Instituto Politécnico de Setúbal
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Enhancing Engagement in a mHealth Solution to Improve Exercise Adherence for Parkinson's Disease Self-Management

Master of Science in **Software Engineering**

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If you're going through hell,
keep going.

Sir Winston Churchill

Prime Minister of the United Kingdom

Resumo

Esta dissertação explora como uma aplicação mobile health (mHealth) pode apoiar a adesão ao exercício físico e a auto-gestão para pessoas com Doença de Parkinson (DP). Sendo uma doença neurodegenerativa progressiva, a DP afeta tanto as funções motoras como não-motoras, exigindo estratégias de gestão abrangentes. O exercício desempenha um papel importante na gestão dos sintomas da DP, embora muitos pacientes enfrentem dificuldades em aderir aos programas de exercício prescritos. O estudo investiga como a teoria da motivação, a tecnologia de sensores e a monitorização remota podem ser integradas numa solução personalizada de mHealth para melhorar a experiência geral com vista a um maior envolvimento do utilizador.

A investigação faz parte do projeto MoveONParkinson, desenvolvido em colaboração com a Associação Portuguesa de Doentes de Parkinson (APDPk), abordando as necessidades das pessoas com DP. A aplicação mHealth, ONParkinson, promove a usabilidade e acessibilidade enquanto fornece ferramentas de auto-gestão para apoiar a adesão à prática de exercício. Através da monitorização remota, os professionais de saúde podem personalizar os programas de exercício de acordo com as necessidades individuais dos pacientes, conduzindo a uma gestão mais eficaz da doença. O estudo também examina como os dados recolhidos pela aplicação podem ser aproveitados para fornecer reforço positivo, melhorando a motivação e o envolvimento do utilizador.

Esta dissertação apresenta quatro contribuições principais: (1) a identificação e aplicação de princípios de design para melhorar a usabilidade e acessibilidade em aplicações de mHealth para indivíduos com DP; (2) o desenvolvimento de um modelo motivacional baseado na teoria da influência e na teoria da autodeterminação, para apoiar o envolvimento sustentado do utilizador e a adesão ao exercício; (3) uma proposta para a integração da tecnologia de sensores para monitorizar a atividade física e fornecer feedback em tempo real, melhorando a monitorização remota e o cuidado personalizado; e (4) a criação do protótipo ONParkinson aplicando as contribuições anteriores.

Os testes preliminares que avaliaram a usabilidade e acessibilidade do protótipo produziram resultados positivos. Os participantes mostraram uma forte disposição para usar a aplicação com mais frequência, sugerindo o seu potencial utilitário na gestão da DP e na sua integração nas rotinas diárias. O trabalho futuro deve focar-se na incorporação da tecnologia de sensores para apoiar a estratégia motivacional proposta, expandir os testes para um maior e mais diversificado grupo de participantes e examinar os efeitos a longo prazo do uso consistente da aplicação.

Keywords: Adesão ao Exercício, Acessibilidade, Doença de Parkinson, Experiência do Utilizador, Gestão de Sintomas, Monitorização Remota, Teoria da Motivação, Tecnologias de Sensores, Usabilidade, mHealth

Abstract

This dissertation explores how a mobile health (mHealth) application can support exercise adherence and self-management for people with Parkinson's Disease (PD). As a progressive neurodegenerative disorder, PD affects both motor and non-motor functions, requiring broad management strategies. Exercise plays an important role in managing PD symptoms, though many patients encounter difficulties adhering to prescribed exercise programs. The study investigates how motivation theory, sensor technology and remote monitoring can be integrated into a personalized mHealth solution to improve user engagement and the overall experience.

The research is part of the MoveONParkinson project, developed in collaboration with the Associação Portuguesa de Doentes de Parkinson (APDPk), addressing the needs of people with PD. The mHealth app, ONParkinson, emphasizes usability and accessibility while providing self-management tools to support exercise adherence. Through remote monitoring, Healthcare Professionals (HCPs) can personalize exercise programs to meet patients' individual needs, leading to more effective disease management. The study also examines how data collected by the app can be leveraged to provide positive reinforcement, improving user motivation and engagement.

This dissertation presents four main contributions: (1) identify and apply existing design principles to improve usability and accessibility in mHealth applications for individuals with PD; (2) the development of a motivational model based on the Self-Determination Theory (SDT) and the Theory of Influence (ToI), aimed at supporting sustained user engagement and exercise adherence; (3) a proposal for integrating sensor technology to monitor physical activity and provide real-time feedback, enhancing remote monitoring and personalized care; and (4) the creation of the ONParkinson prototype applying the previous contributions.

A preliminary assessment evaluating the usability and accessibility of the prototype yielded positive outcomes. Participants showed a strong willingness to use the app more frequently, suggesting its potential utility in managing PD and integrating it into daily routines. Future work should incorporate sensor technology to support the proposed motivational strategy, expand tests to a larger and more diverse participant pool, and examine the long-term effects of consistent app usage.

Keywords: Accessibility, Exercise Adherence, Motivation Theory, Parkinson's Disease, Remote Monitoring, Self-Management, Sensor Technologies, Usability, User Engagement, User Experience, mHealth

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Acronyms

APDPk Associação Portuguesa de Doentes de Parkinson. 2, 47, 78, 84, III

ARIA Accessible Rich Internet Applications. *Glossary:* ARIA

DIP Device-Independent Pixels. 48

ECG Electrocardiogram. 14, 15, *Glossary:* Electrocardiogram

EMG Electromyography. 14, 15, *Glossary:* Electromyography

ESS Escola Superior de Saúde. 2

ESSCVP Escola Superior de Saúde - Cruz Vermelha Portuguesa. 78

EST Escola Superior de Tecnologia. 2

EU European Union. 30

FAQ Frequently Asked Questions. 58

HCI Human-Computer Interaction. *Glossary:* Human-Computer Interaction

HCP Healthcare Professional. 1, 2, 4, 9–12, 15, 17, 32, 34, 35, 37–40, 42–47, 50–56, 58, 60–63, 70, 76, 83, 86, III, VIII

ICT Information and Communications Technology. 2

IPS Instituto Politécnico de Setúbal. 2, 54

MDS Movement Disorder Society. 10

mHealth Mobile Health. 1–6, 9, 10, 37, 43, 45, 83, 85, II, III, *Glossary:* mHealth

MS Motor Score. 32

PD Parkinson's Disease. 1–13, 15–26, 29, 30, 32–35, 37, 38, 41–44, 47–49, 51, 53, 55, 56, 58, 59, 64, 70, 71, 75, 76, 78, 79, 81–86, III, *Glossary:* Parkinson's Disease

PGS Personalized Game Suite. 30–32, VI

SDT Self-Determination Theory. 3, 27, 29, 50, 83, III

SN Substantia Nigra. 6, *Glossary:* Substantia Nigra

ToI Theory of Influence. 3, 27, 28, 50, 83, III

UI User Interface. 34, 38, 64

UN United Nations. 21

UNSW University of New South Wales. 33

UPDRS Borg Rating of Perceived Exertion. 62, *Glossary:* Borg Rating of Perceived Exertion

UPDRS Unified Parkinson's Disease Rating Scale. *Glossary:* Unified Parkinson's Disease Rating Scale

VR Virtual Reality. 41

WHO World Health Organization. 21

Glossary

Abstract concepts refer to the cognitive ability to think beyond directly observable information and engage with ideas, theories and principles that are not immediately tangible. Thinking beyond existing knowledge, allows the creation of solutions that aren't immediately obvious. Essential in problem-solving, decision-making and critical thinking. 25

Accelerometry is a method used to measure acceleration or change in velocity of an object in three-dimensional space. In the context of healthcare and wearable devices, accelerometers are sensors that detect and measure the acceleration of bodily movements. They are commonly used to monitor and assess physical activity levels, quantify movement patterns and evaluate postural changes. 15

Age of onset is the age at which an individual acquires, develops or first experiences a condition or symptoms of a disease or disorder. 25

Android is a mobile operating system based on a modified version of the Linux kernel and other open source software, designed primarily for touchscreen mobile devices such as smartphones and tablets. 30, 38, 47

Apathy is a lack of feeling, emotion, interest or concern about something. 7, 41

Autonomic dysfunction refers to a group of conditions that occur when the autonomic nervous system (ANS) does not work properly. The ANS controls the involuntary functions of the body, such as heart rate, blood pressure, digestion and temperature regulation. 7

Biomechanical data refers to quantitative measurements and analyses of the mechanical properties and movements of living organisms, particularly humans. Biomechanical data encompasses a wide range of parameters, such as forces, pressures, angles, velocities, accelerations and displacements, that provide insights into the mechanics and dynamics of human movement and function. 15

Biomechanics is the study of how our body moves and how different parts like muscles, bones and joints work together to create movement. It helps us understand how we walk, run, lift things and maintain balance. When it comes to Parkinson's disease, biomechanics looks at how the disease affects a person's ability to move. 84

Bitwise are operations that directly manipulate the individual bits (binary digits) of numbers. Common bitwise operations include AND, OR, XOR (exclusive OR), NOT (inversion) and bit shifts (moving bits left or right). 74

