com resultados muito positivos na primeira fase de avaliação, antes de passar à avaliação final com os pacientes. A investigação produziu conclusões sobre os dispositivos a utilizar, mas também sobre o processo de conceção destas soluções, desde a Realidade Virtual não imersiva até à totalmente imersiva.

Palavras-chave: Doença de Parkinson, Exercício Físico, Computação Persuasiva, Gamificação, Jogos Sérios, Realidade Virtual.

Contents

List of Figures

List of Tables

Acronyms

API Application Programming Interface
AR Augmented Reality

HCI Human-Computer Interaction
HMD Head-Mounted Display

PC Persuasive Computing
PD Parkinson's Disease
PGS Personalized Game Suite
PT Persuasive Technology

RGS Rehabilitation Gaming System

SGs Serious Games

VR Virtual Reality

1

Introduction

Persuasive Technology (PT) was originally conceptualized as being any interactive computing system designed to change people's attitudes and behaviors. The earliest signs of PT appeared in the 1970s and 1980s when a few computing systems were designed to promote health and increase workplace productivity [21].

Nowadays, this evolving field is increasingly targeted at influencing behavior in the areas of health and wellness. Over the past decade, several PT solutions have been developed to target not only health promotion by preventing illness, detecting early illness symptoms, and maintaining general well-being, but also for disease management by helping patients improve health-related self-management skills and helping them comply and adhere to treatment procedures [45].

Moreover, each of these health behavior domains has attracted considerable attention and people with neurodegenerative diseases, such as Parkinson's Disease (PD), which are limited by several motor and non-motor symptoms, can benefit immensely from this technology to get motivation to be active and improve their quality of life.

1.1 Motivation

PD is the second most common neurodegenerative disorder, after Alzheimer's disease. It is pathologically characterized by the loss of neurons in the *substantia nigra* which can cause tremor, bradykinesia, rigidity, and postural instability. PD can get worse over time and as the disease progresses, people may have more difficulty walking and talking, along with other non-motor problems [25].

With a prevalence of approximately 0.5 to 1 percent among persons with 65 to 69 years of age, rising to 1 to 3 percent among persons with 80 years of age and older, PD is still incurable and it is important that patients continue to do as many daily activities as possible, take their medication, have physical and occupational therapy, and follow a program of regular exercise in order to maintain mobility and independence [23][25].

Physical exercise is essential in the treatment process since it complements the medication intake, keeps the patients active, improves their quality of life, and increases physical performance and muscle strength. One major problem is the reduced levels of dopamine in the brain that make people with PD more vulnerable to apathy and lack of motivation. Therefore, the need to encourage patients in exercising emerges.

Usually, therapists have a hard time getting patients to exercise, because most of them have been dealing with pain, motor symptoms, trouble sleeping, fatigue, declining mobility and, maybe, even depression for many years. They are suddenly told that, along with taking their medication, exercise is one of the very best ways to feel better, lessen their symptoms and slow progression of PD, after spending most, if not all, of their life not exercising [22].

Although motivating patients through education, consistent monitoring, group classes and good communication has brought improvements in their lives, the developments that various technologies have shown these days almost make them a must-use.

PT is defined as technology that is designed to change the attitude or behavior of user through persuasion and social influence, but not through coercion. It has been applied in health, environment conservation, sales, diplomacy, safety, along others domains, and is found to be quite effective in changing people's attitudes and behavior. The use of these technologies to persuade, motivate and activate individuals for health behaviour change has been a quickly expanding field of research and, if applied along with gamification strategies, has great potential [58].

Therefore, PT and Gamification should take huge part in this process as they have demonstrated benefits in increasing physical activity levels, improving balance and cognitive functions in older people, while simultaneously keeping patients engaged, having fun, and motivated.

1.2 Description and Context

The *ONParkinson* platform emerged with the assessment of needs through the *Associação Portuguesa de Doentes de Parkinson* together with the triad composed of people with PD, informal caregivers and health professionals. The platform presents a Web app, aimed at health professionals, and integrates a mobile app as a central tool for self-management by people with PD and caregivers, where they can, for example, follow an exercises plan.

This dissertation took part of the *MoveONParkinson* project, which is focused on the exercise component of the platform to make it more interesting and intelligent in order to keep patients active in controlling the disease, also contributing to mitigate the distance caused by the COVID-19 pandemic.

The main goal of this dissertation was to implement a motivational strategy based on PT and study through *Participatory Design* how the integration of gamification elements with Serious Games and Virtual Reality can enhance the motivation of patients (with their caregivers) in the execution of the exercise plans needed to mitigate the progression of the disease.

The final implementation should serve as a motivational tool for people with PD that face problems with motivation to do physical exercise and stay active on a daily basis, by introducing Gamification, PT, where Serious Games (SGs) that use Virtual Reality (VR) could take place.

Gamification is a tool considered fundamental for the persuasive purpose. The central idea of gamification is to use the "building blocks" of games and implement them in real-world situations, often with the aim of motivating specific behaviors within the gamified situation [14].

The recent emergence of SGs as a branch of the digital games field has introduced the concept of games designed for a serious purpose other than pure entertainment. Health-care is a major application domain for SGs and many studies have identified the benefits of using them in rehabilitation and therapy. It has primarily been used as a tool that gives players a novel way to interact with games in order to promote physical activities. Since games technology is cheap, widely available, fun and entertaining for people of all ages, if combined with conventional healthcare it could provide a powerful means of encouraging patients more effectively. It also has been suggested that playing games can improve neuromotor coordination, and VR based games have been designed to engage patients' active participation in motor learning and to treat sensory-motor deficits [36].

The study, implementation and evaluation that occurred during this dissertation produced answers to the following research questions:

- **RQ1** - What characteristics of Serious Games and which interaction modalities and technologies are more adequate in producing engagement in people with Parkinson's Disease treatment?

- **RQ2** - How can Serious Games as Persuasive Technology be designed to enhance motivation in people with Parkinson's Disease to practice exercise?

1.3 Proposed Solution

After studying the difficulties and needs of people with PD and analysing how to use PT, it became clear the most suited technology for this research work was VR. The approach of VR in neurorehabilitation is innovative, as it provides a simulated training of functional tasks at a higher dosage than conventional therapies. It challenges the user for problem-solving and mastering skills of real-life situations in a virtual environment, thus providing the space for harmless failing and learning [52].

The particularities of a target audience such as people with PD required that a preliminary study was conducted to determine which interaction devices would be best suited to support a viable solution with VR and its sub-types, i.e. semi-immersiveness and non-immersivenesss. A minigame was developed for each of the devices, Kinect V2, Dance Dance Revolution Pad, Wii Balance Board and Oculus Quest 2, with the exception of the last one, which used a simple already existing game. Several test sessions were carried out with real users in a clinical environment, which enabled important decisions to be made that impacted the course of the work, especially the development phase.

The final solution consists of two game prototypes that support exercises plans for people with PD, involving several technologies and motivational strategies that help covering different kinds of medical conditions, studying which approach can be more successful. The SGs follow the physical treatments that the patients go through in the clinic and produce similar positive effects, although with the advantage of the whole new level of engagement that is only possible through gamification environments and other devices that create emerging, motivating and fun experiences. While playing the games, the patients can also stimulate their brain and cognitive functions, because of the challenges they are faced or by the experience itself.

In the developed prototypes the presence of encouraging elements stands out, which compact with the evidence studied and form the basis of the motivational strategy. Some examples of these elements are increasing difficulty over time, visual and score rewards, the presence of a virtual therapist who interacts with the player, and positive and simple feedback according to the user's performance. Not only is the focus on user experience important, but also the concern that the physiotherapist has tools to configure the games and visualize the performance of each user to evaluate their progression. Therefore, a web interface was integrated into the solution to allow monitoring the data mentioned above.

Additionally, the two game prototypes developed led to a *Human Factors Study*. The students that participated interacted with the games according to a defined protocol in order to evaluate the usability of the solution, verify if the functionalities were well integrated and help to evaluate the therapeutic intention. At the end of the sessions users answered a questionnaire about System Usability Scale and Domain Specific Questions, and how the gaming experience went according to the NASA Task Load Index.

1.4 Main Contributions

As result of the research work of this dissertation, the main contributions are:

- **Preliminary Interaction Devices Study:** Ideation and implementation of game prototypes for people with Parkinson's Disease using sketches that consider the usage of different technologies and interaction devices. Then, presentation and discussion of prototypes in sessions with healthcare team members. Testing sessions with patients to get feedback and take advantage of Participatory Design in order to improve the quality of the implementation.

- ***MoveONParkinson* Game Prototypes:** Development of two Serious Games that are the main element of the motivational component for patients' therapy sessions in order to maintain their condition to cope with Parkinson's Disease.

- **Integration with *ONParkinson* platform:** Integration of the motivational approach with *ONParkinson* platform. Creation of interface that allows therapists to manipulate the games configurations and visualization of session results.

- **Human Factors Study:** Study of the usability and efficacy of the Game Suite by testing it with young and healthy students. Analysis of the sessions, elaboration of user testing report and extraction of considerable improvements.

- **Publications:** A paper focusing on the Preliminary Interaction Devices Study was accepted at the International Conference on Mobile and Ubiquitous Multimedia (MUM'22) [48]. A second paper was submitted to EAI PervasiveHealth 2023 - 17th EAI International Conference on Pervasive Computing Technologies for Healthcare, integrating the study with patients that is being conducted.

1.5 Report Structure

The structure of the present dissertation is the following:

- **Chapter 1 - Introduction:** The first Chapter presents a general summary of the work accomplished in this dissertation. It is focused on the motivation and description of the problems approached, as well as the proposed solution and the main expected contributions of the final work.

- **Chapter 2 - Background and Related Work:** This Chapter covers important related work for this area of study and relevant concepts needed in order to understand the context of the dissertation. In general, it presents Parkinson's Disease, the motivation for Persuasive Technology, Gamification and Serious Games, context for the use of Virtual Reality, suitable interaction devices, Game Development concepts and related work.

- **Chapter 3 - Exploring Serious Games and Virtual Reality:** This Chapter describes the initial approach and how the study of Virtual Reality and Serious Games was conducted. It presents the four interaction devices that were considered for the preliminary study and sketches of game ideas for each modality, followed by details about the implementation of the selected mini games. Moreover, it presents an overview of the *Design Study* and a discussion on the obtained results.

- **Chapter 4 - MoveONParkinson Game Prototypes:** This Chapter corresponds to the implementation phase of this dissertation. It goes over the technologies used, game design considerations and the final game prototypes developed. In addition, the integration with the web platform is presented.

- **Chapter 5 - Evaluation:** This Chapter addresses the evaluation phase of the developed prototypes. It presents details about the participants, evaluation goals and methods used in testing. Additionally, it provides the obtained results along with a discussion on the *Human Factors Study*.

- **Chapter 6 - Conclusions and Future Work:** The last Chapter reviews the work accomplished in this dissertation and compares the final solution with the initial motivations. The research questions proposed in Chapter 1 are answered here based on the developments and final results. Moreover, it provides ideas for future improvements that can improve the efficiency and usability of the strategy.

2

Background and Related Work

This Chapter presents previous study and research, in addition to projects related to the approached fields in this dissertation. Therefore, it will be divided into the following sections:

- Parkinson's Disease
- Persuasion
- Game-Based Approached for Healthcare
- Virtual Reality
- Related Work

2.1 Parkinson's Disease

2.1.1 Definition

PD is a slowly progressive neurodegenerative disorder that affects the dopaminergic neurons in part of the basal ganglia area of the brain, the *substantia nigra* (see Figure 2.1), which is essentially responsible for dopamine production [50]. Dopamine is the chemical responsible for carrying messages around the brain. For example, when a person feels the need to itch, it is dopamine that carries the message to the nerve cells that control the muscles she needs to itch herself [50].

Mainly, the collection of nerve cells that constitute the basal ganglia help to initiate and smooth out intended muscle movements, suppress involuntary movements and coordinate changes in posture [23].

When those nerve cells degenerate, they produce less dopamine and the number of connections between cells in the basal ganglia decreases. As a result, muscle movement is not controlled as it is normally, leading to tremor, slow movement (bradykinesia), a tendency to move less (hypokinesia), problems with posture and walking, and some loss of coordination [23].

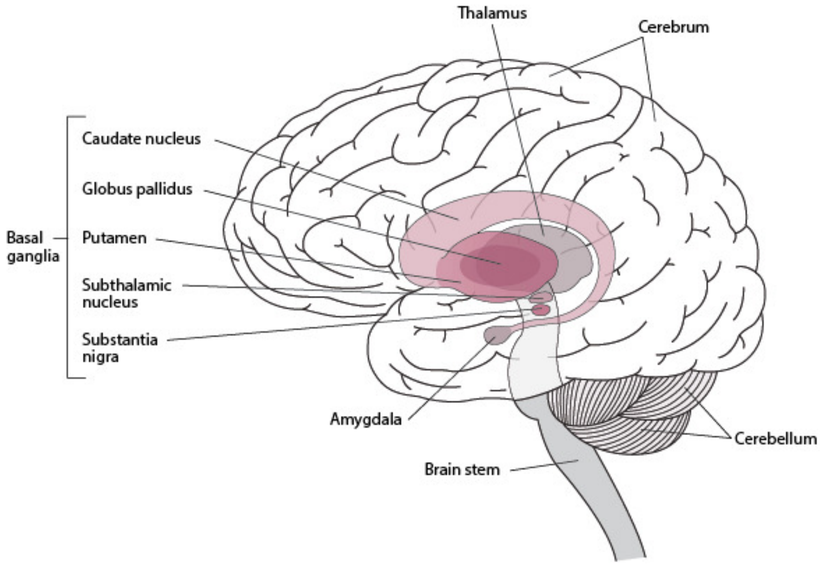


Figure 2.1: Locating the Basal Ganglia [23]

A lot of speculation about the cause of PD is made regarding the genetic, hereditary and environmental factors involved with this disease. Although hereditary causes of the disease are quite rare, some genes have been found to be linked to the disease and 15% of Parkinson's patients have been found to have a family history of it [50].

PD commonly begins between the ages of 50 and 79 and only rarely occurs in children or adolescents [23]. It is generally accepted that the prevalence of the disease ranges from one to two per 1000 in unselected population and that the disease affects 1 percent of the population above 60 years [59].

2.1.2 Symptoms

PD is characterized by its three main motor symptoms, which are bradykinesia, rigidity and tremor, but also has additional motor and non-motor characteristics [59]. Usually, PD begins subtly and progresses gradually so, according to the *Hoehn and Yahr Scale*, there are five stages that can be identified [50]:

1. The first stage of PD is characterized by mild symptoms that do not change the person's quality of life and daily activities are not much affected.

2. In the second stage of the disease, the symptoms worsen, making day to day activities more difficult and increasing the time to complete a simple task.

3. It is around the mid stage that PD starts getting severe and causes difficulties in the performance of daily activities like dressing, eating, brushing, among others.

4. At stage four, PD gets very severe and the patient requires assistance in her/his daily activities and also walking.

5. The final stage is the advanced stage of PD, rendering a person completely helpless. Such persons require complete monitoring and assistance with living.

PD was originally considered a pure movement disorder with three cardinal signs, but over the years postural changes in general and postural instability in particular have been used as a fourth cardinal sign [59]. The main characteristics of PD's motor symptoms are:

- **Bradykinesia** - movements become slow and smaller and are difficult to initiate. Thus, people tend to move less. When they move less, the act of moving becomes more difficult because joints become stiff and muscles weaken.

- **Rigidity** - muscles become stiff, making movement difficult. When a doctor tries to bend the person's forearm back, or straighten it out, the arm resists to the movement.

- **Tremors** - usually starts in hands and occur when muscles are relaxed, decrease when the hand is moving purposefully and disappear completely during sleep. It may be worsened by emotional stress or fatigue; and it may eventually progress to other parts of the body.

- **Improper gait and balance** - posture becomes stooped, and balance is difficult to maintain. Thus, people tend to topple forward or backward. Because movements are slow, people often cannot move their hands quickly enough to break a fall. These problems tend to develop later in the disease.

Other secondary symptoms, including non-motor symptoms can also be caused, such as insomnia, urination problems, difficulty swallowing, constipation, sudden decrease in blood pressure, scales, loss of smell, anxiety, dementia, depression, and paranoia (usually when dementia is present). Some mental symptoms, including psychosis, may be caused by drugs used in treatment [23].

2.1.3 Treatment

There is currently no cure for PD, however medication, physiotherapy and, in a few cases, surgery might prove beneficial [50].

Levodopa plus *carbidopa* is the mainstay of treatment for PD and can make movement easier and enable people to function effectively for many years. This drug is converted into dopamine in the basal ganglia and compensates for its decrease due to PD [23].

In PD, there is a phenomenon called *on-off* effects. After taking *levodopa* for five or more years, more than half the people begin to alternate rapidly between a good response to the drug and no response at all. Within seconds, people may change from being fairly mobile to being severely impaired and immobile. Taking lower, more frequent doses, switching to a different form of *levodopa* or adding a dopamine agonist can be used to control the off effects [23].

Physiotherapy does not exclude the need to take the medications indicated by the neurologist, being just a way to complement the treatment. However, it plays a really important role as it provides an improvement in the patient's general physical condition, in addition to restoring and/or maintaining independence in the performance of daily activities [50].

Typically, surgery is advised when the *off* effects become hard to suppress or the patient has reached an advanced stage of the disease and has unmanageable motor symptoms (e.g., Pallidotomy, Thalomotomy, Deep Brain Stimulation) in order to increase quality of life, although this area is in constant development and other techniques will certainly gain value in some years [50].

2.1.4 Physiotherapy

The main idea behind this really important component is to address the issues of mobility, flexibility, posture, and balance offering functional independence to PD patients. Physiotherapy exercises also help to mobilize stiff joints, decrease risk of falling, provide flexibility to tight muscle, improve muscle tone, and maintain range of motion [23][50][47].

Physical Exercises for Parkinson's Disease	
Technique name	Description
Relaxation	should be performed at the beginning of the session to reduce stiffness, tremors and anxiety, through rhythmic activities, involving a slow and careful balancing of the trunk and limbs
Stretches	should be done by the individual with the help of the physiotherapist, stretching for the arms, trunk, shoulder/pelvic girdle and legs
Active exercises and muscle strengthening	should be performed preferably sitting or standing, through movements of the arms and legs, trunk rotations, using sticks, rubber bands, balls and light weights
Balance and coordination training	it is done through activities such as sitting and standing, rotating the trunk, leaning the body, exercises with changes of direction and at various speeds, grabbing objects and dressing
Postural exercises	should be performed looking for the extension of the trunk and in front of the mirror so that the individual is more aware of the correct posture
Facial mimicry exercises	encouragement to open and close the mouth, smile, frown, pout, open and close the eyes, blow a straw or whistle and chew food
Gait training	try to correct and avoid shuffling gait by taking longer steps, increasing trunk and arm movements. You can make marks on the ground, walk over obstacles, train to walk forwards, backwards and sideways
Group exercises	help to avoid sadness, isolation and depression, bringing more stimulation through mutual encouragement and general well-being. Dance and music can be used

Table 2.1: Physical Exercises for Parkinson's Disease [47]

PD can make daily activities seem frustrating and time-consuming. Physical therapists will become a real partner and it is important that the whole family is involved in the treatment of the patient, so that activities are also encouraged at home, as prolonged periods of breaks can compromise goals [47].

The exercises must be prescribed after an evaluation made by the physiotherapist, where the short, medium and long term goals will be established. As the condition changes, the treatment program will be adjusted [47]. The most often used exercises are described in the table below (see Table 2.1).

Generally, physiotherapy will be necessary for life, so the more attractive the sessions, the greater the dedication and interest of the patient and, consequently, the better the results obtained [47]. For this to happen, arrives the need to access apathy levels of PD's patients and its relation to disability, mood, personality and cognition to be possible to find an effective way to motivate them.

2.1.5 Apathy

Apathy is a symptom that refers to a constellation of behavioural, emotional, and motivational features, including a reduced interest in normal purposeful behaviour, difficulty initiating activities, lack of concern or indifference, inability to feel pleasure that can even affect mood (particularly depression), aspects of personality and cognitive function [49].

PD is a classic example of a neurodegenerative disorder where apathy is observed and patients who are affected start to no longer find enjoyment in general activities, such as being around friends or family, taking a walk and cooking a meal [55].

Almost by definition, apathy has a direct impact on the overall level of handicap, as it reduces participation in age appropriate activities due to other aspects of the disease. It contributes significantly to caregiven burden and has negative implications for treatment as it can severely affect the quality of life of both patients and caregivers [49].

According to some recent studies, current estimates of the prevalence of apathy in Parkinson's disease vary between 16.5% and 42% as the levels of apathy in PD appear to be unrelated to disease progression [49][55].

When it comes to managing apathy, medications are not typically effective for its treatment and better results can be achieved by:

- Keeping a consistent sleep schedule.
- Pursuing physical, social and cognitive activities.
- Setting personal goals and doing fun things.
- Getting regular exercise.

In order to maintain quality of life and quality relationships with caregivers, family, and friends, it is fundamental to learn to recognize and understand apathy as a symptom of PD and identifying ways to cope with it. It is important to try to make things fun again like cooking or dining out for a favorite meal, trying hobbies enjoyed in the past, watching a movie, and pursuing enjoyable activities [55].

2.2 Persuasion

In this section, the concept of persuasion and what it brings on about will be introduced, in addition to some sub-themes, such as Persuasive Technology, Fogg Behavioral Model and Influence Awareness.

2.2.1 Definition

Persuasion is a powerful tool that aims to encourage users to change their behaviors and attitudes. However, it must be used in an ethically correct way, causing users to change their behavior when using systems in a way that contributes to the their own good or for a greater good, not harming themselves.

For technology purposes, persuasion is defined as the attempt to change attitudes or behaviors or even both (without using coercion or deception). It is important to note the difference between persuasion and coercion. Coercion implies force and, while it may change behaviors, it is not the same as persuasion, which implies voluntary change. Similarly, persuasion and deception are different, because deception is the act of tricking someone and changing what she/he thinks and does. Nevertheless, computer-based coercion and deception are not covered under the scope of captology, because they do not depend on persuasion [21].

2.2.2 Persuasive Technology

B.J. Fogg defines PT as any interactive computing system designed to change people's attitudes or behaviors. One may think that PT resumes itself to Web sites and computer apps but, nowadays, PT can take on many forms, from mobile phones to "smart" toothbrushes to the computerized trailers that sit by the roadside and post the speed of passing cars in an attempt to persuade drivers to obey the speed limit. From this definition, analysis and attempt to describe this emerging area, surged a term called captology [21].

Captology focuses on the change of behaviour or attitude through Human-Computer Interaction (HCI) and not Computer-Mediated Communication (CMC). Specifically, captology investigates how people are motivated or persuaded when interacting with computing products rather than through them. In other words, it focuses on the planned persuasive effects of computer technologies and requires intentionality, which is what distinguishes between a planned effect and a side effect of a technology [21].

Captology, also defined as "computers as persuasive technologies" or Persuasive Computing (PC), focuses on the design, research, and analysis of interactive computing products created for the purpose of changing people's attitudes or behaviors. It describes the area where technology and persuasion overlap (see section 2.2).

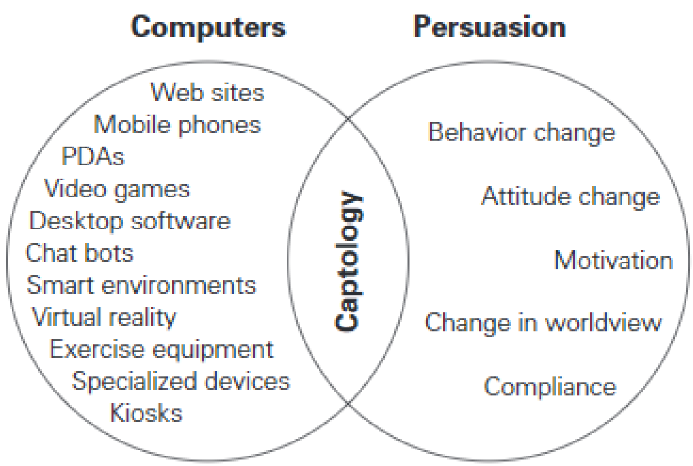


Figure 2.2: Captology describes the area where computing technology and persuasion overlap [21]

PC is most effective when applied to interactivity. Persuasion techniques are most effective when persuaders adjust their strategies based on user feedback, their needs and the situation they are in. In this way, the approach can be changed so that it is more personalized, thus improving the final product.

Moreover, there are several advantages on using computers to persuade humans instead of humans. Firstly, computers can be more persistent than humans and can guarantee anonymity, which can be an advantage in certain situations. Secondly, computers can generate and manipulate large amounts of data and information what can provide different and better suggestions. Lastly, computers bring more ways to persuade, for example visual, audio or textural experiences and offer better and easier scalability than humans.

Finally, it can be concluded that computers are able to go where humans cannot go or are not welcome since, nowadays, computer systems are embedded in everyday objects, or environments, so they have inevitably greater power of persuasion than humans.