Bluetooth is a wireless technology standard used for exchanging data over short distances (usually up to 30 feet) between electronic devices. 45, 52, 73

Borg Rating of Perceived Exertion is a scale used to measure the intensity of exercise, based on an individual's personal perception of effort and exertion during physical activity. 62

Bradykinesia means slowness of movement and it is one of the cardinal symptoms of Parkinson's Disease. 1, 7, 11, 22, 35, 48

Bradyphrenia is a medical term for slowed thinking and processing of information. It's sometimes referred to as mild cognitive impairment. 25

Brisk walking is walking quickly in a way that increases your heart rate and breathing. It's faster than a slow walk but you can still talk while doing it. 9

Cadence refers to the rate or rhythm of an activity or movement, particularly in the context of physical activities such as running, cycling or walking. It is often described as the number of steps, pedal revolutions or strides per minute. 14

Conversational agent is a software program designed to interact with users through natural language, simulating human conversation. These agents can be voice-activated or text-based and are often powered by artificial intelligence and natural language processing techniques. 64

Cross-sectional studies are observational studies that analyze data from a population at a single point in time. 84

Cue is something serving as a signal or suggestion. 9

Dance movement therapy is a therapeutic form of treatment that integrates psychological concepts with movement and dance to improve mental, emotional, physical and social well-being. It is based on the interconnectedness of movement and emotion, using body movement as a means of expression and communication, especially when verbal articulation is challenging. 9

Dart is a programming language created by Google, mainly used for building web and mobile apps. It's the language used in the Flutter framework to create apps that work on different platforms like Android, iOS and the web. 38

Data Science is an interdisciplinary field that involves extracting insights and knowledge from data using various techniques, tools and algorithms. It combines aspects of statistics, computer science, mathematics and domain expertise to analyze and interpret complex data sets. 84

Deep Brain Stimulation is a medical procedure where electrodes are implanted in specific areas of the brain to deliver electrical impulses. These impulses regulate abnormal brain activity and are used to treat neurological conditions such as Parkinson's disease. 1

Dopamine is a neurotransmitter in the brain that regulates movement, mood, motivation and the brain's reward system. In the context of disorders like Parkinson's disease, dopamine deficiency affects motor control, leading to symptoms such as tremors and rigidity. 1, 6, 8

Dopaminergic neurons of the midbrain are the main source of dopamine in the mammalian central nervous system. These dopaminergic neurons play an important role in the control of multiple brain functions including voluntary movement and a broad array of behavioral processes such as mood, reward, addiction and stress. 1, 6, 8

Dyskinesia are involuntary, erratic, writhing movements of the face, arms, legs or trunk. 11, 23, 26, 34

Dystonia is a movement disorder in which your muscles contract involuntarily, causing repetitive or twisting movements. 6

eHealth is an emerging field referring to health services and information delivered or enhanced through the Internet and related technologies. 9, 27, 47, 50

Electrocardiogram is a medical test that records the electrical activity of the heart. It is a common diagnostic tool used to evaluate the heart's rhythm and detect any abnormalities in the heart's electrical signals. 14

Electrodermal activity is a physiological response that reflects changes in the electrical conductance of the skin's surface due to changes in sweat gland activity. This response is regulated by the autonomic nervous system, which is responsible for controlling involuntary bodily functions. When an individual experiences emotional or physiological arousal, such as stress, anxiety, excitement or fear, the autonomic nervous system triggers changes in sweat gland activity. This leads to changes in the skin's electrical conductance, which can be measured using electrodes placed on the skin's surface. The resulting electrodermal activity is typically recorded as a continuous signal that varies over time. 15

Electromyography is a medical test that measures the electrical activity of muscles. It is used to evaluate the health and function of muscles and the nerves that control them. 14

Festination corresponds to a tendency to speed up when performing repetitive movements. 24

Flutter is an open-source UI (User Interface) software development toolkit created by Google. It is designed for building natively compiled applications for mobile, web and desktop from a single codebase. 38, 47

Gait is the manner or style of walking. 9, 11, 12, 14–16, 18, 24, 54

Gamification is the application of game elements and mechanics in non-game contexts to engage and motivate individuals, encouraging participation and behavior change. It involves incorporating elements such as challenges, rewards, leaderboards and progress tracking to make tasks or activities more enjoyable and stimulating, ultimately increasing user engagement and motivation. 33, 38, 41, 58, 68

Hypertrophy refers to the increase in size of an organism or a specific tissue or organ, primarily through the growth of its cells. In a biological or medical context, it often describes the enlargement of muscles (muscle hypertrophy) which occurs as a result of physical exercise, particularly strength training. 59

Hypophonia is soft speech, especially resulting from a lack of coordination in the vocal musculature. 7

Hyposmia is a decreased sense of smell or a decreased ability to detect odors through your nose. 7

iOS is a mobile operating system created and developed by Apple Inc. exclusively for its hardware. 38, 47

Material Design is a design system created by Google that offers guidelines for building user-friendly interfaces. It focuses on making apps look clean and consistent by using simple elements like buttons, menus and colors. Material Design also ensures that apps are easy to use for everyone, including people with disabilities. 38

mHealth is an abbreviation for mobile health, a term used for the practice of medicine and public health supported by mobile devices. 1, 6, 37, 83, II, III

Natural language processing is a part of artificial intelligence that helps computers understand and work with human languages. It includes tasks like translating languages, recognizing speech and analyzing the feelings in text. 85

Neurodegenerative refers to the gradual loss of function or death of nerve cells (neurons) in the brain or nervous system. 1, 2, 6, III

Neuroplasticity is a process by which the brain encodes experiences and learns new behaviors and is defined as the modification of existing neural networks by adding or modifying synapses in response to changes in behavior or environment, that encompasses exercise. 8

Neurotrophic factors are molecules that enhance the growth and survival potential of neurons. They play important roles in both development, where they can act as guidance cues for developing neurons and in the mature nervous system, where they are involved in neuronal survival, synaptic plasticity and the formation of long-lasting memories. 8

Noise reduction is the process of minimizing or eliminating unwanted or irrelevant data to enhance the quality of the information you want to extract. 20

Normalization is a data preprocessing method aimed at bringing different data features or variables to a common scale, ensuring they have similar ranges, so that they can be more fairly compared or used together in analyses. 20

Orthostatic hypotension is a sudden drop in blood pressure when an individual stands from a seated or prone (lying down) position. 7

Osteoporosis is a bone disease that occurs when the body loses too much bone, makes too little bone or both. As a result, bones become weak and may break from a fall or, in serious cases, from sneezing or minor bumps. 9

Outlier handling is a process used in data analysis and statistics to identify, manage or mitigate outliers within a dataset. Outliers are data points that significantly deviate from the majority of the data and can distort statistical analyses and modeling. 20

Parkinson's Disease is a neurodegenerative disorder in which parts of the brain become progressively damaged over many years. Common symptoms include involuntary shaking of particular parts of the body (tremor), slow movement, stiffness and inflexible muscles. 1, 6, 37, 58, 83, III

Personal digital assistant is a handheld electronic device designed to provide various functionalities to assist individuals in managing personal information and tasks. 9

Persuasive technology is a field of study that focuses on the development, design and implementation of technology aimed at changing users' attitudes or behaviors in a predetermined way, typically without coercion or deception. Rooted in principles of psychology and behavioral science, it explores how digital and interactive technologies can be structured to influence people's decisions, habits and perceptions. 58, 65, 83

Physiological data refers to measurements and recordings of various physiological parameters and processes in the human body. These parameters include vital signs such as heart rate, blood pressure, respiratory rate, body temperature, as well as other physiological signals like electrocardiogram (ECG), electroencephalogram (EEG), electromyogram (EMG) and many others. 14, 15, 38, 62, 85

Psychosis is characterized as disruptions to a person's thoughts and perceptions that make it difficult for them to recognize what is real and what isn't. 7

Rapid eye movement sleep behavior disorder is a condition where people act out their dreams. These dreams are usually vivid and can involve talking, shouting or moving around. 7

Sialorrhea also known as hypersalivation or drooling, means excessive saliva flow. 7

Sleep-maintenance insomnia is difficulty staying asleep or waking too early and struggling to get back to sleep. 7

Spike is, in software development, a type of experiment or research activity undertaken to explore a specific technology, feature or problem. The purpose of a spike is to gather information and reduce uncertainty in a project by building a prototype or conducting a feasibility study. 5, 45, 52

Structural adaptations are physical features of an organism that enable them to survive in their environment. 8

Substantia Nigra is a part of the brain located in the midbrain, rich in dopamine-producing neurons, which are critical for regulating movement and coordination. Degeneration of these neurons is a hallmark of Parkinson's disease, leading to the characteristic motor symptoms such as tremors, stiffness and slow movement. The name Substantia Nigra means "black substance" in Latin. It got this name because the cells in this part of the brain appear darker than nearby areas due to a pigment called neuromelanin. 6

Synaptic plasticity is the ability of neurons to bring about changes in the connections between neuronal networks in response to use or disuse. 8

Telemedicine refers to the use of telecommunications technology to provide remote medical services and healthcare consultations. It involves the exchange of medical information between patients and healthcare professionals who are physically separated, allowing for the diagnosis, treatment and management of various health conditions from a distance. 12

Visuospatial function refers to cognitive processes necessary to identify visual and spatial relationships among objects. Visuospatial ability is measured in terms of the ability to imagine objects, to make global shapes by locating small components or to understand the differences and similarities between objects. 7

Chapter 1

Introduction

Parkinson's Disease (PD) is a progressive and chronic neurodegenerative disorder that affects millions globally [1], primarily manifesting as a movement disorder with both motor and non-motor symptoms. It is characterized by the death of dopaminergic neurons in the brain, leading to symptoms such as tremors, rigidity, bradykinesia and postural instability. These symptoms impair an individual's ability to perform daily tasks and significantly impact their quality of life. In addition to motor impairments, people with PD also experience non-motor symptoms, adding complexity to disease management.

Standard medical interventions often encompass pharmacological treatments, including dopamine replacement therapies, and surgical options such as deep brain stimulation. While these treatments primarily aim to manage symptoms, they do not stop the progression of the disease and their effectiveness can diminish over time or may not be suitable for everyone [2]. As a result, complementary therapies are often integrated, with exercise becoming a central part of PD management.

Exercise benefits individuals with PD, including improvements in mobility, balance and overall well-being [3]. However, the impact of exercise depends on consistent adherence to exercise programs, which can be difficult. Many individuals with PD face challenges like depression and fatigue that hinder motivation and engagement in exercise programs [4].

Mobile health (mHealth) offers a potential solution to help individuals with PD manage symptoms and stay on track with exercise programs. Mobile apps and wearable technologies allow real-time tracking of motor symptoms, providing insights into disease progression and treatment effectiveness for both patients and Healthcare Professionals (HCPs). Additionally, mHealth platforms can deliver personalized exercise programs, monitor adherence and offer motivational feedback to support continued participation [5].

1.1 Motivation

The motivation for this research stems from the need to support people with PD by increasing their engagement and motivation in managing their condition.

PD is a progressive neurodegenerative disorder that significantly impacts both motor and non-motor functions, reducing patients' quality of life and ability to perform daily activities. While exercise has proven benefits in managing PD symptoms, enhancing mobility, balance, and overall well-being, adherence to exercise programs remains a major challenge for patients due to barriers such as low motivation, fatigue, and lack of personalized support. Current mHealth applications designed for PD self-management often lack adequate motivational components and tailored feedback systems to engage users consistently over time. This gap highlights the need for a comprehensive mHealth solution that integrates motivational theory, sensor technology, and personalized feedback to support sustained exercise adherence and self-management for PD patients.

mHealth offers the potential to improve self-management for individuals with PD by providing tools for continuous monitoring and daily management. These platforms can deliver personalized reminders and adaptive exercise programs using real-time data, helping patients follow their treatment plans and promoting sustained engagement in the self-management of PD.

1.2 Context Description

The MoveONParkinson project emerged from the collaboration between researchers from the Escola Superior de Tecnologia (EST) and Escola Superior de Saúde (ESS) of Instituto Politécnico de Setúbal (IPS), in partnership with the Associação Portuguesa de Doentes de Parkinson (APDPk), to address the needs of a triad consisting of people with PD, caregivers and HCPs. The project focuses on developing Information and Communications Technology (ICT) methods, models and tools that support the self-management of PD, using technological advancements to improve disease management within the triad [6, 7].

The project features a web platform designed for HCPs and a mobile app for patients and caregivers. The web component allows HCPs to create personalised exercise programs for patients. The mobile app, called ONParkinson, provides information about PD and helps patients follow their prescribed exercise programs.

This dissertation focused on designing an mHealth solution for people with PD, aiming to enhance user engagement, motivation and confidence in managing their condition. It applies design principles to influence these factors, with the goal of improving the ONParkinson prototype, which serves as the foundation for future development and testing.

1.3 Objectives

This thesis aimed to develop and evaluate a mHealth solution designed to improve exercise adherence and support self-management among individuals with PD. Specifically, this research pursued the following objectives.

Identify and Utilize Design Principles: Leverage existing design principles focused on enhancing usability, accessibility, and patient engagement in mHealth applications for individuals with PD.

Develop a Motivational Framework: Create a motivational model to foster sustained user engagement. This framework will focus on addressing the psychological needs of PD patients, incorporating features that support motivation, exercise adherence, and consistent self-management.

Integrate Sensor Technologies: Propose and implement sensor technology solutions within the mHealth application to enable real-time monitoring of physical activity, provide immediate feedback, and enhance the personalized nature of exercise programs. This integration aims to empower patients and healthcare professionals with accurate, actionable insights on patient progress and adherence.

Develop and Test the ONParkinson Prototype: Build a functional prototype of the ONParkinson mHealth application based on identified design principles, the motivational framework, and sensor integration. This prototype will be designed specifically for PD self-management, addressing accessibility and usability issues to better accommodate PD-related motor and cognitive impairments.

Evaluate Usability and Engagement Outcomes: Conduct preliminary user testing to evaluate the ONParkinson prototype's usability, accessibility, and potential impact on user motivation and engagement. If possible, it will assess the app's effectiveness in promoting exercise adherence, gathering feedback to guide future refinements and development.

1.4 Contributions

Following the general objectives, this dissertation's research has led to the following contributions:

- **Identification of Design Principles for mHealth Applications:** The research identified and utilized existing design principles to improve usability and accessibility in mHealth applications for individuals with PD;
- **Motivational Model Based on the Self-Determination Theory (SDT) and the Theory of Influence (ToI):** A motivational model was developed, based on the SDT and the ToI. This model aims to promote sustained user engagement and adherence to exercise programs by addressing psychological needs, enhancing motivation and incorporating persuasive technology to deliver reminders and feedback;

- **Sensor Technology Integration Proposal:** The research examined the potential of devices with integrated sensors to monitor physical activity, providing real-time feedback to both patients and HCPs. The goal was to improve adherence to exercise programs and support remote monitoring for more personalized care;
- **ONParkinson Prototype Development:** The study resulted in the development of the ONParkinson mHealth application, designed to support individuals with PD. The prototype was made to address usability and accessibility challenges, accommodating the motor and cognitive difficulties associated with the condition. Testing showed positive outcomes in terms of usability and engagement potential.

Moreover, part of the research was published in:

- **Frontiers in Public Health journal**, under the full paper "MoveONParkinson: developing a personalized motivational solution for Parkinson's disease management" [8].

1.5 Structure of the Thesis

- **Chapter 1 (Introduction)**

  This chapter outlines the research problem, focusing on the impact of PD and the need for mHealth solutions to improve exercise adherence. It covers the motivation, research objectives and contributions of the study.

- **Chapter 2 (Research Context and Theoretical Foundations)**

  This chapter reviews the relevant literature and concepts for the study. It provides an overview of PD, the role of exercise in its management, mHealth technologies, sensor integration for patient monitoring and existing mobile applications for PD.

- **Chapter 3 (The User Engagement Solution)**

  This chapter details the design and development of a user engagement solution for mHealth applications. It explains the system architecture, integration of sensor technologies and how the solution addresses user needs and accessibility for managing PD.

- **Chapter 4 (Results and Evaluation)**

  This chapter presents the exercise module interfaces of the prototype, along with the interfaces and notifications aimed at improving user engagement and motivation. It includes a spike on the integration of sensor technologies and a study evaluating how patients with PD interacted with ONParkinson to assess the app's usability.

- **Chapter 5 (Conclusions and Future Work)**

  The final chapter summarizes the study's key contributions, discusses the research limitations and potential areas for future work.

Chapter 2

Research Context and Theoretical Foundations

This chapter provides the necessary background and theoretical framework for the study. It explores important concepts related to Parkinson's Disease (PD), the role of exercise in its management and the emerging field of mobile health (mHealth). Additionally, it covers the use of sensor technologies for monitoring and managing PD, the application of engagement and motivation strategies, the importance of usability and digital accessibility and a review of existing mobile applications for PD exercise.

2.1 Parkinson's Disease (PD) Overview

PD is a progressive neurodegenerative disease first described by James Parkinson in his 1817 publication, "Essay on the Shaking Palsy" [9]. PD is the second most common neurodegenerative disorder [10], affecting around 10 million people worldwide [1].

PD is caused by the death of dopaminergic neurons in the Substantia Nigra (SN) [11]. The SN plays a role in brain function, including eye movement, motor planning, reward-seeking, learning and addiction [12]. These neurons produce dopamine, a chemical that acts as a messenger between parts of the brain and nervous system to help control body movements. When these nerve cells die or become damaged, the amount of dopamine decreases, causing impaired movement. Symptoms of PD typically appear after around 80% of the nerve cells in the SN have been lost [13].

Symptoms

PD causes motor and nonmotor symptoms [11, 14, 15]. Motor symptoms include:

- **Tremors**: Shaking that usually starts in the hand or arm, often when the limb is at rest;
- **Stiffness**: Muscle tension that restricts movement and facial expressions, sometimes causing painful cramps (dystonia);

- **Slowness (bradykinesia)**: Slowed movements that make daily tasks harder and can cause a slow, shuffling walk;
- **Imbalance**: Difficulty maintaining or changing postures, affecting walking or standing.