2.2.3 Fogg Behavior Model

The Fogg Behavior Model (FBM) influences the change in human behavior showing that three elements must converge at the same moment for a behavior to occur: Motivation, Ability and a Prompt [20]. This model states that for a user to achieve the desired behavior it is necessary to be sufficiently motivated, to have the ability to perform the behavior and to be able to perform the intended behavior. When a behavior does not occur, at least one of those three elements is missing. Therefore, it can be concluded that B = MAP, that is, Behavior (B) happens when Motivation (M), Ability (A), and a Prompt (P) come together at the same moment, as seen in the Figure 2.3 [28].

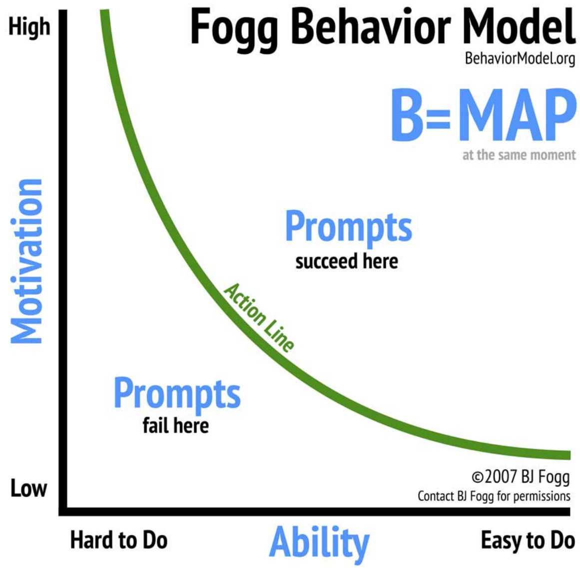


Figure 2.3: Fogg Behavior Model [20]

This model is useful in analyzing and designing persuasive technologies efficiently, helping teams to work together, as it provides a shared way of thinking about behavior change. For this change to take place, it is necessary to know what drives human behavior. Without this understanding, the correct techniques will not be used to solve the problem.

Thus, increasing motivation is not always the right answer. Sometimes, it is necessary to increase capacity, making the behavior simpler, which consequently increases the performance of the behavior. Users with low motivation can perform a behavior if it is simple enough, e.g., trying to be healthy and preparing vegetables takes time, work and high motivation, but buying vegetables already washed, prepared and ready to cook is easy to do with low motivation. However, if motivation is high enough, people can perform extraordinary tasks, even if they are difficult to complete. Studying the balance of all three elements is the key to finding a good motivational solution.

2.2.4 Motivation in Digital Healthcare

A case study addressed the inclusion of motivation in the development of e-Health systems. Even though motivation, “the general desire or willingness to do something”, is not essential in rehabilitation, it has been acknowledged as a booster of productivity while performing it and is considered a key factor, because it influences people’s ability to use, learn and make decisions, among other things. There has been much research related to this topic, with important implications for rehabilitation and, therefore, its consideration must be taken into account in the e-Health domain [35].

Awareness has been used in different domains (virtual reality, military tasks, games) to provide that extra information, which, provided at the right time, improves the interaction of the user with the applications. In this work, this concept has been extended to specify how awareness information can be used to influence the patients' motivation. Several motivation theories have been used as the foundation of Influence Awareness. The main inspirations were the six principles from the Theory of Influence [35]:

Reciprocity - This is a principle that reflects the fact that people feel as if they are in debt with someone who gave them something. Thus, it aims at influencing a person by reminding her/him what was given to her/him, and who did it.

Scarcity - This principle is related to the tendency of preferring those things which are scarce. The fear of losing the potential benefits of a scarce element that is likely to become extinct soon is a motivating aspect.

Authority - This principle enunciates that people usually respect authority. When using the authority principle to influence someone's behaviour, awareness contributing to reinforce authority should be provided. Authority can be reinforced in the form of Ranks, Recommendations or Experience.

Consistency - It is easier for us to make commitments if we make them voluntarily and if these commitments are public. Being at least partially responsible for defining the goals will benefit a person's motivation towards those goals. Participatory Design and Design Thinking can be seen as Consistency strategies.

Liking - Liking can also be understood in the sense of how much the patient likes his current goal. Aiming at supporting this principle, awareness can be provided with Similarities (who is similar to us), Supporters (who compliments us) and Collaborators (who collaborates with us).

Consensus - It is very usual to do what other people do. In this principle, the goal is influencing someone's behaviour by providing feedback about what other people are doing, did in past or will do. This principle is really similar to a social network.

These principles were empirically validated and they are concrete enough to be used in a computational environment. To endow this awareness interpretation with more expressiveness, some more theories have been used to enrich it. Two examples are [35]:

Self-Determination Theory (SDT) that relies on three principles:

- Competence principle states that the motivation of a person is increased whenever that person feels competent for the action being performed.

- Relatedness, on the other hand, states that the feeling of belongingness and connectedness with others also has an influence in improving motivation.

- Autonomy principle states that a person is more motivated when she/he feels that has some autonomy and, therefore, has the locus of causality.

Expectancy Theory that builds its motivational theory around three factors:

- Expectancy is related to the belief that increasing the effort in performing a task will also increase the performance. This factor can be influenced by having the right resources, the proper skills or the required support to do the task.
- Instrumentality is the belief that a reward will be obtained given that certain performance expectations are met. Some related issues to this factor are the knowledge of the "game" rules.
- Valence is the importance that the outcome of the task has for the person.

2.3 Game-Based Approaches for Healthcare

As the success and proliferation of video games grows, they have the potential to be more than just entertainment, just like books, movies and television. According to Michael & Chen [42], the time has come for video games to become more relevant, more responsible, and more important or, in other words, to get serious. Consequently, the research community and the game industry moved towards the development of more elaborated games, incorporating both pedagogical and entertaining elements.

It has been showed that games contribute to increase motivation in rehabilitation sessions, which is the major problem in therapy sessions, caused by the repetitive nature of exercises. It is believed that the design of computer games can offer valuable contributions about how to develop more effective games for rehabilitation programs [51].

2.3.1 Serious Games

Serious Games are growing into a significant research area spurred by the advances in game development and in computer graphics hardware, in turn driven by the success of video games. They are becoming so popular that we are assisting the arising of new audiences that before were turned off for the most traditional games. An example of this can be seen by the popularity gained by the Wii system from Nintendo which is being played among families, women, older people and not only by the most "hard-core" players [51].

Although, there are many definitions of the term, it is agreed by different authors that the term refers to the use of computer games that have a main purpose that is not pure entertainment. In fact, Serious Games have been applied in many diverse areas: corporate and military training, health, education, cultural training and government [51].

Many tests from rehabilitation programs of patients with impairments and disabilities show that patients function improves with an intensive training that is oriented in the achievement of a goal and is divided in specific tasks. The problem with this task-specific treatment approaches, however, is the lack of patient interest in performing repetitive tasks and in ensuring that they finish the treatment program [8].

As traditional treatment approaches include exercises often considered repetitive and boring for patients, using computer games to augment physical and cognitive rehabilitation can offer the potential for a significant therapeutic benefit. Games require cognitive and motor activity so they can engage a person's attention. Besides, most games offer increasingly difficult levels that give the player the sense of challenge in his progress and in a way that is also adapted to his skills. Another very important aspect is that games distract the patient's attention and as such they can be used to aid in the management of pain [8] [33].

The application of Virtual Reality (VR) technology for the rehabilitation of cognitive and motor deficits has been growing in the last decade and stroke patients have been one of the main target populations for these new rehabilitation methods. These VR based-methods can offer the patients to be part of immersive experiences that are engaging and rewarding for them [51].

2.3.2 Gamification

Another important sector of game-based approaches for health behaviour changes is Gamification. Gamification and Serious Games differ in terms of gaming experience: a serious game operates as a fully-fledged game while gamification applies particular elements or combinations of elements to activities or processes. However, both employ game elements to motivate and inform health behaviour change. For example, narrative contexts can be used for imparting knowledge and skills and mediating goal-setting processes, while competitive-cooperative game contexts can influence peer pressure [11].

Gamification is the application of game features, mainly video game elements, into non-game context for the purpose of promoting motivation and engagement. In a more practical way, it is the introducing of important components such as avatars, badges, points, levels, leaderboards, virtual rewards, storylines or quests and game elements that allow for social interaction between players in order to increase task engagement, increase motivation and enforce desirable learning behaviors [1].

For example, the application of gamification in a pedagogical context provides some remedy for many students who find themselves alienated by traditional methods of instruction. Often many students lack the motivation and interest to learn and, if given a choice, many of them would prefer to play video games rather than reading a book or completing a homework assignment [1]. Therefore, why not combine both and have the best of both worlds?

This line of thought can also be applied to PD's treatment. When PD's patients are struggling with apathy because of motivation issues, frustration caused by difficulties in movement, lack of interest for exercising or following a certain routine, there are ways to apply similar gamification strategies.

A recent study tested a motivational app that was fitted to exercise bikes in order to provide challenge and interest during the exercise routine, converting it into an exercise enhanced by gamified elements, called *exergaming*. It comprised both VR software, real-life videos and rewards to participants that exercise. Not only did the participants kept up with their exercise routine, their motor disability was significantly better and other patients with worst medical conditions could also do some activity. With the outstanding benefits of this intervention, the patient did not have to leave home either. This paired with the post *COVID-19 pandemic* situation makes it more likely that this therapy can be extended to many potential beneficiaries [32].

2.3.3 Therapeutic Games Design

The combined results of several studies are promising, and with detailed research and development, video game play might be a safe, cost-efficient, and effective supplement to conventional physical therapy. As research in this area grows, however, there is still a lack of criteria by which therapists can judge how games could be integrated into rehabilitation or assist patients in choosing games appropriate for in-home use [34].

One option is designing therapy-specific games, although there are precautions that must be taken in this process. Patients struggle with lack of motivation derived mainly from their condition and to complicate the effects of the functional loss, patients can suffer from depression [34]. The gameplay is the very heart of a video game, and in therapeutic games, it must provide the therapy through relevant game actions while also being able to sustain the patients motivation. Therefore, the game designer has to create a motivating and efficient game, but often lacks the medical knowledge necessary for this design [37].

The video game industry produces accessible and affordable activities that engage users for long periods of time, but there are key specific game mechanics/design principles that increase motivation and engagement, increasing the amount of time players (patients) are willing to spend in the game (as a therapy supplement). A study extracted six key principles of effective game design that have an empirical basis for increasing player engagement and motivation: reward, optimal challenge, feedback, choice/interactivity, clear instructions, and socialization. These are not exhaustive or mutually exclusive factors. For example, changes in feedback could affect the difficulty of the game, which in turn affects a player’s sense of reward and the motivation to continue playing. These six principles should instead be thought of as a framework for conceptualizing engagement and motivation in gameplay [34].

Moreover, a recent paper proposed a game design method for therapeutic games containing a sequential process of three phases [37]:

1. Investigating the problem with health experts.

2. Designing the gameplay.

3. Prototyping the therapeutic game.

These main phases have sub-phases, but, overall, in phase one the objective is to get the health knowledge necessary to design the gameplay, phase two is about getting more specific data, generating solutions and validating a gameplay with health experts and the last phase is similar to a video game pre-production, the objective is to produce and evaluate a pre-production prototype before starting the production.

2.4 Virtual Reality

In this part of the document, it will be presented some motivation and a definition of VR followed by a deep analysis of the technologies and tools that are used to develop and simulate it. The information here presented was really useful in deciding what technologies to consider using in the project solution.

2.4.1 Motivation

VR-based mobility training is a promising tool to provide an enjoyable, engaging, and enriched setting for forms of physical therapy capable of improving functional mobility in older adults, people post-stroke, and individuals with PD [18].

While some studies have found limitations with using video games among "more fragile groups" such as older patients and those with PD, according to the researchers, "counteracting its limitations could make VR a suitable tool for the application of therapeutic and rehabilitation programs, due to its adaptability to the patient, specificity to the pathology and expected high adherence." [7].

A participant of a recent VR intervention of SteamVR Home games refer to its use as "It motivates me to do exercise", while another wrote in a follow-up comment "The best experience I've had to date", which shows the impact these technologies have in creating engagement and fun moments with patients. The team noted that available commercial software and VR exergames "can provide enough exertion to be compared to traditional exercise activities such as walking or dancing (highly recommended in PD physiotherapy clinical guidelines) "[7][10].

Another study compared the *Box & Blocks Test* in two different environments: one using 3D Oculus Rift, the other one a laptop and both with an infrared camera (Leap Motion Controller) for tracking of hand and fingers. Participants in the 3D group demonstrated statistically significant and substantially better performance in average time of manipulation, number of successfully placed cubes and average tremor. Unified PD rating scale for upper limb and also 3D groups substantially improved their game score with training. The outcomes of the study demonstrated that immersive 3D technology may bring increased interests/enjoyment score resulting in faster and more efficient functional performance [12].

Overall, the studied projects and frameworks demonstrate that VR presents enormous potential and can really be a better and more effective way of therapy than the traditional.

2.4.2 Definition

VR is a fully digital, computer-generated, three-dimensional experiential environment. Unlike traditional user interfaces that only allow users to view a screen, VR allows the user to step inside an experience, to be immersed in and interact with a 3D world that can either simulate or differ completely from the real world [27]. By simulating as many senses as possible, such as vision, hearing, touch, even smell, the computer is transformed into a gatekeeper to this artificial world and the only limits to near-real VR experiences are the availability of content and cheap computing power [3].

VR is considered to have begun in the 1950's, but it only came to the public's attention in the late 1980's and 1990's. This can be attributed to pioneering computer scientist *Jaron Lanier*, founder of VPL Research, when he began to develop the gear, including goggles and gloves, needed to experience what he called "Virtual Reality." Even before that, one famous milestone was the *Sensorama* in 1956 by *Morton Heilig*, who wanted to see how people could feel like they were "in" the movie. The experience simulated a real city environment, which you "rode" through on a motorcycle and multisensory stimulation let you see the road, hear the engine, feel the vibration, and smell the motor's exhaust in the designed "world." By 1965, another inventor, *Ivan Sutherland*, offered *the Ultimate Display*, a head-mounted device that he suggested would serve as a "window into a virtual world." The 1970s and 1980s were a heady time in the field, while optical advances ran parallel to projects that worked on haptic devices and other instruments that would allow you to move around in the virtual space. Today's current VR gear owes a debt of gratitude to the pioneering inventors of the past six decades who paved the way for the low-cost, high-quality devices which are easily accessible today [29][38].

Augmented Reality (AR) has also come a long way in terms of evolution and achievements, but let's not confuse it with VR. In AR, the computer uses sensors and algorithms to determine the position and orientation of a camera. AR technology then renders the 3D graphics as they would appear from the viewpoint of the camera, superimposing the computer-generated images over a user's view of the real world. In VR, the computer uses similar sensors and math. However, rather than locating a real camera within a physical environment, the position of the user's eyes are located within the simulated environment. For instance, if the user's head turns, the graphics react accordingly and, rather than compositing virtual objects and a real scene, VR technology creates a convincing, interactive world for the user [3].

Nowadays, there are 3 primary categories of virtual reality simulations [38][27]:

- **Non-Immersive systems** – *Desktop VR* is the simplest type of virtual reality applications and is when a computer user views a virtual environment through one or more computer screens. A user can then interact with that environment, but is not immersed in it. Relies on input devices like keyboards, mice, and controller and no other sensory output is supported. A video game is a great example of a non-immersive VR experience.

- **Semi-Immersive systems** – improved version of *Desktop VR* that provides users with a partially virtual environment. It will still give users the perception of being in a different reality when they focus on the digital image, but also allows users to remain connected to their physical surroundings. Semi-immersive technology provides realism through 3D graphics, a term known as vertical reality depth. They still use a conventional monitor (often with LCD shutter glasses) but generally do not support sensory output.

- **Immersive systems** – the ultimate version of VR systems as they let the user totally immerse in computer generated world with the help of Head-Mounted Display (HMD) that supports a stereoscopic view of the scene accordingly to the user's position and orientation. These systems may be enhanced by audio, haptic and sensory interfaces as the possibilities for their usage are endless.

2.4.3 Technology and Interaction Devices

2.4.3.1 Oculus VR

VR's most immediately-recognizable component is the HMD. Human beings are visual creatures, and display technology is often the single biggest difference between immersive VR systems and traditional user interfaces [3].

VR headsets are called head-mounted displays, which means that the screen is mounted to your face and wherever you move your head, the screen follows you. For certain VR headsets, such as the HTC Vive and the Oculus Rift, a console or computer is needed for the headsets to work and the video is sent from the device to the VR headset. For other headsets, like the Google Daydream and the Samsung Gear VR, a smartphone has to be slotted into the headset and the video plays from the phone [5].

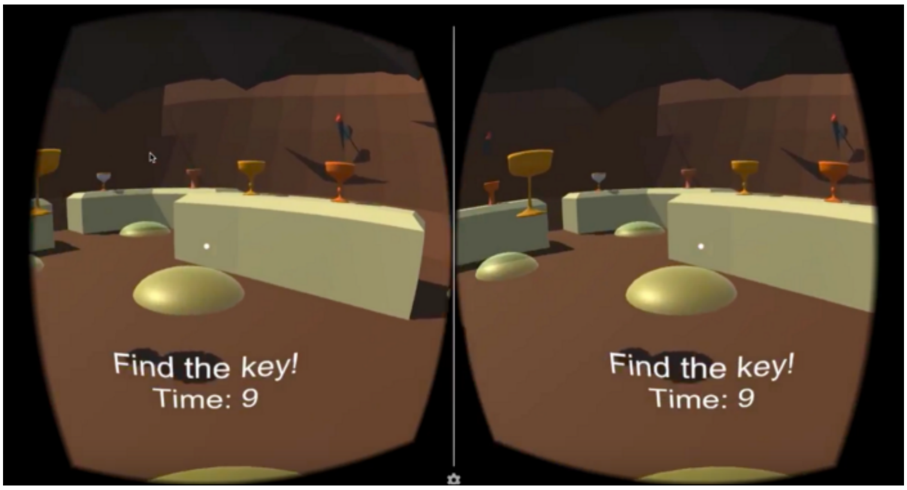


Figure 2.4: Images created by the VR headset lenses [5]

In terms of components, VR headsets either use two LCD displays (one per eye) or two feeds sent to one display. Headsets also have lenses placed between the user's eyes and the screen, which are used to focus and reshape the picture for each eye. They create a stereoscopic 3D image by angling the two 2D images. This is because the lenses mimic how each of our two eyes see the world very slightly differently (see Figure 2.4) [5].

VR headsets also need to have a minimum frame rate of at least 60 frames per second in order for the user to not feel sick. Current VR headsets are able to go way beyond this, with Oculus and the HTC Vive at 90 frames per second and PlayStation VR at 120 frames per second. There are a couple of different components used in a head-tracking system, including a gyroscope, accelerometer, and a magnetometer [5].

For VR to work properly, when the user moves her/his head up and down, or side to side, or tilt the hear, the picture has to move properly with the head. Headsets use the head-tracking system, which looks at the head's position in terms of the X, Y, and Z axis to measure head movements. That system is called three degrees of freedom (3DoF) and some headsets can combine it with the three translational degrees of movement, which can be thought of as moving forward or backward, left or right, and up or down and achieve the six degrees of freedom (6DoF) (see Figure 2.5) [5][4].

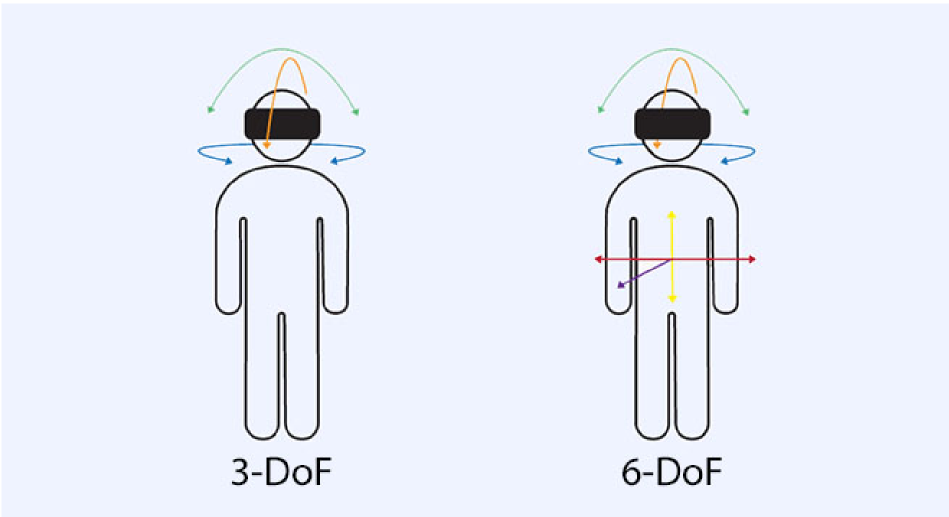


Figure 2.5: 3DoF versus 6DoF [4]

In order for head-tracking to be effective, low latency is needed and it cannot be greater than 30 milliseconds in order for the user to feel comfortable. 3D audio is also something that is used by developers to increase the sense of immersion, giving the allusion that the sound is coming from behind them, next to them, in front of them, or in the distance [5].

The Oculus Rift, HTC Vive, and HTC Vive VR headsets have wireless (hand) controllers that allow the user to control what happens in the VR simulation. There are certain buttons on the controller, as well as a lot of sensors, to detect gestures, such as pointing and waving. Different input methods include voice controls, smart gloves, and even treadmills, which allow to simulate walking around in a VR environment [39].

2.4.3.2 Motion Capture

Motion Capture comes to the equation when it is desired to use a VR Headset without built-in body movement recognition or to develop a non-immersive game/experience. When treating PD patients, it could also be important to consider making non-immersive experiences that prioritize movement amplitude and complexity rather than visual stimulation.

Motion Capture is the process of recording a live motion event and translating it into usable mathematical terms by tracking a number of key points in space over time and combining them to obtain a single three-dimensional representation of the performance. For a human, for example, some of the key points are the joints that act as pivot points and connections for the bones. The location of each of these points is identified by one or more sensors, markers, or potentiometers that are placed on the subject and that serve, in one way or another, as conduits of information to the main collection device [40].

There are different ways of capturing motion, and some systems use cameras that digitize different views of the performance, which are then used to put together the position of key points, each represented by one or more reflective markers. Others use electromagnetic fields, or ultrasound, to track a group of sensors. Mechanical systems based on linked structures, which use potentiometers to determine the rotation of each link, are also available. Combinations of two or more of these technologies exist, and newer technologies are also being tested [40].

A motion gaming system, sometimes called a motion-controlled gaming system, is one that allows players to interact with the system through body movements. Input is usually made through a combination of spoken commands, natural real-world actions and gesture recognition that can be accomplished with motion controllers [57].

The Kinect is a controller-free system, produced by Microsoft for the Xbox 360, with a depth camera and motion sensor. The system uses face recognition and voice recognition to identify users. The depth camera, which “sees” in 3D, creates a skeleton image of the player and the motion sensor tracks their movements. Speech recognition software allows the system to understand spoken commands [57].

Figure 2.6: The Xbox Kinect [13]

This technology has been used immensely in the game industry to allow playing games without a controller, but it does not stop at just playing video games. There are tons of possible applications with the Kinect which are far from the gaming world, such as Robotics, Science and Healthcare [13].

Unfortunately, Kinect has been discontinued and the new product, which was released as its upgrade, Azure Kinect, is too expensive, overwhelming and sophisticated to a thesis context and is more focused on robotics, business and even has cloud integration.

Moreover, there are alternatives to Kinect, such as ASUS Xtion PRO, Intel RealSense and even Orbbec Persee, the world's first camera-computer. Despite problems with software that make it time consuming, it could be interesting to explore them.

2.4.3.3 Dance Dance Revolution Mat

Dance Dance Revolution (DDR), a dance-based videogame, combines the recreational nature of a videogame with the benefits of dance, such as increased balance, coordination, and strength (see Figure 2.7). The game includes a 3-foot×3-foot mat with 1-foot squares marked by four arrows designating the directions forward, backward, left, and right. The monitor instructs the player by a system of scrolling arrows of four types (up, down, left, and right), which arise from the bottom to the top of the screen. As the arrows scroll up to the top of the screen, they cross over a set of four arrow silhouettes (up, down, left, and right). The player's goal is to step on the arrow on the mat corresponding to the scrolling arrow as it crosses its respective silhouette. The steps are synchronized to player-chosen music and increase in complexity and speed as game skills are mastered [44].

Figure 2.7: Dance Dance Revolution Pad

A recent case study provided suggestive evidence that DDR is well tolerated, fun, easy to use, and perceived to be of benefit in PD participants. Common concerns included a distracting interface and financial expense while reports of fear, distress, or discomfort were minimal. There was also no report of pain or loss of balance. Overall, this suggested that interactive videogames that promote physical activity may be beneficial and appealing forms of exercise for the PD population. The findings of this study suggest that DDR is feasible in PD and that such an intervention may be well suited to address the needs of this population [44].