Nonmotor symptoms include:

- **Olfactory loss**: Decreased or absent sense of smell (hyposmia);
- **Sleep dysfunction**: Rapid eye movement sleep behavior disorder, daytime sleepiness and sleep-maintenance insomnia;
- **Autonomic dysfunction**: Issues such as constipation, delayed gastric emptying, urinary urgency and frequency, erectile dysfunction, orthostatic hypotension and blood pressure variability;
- **Psychiatric disturbances**: Depression, anxiety, apathy and psychosis;
- **Cognitive impairment**: Ranges from mild cognitive impairment to dementia, often involving difficulties in attention, executive function and visuospatial function;
- **Other**: Fatigue, hypophonia, sialorrhea and trouble swallowing.

Risk factors

Risk factors associated with PD [10, 11, 16] include:

- **Age**: PD usually starts in middle or late life, with risk increasing with age;
- **Heredity**: Having close relatives with PD may increase the likelihood of developing it;
- **Sex**: Men are more likely than women to develop PD;
- **Head trauma**: Blows to the head may raise the risk of PD;
- **Environmental causes**: Exposure to chemicals and pollutants, including pesticides, herbicides, solvents and metals, may contribute to the risk.

2.2 Importance of Exercise in Parkinson's Disease Management

PD currently has no cure, as existing therapies are unable to stop or reverse its progression. There is no standardized treatment; instead, treatment is personalised to each individual's symptoms [17]. The primary approach to managing PD involves medication and surgical therapy, with most patients receiving medications to alleviate symptoms. Complementary treatments, such as lifestyle adjustments that include rest and exercise, are also recommended [18].

For individuals with PD, maintaining relationship-related goals with partners and family is a priority. Activities that support life goals and prevent derailment are important for mood function and health-related quality of life. To enhance well-being, activities that improve social networks and promote interaction are important [19].

Exercise, a subcategory of physical activity, includes planned, structured and repetitive activities aimed at improving physical fitness [20]. Research highlights the benefits of exercise for neuroplasticity and the brain's ability to repair itself. These benefits are linked to the release of neurotrophic factors and increased cerebral oxygenation, promoting cell growth and survival. In PD, exercise has been shown to stimulate dopamine production in remaining dopaminergic neurons, helping to alleviate symptoms. Five key principles of exercise enhance neuroplasticity in PD [21]:

- Intensive activity maximizes synaptic plasticity;
- Complex activities promote greater structural adaptations;
- Rewarding activities increase dopamine levels and promote learning or relearning;
- Dopaminergic neurons are highly responsive to exercise and inactivity;
- Early introduction of exercise in the disease progression may slow its progression.

Exercise is important for overall health and, in the context of PD, vital for maintaining balance, mobility and daily activities [22]. Psychological benefits also exist, as exercise can give a sense of control over the condition. Paired with proper medication, exercise can enhance quality of life and help maintain independence. A personalized exercise program based on individual abilities and needs is crucial [23].

Types of Exercises

Selecting appropriate activities is important. Overly strenuous or uncomfortable activities can discourage participation and may be harmful. Consultation with medical professionals is essential to develop a safe and appropriate exercise program [23]. An effective program may include [24, 25, 26, 27]:

- **Flexibility Exercises (Stretching)**: Maintain joint flexibility and reduce stiffness;

- **Strengthening Exercises**: Build and maintain muscle strength, preventing muscle weakening;
- **Weight-bearing Exercises**: Activities like running, brisk walking and jumping improve bone health and reduce the risk of osteoporosis;
- **Balance and Fine Movement Control**: Improve balance and hand control;
- **Aerobic Exercise**: Raise heart rate, improve circulation and enhance oxygen delivery;
- **Balance Training**: Address stability, postural adjustments and dynamic stability during gait;
- **Gait Training**: Improve parameters like velocity and stride length;
- **Cueing Strategies**: Use external cues to initiate and sustain movement;
- **Tai Chi**: Improve balance and coordination through controlled movements;
- **Dance movement therapy**: Use movement and dance to enhance emotional, cognitive, physical and social well-being.

Physical activity levels tend to decrease with age and the progression of PD. Individuals with PD often reduce their activity levels more rapidly than healthy individuals [21]. Thus, treatment goals should be regularly reassessed and adjusted by a team of Healthcare Professionals (HCPs) in collaboration with the patient and caregivers [27].

2.3 Mobile Health (mHealth)

mHealth, a subset of eHealth, refers to the use of mobile devices, such as mobile phones, patient monitoring devices and personal digital assistants (PDAs), to support medical practices and public health efforts [28]. The growing integration of these mobile technologies in healthcare has the potential to change the way services are delivered, making them more accessible and efficient. The rise of mHealth aligns with the increasing global use of mobile devices, creating new opportunities for healthcare delivery that were previously not possible.

One of the benefits of mHealth is patient empowerment. By providing tools for self-assessment and remote monitoring, mHealth allows individuals to take a more active role in managing their healthcare. This helps patients monitor their conditions independently, reducing the need for frequent in-person consultations. This is particularly helpful for patients with chronic illnesses, where continuous monitoring and lifestyle adjustments are important to maintaining health. mHealth also supports HCPs by improving the efficiency of patient treatment. Mobile applications allow HCPs to communicate more effectively with patients, track progress and adjust treatment plans as needed. In addition, mHealth encourages healthier lifestyle habits through mobile platforms, helping patients stick to exercise routines and medication schedules [5].

mHealth applications offer a way to extend physical therapy beyond traditional, in-person sessions. By providing remote access to therapeutic exercises, these apps make physical therapy more accessible to a wider population, addressing limitations of reach and scalability in traditional healthcare settings. Some features of mHealth apps include [29]:

- Increased patient engagement through interactive features;
- Real-time data collection and feedback for continuous monitoring;
- Personalized exercise programs based on individual needs;
- Remote progress tracking and reporting to HCPs;
- Ongoing goal setting;
- Real-time feedback for positive behavior changes;
- Regular adjustments to personalized programs;
- Continuous communication with HCPs through messaging features.

The Movement Disorder Society (MDS) Task Force on Technology has emphasized the growing need to integrate mHealth technologies into the routine assessment and management of patients with PD. Given the need for continuous monitoring of motor and non-motor symptoms, remote data collection through mobile and wearable technologies is becoming more important. These tools provide real-time insights into tremors, movement patterns, medication adherence and other relevant metrics, offering HCPs a more complete view of disease progression beyond clinical visits.

Advances in wearability have made continuous data collection feasible and practical for patients and HCPs. These devices can gather detailed information on motor fluctuations and daily activity with minimal disruption to patients' lives, supporting more personalized and responsive care for managing PD.

To optimize these technologies, the MDS Task Force recommends that mHealth solutions should [30]:

- Focus on deficits relevant to patients;
- Use a single device or combination of devices with a favorable benefit-to-burden ratio and provide clinically meaningful data;
- Integrate into patient management platforms, delivering personalized data to patients, caregivers and HCPs;
- Obtain regulatory approval, be incorporated into digital health systems and achieve widespread adoption by healthcare organizations.

2.4 Devices with Integrated Sensors

Devices with integrated sensors are transforming healthcare by enabling continuous monitoring and data collection. For PD, these technologies can provide detailed insights into a patient's movement and specific symptoms such as tremors, freezing of gait, bradykinesia and dyskinesia. This section will explore how sensor technologies can be applied to PD management, their role in patient monitoring and a comparison of devices with integrated sensors. It will also address the distinction between raw sensor data and processed data, highlighting the importance of data analysis in extracting meaningful insights.

2.4.1 Technology for Parkinson's Disease

Technology, particularly sensors, can play an important role in managing PD. Sensors enable continuous, objective monitoring of motor symptoms such as tremor, bradykinesia and rigidity. This real-time tracking is especially valuable for capturing symptom fluctuations throughout the day, which are often missed during periodic clinical visits. It provides HCPs with a more comprehensive view of the patient's condition.

Wearable sensors and mobile devices equipped with accelerometers, gyroscopes and other motion-detection technologies collect real-time data on patient movement patterns. These devices monitor daily activities, detect abnormalities in gait, balance, or postural stability and measure changes in motor performance over time. The collected data can be sent to HCPs or processed using machine learning algorithms to detect trends and variations, allowing for more precise treatment adjustments.

By integrating technology into treatment plans, personalized care can be offered to patients with PD, providing interventions adjusted to individual symptoms and disease progression. In the context of PD, sensors can be used in several ways:

- **Movement Monitoring:** Sensors, such as accelerometers and gyroscopes, track and analyze movement patterns and abnormalities in individuals with PD. This technology facilitates the objective assessment of motor symptoms, leading to more accurate monitoring of disease progression and response to treatment [31];
- **Gait Analysis:** Wearable sensors assess gait characteristics, including stride length, walking speed and balance, which are commonly affected by PD. Detecting abnormal gait patterns early helps identify fall risks and guide interventions to improve mobility and reduce the risk of accidents [32];
- **Medication Management:** Sensors embedded in smart pillboxes or wearable devices track medication adherence by monitoring pill intake. This assists individuals with PD and their caregivers in ensuring timely and accurate medication administration, improving treatment outcomes and symptom management [33];
- **Voice Analysis:** Speech impairment is a common symptom in PD. Voice analysis technologies, including smartphone apps and wearable devices, monitor changes in voice characteristics and detect speech abnormalities. These tools support early detection of speech deterioration and assist in speech therapy interventions [34];

- **Remote Monitoring and Telemedicine:** Remote monitoring systems equipped with sensors enable HCPs to assess patients' symptoms remotely and adjust treatment plans as needed. Telemedicine platforms offer virtual consultations and remote therapy sessions, reducing the need for in-person visits and providing convenient access to healthcare, particularly for individuals with mobility challenges [30].

2.4.2 Monitoring Parkinson's Disease Patients

The integration of sensors and medical devices for remote monitoring can significantly improve the management of PD. These technologies provide HCPs with real-time data on motor function, tremors and other symptoms. Devices like wearable sensors can track movement patterns and detect changes in symptoms throughout the day, offering insights into disease progression. This allows for adjustments to medications and therapies, ensuring treatments are personalised to the patient's evolving condition.

Remote monitoring can expand care for PD patients by allowing observation in their daily environments, reducing reliance on clinic visits. This is particularly helpful for those with mobility challenges, as frequent in-person appointments can be difficult. Continuous access to symptom data enables HCPs to modify treatment plans as needed, addressing fluctuations in the disease more effectively.

Continuous monitoring is particularly valuable in PD, where symptoms like tremors, gait and other motor functions can vary significantly throughout the day. By tracking these changes, HCPs can intervene earlier to prevent worsening symptoms and avoid complications like falls or freezing episodes, which are common in PD.

From a cost-effectiveness perspective, remote monitoring can help reduce healthcare expenses by preventing hospital admissions and minimizing the need for emergency care. Managing the disease efficiently at home helps patients avoid costly interventions, while healthcare systems can allocate resources more effectively. Early intervention and continuous monitoring offer a sustainable approach to managing PD, lessening the personal and financial burdens of the disease. Some key advantages include [35, 36, 37, 38]:

- **Objective Measurement:** Sensor technology provides quantitative data collection, minimizing subjective bias in manual assessments, which is crucial for accurately monitoring motor symptoms;

- **Continuous Monitoring:** Sensors enable continuous data collection, providing a comprehensive view of a patient's symptom fluctuations, response to medication and disease progression. This long-term data helps HCPs in identifying patterns, refining treatment plans and personalizing interventions;

- **Real-time Feedback:** Sensors offer immediate feedback to patients, enabling them to monitor symptoms and adjust activities or medications as needed, which promotes patient engagement in self-management;

- **Remote Monitoring:** In the context of telemedicine, sensor technology allows HCPs to monitor patients remotely, reducing the need for frequent clinic visits and improving access to care.

Despite the benefits, there are challenges to sensor-based monitoring for PD patients:

- **Cost and Accessibility Considerations:** The expense of sensor technologies may limit access, especially for individuals with financial constraints, making it difficult for some PD patients to benefit from more advanced monitoring systems;
- **Data Management Challenges:** The large volume of data generated by sensors requires complex algorithms for accurate interpretation. Integrating this data with existing healthcare systems and electronic medical records also poses challenges in terms of management and interoperability;
- **User Acceptance and Compliance:** The need for patients to consistently wear or carry monitoring devices may lead to reduced compliance. Discomfort, inconvenience, or the intrusive nature of the devices can affect patient willingness to use them regularly;
- **Privacy and Data Security Risks:** Collecting and transmitting sensitive health information through sensors raises concerns about privacy and data security. Strong security measures and compliance with data protection laws are essential to safeguard patient information.

2.4.3 Study of Devices with Integrated Sensors

This study examined several devices with integrated sensors, considering their compatibility with project objectives and requirements to understand potential applications.

Name	**Description**	**Clinical Concept of Interest**	**Type of Monitoring**	**Anatomical Region (Placement)**
BioStamp RC	Device fixed to the body, measures accelerometry, Electrocardiogram (ECG) and Electromyography (EMG)	Summary of physical activity, gait analysis and movements during sleep	Continuous	Indifferent
STAT-ON	Device fixed to the body, measures cadence, fluidity and length of steps, number and duration of freezing and falling episodes	Summary of physical activity, gait analysis and movements during sleep	Continuous	Thoracic area (skin level) and waist
Shimmer (Verisense)	Device fixed to the body, measures ECG, EMG and physiological data	Movement analysis, physical activity and sleep, muscle atrophy, heart rate and respiratory rate	Continuous	Several
GENEActiv	Smartband	Summary of physical activity, gait analysis and movements during sleep	Continuous	Wrist
Xsens DOT	Device fixed to the body	Movement analysis	Continuous	Indifferent

Table 2.1: Description of the devices with integrated sensors

The Biostamp RC (Figure 2.1) and STAT-ON (Figure 2.2) devices were selected for their relevance to PD management. The Biostamp RC, a sticker-like device and the STAT-ON, a holster-style device, were chosen for their ability to facilitate remote and continuous monitoring. They capture physiological data, including ECG, EMG, gait analysis, fall risk assessment and accelerometry. Their automated data processing simplifies the analysis and interpretation of collected information.

Figure 2.1: Biostamp RC

Figure 2.2: STAT-ON

Formerly known as Shimmer, Verisense (Figure 2.3) focuses on continuous monitoring of physiological and biomechanical data. It includes wearable sensors designed for integration into daily life. These sensors gather data such as heart rate, electrodermal activity, temperature, motion and gait analysis. The data from these sensors provides insights into an individual's health, activity patterns and potential irregularities.

Figure 2.3: Shimmer (Verisense)

The platform uses data processing to convert raw sensor data into actionable insights. Data analysis, both real-time and retrospective, helps researchers and HCPs identify patterns and anomalies, facilitating decision-making, personalized interventions and optimized treatment strategies.

The GENEActiv (Figure 2.4) wearable sensor measures acceleration, enabling the detection of movement patterns and physical activity profiles. Its ability to capture data on human movement provides raw data about physical behaviors, including gait patterns, postural shifts and overall activity levels. Designed for wearability, it supports continuous data collection in daily life. However, the large volume of acceleration data it generates requires developing processing and analytical algorithms to interpret and extract insights.

Figure 2.4: GENEActiv

Figure 2.5: Xsens DOT

The Xsens DOT (Figure 2.5) is a wearable motion capture system equipped with accelerometers, gyroscopes and magnetometers. Placed on various body locations, these sensors enable the analysis of human movement and orientation, which is useful in diagnosing movement disorders, tracking rehabilitation, and shaping treatment strategies. Their non-invasive design and real-time feedback are especially beneficial in therapies focused on improving motor skills, balance, and coordination.

The devices discussed above all support continuous and remote monitoring, reducing the need for frequent clinical visits and enabling more comprehensive data collection, which is important for disease management. Additionally, the ability to perform movement analysis is important, as many PD symptoms are motor-related. This capability aligns with the ONParkinson focus on exercise, aiming to create a motivational model that encourages regular adherence.

Two additional monitoring devices were used: a smartphone and a smartwatch (Figure 2.6). While no data has been directly extracted from these devices yet, high acceptance is anticipated based on participant behavior during test days and their responses to device-related questions. Smartphones help bridge the gap between clinical care and daily life for individuals with PD, allowing them to monitor symptoms and engage more actively in their care, improving their quality of life [39]. The benefits of using smartphones in PD management include:

- **Voice Control and Commands:** Integration of voice recognition technology for easier app navigation and typing, aiding those with motor control challenges;
- **Gait Analysis:** Utilizing built-in accelerometers and gyroscopes for gait and balance evaluation, guiding users in exercises to improve walking and stability;

- **Speech Therapy:** Features supporting speech exercises, using the microphone for instant feedback on vocal command and articulation, addressing speech impairments common in PD;
- **Cognitive Training:** Games and exercises to maintain cognitive function, focusing on memory, problem-solving and mental agility;
- **Mood Tracking:** Tools for tracking emotional well-being, offering relaxation exercises and resources when needed;
- **Medication Management:** Customizable medication schedules and barcode scanning for accurate medication data entry, ensuring adherence to prescriptions;
- **Integration with wearables:** Syncing with smartwatches and fitness trackers for a comprehensive health profile, including heart rate, activity levels and sleep patterns;
- **Remote Monitoring:** Enabling data sharing with HCPs, including symptom logs, medication adherence and vital signs from wearables for collaborative care management;
- **Data Visualization:** User-friendly tools for visualizing health trends, making complex data more understandable through simple graphs and charts;
- **Educational Resources:** A library of resources on PD, treatments and lifestyle tips, keeping users informed and engaged;
- **Community Building:** Social features to connect with others managing PD, fostering a sense of community through forums and support groups;
- **Emergency Assistance:** A feature for quick emergency contact in cases of falls or medical issues;
- **Accessibility:** Features like text-to-speech, larger text and high-contrast themes for users with visual or hearing impairments;
- **Personalized Recommendations:** Machine learning algorithms analyzing user data to offer personalised exercise, diet and medication suggestions;
- **Research Participation:** Opportunities for users to contribute to PD research, sharing de-identified data with researchers.