Furthermore, a study on how to use a video game-based exercise treatment in individuals with Huntington's disease, a neurological condition that causes physical, cognitive, and psychological deterioration, had positive results. The intervention used the game Dance Dance Revolution and it appeared to be feasible, acceptable, and safe in individuals with Huntington's disease. Most participants improved on game play and the compliance rate was high, indicating that Dance Dance Revolution may be useful as a motivating exercise intervention for this population [31].

2.4.3.4 Wii Balance Board

The Wii Fit video game system has the potential to serve as a home-based system for exercise and balance training. The Wii Fit uses a novel balance board system that tracks changes in the center of pressure during exercise games (see Figure 2.8). It is widely available, portable, and far less expensive than typical costs incurred with therapy interventions, for example, physical therapy [41].

Figure 2.8: Wii Balance Board

A study assessed the effect of exercise training in patients with PD by using Wii balance board games, with the ultimate goal being the developing of a program to improve balance and gait in this patient population. The 8-week exercise training class improved selective measures of balance and gait in adults with PD. However, no significant changes were seen in mood or confidence regarding balance [41].

Over the 8-week study, the intervention was found not only a safe and feasible activity for individuals with PD but it also required minimal supervision and could be an enjoyable and motivating activity for participants. Motivation is a key factor for long-term success in rehabilitation, and games promise to uniquely provide this motivation [41].

A recent systematic review analysed the efficacy of Nintendo Wii therapy (NWT) on functional balance in children with cerebral palsy, a permanent condition that produces pathological changes in muscle tissue, such as spasticity, stiffness, muscle weakness, decreased strength, or muscle pain. The results showed that NWT can be considered an effective treatment for improving functional and dynamic balance in children with CP, especially when combined with CPT in 30-minute sessions with interventions lasting longer than 3 weeks [43].

2.4.4 Game Development Engines

Many developers choose to develop a game using a Game Development Engine. Research project teams try to use tools like this in order to minimize the time spent on development, because by offering higher abstraction layers allow to quickly implement a game without a large expertise.

Game Engines can make the process of creating a game much easier and enable developers to reuse lots of functionality. It also takes care of rendering for 2D and 3D Graphics, physics and collision detection, sound, scripting and much more. Some Game Engines have a very steep learning curve, yet other tools are very accessible to beginners and some do not even need you to be able to write code to build a game. The Unity Game Engine ranges somewhere in the middle, while it is beginner friendly, some popular and commercial games have been built using it [61].

Unity is a 3D/2D game engine and powerful cross-platform IDE for developers that provides many of the most important built-in features that make a game work, such as physics, 3D rendering, and collision detection. From a developer's perspective, this means that there is no need to reinvent the wheel, such as starting a new project by creating a new physics engine from scratch. What makes Unity even more powerful though is that it also includes a thriving *Asset Store*. This is essentially a place where developers can upload their creations and make them available to the community. [54].

The Unity game engine faces stiff competition from the likes of *Unreal Engine*[1] and *Cryengine*[2]. So, why choose Unity?

- For starters, Unity is a good all-around engine that can handle almost anyone's needs and is also great for prototyping games.
- Has a huge, free and time-saving library of resources available to everyone.
- Its C# scripting Application Programming Interface (API) is also one of the more beginner-friendly programming languages.
- The prefab system makes it easy to reuse code and assets from other projects and edit them for new purposes.
- Has an excellent VR support for those developers interested in developing for the Oculus Rift or HTC Vive.

On the other hand, Unity is not quite as capable of incredible top-end graphics, but those who are like Unreal Engine and Cryengine are also significantly less welcoming for newcomers, with a much steeper learning curve. Also, Unity's multi-purpose approach makes it clunkier than engines with more focus [46][54].

[1] https://www.unrealengine.com
[2] https://www.cryengine.com

Unity VR lets you target most virtual reality devices directly from Unity, without any external plugins in projects. It provides a base API and feature set with compatibility for multiple devices. It has been designed to provide forward compatibility for future devices and software. The VR API surface is minimal by design, but will expand as this technology continues to grow [60].

2.5 Related Work

Gamification has the potential to help patients stay motivated in exercising and avoid a sedentary lifestyle.

This section presents three different projects that used gamification with sorts of VR and aimed to help the rehabilitation or therapy of patients with some type of motor dysfunction. The results showed that not only did the games motivate and encourage patients, but it also helped increasing physical activity levels, improving balance and cognitive functions in older people.

2.5.1 i-PROGNOSIS

The i-PROGNOSIS project is an EU HORIZON 2020 project that aims to build early detection tests for PD based on users' interaction with everyday technology, design interventions to sustain the quality of patients‘ life and raise social awareness on the disease's early detection [16].

The Personalized Game Suite (PGS) is the project's main element and it is the integration of different SGs in a unified platform covering different types of styles, each one tackling its corresponding symptoms (see Figure 2.9):

- **ExerGames** - Walk movement, gait freeze, presence of tremor, bradykinesia, rigidity, limited range of motion, balance and coordination, abnormal posture.
- **DietaryGames** - Dysphagia, compulsive eating behavior, anosmia, constipation.
- **EmoGames** - Depression, hypomimia, loss of self-confidence, feelings of shame, anxiety, deterioration of body image, embarrassment and stress, social isolation, decreased blink rate.
- **Handwriting/VoiceGames** - Micrographia, dysarthria, dysphonia.

The PGS is based on five key transversal aspects, namely: (i) Data types and acquisition devices, such as depth cameras (Kinect), touch screens and tablets; (ii) Exchange of data, storing and analysis, such as metrics during the game (in-game metrics), frequency of playing the game; (iii) Issues regarding safety and feasibility, such as any possible feedback to avoid injuries; (iv) Issues referring to personalization and socialization, such as, how much adaptive are the SGs to PD patients' performance; potentialities for group-based playing to promote emulation among the patients; and (v) Systems that provide rewarding and output parameters, such as specific messages that serve as rewards and/or motivational triggers to increase the engagement of the users during the game (see also Figure 2.9) [17].

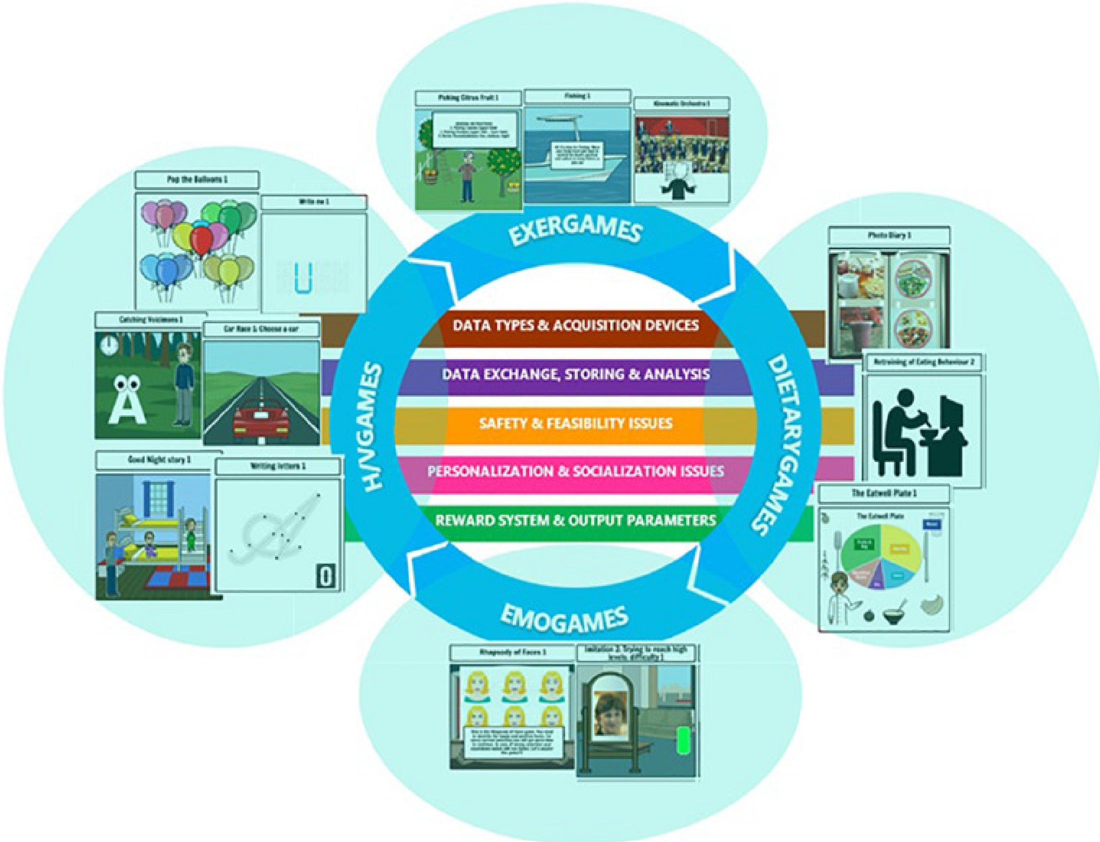


Figure 2.9: The i-PROGNOSIS Personalized Game Suite [17]

With SGs such as *Picking Citrus Fruit*, *Fishing*, *The Eatwell Plate* and *Pop the Balloons* described in [16], the PGS tackles the PD symptoms as it incorporates the practicing of walk movement, improvement of gait mechanisms, balance and coordination aspects, encouragement and/or re-education of healthy and balanced diet, retraining of eating behaviour, improvement of facial expressiveness, improvement/maintaining of writing skills, practicing of narration/vowels/letters and speech dynamics. Via the PGS, the management of the PD patient's condition is placed within a serious games context, in order to improve, sustain or slowing down its progressive deterioration, taking into account safety, feasibility, personalization, socialization, and behavioural change aspects [16].

A further study approaches *Serious Games Co-design Insights* in order to identify the most significant game-design factors in terms of increasing PD patients' quality of life, etc. In the study, two main data sources were involved, semi-structured interviews involving 10 PD patients and four clinicians and an online questionnaire addressed by 104 participants including PD patients, physicians and game developers [16].

By means of several data analysis techniques and focusing at the core design factors, overall, the results were satisfactory, revealing that the participants prioritize some game characteristics such as a challenging gameplay and clear game rules, enough surprises and game options, a good story development and logical plot, completable game goals and an interesting content [16]. The interviews had good outcomes as well, showing some potentially good features and ideas to consider when developing this type of games:

1. PD patients do not like difficult and sad activities, in general.
2. retro games resemble childhood environments of the participants and were a positive point of the study.
3. the users must feel that the game is useful for them to engage with the game.
4. in a specific mimic game, the users suggested mimicking fun faces of their friends.
5. a complex game such as *Sudoku* could be replaced with memory games format.
6. users find games that are related to real life scenarios more fun and engaging.
7. game surprises could also generate manageable cognitive conflicts that can stimulate players to engage more in the processes.

The findings of this case study assist game designers to focus on the use of the most significant game-design factors of HCI-SGs in order to sustain and/or improve the quality of everyday living of PD patients [17].

2.5.2 The Rehabilitation Gaming System

The Rehabilitation Gaming System (RGS) is an innovative and effective rehabilitation tool, developed by the SPECS group, that uses VR games to address deficits of the upper extremities resulting from brain lesions in stroke patients [56].

A stroke happens when the blood supply to part of the brain is cut off and it is a frequent cause of adult disability that can lead to enduring impairments, however, given the life-long plasticity of the brain one could assume that recovery could be facilitated by the harnessing of mechanisms underlying neuronal reorganization [9].

The RGS was built on these neurobiological considerations and offers a portable home-based rehabilitation platform with a variety of virtual reality-based video games tailored to individual patients. It uses task-oriented game training, adjusts complexity levels to patients' abilities, and uses motion sensing technology to track body movements and obtain data about the patient's performance [2][56].

The system only requires a computer, motion sensor and tripod, but can also additionally have data gloves to track finger movements and 3D glasses for a more immersive virtual experience (see Figure 2.10).

Furthermore, the system retains qualitative and quantitative information of the performance of the subject during the tasks sending it to clinicians for analysis, hence allowing

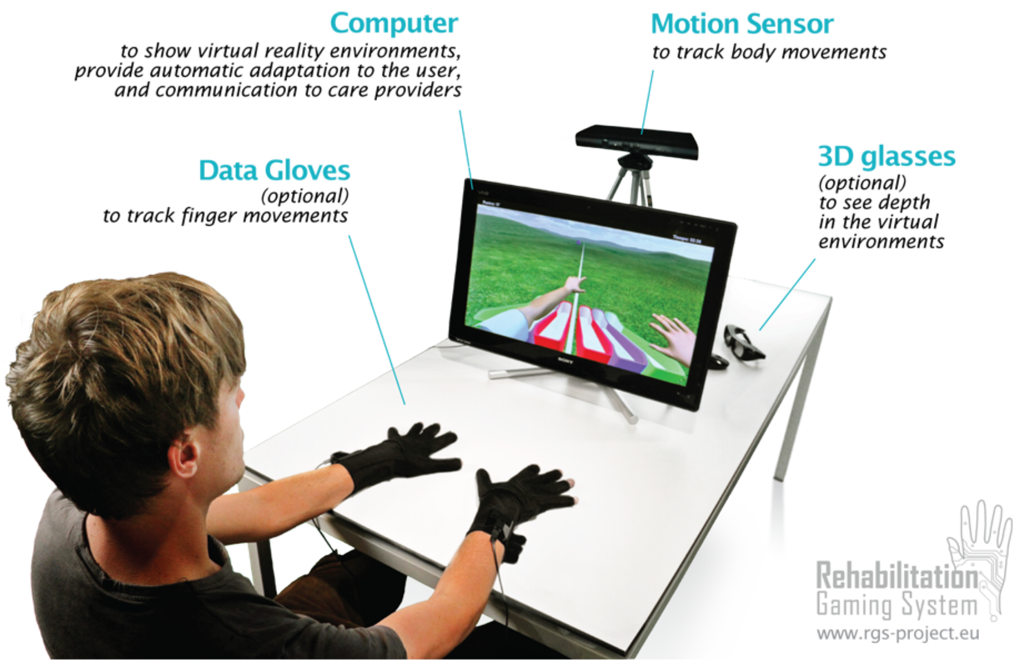


Figure 2.10: The Rehabilitation Gaming System [2]

for a detailed assessment of the deficits of the patient player and their recovery dynamics [2].

The RGS is expected to directly improve the quality of life of the increasing number of elderly people in need of rehabilitation and its proof of concept has been tested over the years. Studies have shown that some of its characteristics have gained value in these way of treatment, such as, the use of VR that allows for the flexible creation of scenarios directed towards specific needs, following an individualized training approach adjusted to the capabilities of the user, continuous monitoring of the patient to evaluate his/her progress over time, complementing clinical standard evaluation and automatic adjustment of the difficulty level of the task to the user. Moreover, the usability assessments show that the RGS is highly accepted by stroke patients as a rehabilitation tool [9].

Nowadays, RGS is being used in a number of hospitals, clinics and rehabilitation centers (e.g., *centro CEREBRO* in Braga, Portugal) and despite being a technology focused on stroke patients, most of its efficient techniques could be adopted to PD patients' treatment.

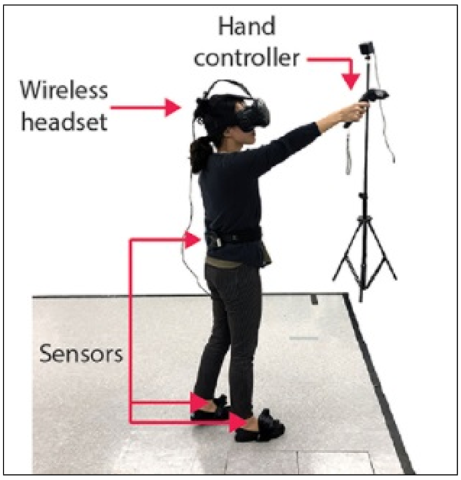
2.5.3 WordPlay VR

WordPlay VR is a virtual reality training application that allows people with PD to practice skills such as turning, obstacle avoidance and problem solving during overground walking. The game immersive settings offer the player an opportunity to attend a rehabilitation session without actually giving him/her the notion of being in one as well as experiencing a wide range of dynamic environmental challenges during the gameplay [53].

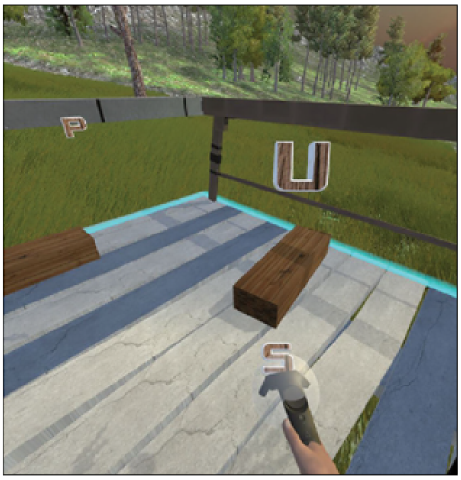
The goal of Wordplay VR is for users to complete a puzzle that consists of a word with missing letters located at eye level in the virtual environment. The player has to determine which letters are necessary to complete the puzzle, collect the necessary virtual letters as they float in 3D space, and then place them in the appropriate location [18].

This training application was specifically designed to encourage people with PD to practice walking, reaching, turning, obstacle negotiation, and dual-tasking in a fully immersive, 3D virtual environment. The level of challenge and the required speed of movement were customized on an individual basis by varying word difficulty, the number of missing letters, the time allotted to complete the task, the spatial distribution of solution letters, whether the solution letters disappear and reappear, and whether participants need to negotiate virtual obstacles simultaneously [18].

The hardware used was an HTC Vive headset, hand controllers and sensors that were worn on the feet and the lower back to track the participants' movement in real time and presented in VR using an avatar (see Figure 2.11). The avatar was rendered and controlled via the IKINEMA Orion plugin and the application was programmed in Unity, so as to play the only two complex requirements are an open physical space of approximately 4x4 meters plus a therapist to remotely control levels and scenarios via a tablet [53].



(a) Hardware



(b) Gameplay

Figure 2.11: WordPlay VR hardware and in-game view [18]

A framework was developed with primary objective to evaluate the usability of the system from the perspective of people with PD and their physical therapists. It was found that both groups of participants provided high ratings on the interest/value and provided assessments of the system's usability that were equal to or above the average score for many types of products across a wide range of development stages. There was also found no evidence of adverse effects following exposure to the virtual environment, such as Simulator Sickness and Safety, and this suggests that the application is unlikely to produce adverse effects in people with similar characteristics [18].

This design and evaluation framework addressed several previously acknowledged barriers and facilitators to clinical translations of VR-based training applications and satisfied the main objectives: i) address specific functional limitations of people with PD, (ii) integrate gameplay features that provide a low barrier to use, (iii) motivate the patient, (iv) stimulate a desire for replaying, and (v) incorporate principles of motor skill learning. As a result, the project objective was accomplished and it is expected that after some more future studies it will to be clinically viable [18].

3

Exploring Serious Games and Virtual Reality

This Chapter aims at presenting the details about the preliminary study that took part in this dissertation. Furthermore, there is a description of the various steps of the defined approach, the strategical decisions that were taken along the way for the design study and the final considerations for the implementation.

3.1 Main Principles

The main goal of this dissertation is to study a motivational approach based on PT that helps PD patients in exercising, being active and stimulate the cognitive function with the intention of delaying the progression of their condition.

In order to achieve a well cemented solution, an initial strategy had to be defined for this research. Hence, the MoveONParkinson team decided to conduct a preliminary user study with PD patients to find, mainly, which devices would suit more efficiently the interaction with the therapeutic games. In addition, this study would help finding what eventual limitations could be critical during the tasks and what motivational elements or game characteristics could be more positively impactful.

The commercial devices to be tested were selected based not only on the reachable level of immersiveness in VR (non-immersive, semi-immersive and immersive) but also taking into account their price, which needed to be as low as possible, and the evidence from other research, preferable positive and promising.

Initially, the discussed ideas were only focused on using a depth camera and Oculus VR, but as stated before, none of the other technologies and devices available today were excluded. A review of the decisions previously taken was eventually done and it was through a second analysis of the technologies used in healthcare and by discussing them with team members that two other devices turned out to be relevant for this study. Therefore, four devices fit into these characteristics and were proposed to be tested, as displayed in Figure 3.1.

For non-immersive and semi-immersive games, three devices were selected: (a) Kinect V2, a motion capture device developed by Microsoft, (b) Dance Dance Revolution Mat, a classical dance gaming mat developed by Sony and (c) Wii Balance, a sensory balance created by Nintendo that is suitable to physical exercise in therapeutic games. Regarding the fully immersive Virtual Reality experience: (d) Meta Quest 2, a VR headset developed by Meta that offers the possibility to play wirelessly, a crucial feature when dealing with elderly and physically limited patients.

(a) Kinect 2

(b) Meta Quest 2

(c) DDR Mat

(d) Wii Balance Board

Figure 3.1: Selected devices to the preliminary study.

Then, the five big steps that composed the followed approach and allowed the team to make crucial decisions for the solution proposal were:

1. Study of project background and previous work accomplished;
2. Study of interaction devices and design of minigame prototypes based on mapping of in-game movements with real exercises done in physiotherapy;
3. Implementation of selected minigame prototypes;
4. Usability testing of interaction devices with PD patients;
5. Analysis of results and final decisions for the motivational model.

3.2 Study of *ONParkinson*

As previously discussed, the *ONParkinson* project started after a needs assessment with the triad of people with PD, their caregivers and health professionals, having identified difficulties in the orientation/monitoring of exercise plans and the provision of reliable information on PD.

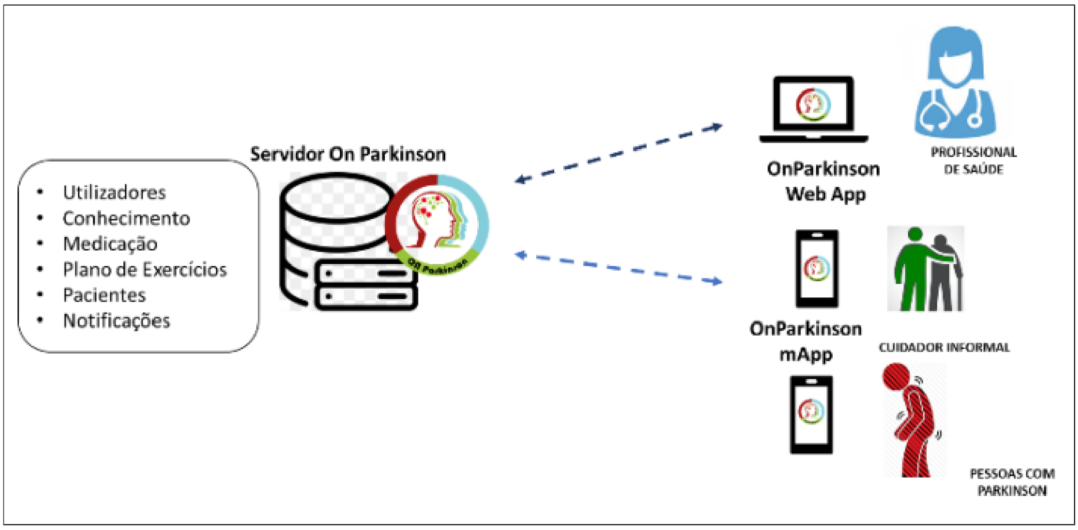


Figure 3.2: Architecture of *ONParkinson*

The platform presents a web app, from which health professionals define individualized plans and make remote monitoring of patients, and a mobile app for self-management by PD people and caregivers. Moreover, the platform also provides a module for knowledge management about PD.

The study of the platform's architecture (see Figure 3.2) was important to acknowledge how to approach the motivational strategy envisioned to be integrated with it.

The mobile app already has prototypes of the conversational agent, that focuses on helping the patients through a *chatbot* that also supports voice/audio communication. The solution aims to consider a possible integration of this technology with the SGs.

Moreover, a couple of working sessions (see Figure 3.3) between the team took place where behavioral models were discussed and a brainstorming brought up to the table crucial ideas untouched for a while and possible future introductions:

- the "place" of the informal caregiver in the therapy.
- introduction of cooperative and collaborative options of motivation.
- the value of competitiveness.
- how to characterize the idea of perceived self-efficacy.
- the role of serious games.
- how can patients that do not use technologies benefit from the solution.

PT has the potential to tackle these ideas and the sessions ended up being really productive in terms of motivation for this dissertation work.

Figure 3.3: *MoveONParkinson* team's working session

3.3 Interaction Devices Study

At the end of this preliminary study, it was expected to determine which devices are more suited to use in the implementation of the motivational strategy, however it is not possible to test the chosen devices without suitable games or activities for the patients to interact with.

Initial working sessions focused on brainstorming for game concepts and mechanisms that would allow accurate mapping of actual exercises done by patients in conventional physical therapy sessions to body movements within games for each device. It was important to consider various types of immersion and different game genres, so later in the study we would have distinct aspects to compare in terms of efficiency and success rate. In an effort to achieve this result, a study was conducted on how the devices work, what interactions are possible for the games, and what are typical uses in other similar research.