Figure 2.6: Smartphone and smartwatch used during the tests

In the management of PD, smartwatches have become relevant due to their capability to monitor various health parameters continuously and unobtrusively. These devices, equipped with multiple sensors, provide support in the personalized management of the disease. Key functionalities of smartwatches in this context include the tracking of movement patterns, heart rate monitoring, sleep quality assessment and fall detection. The advantages of a smartwatch can be listed as follows:

- **Wearable Convenience:** Smartwatches are lightweight on the wrist, providing access to important features without the need to carry additional devices;
- **Continuous Monitoring:** These devices collect real-time health metrics data, including heart rate and physical activity. The monitoring of movement provides insights into gait, balance and mobility, important in PD management;
- **Sleep Tracking:** Smartwatches monitor sleep patterns, offering information on sleep quality, which is useful for addressing sleep disturbances common in PD;
- **Medication Reminders:** They deliver medication reminders, aiding individuals in maintaining adherence to their treatment plans;
- **Fall Detection:** Certain models are equipped with fall detection capabilities, enabling automatic detection of falls and sending alerts to emergency contacts or services;

- **Voice Assistants:** Integration of voice-activated assistants allows users to use voice commands for tasks, reminders, or information retrieval, facilitating interaction, particularly for those with motor difficulties;

- **Data Integration:** Smartwatches synchronize with smartphone applications, ensuring a continuous flow of health data, which is useful for more comprehensive health management.

Smartphones and smartwatches hold potential for assisting people with PD in managing their condition, but their effectiveness is sometimes hindered by certain challenges. As PD often involves motor and cognitive impairments, navigating the technology and interface of smartwatches and smartphones can be challenging, particularly for those in advanced stages of the disease. Menus, touchscreens and various features can limit accessibility. Additionally, the limited screen size of both smartwatches and smartphones may pose difficulties for those with motor or visual impairments. The small screens make interacting with apps and reading text challenging, reducing usability for this population. Another consideration is cost. High-quality smartwatches and smartphones can be expensive, potentially limiting access for individuals with limited financial resources who could benefit from these technologies. Ensuring accessibility is important, particularly for older adults and individuals with cognitive impairments who may struggle to use these devices. To maximize the benefits of these technologies for individuals with PD, it is essential to design user-friendly interfaces and provide support, including training and resources, for both individuals affected by the disease and their caregivers.

2.4.4 Sensor Data vs Processed Data

Data gathered from a sensor is typically referred to as ”sensor data.” This term encompasses all raw, unprocessed measurements or readings captured directly by sensors in response to physical phenomena [40]. These measurements are often in their original format, such as numerical values, voltage readings, or analog signals. Sensors capture various types of data based on their applications, including:

- **Temperature Data:** Measurement of temperature in a specific environment or object;

- **Motion Data:** Information generated by sensors that detect physical movements;

- **Positional Data:** Geographic or spatial coordinates of an object, person, or point of interest at a specific time;

- **Sound Data:** Digital representation of sound or audio signals, capturing variations in air pressure caused by sound waves;

- **Pressure Data:** Quantification of force per unit area exerted on a surface or within a confined space.

Example: In the context of a fitness tracker, sensor data could include raw accelerometer readings that record movements as voltage changes.

Working with sensor data involves challenges like noise and anomalies in raw data, requiring cleaning and preprocessing. High data volume necessitates resources for management and storage. Sensor calibration demands precise setup and maintenance. Integrating data from multiple sensors is complex due to variations in formats, sampling rates and synchronization issues.

Processed data refers to sensor data that has undergone operations or transformations through algorithms or analysis, converting it into more usable and understandable forms.

Example: Using the raw accelerometer readings mentioned earlier, processed data might involve algorithms that detect step patterns and calculate the number of steps taken, presented as a step counter.

The transformation of sensor data to processed data is a complex process. It begins with collecting raw data, often containing imperfections and anomalies. Preprocessing follows, involving tasks like noise reduction, outlier handling and normalization. Feature extraction isolates relevant patterns or characteristics within the data. In multi-sensor scenarios, data integration is necessary, requiring synchronization. Processed data is then analyzed using statistical or machine learning techniques, with effective visualization aiding in decision-making. Storage and retrieval are also crucial. This transition from raw data to actionable information requires domain expertise and data science skills, depending on the application and complexity of the data [41, 42].

2.5 Usability and Digital Accessibility

The concepts of usability and digital accessibility are closely related, both aiming to improve user interaction with digital systems. While usability focuses on making systems intuitive and efficient for all users, digital accessibility ensures that these systems are usable by individuals with disabilities, providing equal access. Together, they contribute to creating a more inclusive digital environment where technology can be effectively used by a wide and diverse audience.

The following subsections explore these themes in more detail, focusing on principles and design strategies that address the specific needs of individuals with PD, with the aim of enhancing both usability and accessibility in digital products for this group.

2.5.1 Overview

Usability refers to the effectiveness, efficiency and satisfaction with which users can achieve their goals using a system, product, or service [43]. It emphasizes intuitive designs that enable users to complete tasks with minimal effort and error. A usable system aligns with user expectations, is easy to learn and allows even first-time users to quickly understand how to navigate the interface or process.

An important aspect of usability is the system's responsiveness to user input and its ability to guide users smoothly through tasks without causing confusion. This includes clear navigation, logical workflows and feedback mechanisms that keep users informed of the system's status or progress. When tasks are completed efficiently and accurately, it reflects a well-designed product that reduces cognitive effort.

Another aspect of usability is its adaptability to different user needs and contexts. A system should be flexible enough to accommodate a diverse range of users, including those with varying levels of expertise, physical abilities, or technological preferences. This can include alternative input methods, adjustable settings, or assistive technologies to enhance accessibility. By considering diverse user requirements, usability promotes inclusivity and supports the product's long-term effectiveness.

Digital accessibility refers to designing digital products, services and technologies to ensure they can be used by all individuals, including those with disabilities, temporary impairments and older adults [44]. It aims to eliminate barriers that prevent equal access to information and services, considering the needs of individuals with visual, auditory, cognitive and motor impairments.

Incorporating accessibility into design broadens the user base by making digital platforms more functional for a diverse audience. Accessible design not only ensures equal access but also helps developers meet legal standards and fosters a more inclusive digital environment. The importance of accessibility lies in:

- **Facilitating Inclusion and Equal Opportunities:** Ensuring people with disabilities have comparable access to education, employment and technology, removing barriers and promoting full participation;
- **Upholding Human Rights and Social Justice:** Aligning with human rights principles, recognizing the dignity of every individual and advocating for fair treatment of people with disabilities;
- **Enabling Empowerment and Independence:** Providing accessible tools and services that empower individuals with disabilities, promoting independence and societal engagement;
- **Aligning With International Directives:** The United Nations (UN) Convention on the Rights of Persons with Disabilities highlights accessibility as a fundamental right [45]. The World Health Organization (WHO) similarly emphasizes accessibility's role in inclusive healthcare [46].

To design a mobile app that is accessible to individuals with PD, the following guidelines should be considered [47]:

- Create a clear interface with distinguishable elements such as buttons, text and icons. Incorporate adjustable font sizes for improved readability;
- Implement intuitive navigation with consistently labeled menus and buttons, avoiding complex gestures that may pose difficulties for users with PD;

- Integrate voice control and dictation features to address motor challenges and consider speech difficulties often associated with PD;
- Provide captions or transcripts for audio and video content to ensure accessibility for users with hearing impairments or comprehension challenges;
- Use high color contrast between text and background elements to enhance visual accessibility.

2.5.2 Impact Of Parkinson's Disease On Smartphone Interaction And Usability

This subsection focuses on how PD affects the use of smartphones and apps. PD is a neurological condition that worsens over time, causing a range of physical and mental symptoms. These symptoms can make it hard for people with PD to use technology in everyday life. The goal is to understand these challenges and highlight some keep-in-mind information when designing technology that is easy for everyone to use, including people with PD [48].

Bradykinesia

Bradykinesia is a medical condition consisting of a decline in the speed and amplitude of movements, particularly in tasks that require sequential or simultaneous actions. This symptom, often associated with movement disorders such as PD, affects fine motor skills. For instance, individuals with bradykinesia may struggle with activities like buttoning a shirt or using utensils due to reduced precision and control in their hand movements. The impact of bradykinesia extends beyond just motor control. It can cause changes in facial expressions and speech, often leading to a reduced ability to convey emotions or speak. Handwriting typically becomes smaller and less legible as the condition progresses.

A practical example of bradykinesia's effect can be seen in tasks that require repetitive motions, such as hammering a nail. A person with this condition might start with a normal range of motion but gradually, the ability to lift and strike the hammer effectively diminishes. This decrease in movement amplitude can eventually render them unable to complete the task. Similarly, repetitive tasks like pressing a button repeatedly become increasingly slow and challenging.

Bradykinesia can make using a smartphone difficult by slowing down actions like typing, swiping, or tapping.

Rest Tremor

Rest tremor is an involuntary oscillating movement that occurs when the muscles are relaxed or supported by a surface. This type of tremor mostly disappears or is attenuated when an action is started. Therefore, it is not likely to affect fine motor skills.

Rest tremor is unlikely to significantly affect smartphone use because it lessens during movement and doesn't impact fine motor skills.

Rigidity

Muscle rigidity refers to an increase in resistance to the passive movement of a limb, a resistance that is present throughout the movement, regardless of its speed. This condition impacts fine motor tasks, affecting activities such as turning around, rising from a chair and even making facial expressions due to increased stiffness in the muscles.

The presence of rigidity not only complicates movement by making it more difficult and less fluid but also contributes to physical discomfort and pain. The increased stiffness forces muscles to work harder to accomplish movements that were previously effortless, leading to a reduction in overall movement speed and dexterity. Consequently, tasks take longer to perform and require greater effort, often resulting in less accurate or coordinated execution.

Muscle rigidity makes using a smartphone harder by slowing down and reducing the accuracy of tapping, swiping, and typing.

Dyskinesia

Dyskinesias are characterized by involuntary, erratic movements that can affect various parts of the body including the face, arms, legs, or trunk. These movements are often fluid and dance-like, but they can also manifest as rapid jerking motions or prolonged muscle spasms. They are not a symptom of PD itself. Rather, they are a complication from certain PD medications.

When individuals with PD have an excess of medication in their system, they may develop dyskinesias. These movements are uncontrollable and involuntary, impacting activities requiring fine motor skills. For instance, using a smartphone or interacting with apps can become difficult due to the inability to control hand movements.

A practical way to visualize the impact of dyskinesia is to imagine a person without PD attempting to use a mobile phone while standing on a moving bus. The constant, unpredictable motion of the bus makes it challenging to keep their arms steady, similar to how dyskinesias disrupt normal movement control.

Dyskinesias can severely disrupt smartphone use by causing uncontrollable and erratic hand movements.

Postural instability and gait impairment

Postural instability and gait impairment are common, especially in more advanced phases of the disease. People with PD tend to adopt a stooped posture, with head and shoulders hanging forward, due to the loss of postural reflexes. As the disease advances, gait becomes slower and unstable. Steps become smaller and turning becomes slow. Freezing of gait is common, especially in crowded or narrow spaces.

Another symptom that may occur is festination. This involves taking rapid, small steps and being unable to stop quickly, leading to collisions with obstacles. This contributes to difficulty in controlling movement, further complicating mobility and increasing the risk of falls and injuries.

Postural instability and gait problems can make smartphone use harder by affecting balance and control, increasing the chances of dropping the device or having trouble using it while moving.

PD may hinder speech

PD impacts the muscles involved in speech production. In the early stages of the disease, these changes may be subtle. However, as the disease progresses, its effects on speech can become more pronounced, potentially leading to a decline in speech clarity and intelligibility.

Using common speech interfaces may become hard for people with PD in later stages.

Some people with PD may experience visual disabilities

PD is not associated with significant visual damage, however blurred and double vision can occur because of muscular incoordination. Decrease in color and contrast discrimination also occurs.

These limitations may be aggravated when considering the effect of age-related changes on vision.

Short-term memory loss is accentuated on people with PD

People with PD commonly experience short-term memory loss as part of the disease, which is mainly noticed when planning tasks, or when adjusting to a new medication.

These problems coexist with the effect of age-related changes to memory.

Thought is slowed by PD

Slowed thinking, also known as bradyphrenia, affects cognitive abilities such as problem solving and daily activities like carrying on a conversation.

Slowed thinking or processing affects how people with PD can process and respond to information.

Depression and apathy are common in PD

Many people with PD exhibit some form of depression and apathy, sometimes even before the first motor symptoms appear.

People with PD may not be as motivated to learn to use new technologies and may feel frustrated or lost when facing novel situations.

Dementia

Problems with cognitive function, including forgetfulness and trouble with concentration, may arise at later stages of the disease. As it gets worse, many people develop dementia. This can cause memory loss and makes it hard to maintain relationships. PD dementia can cause problems with:

- Speaking and communicating with others;
- Problem solving;
- Understanding abstract concepts;
- Forgetfulness;
- Paying attention.

Someone with PD and dementia likely won't be able to take care of themselves. Dementia affects their ability to do so, even if they can still physically do tasks.

If a person with PD develops dementia, they may not be able to independently use a smartphone/apps.

PD symptoms vary across different afflicted people

The symptoms of PD and the rate of progression differ among individuals. However, in general, the older the age of onset, the faster the disease progresses. Design flexibility should be kept in mind not only to adjust to different users but also because a single user alone can experience a noticeable progression over short periods of time.

The disease progresses differently from person to person, as such designs should be flexible enough to adapt to the characteristics of each person.

On/Off phenomenon

The On/Off phenomenon is a characteristic of PD that appears only in medium to advanced phases of the disease.

A person with PD is said to be on the On phase when the medication is acting with strength and thus the patient shows fewer symptoms. On the Off phase, however, the medication stops being effective and the person with PD might experience an impact on their autonomy.

As the disease progresses, Levodopa, the most common medication for the disease, is less effectively absorbed by the brain. This means that in the medium to later stages of the disease, patients can fluctuate between On and Off phases. The long-term intake of Levodopa is also likely to produce dyskinesias, during the On phase.

As a result of the progression of the condition, many people with PD experience the On and Off phenomenon. An individual can be functional on the On phase and impaired while on Off.

Symptoms vary between On and Off phases. This translates into changes in the interaction with the smartphone/apps.

Autonomy is gradually lost

A loss of autonomy is the inability to perform daily activities such as bathing, eating, getting dressed, etc. Not all people with PD face a loss of autonomy. It is impossible to know if they will be affected or when it will happen.

At the beginning of the disease, people with PD can lead their lives without major limitations and as the disease progresses, they become less autonomous in pursuing daily activities. Existing treatments alleviate symptoms without slowing the progression of the disease. Worsening symptoms or the appearance of new symptoms in the advanced stages of the disease can lead to a loss of autonomy.

In advanced stages of Parkinson's disease, a loss of autonomy can make smartphone use challenging as daily tasks become harder to manage, though this varies by individual and may not happen to everyone.

2.6 User Engagement and Motivation Theories

User engagement refers to the degree of interaction, interest and involvement users display when interacting with a digital product, service, or platform [49]. It is an indicator of how well a platform meets user needs and maintains their attention. Engagement can take various forms, including time spent on the platform, frequency of visits, clicks, comments, shares, or other actions reflecting participation.

High engagement typically indicates that users find the platform valuable or enjoyable, promoting loyalty and encouraging repeat interactions. Measuring engagement involves tracking metrics like click-through rates, session duration and conversion rates. Click-through rates measure how often users click on links or features within the platform. Session duration refers to how much time users spend interacting with the platform during a visit. Conversion rates track the percentage of users who complete a desired action, such as making a purchase or signing up for a service, compared to the total number of visitors. These metrics provide insights into how users interact with the platform and help identify areas where improvements may be needed.

Personalization and relevance impact engagement. Users are more likely to engage with content or features personalized to their preferences. Providing personalized experiences, such as targeted recommendations or notifications, can enhance interaction, while irrelevant content may lead to disengagement.

Motivation is the internal drive that compels individuals to take action, pursue goals and persist in their efforts, even when faced with challenges. Understanding and fostering motivation is important, especially in areas like healthcare or rehabilitation, where ongoing effort and adherence to treatment plans are essential. Understanding the concepts of motivation, persuasion and influence helps design effective eHealth systems that encourage patient engagement and improve outcomes [50]:

- **Motivation:** Refers to the internal processes that initiate, guide and sustain goal-directed behaviors. It is what compels individuals to engage in activities and persist in them to achieve outcomes;
- **Persuasion:** Is the process of changing someone's beliefs, attitudes, or behaviors through communication, reasoning, or appeal to emotions. It involves convincing someone to adopt a particular viewpoint or take a specific action;
- **Influence:** Is the power to affect a person's behavior or the course of events without taking direct action. It operates as a force that shapes others' decisions and actions through indirect means.

Motivation might not be essential for rehabilitation, but it plays a role in helping patients stick to and complete their treatment. In healthcare, motivated patients are more likely to follow through with their plans, leading to better recovery outcomes. Neglecting motivation in the design of eHealth systems risks creating tools that patients may find discouraging or unengaging, which could obstruct their progress.

Motivation theories provide frameworks that explain why individuals start, continue, or stop behaviors. Two theories form the foundation for understanding motivation and guide the design of the current eHealth prototype. The Theory of Influence (ToI) demonstrates how external factors can nudge patient behavior, while the Self-Determination Theory (SDT) explores the internal drives that keep people motivated and support their personal development.

Theory of Influence

The ToI examines how individuals or groups can shape the thoughts, beliefs and actions of others. This concept is essential in understanding the dynamics of interpersonal communication, persuasion and social interactions. The ways in which influence is exerted are varied and can be subtle or direct, depending on the context and the individuals involved. Understanding influence allows for a deeper exploration of human behavior. By studying influence, we can identify the mechanisms that make people more receptive to certain ideas or resistant to others.