Most of the game sketches resulted from this phase, thus marking the beginning of the design process. These prototypes were intended to support the initial study already conducted and, more importantly, the next decision phase, where the definitive interaction devices would be determined based on Participatory Design.

Therefore, the next subsections present the thought process for each device study, the sketches that were designed and considerations taken.

3.3.1 Kinect

On one hand, it was considered a non-immersive environment implemented with a depth camera with a focus on being a more simple experience and not so overwhelming as the ones with a VR Headset, so it does not impact negatively people who are not used to this technologies. In terms of gameplay, whenever the player moves a body part an in-game avatar would imitate that movement, due to the depth camera motion capture function, which is what creates the VR component.

The study of i-PROGNOSIS (section 2.5.1) was decisive in these games' design since the depth camera use was a success and the ideas for simulating real exercises in games were captivating. Dual-tasking was also a key aspect taken from the overall study, since it is more challenging for the patients and motivates them even more. Therefore, the proposed minigame prototypes combine cognitive function with movement to achieve that level of engagement and stimulation. Therefore, the design process for the prototypes originated several ideas for this device usage:

Chuva de Letras (Rain of Letters)

This game requires the patients to be standing and moving their arms to play, but it additionally introduces a voice component. Through a voice recognition device, the game will be able to detect the player's voice and act accordingly. The goal of the game is to catch as many letters as possible in the time available, but with a twist. The letters fall uncatchable from the sky and the player needs to unlock them first. Therefore, the patient has to say its name and color, e.g., *"B Red!"*, in order to be able to catch it.

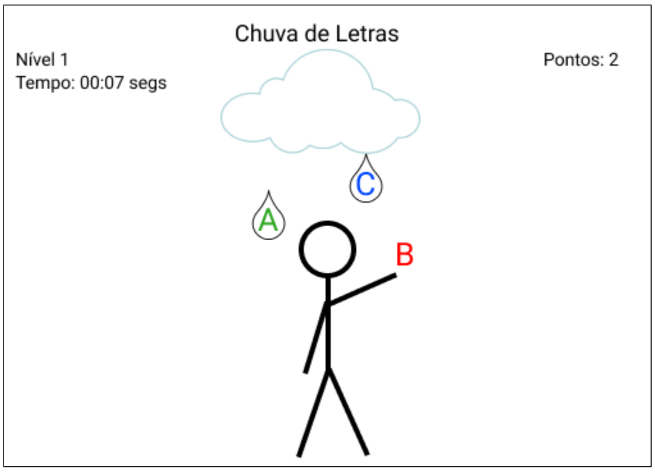


Figure 3.4: Sketch of *Chuva de Letras*

Jogo da Memória (The Memory Game)

This game, as the name suggests, involves *The Memory Game* in which the patient is standing and can select cards with arm movements followed by an hand signal. The goal is to find all pairs of cards and complete the game in the shortest time possible. This approach combines exercising by moving arms and hands with cognitive stimulation through the need to memorize cards.

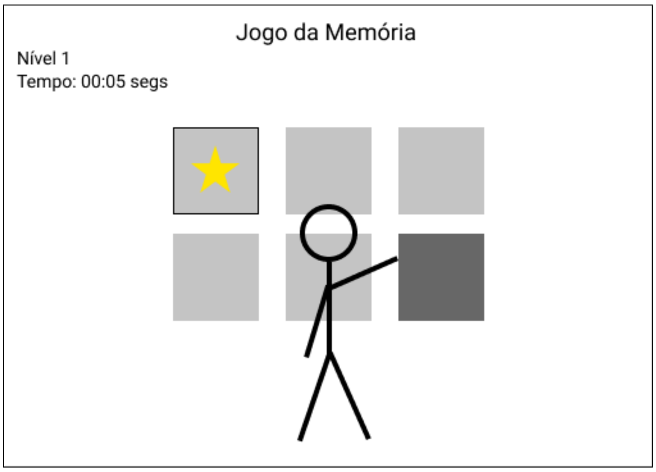


Figure 3.5: Sketch of *Jogo da Memória*

Coordenação dos Membros (Limbs Coordination)

In the *Limbs Coordination* game, the patient will use his upper and/or lower limbs in order to make a match between the colors that appear in the squares and the colors that are in his hands and feet with the goal of gaining the maximum points in the available time.

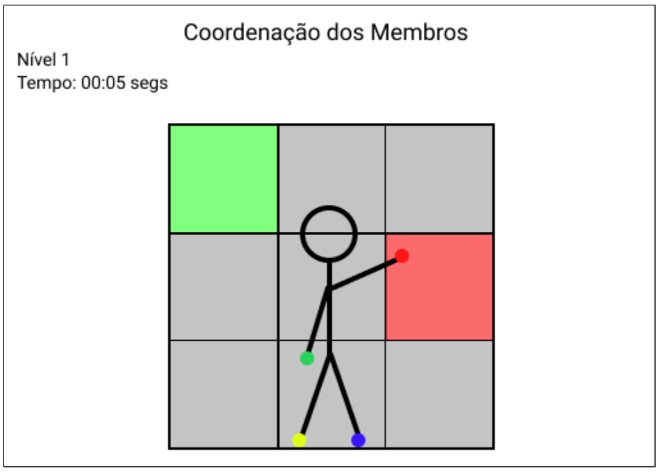


Figure 3.6: Sketch of *Coordenação dos Membros*

Controla a Asa Delta (Control the Hang Glider)

In this game, the patient's goal is to perform simultaneous rotation movements of the trunk and upper limbs, in order to control the hang glider and be able to hit the largest number of targets in the time available.

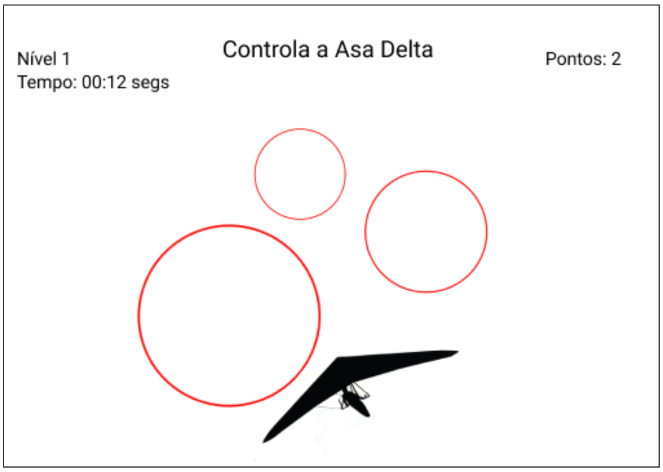


Figure 3.7: Sketch of *Controla a Asa Delta*

Soltem a Parede (Hole in the Wall)

In *Hole in the Wall*, the patient will have to adapt the shape of his body taking into account the hole, shape or figure present in the successive walls that go towards him. The goal is to get through as many walls as possible in the time available.

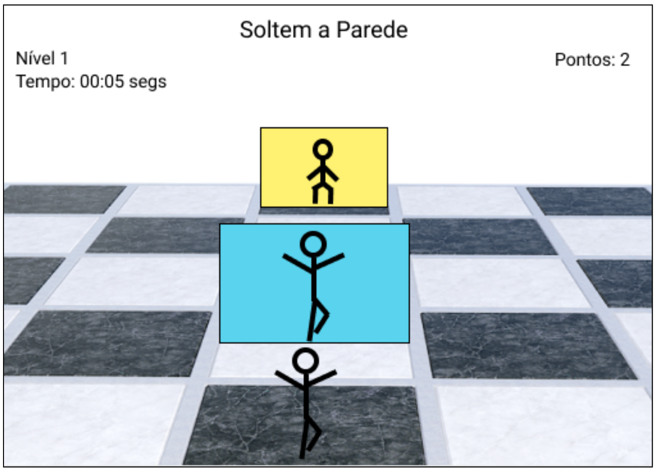


Figure 3.8: Sketch of *Soltem a Parede*

Descer o Rio (Go Down the River)

In this game the player will have to control the “virtual kayak" by controlling the paddle through the rotation of the trunk and the movement of the upper limbs. By doing this, the goal is to reach the end of the river, while dodging obstacles and collecting as many coins as possible.

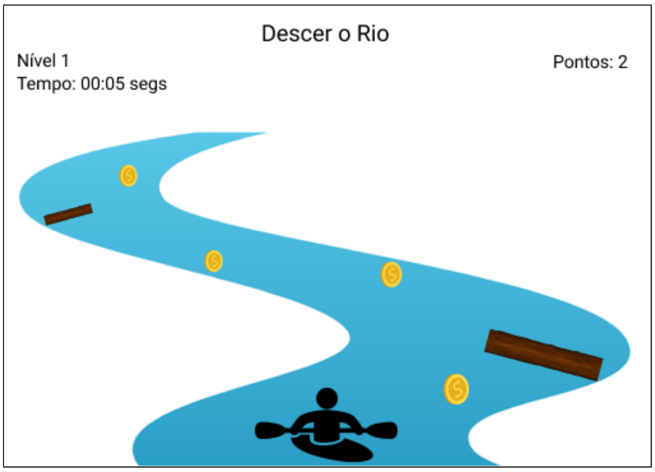


Figure 3.9: Sketch of *Descer o Rio*

3.3.2 Oculus Quest 2

On the other hand, fully immersive VR game ideas were as well thought about and sketched. The study of this approach is really important to understand how patients would react to this more complex environment of VR where the player needs to be equipped with an headset and hand controllers to be able to play the game.

For these designs, the projects from sections 2.5.2 and 2.5.3 were crucial in understanding how to build fully immersive games that can help PD patients without harming or limiting those who are more conditioned.

It is noteworthy that several games features exist and must be treated delicately when applied to therapy:

- it is important that a *GAME OVER* concept does not exist so the player does not feel frustrated and less motivated.
- a Seated Mode should be considered for every game due to player's special conditions.
- presence of several levels of difficulty are essential to match each player's capacities and stage of PD.

The overall goal is to test and discuss several ideas in order to study how to motivate the patient with this type of games. For fully immersive games, three games were also sketched:

Organizar as Frutas (Organize the Fruits)

The goal of *Organizar as Frutas* is to arrange each type of fruit, which is randomly ordered on the table, in its corresponding basket and in the shortest time possible. This may seem simple but requires coordination, fine hand motor skills and cognitive function, simultaneously. This idea could evolve to a more complex one, where it could be interesting to simulate an entire kitchen with more tasks to be done in the same game, such as, cleaning the dishes, organize the pantry and set the table.

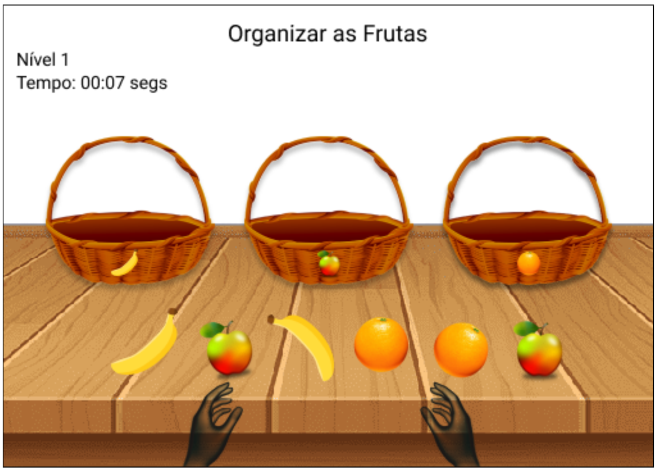


Figure 3.10: Sketch of *Organizar as Frutas*

Salvar o Jardim (Save the Garden)

The second game simulates a garden in which the player has two main tasks: water the plants with the watering can, filling it with water from the tap and cut the garden weeds with the scissors. This game combines exercising and coordination with the fact that most elderly people may relate to gardening from their lives and simulating real (past) habits of PD in games has shown great success.

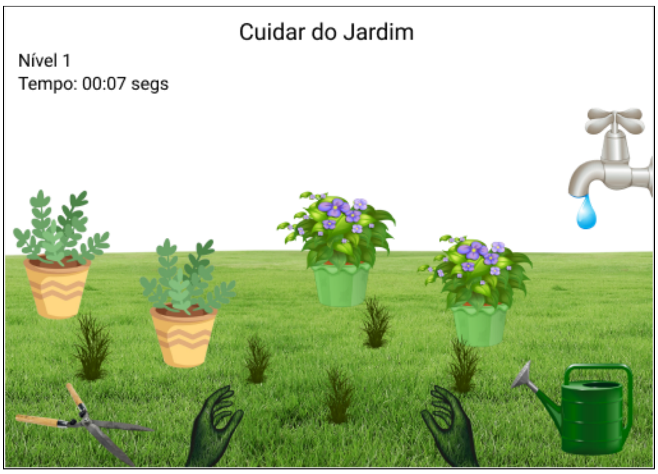


Figure 3.11: Sketch of *Salvar o Jardim*

Balão ao Alvo (Balloon Target)

In the last game the goal is for the patients to catch and throw water balloons, hitting the corresponding targets. There are several colors of balloons for specific targets that give more points and also a neutral target that gives points with any balloon. The targets will be moving and disappearing and possibly reappearing in a different color and position.

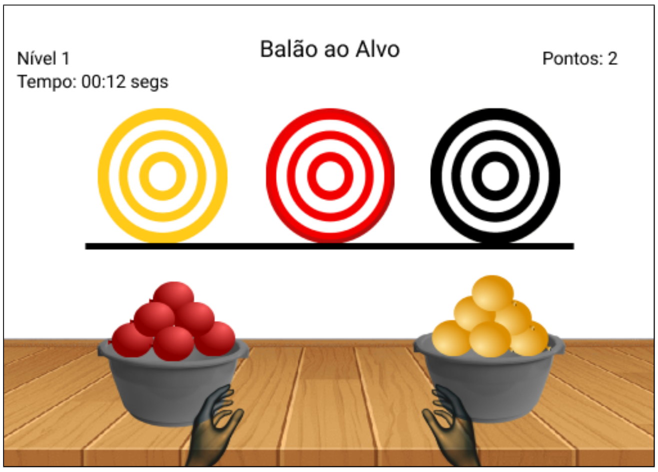


Figure 3.12: Sketch of *Balão ao Alvo*

3.3.3 DDR Mat

The Dance Dance Revolution Mat has proven that can be very useful in healthcare and therapy of neurological conditions. The way the original game was designed combines music and dance with cognitive function and motor coordination, which is a very suited concept for this study. In an attempt to create a similar but simpler idea, a game prototype sketch was designed for this device:

Jogo do Ritmo (Rhythm Game)

In the Rhythm Game when the music starts playing, notes fall from the top of the screen towards the colored squares and the goal is to hit the correct note at the most accurate moment possible in order to win more points. The left arrow corresponds to the left side of the mat and and so forth.

3.3.4 Wii Balance Board

Wii Games have been used for therapy for a considerable amount of time and showed promising results compared to conventional therapy. The devices that support those games require both physical and cognitive effort to be used properly in order to play and succeed at the game sessions. These technologies have a huge potential, although they were not designed for healthcare. This way, an opportunity was found here and after

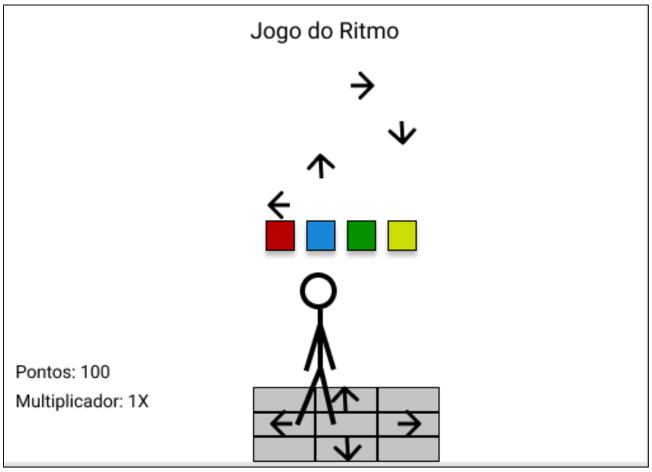


Figure 3.13: Sketch of *Jogo do Ritmo*

analysing the Wii Balance Board, it has seen fit for this study. As a result of this analysis, two game sketches were designed:

Apanhar as Estrelas (Catch the Stars)

The main concept of this game is to control the player movement changing the amount of pressure done in each side of the device, requiring an effort in maintaining balance. The goal of the game is to avoid the obstacles and catch the most amount of stars until the finish line.

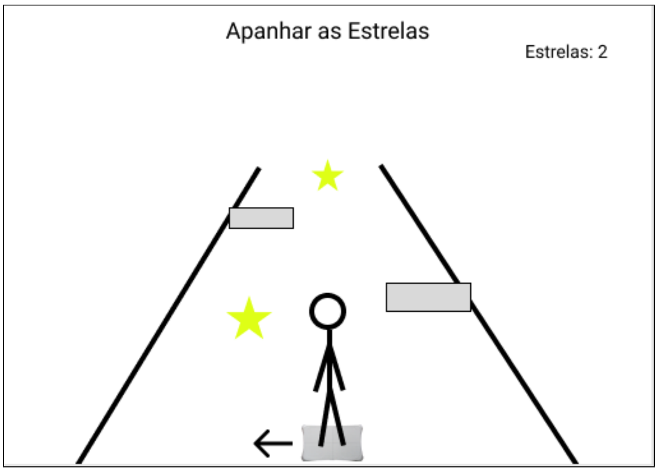


Figure 3.14: Sketch of *Apanhar as Estrelas*

Pista de Obstáculos (Obstacle Track)

The main concept of this game is really similar to the previous one, although the virtual environment and task is different. The goal of the game is to avoid the road barriers and catch coins along the way.

Figure 3.15: Sketch of *Pista de Obstáculos*

3.4 Implementation of Minigames

Following the brainstorming moments and game ideas sketching, a direction for the study needed to be outlined and the next main goal was to define which games to implement. This phase of the work was key because it would determine what games would be tested with real patients, hopefully aiming to get conclusive results.

Two implementation options were considered: develop the same game for all devices or develop one unique game for each device. This question occurred regarding the comparison of the final results that could be dubious because when asking a patient if he liked a certain immersive experience, he could answer positively or negatively because of the game preference and not the device, which was the main focus of this preliminary study. But this problem in the comparison can go both ways, because a certain game can be more pleasant to play in a certain device and thus the patient could prefer a device just because he had more fun in that setup, but it could go otherwise as well. Not the mention the difficulty that is designing a game to be playable in such distinct devices.

As result of the several team meetings including the physiotherapy members that helped refining the game ideas, it was decided to implement one minigame for each device, with the exception of the fully-immersive VR experience using the Meta Quest 2.

This development option was the chosen one because it would not only give the patients a more pleasant testing session and not bore them with the same game over and over, it would also allow for extra feedback on game characteristics and features on the different games. However, not forgetting that the protocol for the testing session should consider such decisions, as it will be discussed ahead.

Regarding the Oculus VR, it was decided to use a simple already existing game, mainly because of the low expectations that the team had concerning the device's acceptance by the patients, but also because of its development complexity and time resources available.

After looking at the game sketches and discussing the alternatives, the minigames were chosen and some general considerations were defined. The next segment will briefly explain the game mechanics, the main features and important details of the implementation.

The Memory Game - Kinect v2 Sensor

The Memory Game is a card game known all around the world, in which all of the cards are laid face down on a surface and two cards are flipped face up over each turn. The goal is to find all the pairs of cards in the least amount of time. This was one of the choices for implementation because most of the patients would certainly recognize it and it's simple to explain to those who never player it.

In the implemented game, the mechanics of turning a card up are unusual because the interaction device used is the Kinect v2 and the player can only control the position of its virtual hands. By moving the upper limbs and hands, the player can hover a card and hold the position for a short period of time. Then, a green slider will start to fill up until it reaches the maximum value and the card turns. After doing the same for another face down card, the usual mechanic of detecting a match occurs. When all pairs are found the game ends and shows onscreen how much time it took to complete the task.

Figure 3.16: Developed minigame for Kinect v2 - The Memory Game

Feature-wise, there is a tutorial screen that can support the therapist's explanation of the game mechanics at the start of a session, which is really important because PD patients tend to lose concentration and forget information easily. Next up, in case the player has difficulties in moving one specific upper limb, there is the option to choose to consider only the left or the right hemisphere in-game. It is possible to choose the difficulty of the task, with values between *Easy* - *Medium* - *Hard* and as a result the number of cards increases as well as the area of play. Every time a new game starts the cards position randomly changes.

Catch the Stars - Wii Balance Board

The main concept of this game is to control the left and right movements of an in-game avatar by changing the pressure values of the Wii Balance Board in order to collect objects and avoid colliding with obstacles. Therefore, if the player's body balance tends to the right the avatar will go right and vice versa while the avatar will be always moving forward at a constant speed to simplify the task. The main goal is to catch as many stars as possible.

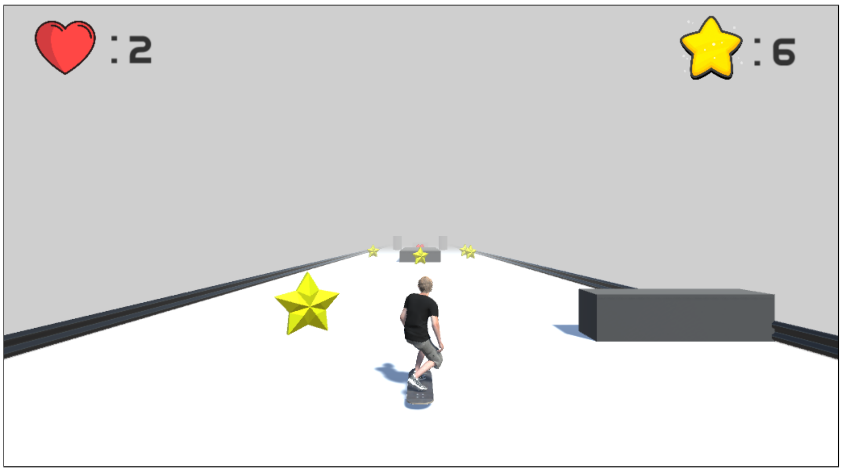


Figure 3.17: Developed minigame for Wii Balance Board - Catch the Stars

There is a tutorial screen that can support the therapist's explanation of the game mechanics and has a virtual representation of the pressure exerted on the board, where the player can try and understand how the value changes with body balance fluctuations.

The approach for this game was that each time the game starts the player has three lives and each time he collides with an object he loses one. The game ends when it reaches zero lives or if the player passes the finish line, although along the way extra lives can be collected so the player can survive longer. The difficulty of colliding with objects increases as the game progresses. When the game finished the number of collected stars is showed onscreen.

Rhythm Game - Dance Dance Revolution Mat

The Dance Dance Revolution Mat can be used for different game genres however in this case the goal was to make a simple task to see how patients would behave when interacting with the device and observe any limitations. Therefore, the developed concept stuck to the mat's origins because music has proven helpful when used in therapy of patients with neurological disabilities.

The main goal of the Rhythm Game is, while listening to the music, to hit the correct music note at the most accurate moment possible, pressing the mat's corresponding zone with the left or right foot. The DDR Mat zones used were the four main ones corresponding to up, down, left and right. The player will receive more points for hitting a perfect note than a good note and will earn a streak that rewards consistency. If he/she misses a note the streak is lost.

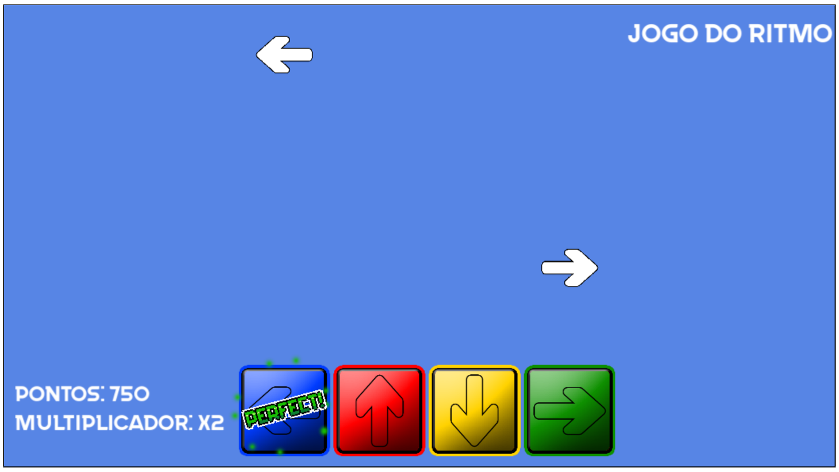


Figure 3.18: Developed minigame for Dance Dance Revolution Mat - Rhythm Game

There is a tutorial screen that can support the therapist's explanation of the game mechanics and has a virtual representation of the mat, where the player can try to press a certain zone and see the effect onscreen.

When the game starts the music begins playing and the notes start falling from the top of the screen into coloured boxes. The perfect time to hit the music note is when it is completely inside its box and a small animation of success will pop. As the game progresses the difficulty of transition from one note to another increases and when the music stops playing the score and the success rate is displayed on screen.

First Steps - Meta Quest 2

First Steps is a tutorial game designed for Meta Quest 2 and its goal is mainly for newcomers to get to know the controllers in a short experience that showcases the power of Virtual Reality [19].

The game starts by introducing the player to the virtual world through a voice that explains each task step by step. After going through all the buttons of the controllers and hand gestures that can be performed, a few objects appear on the surface of a table and become available to be interacted with, such as, a stack of cubes, a ping pong racket and ball, a controlable hand size airship and a box ball. This was the key aspect about this game because it lets the user play around freely and get a sense of being in a virtual world interacting with virtual objects without any pressure.

Figure 3.19: Screenshot of game for Meta Quest 2 - First Steps

3.5 Interaction Devices Assessment

We then conducted a preliminary user study with six potential end-users diagnosed with PD by using the four minigames. All of the participants were male, with an average age of 71.2 years (minimum age of 49 and maximum of 83). They were all retired, they had varying levels of education, and they lived with someone else. They were diagnosed on average 10 years ago (with a minimum of 1 year and a maximum of 17) and they were all medicated, with 3 of them having other health problems. The participants were also all engaged in some kind of physical activity, with 5 of them doing physiotherapy and 3 of them practicing in other types of exercises. Finally, it is also worth noting that two of the participants considered themselves to have difficulties in using new technologies and they only used a feature phone (not a smartphone).

Each test started by having a member of the research team brief the participant about the user study. They were also asked to answer a few questions to characterize them. The participants then experimented playing each of the minigames by using the corresponding device in the following order: Kinect; Dance Dance Revolution Mat, Wii Balance Board, Meta Quest 2. The order was the same throughout all sessions in order to get coherent the results in that sense. To minimize results incoherence due to patients being tired for latest parts of the session, before each experience they were suggested to rest if needed and only start when fully recovered. Each moment of device interaction was also defined with a maximum of 3 minutes.

While the patients were performing the tasks, another researcher was responsible for observing and taking notes throughout the whole test. After testing each minigame/device combination, the participants were asked to answer to a series of Likert items with a value between *1 – Strongly Disagree* and *5 – Strongly Agree*. After going through all minigames/devices, the participants were asked a few final questions about the overall experience to better understand how they compare to each other. This testing sessions

Table 3.1: Participant characterization (**P1** to **P6** represents each participant).

	Age	**Education**	**Lives with**	**Hoehn and Yahr Stage**	**Years since diagnosis**	**Health Issues**	**Physiotherapy**	**Exercise**	**Devices Used**
P1	75	11th grade	Spouse	2	9	No	2/week	No	Smartphone, PC
P2	71	5th grade	Sister	2	17	Prostate problems	3/week	No	Feature phone
P3	83	4th grade	Spouse	2	1	Sleep apnea, Stroke	2/week	No	Feature phone
P4	82	Higher Education	Daughter	3	4	No	2/week	1/week Exercise Bike and Rowing	Smartphone
P5	67	6th grade	Partner	2	13	Diabetes, Hypertension	2/week	Walks every day	Feature phone, PC
P6	49	12th grade	Other	2	16	No	No	3/week various sports	Smartphone

took place in *Associação Portuguesa de Doentes de Parkinson (APDPk)* and *Clínica Saúdis*.

3.5.1 Results

The answers and feedback received from the participants were generally positive, but there were some trends and preferences that are worth noting and that served as basis to decide how to design the motivational model in the following section.

The Kinect minigame was one of the two most well received experiments, with almost all of the participants having a high level of agreement in understanding how they could control the character in game by following their movements, given that 5 out of the 6 participants gave it a score of 4 or 5 in at least one of the two questions directly related to moving their hands (**K1** and **K2**). Moreover, only 2 participants considered that they had a few difficulties in this game (**K3**), with the remaining having little to no difficulties, and the majority (4 out of 6) considered that the game was adequate for physiotherapy (**K4**). Finally, there was an overall positive sentiment towards this game since all of the participants agreed that they liked the game (**K5**) and that they would like to play other similar games (**K6**) (see Table 3.2).

The VR minigame was also received fairly well, with only 2 of the participants reporting some difficulties using it (**V6**), all but one agreeing that they would like to exercise using VR (**V7**), and 4 of them thinking that they would like to incorporate VR into physiotherapy (**V8**). In general, all of them liked to play the minigame (**V9**) and they would like to try more VR experiences (**V10**). It is also worth noting that other than **P6**, participants

Table 3.2: Participant answers to questions about the Kinect Game ($\bar{x}$ stands for the mean, $\tilde{x}$ for the median and s for the standard deviation).

Questions	P1	P2	P3	P4	P5	P6	$\bar{x}$	$\tilde{x}$	s
Memory Game using the Kinect									
K1: I understood where my hands were.	4	5	4	5	4	5	4.50	4.5	0.50
K2: I could control the position of my hands.	4	5	3	5	4	5	4.33	4.5	0.75
K3: It was difficult to use this equipment.	1	2	4	2	4	1	2.33	2.0	1.25
K4: This game is suitable for physiotherapy.	3	4	5	5	3	5	4.17	4.5	0.90
K5: I liked the game.	5	4	5	5	4	5	4.67	5.0	0.47
K6: I would like to play this type of game again.	5	4	4	5	4	5	4.50	4.5	0.50

had no considerable balance issues while using the VR headset (**V4**), which is very important in terms of safety for people with Parkinson's disease. Nevertheless, 2 participants reported that they had problems seeing the virtual world (**V1**) and 3 participants also had some issues interacting with the virtual world (**V2** and **V3**), which led to the decision of reducing the amount of buttons used to a minimum in future by focusing on only using the trigger buttons of the Quest 2 controllers (see Table 3.3).

Table 3.3: Participant answers to questions about the VR Game ($\bar{x}$ stands for the mean, $\tilde{x}$ for the median and s for the standard deviation).

Questions	P1	P2	P3	P4	P5	P6	$\bar{x}$	$\tilde{x}$	s
First Steps using the Meta Quest 2									
V1: I had trouble seeing the VR world.	2	5	5	1	3	1	2.83	2.5	1.67
V2: I had trouble interacting with the VR world.	3	4	4	4	3	2	3.33	3.5	0.75
V3: The hand controllers were easy to use.	3	4	3	4	2	5	3.50	3.5	0.96
V4: I felt that I could lose my balance.	2	3	3	1	1	4	2.33	2.5	1.11
V5: I felt sick or dizzy.	2	1	3	1	1	1	1.50	1.0	0.76
V6: It was difficult to use this equipment.	2	4	3	2	4	1	2.67	2.5	1.11
V7: I would like to exercise in VR.	4	2	5	5	4	5	4.17	4.5	1.07
V8: VR is suitable for physiotherapy.	3	3	5	5	4	5	4.17	4.5	0.90
V9: I liked the VR environment.	4	4	5	5	4	5	4.50	4.5	0.50
V10: I would like to interact with VR environments again.	4	4	4	5	4	5	4.33	4.0	0.47

The remaining two devices had more mixed results, with more participants having difficulties in coordinating their movements to play the respective game. Due to this limitations, this then led to consider that it was more difficult to use these devices. Regarding the Rhythm Game, some participants mixed up the arrows they had to step on (**D1**), but only one felt that the mat's size was limiting its movements (**D2**) (see Table 3.4).

Table 3.4: Participant answers to questions about the DDR Mat Game ($\bar{x}$ stands for the mean, $\tilde{x}$ for the median and s for the standard deviation).

Questions	P1	P2	P3	P4	P5	P6	$\bar{x}$	$\tilde{x}$	s
Rhythm Game using the Dance Dance Revolution Mat									
D1: I understood which arrows I had to step on.	4	2	3	4	4	5	3.67	4.0	0.94
D2: The mat limited my range of movement.	2	2	4	2	3	1	2.33	2.0	0.94
D3: It was difficult to use this equipment.	2	4	4	2	4	1	2.83	3.0	1.21
D4: This game is suitable for physiotherapy.	4	4	4	5	4	5	4.33	4.0	0.47
D5: I liked the game.	4	4	4	5	4	5	4.33	4.0	0.47
D6: I would like to play this type of game again.	4	4	4	5	4	5	4.33	4.0	0.47

In Catch the Stars game, most players understood how to play and how to use the device in order to control the character (**W1**) but the weight distribution was unclear at times (**W2**) (see Table 3.5). Nevertheless, there seemed to be roughly the same difficulty with DDR Mat and the Wii Balance Board (**D3** and **W4**), but participants seemed to like the DDR game slightly more (**D5** and **D6**).

Table 3.5: Participant answers to questions about the WBB Game ($\bar{x}$ stands for the mean, $\tilde{x}$ for the median and s for the standard deviation).

Questions	P1	P2	P3	P4	P5	P6	$\bar{x}$	$\tilde{x}$	s
Skate Game using the Wii Balance Board									
W1: I was able to understand how to control the movements of the character.	4	3	4	4	4	5	4.00	4.0	0.58
W2: The weight distribution that I had to apply was adequate.	4	3	2	4	3	3	3.17	3.0	0.69
W3: I felt that I could lose my balance.	2	2	2	2	1	1	1.67	2.0	0.47
W4: It was difficult to use this equipment.	2	2	4	2	4	5	3.17	3.0	1.21
W5: This game is suitable for physiotherapy.	4	3	4	5	3	5	4.00	4.0	0.82
W6: I liked the game.	4	4	4	5	3	5	4.17	4.0	0.69
W7: I would like to play this type of game again.	4	4	4	4	3	5	4.00	4.0	0.58

These findings are also corroborated by the observations we made and the trends found in the answers to final questions where we focused on identifying whether the participants liked each device and if they felt motivated to use them in the future (see Table 3.6).

Table 3.6: Participant answers to the final questions about the overall experience ($\bar{x}$ stands for the mean, $\tilde{x}$ for the median and s for the standard deviation).

Questions	**P1**	**P2**	**P3**	**P4**	**P5**	**P6**	$\bar{x}$	$\tilde{x}$	s
F1: I liked to use the Kinect.	4	4	4	5	4	5	4.33	4.0	0.47
F2: I feel motivated to exercise using the Kinect.	4	3	3	4	3	5	3.67	3.5	0.75
F3: I liked to use the DDR Mat.	4	4	4	5	4	5	4.33	4.0	0.47
F4: I feel motivated to exercise using the DDR Mat.	4	3	3	4	3	5	3.67	3.5	0.75
F5: I liked to use the Wii Balance Board.	4	4	4	5	3	5	4.17	4.0	0.69
F6: I feel motivated to exercise using the Wii Balance Board.	4	3	3	4	3	5	3.67	3.5	0.75
F7: I liked to use the VR headset.	4	3	5	5	5	5	4.50	5.0	0.76
F8: I feel motivated to exercise using the VR headset.	4	3	5	5	4	5	4.33	4.5	0.75

3.6 Summary

This study was not as conclusive as envisioned because it was based on only six participants, as some decisions had to be made almost simultaneously in order to start designing the final prototypes, as the testing process with people with PD is time-consuming.

However, this whole process allowed the team to have a better understanding of which interaction devices work best with PD patients, based on the results of the experiments and the feedback obtained, both visual and vocal. In addition, a consolidation of the most effective game features, design techniques, and functionalities was achieved.

4

MoveONParkinson Game Prototypes

This Chapter focuses on the development of the main solution that explores Serious Games and Virtual Reality toward a motivational approach for physical exercising in the domain of the research. The results obtained in the previous chapter allowed us to build a basis for the motivational model, which is described here, along with the solution architecture and design details. The game prototypes created during this phase are also presented, more specifically, their goals, requirements, functionalities, and features.

4.1 Design Principles

One of the MoveONParkinson project goals is to study how new technologies can be used to provide people with PD with new digital and innovative tools that can improve their quality of life, mainly by increasing physical exercise levels and stimulating cognitive function. As discussed before, the expected contribution of this dissertation is a motivational model that uses PT, Gamification, and VR in order to help fulfill the overall goal of the project. It is hoped that the model developed here, the design techniques used and the technologies explored should serve as guidelines for other third parties that are starting in this area of work.

The design process is a crucial step because the target audience of this dissertation's work needs to be treated carefully. People with PD should feel encouraged and motivated when performing the activities. Therefore, Serious Games should be designed to be both challenging and enjoyable. The pillars of this approach must also be well established to make it appealing to use in the healthcare area.

It was by bringing together the foundations obtained from the literature, the developed aspects that were successful in the preliminary study and the shared experience of healthcare therapists that a motivational approach was designed.

Two prototypes of SGs were developed and the next part of this section presents their purpose, the environment and conditions of their use by the patients, game features implemented, design aspects taken into account and motivational elements considered.

Purpose and Environment

The developed SGs represent a complement to the exercise plan prescribed for each patient, whose physical and cognitive condition must be taken into account for the difficulty level and game mode. Thus, it is possible for both a recent Parkinson's patient with most of his abilities to play, as well as a more debilitated one, either physically or cognitively (difficulty in speech, slowness of thought, bradykinesia, rigidity, dependence on a wheelchair and lack of balance). According to physiotherapists, a game session should ideally take place at the end of a conventional therapy session.

Although the general objective of the MoveONParkinson project is to offer autonomy to patients so that they can exercise in their homes, at first the Serious Games collection must only be available in specific clinics, with the appropriate setup for its use and with professionals to supervise the patients during the tasks. This is due to the fact that is unthinkable for each patient to buy the required VR devices and set them up in a large space in their homes, as well as there may be risk of falling or having an accident with furniture and objects present in the room without any prior training.

Despite the fact that this study has no commercial objectives, it should be clear that the developed SGs should also be made available for acquisition and use at home for patients with a minimum number of supervised sessions in physical therapy. Nevertheless, all the safety conditions should be guaranteed in the person's home and then their informal caregiver should be committed to supervising the autonomous sessions.

Game Design Characteristics

Developing a good game experience to people with PD and elderly users requires a series of specific game design characteristics to be considered. Therefore, these are features that influence not only the games' usability by physical impaired players but also the motivation to keep playing it, which is crucial in an exercising and therapeutic gaming approach:

1. **Trained function** - The games are designed to train purely motor functions, cognitive factors, or both, by having dual-task challenges, which are recommended in therapeutic exercises with people with PD.

2. **Feedback type** - The type of messages given to the player after completing a task can be positive and motivating, or negative, implying that the user should know that he did not perform quite so well. The decision in the type of feedback used may vary according to the target audience and main purpose of the game. Given that people with PD are mostly an elder audience, the messages should contain motivating factors, putting aside the majority of competitive factors with the intention of reducing the frustration levels. The game feedback can be visual, audible and textual, depending on the game situation, or even a different approach of feedback,

for example an in-game representation of the physical therapist that congratulates and motivates the player.

3. **Rewarding system** - Similarly to the feedback, the score and rewarding system should have a non-negative approach, but they could be positive, negative or challenging, depending on which is more suitable for each patient. Each time the patient succeeds in a task there should be an in-game reward, either by increasing the points and number of items collected, a colorful visual animation, or even by an encouraging voice. To motivate consistency and continuity of sessions, rewards external to the games themselves could be created. Essential aspects of gamification such as receiving a new avatar for completing a monthly mission or having exercise milestones that can be completed by playing the games could be interesting.

4. **Incremental challenge** - Games should have an incremental difficulty implemented with different levels and game variations or throughout one session of gameplay, increasing complexity overtime. This aspect has a lot of relevance, because when a task becomes too easy and repetitive it gets boring, that is why there is the need to keep the patient challenged. The same applies to when a task is difficult and the complexity needs to be decreased to avoid demotivation. These several game modes or levels can change without the physiotherapist intervention as the game progresses or rely on a settings menu with various options.

5. **Type and Amount of help** - Could be directly on screen, a text-to-speech agent or simply rely on the physiotherapist help to play the game. The amount of information displayed should be carefully considered, as too much details may cause the game to be overwhelmingly hard to play and understand. The more concise and simplistic the help the better, because it is important for the user to easily understand what he is doing wrong and also not to lose concentration.

6. **Initial instructions** - It may be important to have a tutorial that contains small tasks for the patient to perform that make him/her understand the purpose and goal of the game. Often a visual and textual or even vocal explanation by the physical therapist is not enough, because many of the people with PD suffer from memory and concentration problems. Thus it is great to introduce them to small tasks accompanied by a brief explanation of what they will have to accomplish during the game.

7. **Relatability** - The game's environment could have connections with the players' reality, past hobbies and familiar activities, so that it can provide a more engaging and motivating content. The player should have customization options at his disposal to enhance his experience.

8. **Accessibility** - The more physical impaired patients should be taken into account and be able to play the games. The design should consider accessibility options

like a sited mode (mostly to players who can't stand straight for longer periods or have their legs movement impaired), left or right hemisphere complications and colorblind modes.

9. **Session evaluation** - The information that is retrieved from the gaming sessions, such as highest level, best time or score, can be evaluated in a metric that compares the progression of a *normal* disease with the progression of each patient in order to convey *improvements*. This is based on the idea of perceived self-efficacy, which means that at the end of a session the patients should be left with the notion that having completed the tasks was productive and that they can get back on track and improve their health condition by continuing to play the games.

4.2 Proposed Prototypes

This section presents the proposed prototypes for this motivational model, which were developed aiming to be used in the final tests that conclude this research project.

4.2.1 Hole In The Wall

The first game prototype that was designed aims to give patients the opportunity to perform a sequence of exercises through semi-immersive VR. This prototype uses Kinect V2 in order to capture the player's body movements to replicate them in an avatar, giving players the illusion of being inside a virtual world.

Concept and Goals

This game idea was proposed previously in section 3.3.1 as *Hole in the Wall* and it comes from a digital version of the Japanese television game show *Brain Wall*, which challenges players to pass through a cutout hole in a wall without ever touching it. The player must replicate and maintain a correct body posture, for a certain amount of time, in order to fit into the approaching walls, as shown in Figure 4.1.

As the wall progresses towards the player, he/she may adjust his/her pose by looking at the colors of the avatar's body. A body part becoming red means that the player would not pass correctly through the wall and needs to adjust her/his position. These walls allow us to mimic poses that people with PD should accomplish in real physiotherapy contexts. Physiotherapists can define sequences of walls intending to represent real sessions that mainly require effort in maintaining balance and body coordination. Having an adequate approach to what is required in people with PD physiotherapy sessions can be combined with motivational approaches, to engage players on exercising in a fun and challenging environment.

Figure 4.1: Developed Serious Game Prototype for Kinect V2 - *Soltem a Parede*

Gameplay

Hole in the Wall base walls consist of an entrance similar to the silhouette of a human position, e.g. T-pose. Some effort is required in order to pass these walls correctly, but it is mainly in the transition between positions that the challenge lies. To introduce some difficulty, in cognitive terms, were created walls with two entrances, where only one is considered right. To make this distinction is presented either a question, a mathematical challenge, an image or a sequence of digits, and the player must choose the option that seems correct, based on the answers present on the left and right entrances. If a player has difficulty standing for a long time, due to balance problems and/or tiredness, there are specific walls available for seated mode, which have been designed so that the patient can play on a chair preferably with armrests.

Game Interface

The game interface is composed of several essential elements that are meant to motivate the patient through progress metrics, rewards and tips for the current exercise:

- **Points and Multiplier** - Number of points and number of consecutive correct exercises.
- **Collectables** - Number of collected stars until the current game time.
- **Exercise count** - Number of the current exercise and the total number of exercises.
- **Bonus bar** - Bar that fills whenever the patient is doing the right position, even before the wall is nearby. If filled it doubles the points earned.
- **Target position** - Image presenting the target position that allows the player to pass through the wall correctly.

Rewards and Performance Evaluation

Evaluating how the player is doing and rewarding him is crucial throughout the whole game session. There are many ways of keeping a good score and players are rewarded when they manage:

- Not hitting the wall and when the player does the correct position he receives points.
- Maintaining the correct posture for as long as they can while the wall advances by filling the bonus bar.
- Getting through consecutive walls, which gives them a bonus score by being consistent and reaching high multipliers.
- Catching collectable objects with key body parts.

This last rewarding feature is quite important as it forces the player to correctly maintain the desired pose and punishes those who to try to pass through the wall by, for instance, shrinking their body. If that happens the player also misses on some points to reward those who put effort in doing the correct position. All the feedback and reward system throughout the game is positive, meaning the players will not lose points by failing to complete an exercise.

A success animation and a virtual therapist were also incorporated in this game prototype. The animation functions as a visual stimulation and encourages the player to keep performing and the in-game motivational agent motivates the player with text-to-speech voice communication and body expressions.

After each exercise session, a summary is showed and a score is calculated and presented to the player after being transformed in a qualitative metric adjusted to the complexity of the completed session (see Figure 4.2).

Figure 4.2: Final Game Summary - *Soltem a Parede*

Configuration Menu

Before the game begins, a configuration menu is displayed where the supervisor can personalize the session according to the patient needs and likes. There are several options including customization of the walls such as its speed and color, visual preferences that allow to change the scenario theme and define the presence or absence of the in-game motivational therapist, different score modes and feedback types (see Figure 4.3).

Unless the patient wishes to play with a random wall sequence, another screen can be accessed to handle the creation/editing of the exercise routine (see Figure 4.4). There, a list of all supported positions is available, each with a brief description and corresponding image, along with a tag filtering mechanism. The idea is to choose the desired walls by clicking in the *add* button, as they will appear in the list on the right side where it is possible to change the order by dragging and dropping and deleting a specific exercise. After the configuration setup, there is an option to save the preferences of the patient and another to import them in a future session.

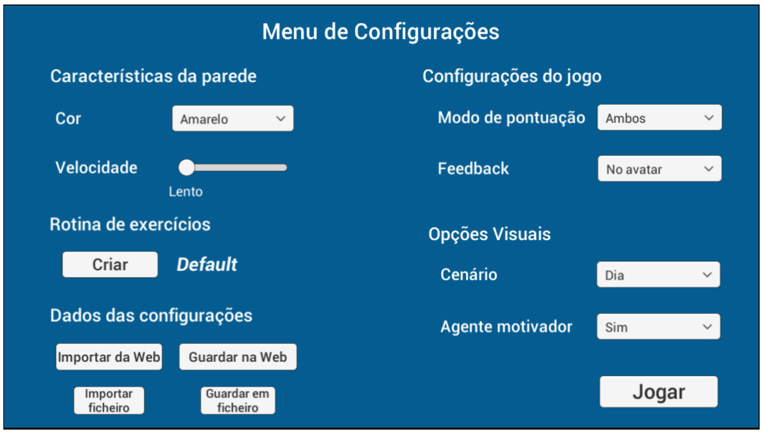


Figure 4.3: Configuration Menu - *Soltem a Parede*

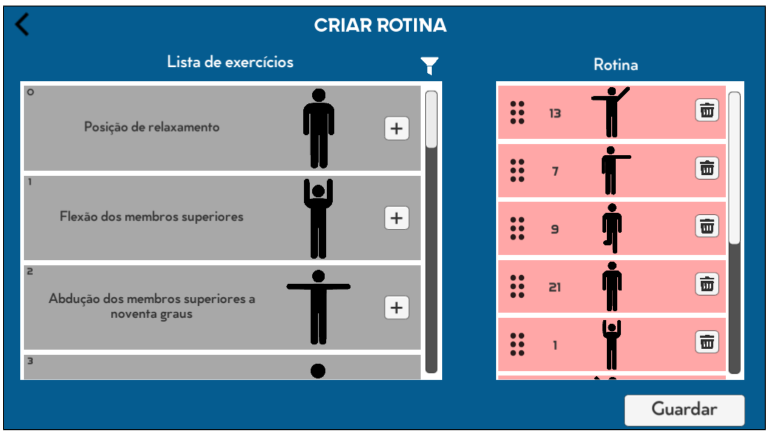


Figure 4.4: Create Exercise Routine - *Soltem a Parede*

4.2.2 Organize The Fruits

Regarding the second prototype, it focuses on offering a fully immersive VR experience through the use of the Meta Quest 2 VR headset. The developed virtual world aims to replicate aerobic exercises using the hand controllers to catch flying objects, by simulating a real grab movement, and place them in the corresponding box.

Concept and Goals

The idea for *Organize The Fruits* is also an adaptation of a sketch done in the initial phase of the preliminary study, as seen in subsection 3.3.2. The concept of grabbing fruits that are on a table and placing it in the corresponding object was simplistic, thus it was improved in a way that the movements required to complete the task resemble aerobic exercises done in a conventional therapy session. These objects spawn up north, far away from the character, and move towards it at different heights and angles, which frequently implies the extension of the player's upper limbs. The difficulty of the game increases as time passes, introducing challenging elements that motivate and reward the patient, such as objects spawning in different directions moving with increased velocity, from east and west of the user's point of view, and giving a bonus point if the player catches the object with a specific hand (see Figure 4.5).

(a) VR environment

(b) Dropping a fruit in its box

Figure 4.5: Developed Full-Immersive VR Game for Meta Quest 2 - *Organizar as Frutas*

Gameplay

Designing a full-immersive VR game for people with PD required several considerations in terms of what complexity could be added to the experience and what should be its cognitive limits. It turned out to be unfeasible to develop a configuration menu and a tutorial because only the patient is in control of the game and it would be overwhelming to put him/her through those tasks. Instead, the game starts in a easy mode in which the player's task is to simply catch a fruit by pressing the grip button of the hand controller and releasing it to drop the object in the correct box. As the game progresses and the player begins to show more fluidity and the score goes up with ease, a new challenge is introduced and either the left or right hand is displayed as green in the UI. If the player catches the object with the required hand he is rewarded with more points. This is essential to induce the player to frequently perform cross movements with the arms and, for instance, grabbing an object flying from the left side with its right arm. The next challenge is objects spawning not only in front of the player, but also in the east and west. This requires the player to perform rotations with his head and trunk, which brings once again more complexity. There were created three different game modes to suit each patient needs and difficulties. These modes determine how the game ends, by reaching a certain period of time, by losing all lives available if performs a certain amount of wrong movements, or by reaching a score goal.

Game Interface

The game interface is composed of several essential elements that are meant to motivate the patient through progress metrics, rewards, and indications for the next movement:

- **Points** - Number of points.
- **Time** - Timer that goes up and determines when the game ends.
- **Representation of Hands** - Images of hands that either the left or the right one becomes green to indicate which will give extra points.
- **Orientation Arrows** - Arrows that help the player understand where the object is spawning, in front, east or west.
- **Area Limits** - Image that changes color if the player leaves the playable area.
- **Hand Position** - Colored dot present in each hand that help the player understand if he/she is doing the right arm movement, based on hand position.

Rewards and Performance Evaluation

In this game, there is only one way of scoring, and that is by placing the objects inside the correct box, which awards the player with 1 point. The boxes have different colors, corresponding to the fruits' color that should go in it. Additionally, players get an extra point if they catch the approaching object with the requested hand.

To have a term of comparison between both games and evaluate the movements performed based on similar principles there were developed certain mechanisms. They analyze if the player is inside a certain area and give feedback based on the position of arms and hands when performing the movement to catch an object. The idea is to relate this movement with the wall positions of the 4.2.1. Abstractly, it can be thought that in *Organize the Fruits* that the player is doing a position trying to pass a wall and is catching a star present on it. Obviously this VR environment offers more independence when playing the game and making hard restrictions is going against the technology itself so it was decided to only analyze the movements and present to the player if he/she is in the right area and if is catching the objects in the right place without penalizing the score.

A virtual therapist was also incorporated in this game prototype with the goal of encouraging the player to keep performing as well as motivating him with text-to-speech voice communication and body expressions.

4.3 Integration with Web Platform

Monitoring a patient's progress is essential, both to adapt the Serious Games sessions to their condition and ability, and to show them the impact it is having on their disease progression. Keeping each patient's game customization information, past settings used and condition details that might change an aspect of the game, such as a conditioned right upper limb or difficulty standing for a long time, can be crucial in turning the outcome of this motivational approach. These reasons triggered the interest to integrate the Serious Games with the existing web platform of the MoveONParkinson project.

A Game Suite Menu was designed where the therapist can log in and choose which patient is going to do a session. This enables to import his profile and saved game preferences to enhance the experience. Then both games' customization becomes available:

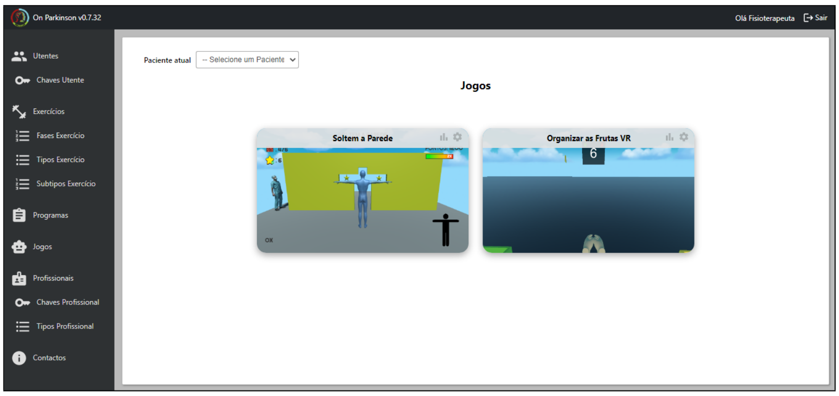


Figure 4.6: Web Platform - Hole in the Wall Configurations

Starting with the first prototype, data structures were created to keep the information regarding the exercises available, session results and the configuration of a therapy session. This last structure includes the chosen wall routine and the chosen menu configurations. It is possible to import the data from the platform or from a local file taking into account the therapist's preference. After each session, a summary of the player performance regarding each position score, bonus and stars caught.

The second prototype retains data structures for game mode information and session results. The therapist can choose which configuration mode is more convenient and input its value, i.e. amount of minutes, lives, points. The data is imported from the Game Suite Menu to the platform and when the game is started in the Oculus there is the option to choose which patient is going to play and import his/her configurations. The session results data that is kept has details essentially about in each side the fruit spawned, which hand was presented to score double points and how the patient performed.

A web interface for the configurations was developed and gives the therapist the option to prepare his sessions in advance to make the sessions more efficient (see Figure 4.6). In the *Games* menu option, the therapist can select the desired patient and then choose the desired game.

In Hole in the Wall configurations, there is a screen similar to the one created in the Game Suite, but with the advantage that can be accessed anywhere with internet connection allowing therapists to organize and configure the sessions in advance. Therefore, the notion of personalized exercise can be accomplished by setting up the game attributes according to the patient as well as the exercises routine (Figures 4.7 and 4.8).

Figure 4.7: Web Platform - Hole in the Wall Configurations

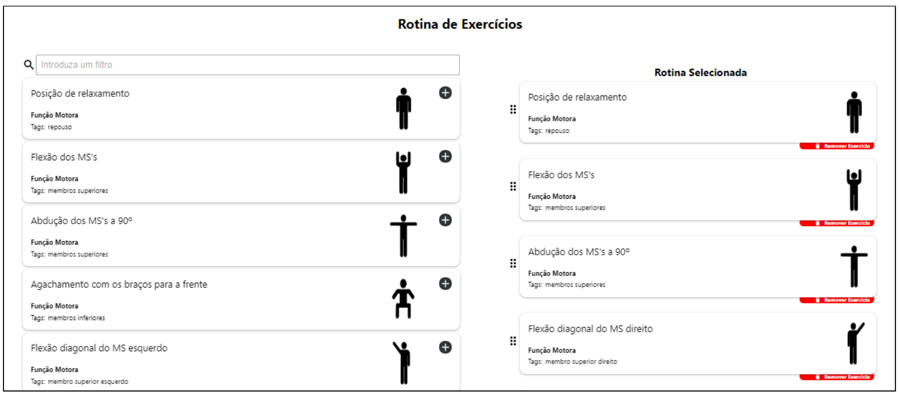


Figure 4.8: Web Platform - Hole in the Wall Exercises Routine

Another important feature of the platform is the session results presentation that the health professional can analyze later on. Therapists can explore information such as score, time elapsed, patient difficulties and performance patterns (see Figure 4.9).

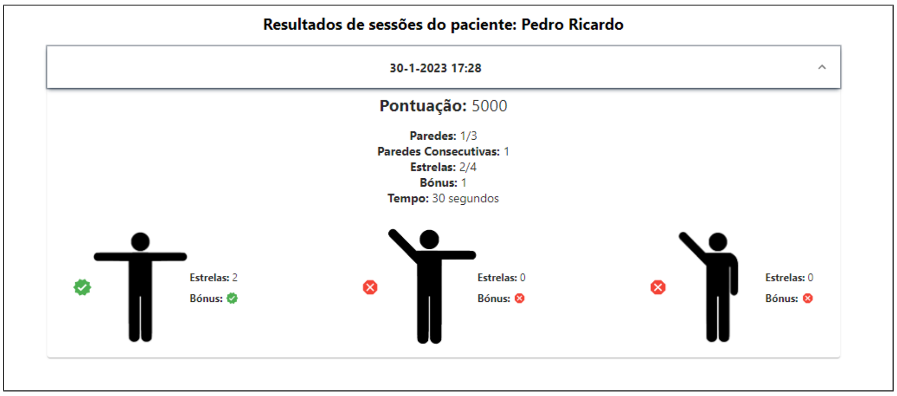


Figure 4.9: Web Platform - Hole in the Wall Session Results

The immersive game *Organize The Fruits* has a simpler configuration interface, but it already allows some customisation of the experience (see Figure 4.10).

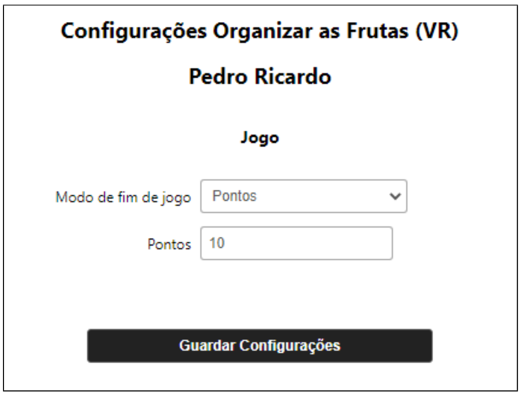


Figure 4.10: Web Platform - Organize the Fruits VR Configurations

5

Evaluation

This chapter outlines the evaluation process for the two developed prototypes, presents the obtained results, and provides a detailed discussion of those results.

5.1 Participants and Methods

For this study, a total of 30 subjects participated, all of whom were students. The participants' ages ranged from 19 to 29, with an average age of 22.87 and a standard deviation of 1.99. Out of the participants, 25 identified as male, 4 as female, and 1 identified as another gender. Regarding their educational background, 12 participants had completed secondary school, 14 held a bachelor's degree, and 4 had obtained a master's degree.

The test phase was designed to evaluate the usability of the prototypes and to answer the proposed research questions. The methods used were adapted from the preliminary device tests and changed in order to simulate a real physiotherapy session using Virtual Reality-based Serious Games. The end goal was to test the prototypes with real patients, however, in order to present the target audience with a solution with proven efficiency, a different approach was taken. It was decided to test the two prototypes with healthy and juvenile participants to ensure that the quality and usability of the serious games reached a stable level before introducing them to people with PD.

A test protocol was created to serve as guidance to follow the participants throughout the experience. The sessions started with an introduction of the MoveONParkinson project followed by the goal of this dissertation's study. The concepts of the two prototypes were explained and then the users were instructed to prepare to start playing the games. The first game played varied depending on the participant number, odd numbers started with *Hole In The Wall* and even numbers started with *Organize The Fruits*, in order to avoid ambiguous results due to tiredness and other external factors.

The practical part of the game session started with a tutorial to give participants insights about the goals, mechanics and functionalities of the games and then proceeded with a 3-minute gaming session (see Figures 5.1 and 5.2). The evaluation method for the Semi-Immersive game *Hole in the Wall* was based on the completion of a sequence of

Figure 5.1: Participant testing the Kinect V2 Game - *Hole In The Wall*

Figure 5.2: Setup of the Kinect V2 Game Test Session - *Hole In The Wall*

previously configured exercises that was used for all participants. The Full-Immersive game *Organize the Fruits* had a more simplistic configuration, thus the evaluation method consisted in all users playing the game for the same period of time and trying to score the most points possible (see Figure 5.3). If a participant had never used the technology before there was an initial briefing explaining the controllers, what to expect when looking through the headset and optionally a period of adaptation to the virtual world.

Then, the participants were invited to answer a questionnaire that included domain specific questions about the games, the 10 questions of the System Usability Scale (SUS) [6] and NASA Task Load Index (NASA TLX) [26] questions (for the complete questionnaire see Appendix A and Annex I). The total duration of a test session was approximately 30 minutes, including the initial briefing, practical gaming session, and answering the questionnaire.

Figure 5.3: Participant testing the Oculus Quest 2 - Organize The Fruits

5.2 Results

This sections presents the results of the user questionnaire that approached aspects such as game domain issues and usability.

5.2.1 Domain Specific

The domain-specific questions for each game consisted of statements to be rated using a Likert-type scale, ranging from '1' ("strongly disagree") to '7' ("strongly agree"). A rating of '7' was considered the most favorable response for all the questions. The questions were divided into two sets, one for the Kinect V2 game and the other for the Oculus Quest 2 game.

Overall, the results were good and showed that the participants understood the basic principles of the games and considered them suitable to be used in a therapeutic environment. Tables 5.1 and 5.2 show the relative frequency of the responses and Figures 5.4 and 5.5 show the mean, standard deviation and median of the responses, for the two games.

5.2.1.1 *Hole In The Wall* Game (Kinect V2)

Beginning with the Kinect V2 game prototype, when participants were asked about their understanding of the game objective (**DSK1**), 93% of them responded with "strongly agree."This indicates that the objective was effectively conveyed and that it became perfectly clear during the session.

When asked about their understanding of the mapping of movements between their own body and the avatar representation in the game (**DSK2**), 63% of the participants responded with a rating of '7' and 17% with a rating of '6'. This suggests that this mechanic of the game was developed correctly, as the majority of users comprehended the connection between their movements and the avatar's actions.

Table 5.1: Relative Frequency of the answers to questions about the Kinect V2 game prototype.

Questions	1	2	3	4	5	6	7
Hole In The Wall using the Kinect V2							
DSK1: I understood the objective of the game.	0.00	0.00	0.00	0.00	0.00	0.07	0.93
DSK2: I understood the mapping between my movements and the movements of game character.	0.00	0.00	0.03	0.00	0.17	0.17	0.63
DSK3: I found it possible to imitate the positions presented on the walls.	0.00	0.00	0.00	0.03	0.10	0.33	0.53
DSK4: I found the virtual therapist's presence encouraging.	0.00	0.03	0.17	0.13	0.17	0.27	0.23
DSK5: I found the game adequate for physical therapy.	0.00	0.00	0.00	0.03	0.03	0.40	0.53

Table 5.2: Relative Frequency of the answers to questions about the Oculus Quest 2 game prototype.

Questions	1	2	3	4	5	6	7
Organize The Fruits using the Oculus Quest 2							
DSQ1: I understood the objective of the game.	0.00	0.00	0.00	0.00	0.07	0.10	0.83
DSQ2: I understood the mapping between the movement of my hands and the behavior of the virtual hands.	0.00	0.00	0.00	0.03	0.00	0.20	0.77
DSQ3: I consider that the movements required to reach the objects are adequate.	0.00	0.00	0.00	0.03	0.07	0.17	0.73
DSQ4: I found the game adequate for physical therapy.	0.00	0.00	0.00	0.00	0.10	0.33	0.57

In questions **DSK3** and **DSK5**, which inquired about the feasibility of correctly achieving the presented positions and the suitability of the game for physiotherapy, respectively, users provided a similar positive response. A significant portion, 53%, awarded the highest rating of '7' for both questions, with 33% and 40% responding with a rating of '6' for **DSK3** and **DSK5**, respectively. This indicates a substantial level agreement with both statements. Nevertheless, there were still some participants that responded with ratings below '6', showing that there is still room for improvement.

The only instance of results leaning towards the negative side was observed in **DSK4**, where some participants expressed that the virtual physiotherapist was not as effective in motivating the player as intended. Around 33% of the participants rated it equally or below the midpoint value of '4'.

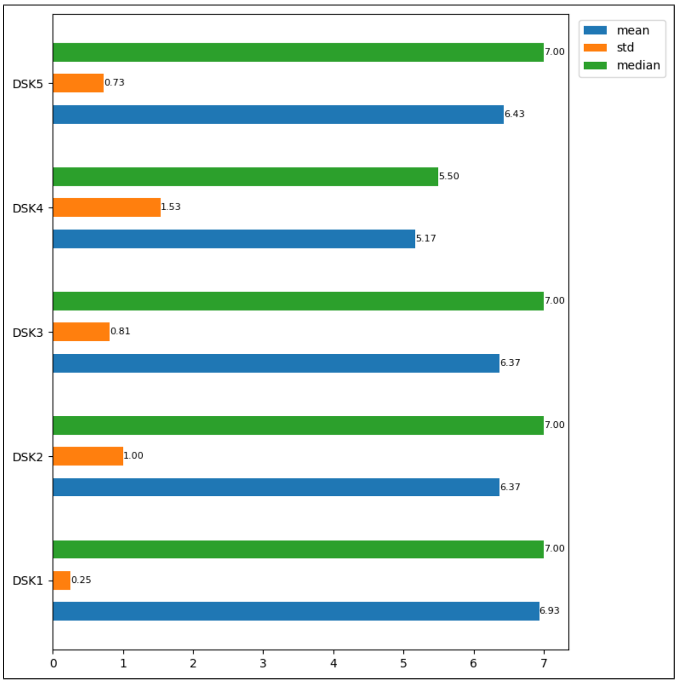


Figure 5.4: Median, Standard Deviation and Mean of Domain Specific Questions about the *Hole In The Wall* game.

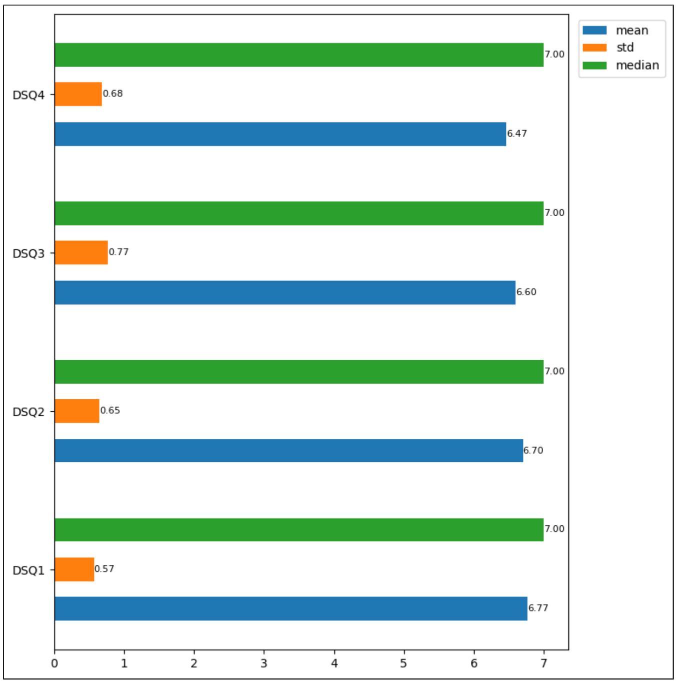


Figure 5.5: Median, Standard Deviation and Mean of the Domain Specific Questions about the Organize The Fruits game.

5.2.1.2 *Organize The Fruits* Game (Oculus Quest 2)

The responses to the domain-specific questions for the Oculus Quest 2 were promising, indicating that users found it easy to comprehend the purpose of the game and the involved mechanics. When asked if they understood the goals of the game (**DSQ1**), 83% of the participants answered with the highest value of '7'.

The following two questions (**DSQ2** and **DSQ3**) had similar results with a percentage of 76% and 73% strongly agreeing with understanding the mapping of the hand movement to the game and considering that the movements required to complete the tasks were adequate, respectively.

Lastly, when participants were asked about the suitability of the game for physiotherapy, 56% of the participants responded with a score of '7', indicating a high level of agreement. An additional 33% of the participants provided a score of '6', which also demonstrates a positive inclination. These results can be seen as generally positive since the remaining 10% chose a score of '5'.

5.2.2 System Usability Scale

The subsequent questions in the user questionnaire aimed to assess usability and user satisfaction using the System Usability Scale (SUS) [6]. Overall, the results of the SUS questionnaire were highly favorable. The Kinect V2 prototype achieved an impressive SUS score of 87.7, while the Oculus Quest 2 prototype received a commendable score of 87.2.

These results can be better contextualized by taking into account a previous study by Bangor et al. that implemented a 7-point Likert scale, characterized by adjectives, alongside SUS surveys, and that revealed a significant correlation between Likert scale scores and SUS scores. These finding emphasize that the adjective rating scale closely aligns with the SUS scale, indicating its utility as a valuable tool for assigning a subjective label to the mean SUS score of a specific study [15].

When comparing the results of the SUS questionnaire completed in the course of the evaluation phase of this dissertation with the scales present in the study mentioned above, both games achieved good usability scores. With a score of 87.7 and 87.2, the prototypes fall into the category of "Excellent"in the Adjective Rating scale, 'B' in the Grade scale and 'Acceptable' in the Acceptability Scale.

Another study developed regression equations that compute benchmarks for SUS items based on an overall SUS score. These findings enable practitioners to interpret the means of SUS items, especially in the light of published norms for interpreting overall mean SUS scores [30].

Looking at the Curved Grading scale present in the study, it is possible to see that the scores from both games, 87.7 and 87.2, fall into the best category 'A+' which has a SUS score range of 84.1 to 100 and corresponds to a range between the 96th and 100th percentile.

5.2.2.1 *Hole In The Wall* Game (Kinect V2)

Regarding the Kinect V2 game prototype, the results of the SUS questionnaire exhibited a positive distribution, with a majority of responses leaning heavily towards the positive side of the Likert scale (see Table 5.3 for relative frequency of the responses and Figure 5.6 for the mean, standard deviation and median of the responses).

Table 5.3: Relative Frequency of the answers to SUS questions about the Kinect V2 game prototype

Questions	**1**	**2**	**3**	**4**	**5**	**6**	**7**
SUS - *Hole In The Wall* using the Kinect V2							
SUSK1: I think that I would like to play this game frequently.	0.00	0.03	0.07	0.03	0.23	0.47	0.17
SUSK2: I found the game unnecessarily complex.	0.40	0.40	0.20	0.00	0.00	0.00	0.00
SUSK3: I thought the game was easy to play.	0.00	0.00	0.00	0.00	0.07	0.53	0.40
SUSK4: I think that I would need the support of a technical person to be able to play this game.	0.40	0.30	0.23	0.00	0.07	0.00	0.00
SUSK5: I found the various functions in this game were well integrated.	0.00	0.00	0.00	0.00	0.23	0.40	0.37
SUSK6: I thought there was too much inconsistency in this game.	0.47	0.40	0.07	0.00	0.07	0.00	0.00
SUSK7: I would imagine that most people would learn to play this game very quickly.	0.00	0.00	0.00	0.00	0.03	0.33	0.63
SUSK8: I found the game very cumbersome to play.	0.70	0.27	0.00	0.03	0.00	0.00	0.00
SUSK9: I felt very confident playing the game.	0.00	0.00	0.00	0.00	0.17	0.47	0.37
SUSK10: I needed to learn a lot of things before I could get going with this game.	0.80	0.20	0.00	0.00	0.00	0.00	0.00

The first statement inquiring if the participants would like to play this game frequently yielded the most varied responses (**SUSK1**). Only 17% of students strongly agreed with a rating of '7', while 47% responded with a rating of '6'. A small percentage, 3% and 6% of users, respectively, provided ratings of '2' and '3'.

When participants were asked whether they found the game unnecessarily complex (**SUSK2**), an overwhelming 80% of the students responded with a value smaller than or equal to '2', indicating an overall disagreement with the statement which is a good indicator.

The statements **SUSK3** and **SUSK5**, which assessed the ease of playing the game and the integration of game functions, respectively, received similar positive responses. All students responded with a value greater than or equal to '5', with 40% and 36% of them selecting '7' as their rating.

In terms of whether users would require the assistance of a technical person to play the game (**SUSK4**), 40% answered with '1', indicating they strongly disagreed with the

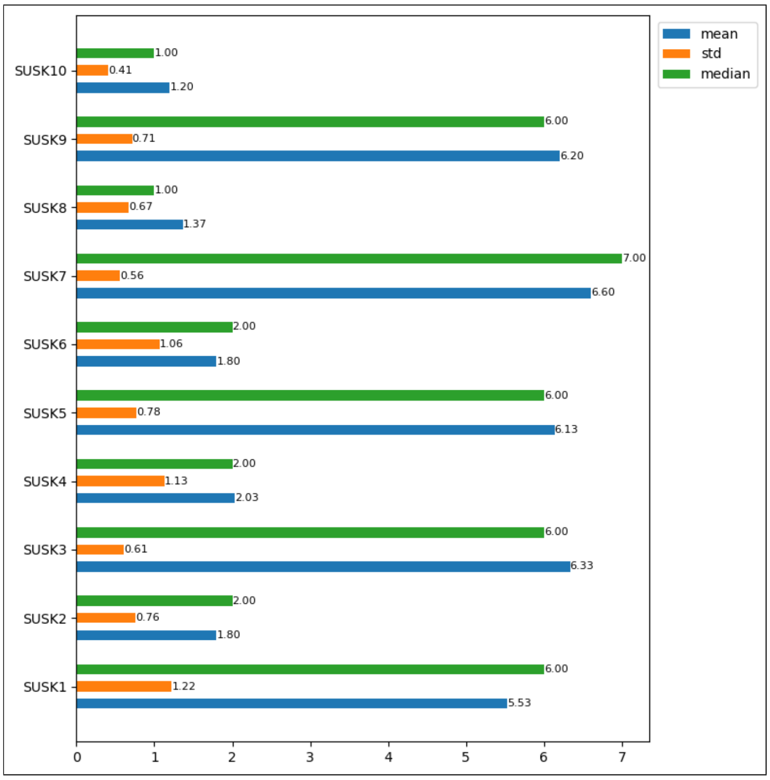


Figure 5.6: Median, Standard Deviation and Mean of SUS of *Hole In The Wall*

statement, while 30% chose '2' as their response. Regarding the presence of inconsistencies in the game (**SUSK6**), the responses were also similar. 47% strongly disagreed with the statemen by choosing '1', while 46% gave a rating of '2'.

When asked if most people would learn to play the game quickly (**SUSK7**), 63% responded with a '7', indicating a high level of confidence in the game's learnability. Additionally, when asked if they found the game complicated to play (**SUSK8**), 70% responded with '1', indicating strong disagreement with the statement.

In terms of confidence while playing the game **SUSK9**, 84% of the students selected a value greater than or equal to '6', suggesting a high level of confidence.

Lastly, 80% of the testers answered with a '1' to the question about having to learn a lot of things before they could get going with the game **SUSK10**.

5.2.2.2 *Organize The Fruits* Game (Oculus Quest 2)

Similarly to the first game, the Oculus Quest 2 game prototype also had promising and positive results on the SUS questionnaire (see Table 5.4 for relative frequency of the responses and Figure 5.7 for the mean, standard deviation and median of the responses).

When participants were asked if they would like to play the game frequently (**SUSQ1**), 33% of students strongly agreed with a rating of '7', and 30% responded with a rating of '6'. While these results are positive, it is worth noting that a small percentage of users, 3%

Table 5.4: Relative Frequency of the answers to SUS questions about the Oculus Quest 2 game prototype

Questions	**1**	**2**	**3**	**4**	**5**	**6**	**7**
SUS - *Organize The Fruits* using Oculus Quest 2							
SUSQ1: I think that I would like to play this game frequently.	0.03	0.07	0.00	0.13	0.13	0.30	0.33
SUSQ2: I found the game unnecessarily complex.	0.47	0.47	0.03	0.00	0.03	0.00	0.00
SUSQ3: I thought the game was easy to play.	0.00	0.00	0.00	0.00	0.07	0.47	0.47
SUSQ4: I think that I would need the support of a technical person to be able to play this game.	0.40	0.23	0.23	0.07	0.03	0.03	0.00
SUSQ5: I found the various functions in this game were well integrated.	0.00	0.00	0.00	0.03	0.17	0.27	0.53
SUSQ6: I thought there was too much inconsistency in this game.	0.53	0.33	0.10	0.03	0.00	0.00	0.00
SUSQ7: I would imagine that most people would learn to plat this game very quickly.	0.00	0.00	0.00	0.03	0.03	0.47	0.47
SUSQ8: I found the game very cumbersome to play.	0.70	0.23	0.03	0.03	0.00	0.00	0.00
SUSQ9: I felt very confident playing the game.	0.00	0.03	0.00	0.07	0.10	0.23	0.57
SUSQ10: I needed to learn a lot of things before I could get going with this game.	0.57	0.37	0.03	0.03	0.00	0.00	0.00

and 6% respectively, provided ratings of '1' and '2', indicating little interest in frequent gameplay.

Regarding whether the participants found the game unnecessarily complex (**SUSQ2**), 93% of the students responded with a value smaller than or equal to '2', indicating a strong disagreement with the statement.

The statement **SUSQ3**, which assessed the ease of playing the game, received positive responses, with 94% of participants selecting a value greater than or equal to '6'. In fact, 45% chose the highest possible value of '7'.

When asked if users would require the assistance of a technical person to play the game (**SUSQ4**), 40% responded with '1', indicating they strongly disagreed with the statement, while 23% selected '2' as their response. Overall, this indicates that the vast majority of the participants had little to no need of receiving technical support to play the game.

Regarding whether the functions of the game were well integrated (**SUSQ5**), 80% of the students responded with a value greater than or equal to '6', indicating that most users did not find major integration issues in the game. Similarly, In terms of the presence of inconsistencies in the game (**SUSQ6**), 53% strongly disagreed with the statement with a rating of '1', while 33% simply disagreed by providing a rating of '2'. This also indicates that according to a vast majority of users there were no serious inconsistencies in this

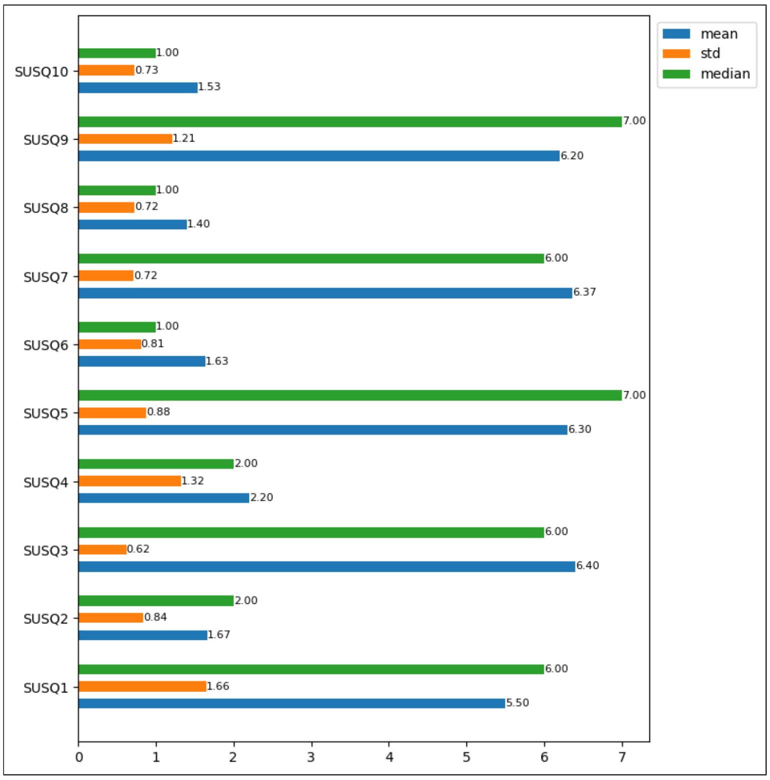


Figure 5.7: Median, Standard Deviation and Mean of SUS of *Organize The Fruits* game

game.

When asked if most people would learn to play the game quickly (**SUSQ7**), 47% responded with ’7’, and another 47% selected ’6’. When asked if the players found the game complicated to play (**SUSQ8**), 70% responded with ’1’, indicating a strong disagreement with the statement. Both of these questions suggest that the game is not too complicated and that it should not not be too difficult to start playing it.

In terms of their confidence while playing the game (**SUSQ9**), 80% of the participants selected a value greater than or equal to ’6’, indicating a high level of confidence. Moreover, 56% of the testers answered with a ’1’ and 37% answered with a ’2’ regarding the question about having to learn a lot of things before they could start playing the game (**SUSQ10**). Both of these questions indicate that there are no major issues with this game.

5.2.3 NASA Task Load Index

This section of the questionnaire aimed to evaluate the cognitive and physical demands associated with playing the game. For this purpose, the NASA Task Load Index (NASA TLX) was utilized as a standardized tool to assess subjective workload. The NASA TLX enables the determination of a participant’s perceived workload for a given task. It evaluates workload across the following six dimensions to derive an overall workload rating:

- Mental Demand
- Physical Demand
- Temporal Demand
- Own Performance
- Effort
- Frustration Level

The participants were requested to evaluate their experience with each of the two games across the six mentioned dimensions, utilizing a scale ranging from 0 to 100. While the original NASA TLX methodology incorporates a weighting step to determine the participants' ranking of the dimensions based on their perceived contribution to the overall workload, this step was omitted in order to avoid overburdening the participants with additional questions. Moreover, this approach simplifies the analysis of the study by allowing for a general assessment of the overall workload without the need for detailed differentiation between the dimensions.

The results for the *Hole In The Wall* (Kinect V2) game and for the *Organize The Fruits* (Oculus Quest 2) game can be seen in Tables 5.5 and 5.6, respectively.

Table 5.5: Participant answers results to NASA TLX questions about the Kinect V2 game prototype ($\bar{x}$ stands for the mean, $\tilde{x}$ for the median and s for the standard deviation).

Questions	$\bar{x}$	$\tilde{x}$	s
NASA TLX - *Hole In The Wall* using the Kinect V2			
NKM: How mentally demanding was the task?	19.7	17.5	12.2
NKP: How physically demanding was the task?	32.2	32.5	20.5
NKT: How hurried or rushed was the pace of the task?	23.8	20.0	19.0
NKO: How successful were you in accomplished what you were asked to do?	19.8	15.0	14.5
NKE: How hard did you have to work to accomplish what you were asked to do?	29.2	27.5	18.8
NKF: How insecure, discouraged, irritated, stressed, and annoyed were you?	13.7	5.0	19.7
NKScore: Overall Score	23.1	20.8	11.6

The Kinect V2 game had an overall mean score (**NKScore**) of 23.1 with the highest component being the Physical Demand **(NKP)** with a score of 32.2 and the lowest being the Frustration Level *(NKO)* with a score of 13.7.

The Oculus Quest 2 game had an overall mean score of 18.6 (**NQScore**) with the highest component being the Mental Demand **(NQM)** with a score of 26.0 and the lowest being the Frustration Level **(NQF)** with a score of 8.8.

In a paper by Grier, a descriptive analysis of more than 1000 global NASA Task Load Index (NASA-TLX) scores from over 200 publications is presented. The frequency distributions and measures of central tendency provided in the study can assist practitioners

Table 5.6: Participant answers results to NASA TLX questions about the Oculus Quest 2 game prototype ($\bar{x}$ stands for the mean, $\tilde{x}$ for the median and s for the standard deviation).

Questions	$\bar{x}$	$\tilde{x}$	s
NASA TLX - *Organize The Fruits* using the Oculus Quest 2			
NQM: How mentally demanding was the task?	26.0	25.0	20.1
NQP: How physically demanding was the task?	19.3	15.0	17.6
NQT: How hurried or rushed was the pace of the task?	16.7	12.5	14.2
NQO: How successful were you in accomplished what you were asked to do?	18.7	15.0	16.7
NQE: How hard did you have to work to accomplish what you were asked to do?	21.8	15.0	17.1
NQF: How insecure, discouraged, irritated, stressed, and annoyed were you?	8.8	5.0	13.4
NQScore: Overall Score	18.6	18.3	11.0

in gaining a better understanding of the observed global NASA-TLX scores in the tests they perform [24].

As previously mentioned, the NASA TLX questionnaire that was answered in this evaluation phase did not consider different weights to the different workload dimensions. This common modification of the NASA TLX questionnaire is often referred to as RTLX or Raw TLX. This means that all the components had the same value when computing the final score. Moreover, Grier could not reject the null hypothesis that there is no difference between weighted and unweighted NASA TLX scores. Therefore, there is some evidence that the weighting phase does not interfere too much with the results, thus supporting our decision of skipping that step [24].

The authors of the mentioned paper reported a mean score of 45.29 for the RTLX tests, which is notably higher than our results of 23.1 for the Kinect V2 and 18.6 for the Oculus Quest 2 [24]. In comparison, both of our scores fall below the 10th percentile value of 26.08 from the analyzed NASA TLX results. These discrepancies suggest that our participants perceived a lower overall workload compared to the broader sample studied by the authors.

Grier's study included a diverse range of tasks from various domains, yielding valuable insights that are worth comparing with the NASA TLX results obtained in this dissertation's tests. For instance, the *Hole In The Wall* game had a NASA TLX Score of 23.1. This score is lower than any of the median scores (50th percentile) across the 20 different task types. In fact, it is lower than the 25th percentile of all of the task types, except Card Storing, Computer Activities and Daily Activities, which are not particularly demanding tasks. Moreover, in the case of the *Organize The Fruits*, which had an even lower score of 18.6, the Daily Activities task type was the only one that had a lower score at the 25th percentile.

5.2.4 Testing Sessions Scores and Metrics

As discussed in Chapter 4, the games' structure was integrated with the MoveONParkinson Web platform and with its database. This allows for the session results of each patient to be saved for posterior analysis by the therapists. The evaluation phase tests took advantage of this mechanism and stored the data generated by the students testing the games.

The *Hole In The Wall* game recorded various metrics, including total points, a list of correct and incorrect walls, the number of stars caught, and the maximum number of consecutive correct walls. In the *Organize The Fruits* game, metrics such as total points, a list of fruits caught and missed, the correct hand designated to catch the fruit, the actual hand that caught the fruit, and the side from which the fruit originated were stored for analysis.

These results can be analyzed to assess whether the game lacked physical effort due to being too easy or posed challenges that resulted in negative scores for healthy young adults. Additionally, examining these metrics allows for the identification of patterns of success or failure in how the participants played the games. Such observations are valuable in determining if certain functionalities are poorly integrated or if certain elements of the game are excessively easy or complex.

While it is crucial to acknowledge that validating the games would require conducting tests with people with PD and comparing the results, the significance of presenting these scores and metrics should not be undermined. They provide valuable insights into the potential of these functionalities in enhancing treatment for individuals with PD. Although further validation is necessary, showcasing these findings can generate interest and highlight the potential benefits of continuing to develop games such as these.

In the *Hole In The Wall* game, participants had the opportunity to pass a maximum of 12 walls. On average, they successfully passed 9.63 walls. Among the 30 participants, three students achieved the highest score of 12 walls passed, demonstrating exceptional performance. Conversely, one student achieved the lowest score, successfully passing only 7 walls. Additionally, participants had the chance to catch a maximum of 17 stars. On average, they managed to catch 12.5 stars. One student excelled with a score of 16 stars caught, while another student achieved the lowest score, capturing only 6 stars.

In the *Organize The Fruits* game, participants had the opportunity to score a maximum of 27 points, with an average score of 20.13 points. Among the 30 participants, four students achieved the highest score of 24 points. On the other hand, only one student achieved the lowest score of 12 points. Another noteworthy metric in the game is the number of fruits caught with the correct hand, which provided bonus points. The maximum possible value was 12, and the average number of fruits caught with the correct hand was 7.6. Five students achieved the highest score of 10 points by catching fruits with the correct hand, while one student achieved the lowest score of 3 points.

As mentioned before, these results do not prove that the games are challenging for people with PD and will motivate them to exercise, for that they needed to play the games and give their feedback. Nonetheless, the results show that the games require effort to get the best scores, with a small group of people having more ease in reaching better performances and usually one person having a harder time to keep up. The mean values are promising for this group of young adults and this analysis adds up to the positive results presented above.

5.2.5 Discussion

An effort was made to compare the questionnaire responses between both games, specifically for the Domain Specific Questions, SUS questionnaire, and NASA TLX dimensions. Given that the Domain Specific Questions and SUS questionnaire employ an ordinal scale, it is more appropriate to employ a non-parametric test that does not assume normal distribution or continuity of the data. Therefore, the Wilcoxon signed-rank test was utilized to determine if there existed a statistically significant difference between paired samples, in this case, the results for the same questions across the two different games. A significance level of 0.05 was predetermined, meaning that a p-value below 0.05 would lead to the rejection of the null hypothesis, indicating a significant difference in medians between the two samples.

The Domain Specific Questions are not entirely comparable between the two games, and only the first question can be directly compared. When evaluating the p-value for the statement regarding participants' understanding of the game's goals, a value of 0.02 was obtained, which falls below the predetermined significance level of 0.05. This indicates a significant difference in this particular response between the two games. Specifically, the audience demonstrated a better understanding of the goals in the Kinect V2 game compared to the Oculus Quest 2 game.

Among the SUS questions, only the p-value for SUS question number 10 meets the specified requirement, yielding a p-value of 0.02. This indicates a statistically significant difference in the responses related to the participants' perception of the learning curve associated with each game. Based on this test, it can be concluded that the participants felt they needed to learn a greater number of things before becoming proficient in the Oculus Quest 2 game compared to the Kinect V2 game. This outcome is not surprising, considering that the Oculus Quest 2 requires users to fully immerse themselves in a virtual world, which may be a relatively new and unfamiliar experience for them.

Regarding the NASA TLX results, we utilized a paired t-test to assess any statistical differences between the mean responses of the two games. The NASA TLX questionnaire employs a 0 to 100 scale that closely resembles a continuous scale. We maintained a significance level of 0.05 for the analysis.

The results of the test indicated statistically significant differences between the two games in two dimensions of the NASA TLX questionnaire: Physical Demand and Effort. The corresponding p-values for these dimensions were 0.0002 and 0.01, respectively.

Consequently, for this group of participants, the Fully Immersive VR experience was found to be less physically demanding and required less effort compared to the Kinect V2.

Moreover, these findings potentially influenced the overall NASA scores for each game. By subjecting the final overall scores to the same paired t-test, we observed a statistically significant difference with a p-value of 0.02.

Therefore, the testing phase gave mostly promising results concerning the understanding and usability of the games. Although the participants were not the target audience of the solution, it was essential to validate the development phase, to identify elements that needed to be improved and to allow proceeding with the planning of the next testing phase with people with PD.

6

Conclusions and Future Work

This Chapter presents the general conclusions drawn from the work carried out in the course of this dissertation and describes future developments and improvements that could prove to be significant.

6.1 Conclusion

This dissertation focused on exploring how Serious Games and Virtual Reality could work together to maintain the quality of life of people with Parkinson's Disease and motivate them in exercising.

An initial study was made about PD, the problem we were facing and the motivations for the project. A literature study was also performed and a review of related work that was important in the beginning of the design phase. The work done in this dissertation started with four devices (DDR Pad, Wii Balance Board, Kinect V2 and Oculus Quest 2) and through brainstorming therapy-related game ideas several prototype sketches were created for each device. Then it was decided, with the collaboration of members of the MoveONParkinson team, to implement one minigame for each device and carry out a preliminary study with the main focus on the study of the usability and effectiveness of the devices with people with PD.

The Interaction Device Study allowed, through Participatory Design, to choose the two most suitable devices to proceed to the Development phase. Moreover, it was possible to get feedback from therapists, informal caregivers, and even users about which strategies are more likely to generate motivation and engagement for people with PD to increase their level of physical activity. Some aspects of game design and features proved to be important, as well as other motivational elements, such as reward systems and difficulty increased over time to prolong the cognitive stimulus produced.

The study resulted in two game prototypes, *Hole In The Wall* and *Organize The Fruits*, that use technologies such as Kinect V2 and Oculus Quest 2, respectively. The first game does not explore the full potential of VR immersiveness, however it offers the possibility of realizing personalized exercise in a playful and motivating environment. The full-immersive VR game uses the capability of abstraction by being in a virtual world to take advantages of aerobic movements and cognitive stimulation.

Moreover, a connection between the game prototypes and the *ONParkinson* project platform was established to ensure that therapists have the necessary tools to set up the sessions and evaluate the progress of each user.

Finally, a User Study was conducted with students in which they were introduced to the topic and motivations of the dissertation, performed a test session for each game, and then answered a questionnaire with about the Domain Specific Questions, System Usability Scale and NASA Task Load Index.

The results obtained allowed to validate the developed games from a functional and usability point of view, but also allowed the team to verify in which aspects is needed more attention when testing with people with PD in the near future.

The challenge presented by the research questions was thus achieved, both through the Preliminary Study and the User Study. Therefore, the **RQ1** and **RQ2** allowed to understand that Serious Games can be a valuable tool in the treatment of PD, as they provide an engaging and interactive approach to therapy. To maximize engagement in people with PD, it's important to consider certain game characteristics and select appropriate interaction modalities and technologies. Key considerations revealed to be an important addition to Serious Games such as Feedback and Reward system, Clear Objectives, Adaptable Features for Personalized Exercise Sessions and Integration with Cognitive Challenges. The interaction modalities that resulted in being more adequate were the Motion-Based Interaction that can be beneficial for this target audience that may experience motor impairments and Virtual Reality technology that can provide immersive and engaging experiences.

6.2 Future Work

There is always room for improvement in any solution and even more in a study like this where Persuasive Technology and healthcare converge, both areas in constant evolution. Not only could a new tool emerge that far surpasses the others, but papers may emerge with promising evidence in terms of the work that is accomplished to slow the progression of Parkinson's disease through exercise.

Thus, plausible suggestions emerged from the User Study conducted with students and should be considered for integration into the two game prototypes:

- **Hole In The Wall**: Increase the time interval between the walls to make it more accessible. Make body parts more translucent to allow a better view of obstacles present in the walls. Enhance the visualization of the distance between the wall and the character, possibly through floor markings or lighting.

- **Organize The Fruits**: Reduce the learning curve in VR games by replacing visual indicators with alternative approaches, such as vibrating the controller or using different colors to make the extra scoring system more explicit. Explore more suitable indicators for fruit direction, such as having the avatar indicate which side the fruit is coming from. Making directional arrows more visible or reduce their size and explore the possibility of making it optional to look at the menu area.

Regarding the motivational strategy that was designed and that part of it was not developed, there are still several aspects that can be improved and other additions can be explored with more depth:

- **Sensory System**: the integration of a sensory system into the collection of serious games may prove to be a good addition, as aspects such as heart rate, blood pressure and burned calories can be measured while the patient is exercising with the games and used for further analysis.
- **Conversational Agent**: the introduction of the virtual physiotherapist was a first attempt to have an agent that interacts with patients, but in a unidirectional and pre-programmed way. In the future, the integration of a conversational agent that responds to the patient's needs and learns from experience could be studied. This could be whether the patient interacts vocally with the agent because he needs help with a task, or wants to change a setting or the game state.
- **Competitiveness and Cooperation**: Studying how features that relate players and bring them closer together within the virtual world in order to motivate them could work, such as the introduction of leaderboards with the highest scores in games to promote an healthy competitiveness among the community and a cooperation mode to motivate players to achieve a common goal.
- **Profile Customization and Missions**: Several gamification tools have showed huge potential in encouraging patients in exercising and having other motivations, such as a profile and patient level, missions that grant rewards (specific missions for each level, special missions considering the time of the year), profile avatar that can be customized (unlocking clothes and accessories as the player completes tasks) and played with in the games. The introduction of a reward system like this can create more engagement and make users eager for better performances in order to receive bonuses and prizes.
- **Everyday life Gamified tasks**: Explore ways to introduce gamification into various aspects of patient's lives as a supplement to serious games in clinics: indoor alone, indoor with caregiver, and outdoor. These tasks could give rewards/experience points to the patient in order to unlock features in his profile or even in a specific game. This could integrate the conversational agent combined with the targeted gamification details in Android mobile devices.

- **Expand the Game Suite**: Throughout the development it was thought to create more not so complex games so that the final collection would be broader and have more variety, however that idea fell through. In the future there is the intention to continue adding new games to the collection and explore other concepts, such as existing traditional games such as Portuguese *Malha* and Boccia. The immersive games can be expanded into a more interactive environment with various mini-games: Kitchen with Organizing the Fruit, Setting the Table, Washing the Dishes, Tidying the Pantry; Farm with Taking Care of the Garden and Feeding the Animals.

Bibliography

[1] R. S. Alsawaier. "The effect of gamification on motivation and engagement". In: *International Journal of Information and Learning Technology* 35 (1 2018), pp. 56–79. ISSN: 20564899. DOI: 10.1108/IJILT-02-2017-0009/FULL/XML (cit. on p. 17).

[2] A. Association. *RGS - AAL Programme*. 2009. URL: http://www.aal-europe.eu/projects/rgs/ (cit. on pp. 29, 30).

[3] J. Bardi. *What is Virtual Reality? VR Definition and Examples | Marxent*. 2019. URL: https://www.marxentlabs.com/what-is-virtual-reality/ (cit. on pp. 20, 21).

[4] D. Barnard. *Degrees of Freedom (DoF): 3-DoF vs 6-DoF for VR Headset Selection*. 2019. URL: https://virtualspeech.com/blog/degrees-of-freedom-vr (cit. on p. 22).

[5] Z. Bhanji. *A New Reality: How VR Actually Works | by Zaynah Bhanji | Predict | Medium*. 2018. URL: https://medium.com/predict/a-new-reality-how-vr-actually-works-663210bdff72 (cit. on pp. 21, 22).

[6] J. Brooke. *SUS - A quick and dirty usability scale*. Ed. by P. W. Jordan et al. 1996 (cit. on pp. 66, 70).

[7] S. Bryson. *Virtual Reality Video Games in Parkinson's May Be Helpful Exercise Tool*. 2021. URL: https://parkinsonsnewstoday.com/2021/07/22/virtual-reality-video-games-parkinsons-may-be-helpful-exercise-tool/?cn-reloaded=1 (cit. on p. 19).

[8] J. W. Burke et al. "Optimising engagement for stroke rehabilitation using serious games". In: *The Visual Computer 2009 25:12* 25 (12 Aug. 2009), pp. 1085–1099. ISSN: 1432-2315. DOI: 10.1007/S00371-009-0387-4. URL: https://link.springer.com/article/10.1007/s00371-009-0387-4 (cit. on pp. 16, 17).

[9] M. S. Cameirão et al. "Neurorehabilitation using the virtual reality based Rehabilitation Gaming System: methodology, design, psychometrics, usability and validation". In: *Journal of neuroengineering and rehabilitation* 7 (Sept. 2010), p. 48. ISSN: 1743-0003. DOI: 10.1186/1743-0003-7-48. URL: https://pubmed.ncbi.nlm.

nih.gov/20860808%20https://www.ncbi.nlm.nih.gov/pmc/articles/PMC2949710/ (cit. on pp. 29, 30).

[10] P. Campo-Prieto et al. "Can Immersive Virtual Reality Videogames Help Parkinson's Disease Patients? A Case Study". In: *Sensors 2021, Vol. 21, Page 4825* 21 (14 July 2021), p. 4825. ISSN: 14248220. DOI: 10.3390/S21144825. URL: https://www.mdpi.com/1424-8220/21/14/4825/htm%20https://www.mdpi.com/1424-8220/21/14/4825 (cit. on p. 19).

[11] C. Y. Chow et al. "Can games change children's eating behaviour? A review of gamification and serious games". In: *Food Quality and Preference* 80 (Mar. 2020), p. 103823. ISSN: 0950-3293. DOI: 10.1016/J.FOODQUAL.2019.103823 (cit. on p. 17).

[12] I. Cikajlo and K. P. Potisk. "Advantages of using 3D virtual reality based training in persons with Parkinson's disease: A parallel study". In: *Journal of NeuroEngineering and Rehabilitation* 16 (1 Oct. 2019), pp. 1–14. ISSN: 17430003. DOI: 10.1186/S12984-019-0601-1/FIGURES/7. URL: https://jneuroengrehab.biomedcentral.com/articles/10.1186/s12984-019-0601-1 (cit. on p. 19).

[13] R. Cong and R. Winters. *How It Works: Xbox Kinect*. URL: https://www.jameco.com/Jameco/workshop/Howitworks/xboxkinect.html (cit. on pp. 23, 24).

[14] S. Deterding et al. "From game design elements to gamefulness: Defining "gamification"". In: *Proceedings of the 15th International Academic MindTrek Conference: Envisioning Future Media Environments, MindTrek 2011* (2011), pp. 9–15. DOI: 10.1145/2181037.2181040 (cit. on p. 3).

[15] *Determining What Individual SUS Scores Mean: Adding an Adjective Rating Scale - JUX*. URL: https://uxpajournal.org/determining-what-individual-sus-scores-mean-adding-an-adjective-rating-scale/ (cit. on p. 70).

[16] S. B. Dias et al. "On Supporting Parkinson's Disease Patients: The i-Prognosis Personalized Game Suite Design Approach". In: *Proceedings - IEEE Symposium on Computer-Based Medical Systems* 2017-June (Nov. 2017), pp. 521–526. ISSN: 10637125. DOI: 10.1109/CBMS.2017.144 (cit. on pp. 27–29).

[17] S. B. Dias et al. "Assistive HCI-Serious Games Co-design Insights: The Case Study of i-PROGNOSIS Personalized Game Suite for Parkinson's Disease". In: *Frontiers in Psychology* 11 (Jan. 2021), p. 4017. ISSN: 16641078. DOI: 10.3389/FPSYG.2020.612835/BIBTEX (cit. on pp. 28, 29).

[18] J. M. Finley et al. "Design and Development of a Virtual Reality-Based Mobility Training Game for People With Parkinson's Disease". In: *Frontiers in Neurology* 11 (Jan. 2021), p. 1692. ISSN: 16642295. DOI: 10.3389/FNEUR.2020.577713/BIBTEX (cit. on pp. 19, 31, 32).

[19] *First Steps for Quest 2 on Oculus Quest 2 | Oculus.* URL: https://www.oculus.com/experiences/quest/3675568169182204/ (cit. on p. 47).

[20] B. J. Fogg. *Behavior Model.* 2007. URL: https://behaviormodel.org/ (cit. on pp. 13, 14).

[21] B. J. Fogg. "Persuasive Technology: Using Computers to Change What We Think and Do". In: *Persuasive Technology: Using Computers to Change What We Think and Do* (2003), pp. 1–282. ISSN: 1569-111X. DOI: 10.1016/B978-1-55860-643-2.X5000-8 (cit. on pp. 1, 12, 13).

[22] D. P. Foundation. *How to Encourage People with Parkinson's to Exercise - Davis Phinney Foundation.* 2019. URL: https://davisphinneyfoundation.org/how-to-encourage-people-with-parkinsons-to-exercise/ (cit. on p. 2).

[23] H. Gonzalez-Usigli. *Parkinson Disease (PD) - Brain, Spinal Cord, and Nerve Disorders - MSD Manual Consumer Version.* Sept. 2020. URL: https://www.msdmanuals.com/home/brain,-spinal-cord,-and-nerve-disorders/movement-disorders/parkinson-disease-pd (cit. on pp. 1, 7–10).

[24] R. A. Grier. "How High is High? A Meta-Analysis of NASA-TLX Global Workload Scores". In: *http://dx.doi.org/10.1177/1541931215591373* 2015-January (Dec. 2016), pp. 1727–1731. ISSN: 10711813. DOI: 10.1177/1541931215591373. URL: https://journals.sagepub.com/doi/epdf/10.1177/1541931215591373 (cit. on p. 76).

[25] A. E. Guttmacher et al. "Alzheimer's Disease and Parkinson's Disease". In: *http://dx.doi.org/10.1056/N* 348 (14 Oct. 2009), pp. 1356–1364. ISSN: 0028-4793. DOI: 10.1056/NEJM2003RA020003. URL: https://www.nejm.org/doi/full/10.1056/NEJM2003ra020003 (cit. on p. 1).

[26] S. G. Hart and L. E. Staveland. "Development of NASA-TLX (Task Load Index): Results of Empirical and Theoretical Research". In: *Advances in Psychology* 52 (C Jan. 1988), pp. 139–183. ISSN: 01664115. DOI: 10.1016/S0166-4115(08)62386-9. URL: https://linkinghub.elsevier.com/retrieve/pii/S0166411508623869 (cit. on p. 66).

[27] C. Heizenrader. *The 3 Types of Virtual Reality - Heizenrader.* URL: https://heizenrader.com/the-3-types-of-virtual-reality/ (cit. on p. 20).

[28] *Hello! | bjfogg.* URL: https://www.bjfogg.com/ (cit. on p. 13).

[29] T. F. Institute. *History of Virtual Reality | The Franklin Institute.* URL: https://www.fi.edu/virtual-reality/history-of-virtual-reality (cit. on p. 20).

[30] *Item Benchmarks for the System Usability Scale - JUX.* URL: https://uxpajournal.org/item-benchmarks-system-usability-scale-sus/ (cit. on p. 70).

[31] A. D. Kloos et al. "Video game play (Dance Dance Revolution) as a potential exercise therapy in Huntington's disease: a controlled clinical trial". In: *Clinical rehabilitation* 27 (11 Nov. 2013), pp. 972–982. ISSN: 1477-0873. DOI: 10.1177/0269215513487235. URL: https://pubmed.ncbi.nlm.nih.gov/23787940/ (cit. on p. 25).

[32] N. M. van der Kolk et al. "Effectiveness of home-based and remotely supervised aerobic exercise in Parkinson's disease: a double-blind, randomised controlled trial". In: *The Lancet Neurology* 18 (11 Nov. 2019), pp. 998–1008. ISSN: 14744465. DOI: 10.1016/S1474-4422(19)30285-6. URL: https://www.news-medical.net/news/20190913/Parkinsons-patients-benefit-from-gamified-home-exercise.aspx (cit. on p. 18).

[33] A. N. Krichevets et al. "Computer games as a means of movement rehabilitation". In: *https://doi.org/10.3109/09638289509166635* 17 (2 2009), pp. 100–105. ISSN: 09638288. DOI: 10.3109/09638289509166635. URL: https://www.tandfonline.com/doi/abs/10.3109/09638289509166635 (cit. on p. 17).

[34] K. Lohse et al. "Video games and rehabilitation: Using design principles to enhance engagement in physical therapy". In: *Journal of Neurologic Physical Therapy* 37 (4 2013), pp. 166–175. ISSN: 15570584. DOI: 10.1097/NPT.0000000000000017. URL: https://journals.lww.com/jnpt/Fulltext/2013/12000/Video_Games_and_Rehabilitation__Using_Design.4.aspx (cit. on p. 18).

[35] V. López-Jaquero, F. Montero, and M. A. Teruel. "Influence awareness: considering motivation in computer-assisted rehabilitation". In: *Journal of Ambient Intelligence and Humanized Computing* 10 (6 June 2019), pp. 2185–2197. ISSN: 18685145. DOI: 10.1007/S12652-017-0652-8 (cit. on pp. 14, 15).

[36] M. Ma and H. Zheng. "Virtual Reality and Serious Games in Healthcare". In: *Studies in Computational Intelligence* 337 (2011), pp. 169–192. ISSN: 1860949X. DOI: 10.1007/978-3-642-17824-5_9. URL: https://link.springer.com/chapter/10.1007/978-3-642-17824-5_9 (cit. on p. 3).

[37] S. Mader, G. Levieux, and S. Natkin. "A game design method for therapeutic games". In: *2016 8th International Conference on Games and Virtual Worlds for Serious Applications, VS-Games 2016* (Oct. 2016). DOI: 10.1109/VS-GAMES.2016.7590333 (cit. on p. 18).

[38] S. Mandal. "Brief Introduction of Virtual Reality & its Challenges". In: *International Journal of Scientific & Engineering Research* 4 (4 2013). ISSN: 2229-5518. URL: http://www.ijser.org (cit. on p. 20).

[39] A. Mattana. *How Does Vr Headset Work? Top Full Guide 2022 - Hooke Audio*. URL: https://hookeaudio.com/how-does-vr-headset-work/#How_Vr_Headsets_Work (cit. on p. 22).

[40] A. Menache. *Understanding Motion Capture for Computer Animation and Video Games - Alberto Menache - Google Livros*. URL: https://books.google.pt/books?hl=pt-PT&lr=&id=9njZ482OYfwC&oi=fnd&pg=PR11&dq=motion+capture&ots=coF5eOCOtF&sig=XvEowzPc_HAeBOWY_JL2Ui2rjdA&redir_esc=y#v=onepage&q=motion%5C%20capture%5C&f=false (cit. on p. 23).

[41] P. V. Mhatre et al. "Wii Fit Balance Board Playing Improves Balance and Gait in Parkinson Disease". In: *PM & R : the journal of injury, function, and rehabilitation* 5 (9 2013), p. 769. ISSN: 19341482. DOI: 10.1016/J.PMRJ.2013.05.019. URL: /pmc/articles/PMC4114762/%20/pmc/articles/PMC4114762/?report=abstract%20https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4114762/ (cit. on p. 25).

[42] D. Michael. *Serious games : games that educate, train and inform /*. Thomson Course Technology, 2006. ISBN: 1592006221. URL: http://www.educaciontrespuntocero.com/experiencias/hablanlosprofes/los-juegos-serios-aprender-jugando-y-jugar-aprendiendo/19907.html (cit. on p. 16).

[43] D. Montoro-Cárdenas et al. "Nintendo Wii Balance Board therapy for postural control in children with cerebral palsy: a systematic review and meta-analysis". In: *Developmental Medicine & Child Neurology* 63 (11 Nov. 2021), pp. 1262–1275. ISSN: 0012-1622. DOI: 10.1111/dmcn.14947 (cit. on p. 25).

[44] L. R. Natbony et al. "Perceptions of a Videogame-Based Dance Exercise Program Among Individuals with Parkinson's Disease". In: *Games for health journal* 2 (4 Aug. 2013), pp. 235–239. ISSN: 2161-7856. DOI: 10.1089/G4H.2013.0011. URL: https://pubmed.ncbi.nlm.nih.gov/24761325/ (cit. on p. 24).

[45] R. Orji and K. Moffatt. "Persuasive technology for health and wellness: State-of-the-art and emerging trends". In: *Health Informatics Journal* 24 (1 Mar. 2018), pp. 66–91. ISSN: 17412811. DOI: 10.1177/1460458216650979 (cit. on p. 1).

[46] J. Petty. *What is Unity 3D & What is it Used For?* URL: https://conceptartempire.com/what-is-unity/ (cit. on p. 26).

[47] M. Pinheiro. *Fisioterapia para Parkinson: para que serve e exercícios - Tua Saúde*. Sept. 2021. URL: https://www.tuasaude.com/fisioterapia-para-mal-de-parkinson/ (cit. on pp. 10, 11).

[48] D. Pinto et al. "Studying the Design of Pervasive Serious Games for Parkinson's Disease". In: *Proceedings of the 21st International Conference on Mobile and Ubiquitous Multimedia*. MUM '22. Lisbon, Portugal: Association for Computing Machinery, 2022, pp. 266–269. ISBN: 9781450398206. DOI: 10.1145/3568444.3570594. URL: https://doi.org/10.1145/3568444.3570594 (cit. on p. 5).

[49] G. C. Pluck and R. G. Brown. "Apathy in Parkinson's disease". In: *Journal of Neurology, Neurosurgery & Psychiatry* 73 (6 Dec. 2002), pp. 636–642. ISSN: 0022-3050. DOI: 10.1136/JNNP.73.6.636. URL: https://jnnp.bmj.com/content/73/6/636%20https://jnnp.bmj.com/content/73/6/636.abstract (cit. on p. 11).

[50] Portea. *Parkinson's Disease - About, Causes, Symptoms, Physiotherapy & More | Portea™*. 2019. URL: https://www.portea.com/physiotherapy/parkinsons-disease-treatment/ (cit. on pp. 7–10).

[51] *Serious games for rehabilitation: A survey and a classification towards a taxonomy | IEEE Conference Publication | IEEE Xplore*. URL: https://ieeexplore.ieee.org/document/5556674 (cit. on pp. 16, 17).

[52] K. Sevcenko and I. Lindgren. "The effects of virtual reality training in stroke and Parkinson's disease rehabilitation: a systematic review and a perspective on usability". In: *European Review of Aging and Physical Activity* 19 (1 Dec. 2022), pp. 1–16. ISSN: 1813-7253. DOI: 10.1186/S11556-022-00283-3/TABLES/2. URL: https://eurapa.biomedcentral.com/articles/10.1186/s11556-022-00283-3 (cit. on p. 3).

[53] H. Singh. *WordPlay VR*. 2018. URL: https://harmeet651.github.io/WordPlay-Vr-Site/index.html (cit. on p. 31).

[54] A. Sinicki. *What is Unity? Everything you need to know - Android Authority*. 2021. URL: https://www.androidauthority.com/what-is-unity-1131558/ (cit. on p. 26).

[55] E. Team. *Apathy in Parkinson's Disease: How to Stay Motivated*. Feb. 2019. URL: https://parkinsonsdisease.net/answers/motivated-dealing-apathy (cit. on pp. 11, 12).

[56] F. Team. *Rehabilitation Gaming System Uses Game Training to Treat Stroke Patients - Fitness Gaming*. Dec. 2014. URL: https://www.fitness-gaming.com/news/health-and-rehab/rehabilitation-gaming-system-uses-game-training-to-treat-stroke-patients.html (cit. on p. 29).

[57] TechTarget. *What is motion gaming (motion-controlled gaming)? - Definition from WhatIs.com*. URL: https://whatis.techtarget.com/definition/motion-gaming-motion-controlled-gaming (cit. on p. 23).

[58] *The Pros And Cons Of Persuasive Technology - 864 Words | Cram*. URL: https://www.cram.com/essay/The-Pros-And-Cons-Of-Persuasive-Technology/PCYJXP4B4MG (cit. on p. 2).

[59] O. B. Tysnes and A. Storstein. "Epidemiology of Parkinson's disease". In: *Journal of neural transmission (Vienna, Austria : 1996)* 124 (8 Aug. 2017), pp. 901–905. ISSN: 1435-1463. DOI: 10.1007/S00702-017-1686-Y. URL: https://pubmed.ncbi.nlm.nih.gov/28150045/ (cit. on pp. 8, 9).

[60] *Unity - Manual: VR overview*. URL: https://docs.unity3d.com/540/Documentation/Manual/VROverview.html (cit. on p. 27).

[61] *What Is Game Development?* URL: https://www.freecodecamp.org/news/what-is-game-development/ (cit. on p. 26).

A

MoveONParkinson Game Prototypes - User Testing Questionnaire

MoveONParkinson - Avaliação física dos Jogos Sérios

Este questionário foi projetado para recolher feedback sobre a experiência obtida pelos participantes ao testar os jogos sérios num espaço físico.

* Indica uma pergunta obrigatória

1. Número de Participante *

2. Idade *

3. Género *

   Marcar apenas uma oval.

   - Masculino
   - Feminino
   - Outro
   - Prefiro não dizer

4. Nível de Escolaridade *

   Marcar apenas uma oval.

   - Ensino Básico
   - Ensino Secundário
   - Licenciatura
   - Mestrado
   - Doutoramento

Domínio do jogo *Soltem a Parede* - Kinect V2

5. Entendi o objetivo do jogo. *

Marcar apenas uma oval.

Discordo Totalmente

1 ⬭
2 ⬭
3 ⬭
4 ⬭
5 ⬭
6 ⬭
7 ⬭

Concordo Totalmente

6. Entendi o mapeamento entre os meus movimentos e os movimentos do boneco. *

Marcar apenas uma oval.

Discordo Totalmente

1 ⬭
2 ⬭
3 ⬭
4 ⬭
5 ⬭
6 ⬭
7 ⬭

Concordo Totalmente

7. Achei possível imitar as posições presentes nas paredes. *

Marcar apenas uma oval.

	Discordo Totalmente
1	◯
2	◯
3	◯
4	◯
5	◯
6	◯
7	◯
	Concordo Totalmente

8. Achei a presença do terapeuta virtual encorajadora. *

Marcar apenas uma oval.

	Discordo Totalmente
1	◯
2	◯
3	◯
4	◯
5	◯
6	◯
7	◯
	Concordo Totalmente

9. Achei o jogo adequado para a fisioterapia. *

Marcar apenas uma oval.

Discordo Totalmente
1 ◯
2 ◯
3 ◯
4 ◯
5 ◯
6 ◯
7 ◯
Concordo Totalmente

Domínio do jogo *Organizar as Frutas* - Oculus Quest 2

10. Entendi o objetivo do jogo. *

Marcar apenas uma oval.

Discordo Totalmente
1 ◯
2 ◯
3 ◯
4 ◯
5 ◯
6 ◯
7 ◯
Concordo Totalmente

11. Entendi o mapeamento entre o movimento das minhas mãos e o comportamento das mãos virtuais. *

Marcar apenas uma oval.

Discordo Totalmente
1 ⬭
2 ⬭
3 ⬭
4 ⬭
5 ⬭
6 ⬭
7 ⬭
Concordo Totalmente

12. Achei os movimentos necessários para alcançar os objetos adequados. *

Marcar apenas uma oval.

Discordo Totalmente
1 ⬭
2 ⬭
3 ⬭
4 ⬭
5 ⬭
6 ⬭
7 ⬭
Concordo Totalmente

13. Achei o jogo adequado para a fisioterapia. *

Marcar apenas uma oval.

	Discordo Totalmente
1	⬭
2	⬭
3	⬭
4	⬭
5	⬭
6	⬭
7	⬭
	Concordo Totalmente

System Usability Scale (SUS) do jogo *Soltem a Parede* - Kinect V2

14. Acho que gostaria de jogar este jogo com frequência. *

Marcar apenas uma oval.

	Discordo Totalmente
1	⬭
2	⬭
3	⬭
4	⬭
5	⬭
6	⬭
7	⬭
	Concordo Totalmente

15. Considerei o jogo mais complexo do que necessário. *

Marcar apenas uma oval.

Discordo Totalmente

1 ◯
2 ◯
3 ◯
4 ◯
5 ◯
6 ◯
7 ◯

Concordo Totalmente

16. Achei o jogo fácil de jogar. *

Marcar apenas uma oval.

Discordo Totalmente

1 ◯
2 ◯
3 ◯
4 ◯
5 ◯
6 ◯
7 ◯

Concordo Totalmente

17. Acho que necessitaria de ajuda de um técnico para conseguir jogar este jogo. *

Marcar apenas uma oval.

	Discordo Totalmente
1	◯
2	◯
3	◯
4	◯
5	◯
6	◯
7	◯
	Concordo Totalmente

18. Considerei que as várias funcionalidades deste jogo estavam bem integradas. *

Marcar apenas uma oval.

	Discordo Totalmente
1	◯
2	◯
3	◯
4	◯
5	◯
6	◯
7	◯
	Concordo Totalmente

19. Achei que este jogo tinha muitas inconsistências. *

Marcar apenas uma oval.

Discordo Totalmente

1 ◯

2 ◯

3 ◯

4 ◯

5 ◯

6 ◯

7 ◯

Concordo Totalmente

20. Suponho que a maioria das pessoas aprenderia a jogar rapidamente este jogo. *

Marcar apenas uma oval.

Discordo Totalmente

1 ◯

2 ◯

3 ◯

4 ◯

5 ◯

6 ◯

7 ◯

Concordo Totalmente

21. Considerei o jogo muito complicado de jogar. *

Marcar apenas uma oval.

	Discordo Totalmente
1	◯
2	◯
3	◯
4	◯
5	◯
6	◯
7	◯
	Concordo Totalmente

22. Senti-me muito confiante a jogar este jogo. *

Marcar apenas uma oval.

	Discordo Totalmente
1	◯
2	◯
3	◯
4	◯
5	◯
6	◯
7	◯
	Concordo Totalmente

23. Tive que aprender muito antes de conseguir lidar com este jogo. *

Marcar apenas uma oval.

	Discordo Totalmente
1	⬭
2	⬭
3	⬭
4	⬭
5	⬭
6	⬭
7	⬭
	Concordo Totalmente

System Usability Scale (SUS) do jogo *Organizar as Frutas* - Oculus Quest 2

24. Acho que gostaria de jogar este jogo com frequência. *

Marcar apenas uma oval.

	Discordo Totalmente
1	⬭
2	⬭
3	⬭
4	⬭
5	⬭
6	⬭
7	⬭
	Concordo Totalmente

25. Considerei o jogo mais complexo do que necessário. *

Marcar apenas uma oval.

Discordo Totalmente
1 ◯
2 ◯
3 ◯
4 ◯
5 ◯
6 ◯
7 ◯
Concordo Totalmente

26. Achei o jogo fácil de jogar. *

Marcar apenas uma oval.

Discordo Totalmente
1 ◯
2 ◯
3 ◯
4 ◯
5 ◯
6 ◯
7 ◯
Concordo Totalmente

27. Acho que necessitaria de ajuda de um técnico para conseguir jogar este jogo. *

Marcar apenas uma oval.

	Discordo Totalmente
1	◯
2	◯
3	◯
4	◯
5	◯
6	◯
7	◯
	Concordo Totalmente

28. Considerei que as várias funcionalidades deste jogo estavam bem integradas. *

Marcar apenas uma oval.

	Discordo Totalmente
1	◯
2	◯
3	◯
4	◯
5	◯
6	◯
7	◯
	Concordo Totalmente

29. Achei que este jogo tinha muitas inconsistências. *

Marcar apenas uma oval.

Discordo Totalmente	
1	◯
2	◯
3	◯
4	◯
5	◯
6	◯
7	◯
Concordo Totalmente	

30. Suponho que a maioria das pessoas aprenderia a jogar rapidamente este jogo. *

Marcar apenas uma oval.

Discordo Totalmente	
1	◯
2	◯
3	◯
4	◯
5	◯
6	◯
7	◯
Concordo Totalmente	

31. Considerei o jogo muito complicado de jogar. *

Marcar apenas uma oval.

	Discordo Totalmente
1	◯
2	◯
3	◯
4	◯
5	◯
6	◯
7	◯
	Concordo Totalmente

32. Senti-me muito confiante a jogar este jogo. *

Marcar apenas uma oval.

	Discordo Totalmente
1	◯
2	◯
3	◯
4	◯
5	◯
6	◯
7	◯
	Concordo Totalmente

33. Tive que aprender muito antes de conseguir lidar com este jogo. *

Marcar apenas uma oval.

Discordo Totalmente
1 ⬭
2 ⬭
3 ⬭
4 ⬭
5 ⬭
6 ⬭
7 ⬭
Concordo Totalmente

Feedback

34. Sugestões e/ou aspetos a melhorar

NASA Task Load do jogo *Soltem a Parede* - Kinect V2

NASA Task Load Index Questionnaire

Figure 8.6

NASA Task Load Index

Hart and Staveland's NASA Task Load Index (TLX) method assesses work load on five 7-point scales. Increments of high, medium and low estimates for each point result in 21 gradations on the scales.

Name	Task	Date

Mental Demand — How mentally demanding was the task?

Very Low — Very High

Physical Demand — How physically demanding was the task?

Very Low — Very High

Temporal Demand — How hurried or rushed was the pace of the task?

Very Low — Very High

Performance — How successful were you in accomplishing what you were asked to do?

Perfect — Failure

Effort — How hard did you have to work to accomplish your level of performance?

Very Low — Very High

Frustration — How insecure, discouraged, irritated, stressed, and annoyed wereyou?

Very Low — Very High