Within the ToI framework, several principles help explain the processes through which influence operates. These principles offer insight into the psychological and social mechanisms that drive people's behaviors and decisions, making it possible to predict and understand how influence can be applied in various contexts. These principles include [50]:

- **Reciprocity Principle:** This principle reflects the idea that people tend to feel indebted to those who have given them something. By reminding someone of what they have received and who provided it, their behavior and decisions can be influenced;
- **Scarcity Principle:** This principle is related to the tendency of valuing things that are in limited supply. The fear of missing out on potential benefits if the scarce item becomes unavailable serves as a motivator;
- **Authority Principle:** This principle states that people generally respect and follow authority. This is because authority figures are seen as more knowledgeable, trustworthy, or credible;
- **Commitment Principle:** It is easier for people to make and stick to commitments when they are made voluntarily and publicly. Taking partial responsibility for defining goals enhances a person's motivation to achieve them;
- **Consensus Principle:** This principle suggests that people are more likely to adopt a behavior or decision if they see that others are doing the same. When individuals observe that a group of people are in agreement, they are influenced by this social proof and are more inclined to follow suit;
- **Liking Principle:** This principle suggests that people are more likely to be influenced by or agree with those they like. Factors such as physical attractiveness, similarities, compliments and associations all contribute to increasing a person's likability. When someone likes another person, they are more likely to be persuaded by their opinions, requests, or actions.

Self-Determination Theory

The SDT is a framework that explores human motivation, focusing on the internal factors that drive individuals to seek personal growth and fulfillment. Unlike theories that emphasize external rewards or pressures, SDT highlights how motivation is sustained when individuals feel engaged in their activities. According to this theory, motivation is not just about achieving outcomes, but also about aligning one's actions with their sense of self and purpose.

SDT provides insights into how environments can either support or inhibit motivation. When people are in environments that nurture engagement and respect for their personal goals, they tend to show determination, creativity and well-being. This has implications for designing systems that promote lasting motivation.

At the heart of SDT are three basic psychological needs (autonomy, competence and relatedness) that must be met to sustain intrinsic motivation. These needs are essential in determining whether an individual can fully engage with and be motivated by their tasks and experiences. Each of these needs addresses an aspect of what drives human behavior and supports personal growth [50, 51]:

- **Autonomy:** This need refers to feeling in control of one's behavior, actions and decisions. It highlights the importance of having the freedom to make choices and take actions that align with one's self and goals;
- **Competence:** This need involves gaining mastery and achieving a sense of efficacy in one's activities. It encompasses feeling effective and capable in managing tasks and challenges;
- **Relatedness:** This need reflects the desire to feel connected to others, to care for and be cared for by others and to experience a sense of belonging with individuals or groups.

2.7 mHealth Solutions for Parkinson's Disease Exercise

In the context of PD management, various digital health solutions have been developed. This section provides an overview of similar projects. The projects included for comparison are i-PROGNOSIS, Walking Tall and KinesiaU. These projects provide examples of how technology can be used to improve symptom tracking, facilitate exercise and enhance patient engagement.

2.7.1 i-PROGNOSIS

The i-PROGNOSIS project, financed by the European Unions (EUs) Horizon 2020 research program, is a collaborative initiative involving eleven partners from academic and corporate sectors across six EU countries, with leadership from Aristotle University of Thessaloniki in Greece [52]. The project's core objective is to leverage technology-driven solutions to address PD, alongside promoting awareness and self-management of the condition [53].

Central to i-PROGNOSIS's mission is the analysis of large-scale community behavior through everyday technology use. This analysis plays a key role in developing a predictive model aimed at identifying early signs of PD, with a focus on symptoms such as increasing frailty, susceptibility to falls, and shifts in emotional state that may indicate progression towards depression [52].

iPrognosis Games

The iPrognosis Games application, designed for Android devices, encompasses a suite of fourteen games (Figure 2.7) that are part of the Personalized Game Suite (PGS), in addition to the Warming up game and motor Assessment Tests. These games are structured into categories, each aiming to address aspects related to PD management and wellness [54, 55]:

- **ExerGames:** Available on TV, personal computer, or tablet, these games offer exercise scenarios in a 3D gaming format. The focus is on muscle tension, walking/posture and fitness. Interaction with the games is facilitated through the Microsoft Kinect 2 sensor. Performance is analyzed based on Kinect data, with feedback provided to the user, their doctor and caregiver;

- **Dietary Games:** These games, accessible on TV, personal computer, tablet, or smartphone, guide users towards healthier dietary habits. The goals include addressing issues like constipation and depression, enhancing the quality of life;

- **Affective Games:** Playable on TV, personal computer, tablet, or smartphone, these games are aimed at training in facial expressions and reestablishing blinking patterns. Additionally, they contribute to combating depression;

- **Handwriting Games:** Designed for use on a personal computer, tablet, or smartphone, these games focus on maintaining and correcting handwriting patterns, an aspect often affected by Parkinson's disease;

- **Voice Games:** Available on TV, personal computer, tablet, or smartphone, these games target the sustainment of voice quality, a component for communication often impacted by Parkinson's disease.

Figure 2.7: User playing the serious games of the PGS

These same games are based on the following PD-targeted symptomatology [56]:

- **Motor Improvement (six games):** posture, gait, postural instability, fine motor skills impairment, and tremor;
- **Non-motor Improvement (five games):** facial expression, depression, and constipation;
- **Speech Improvement (three games):** voice and speech difficulties.

Furthermore, they differ in the required equipment for playing them [56]:

- Games requiring the MentorAge® or Microsoft Kinect 2 sensor device (four games);
- Games requiring a smartwatch or tablet (with microphone and frontal camera) (ten games).

iPrognosis Motor Assessment Tests

The Assessment Tests within the PGS serve as an initial diagnostic tool, facilitated by HCP supervision [55]. These tests utilize the iPrognosis Assessment Tests environment to analyze and assess movements or actions of PD patients. This assessment generates a Motor Score (MS), which reflects various metrics or features related to each Assessment Test [56].

This process involves capturing and processing skeletal data, which includes the 3D coordinates of the patient's skeletal joints (Figure 2.8). This data is normalized, considering the patient's height and positional variance relative to the MentorAge® sensor. In each Assessment Test, a selection of joint types is analyzed to compare the patient's performance with that of a pre-recorded expert performance, enhancing the assessment's accuracy [56].

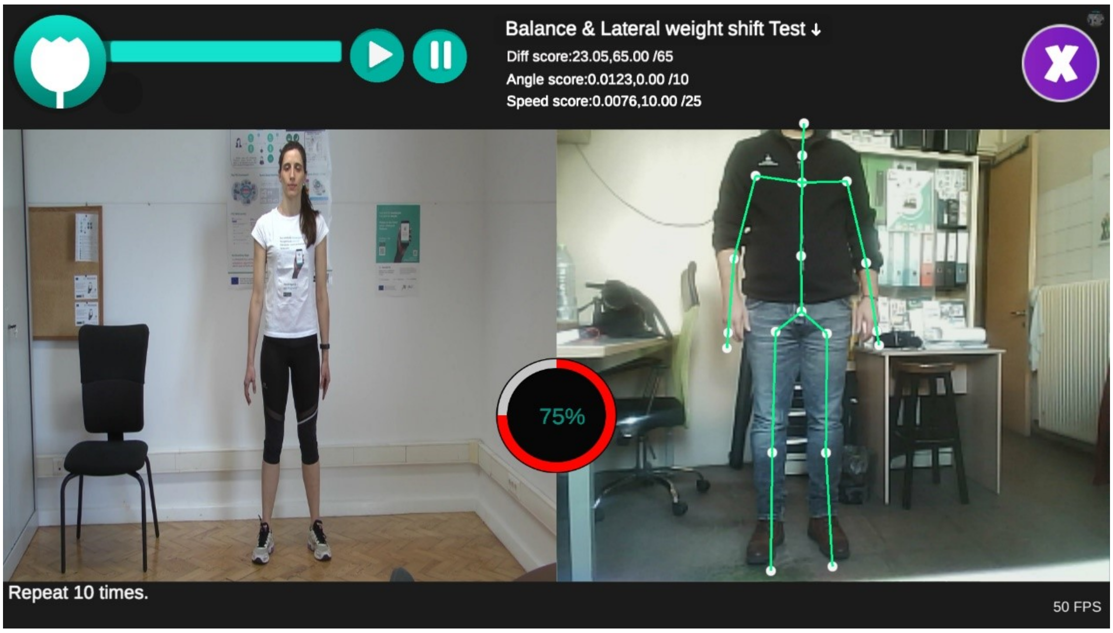

Figure 2.8: Depiction of an assessment test execution

Figure 2.8 provides a depiction of an assessment test execution: On the left, a video of an expert conducting the exercise is shown, while on the right, a user is seen performing the same exercise with their skeleton being digitally tracked. At the center, a circular display presents the MS calculated by comparing the user's performance to the expert's [55].

2.7.2 Walking Tall

Walking Tall is a mobile application developed to help individuals with PD improve their walking ability and endurance. The app was designed in collaboration with PD and is led by a team at University of New South Wales (UNSW) [57]. A main feature of the app is its gait re-training tool, which allows users to customize their training sessions by adjusting the timing and speed of exercises. This is achieved using metronomic beats set to three specific walking speeds, helping users maintain a steady pace, which can benefit those experiencing gait freezing or irregular stride lengths.

The interface of Walking Tall is designed to accommodate the challenges faced by people with PD. The app features large interactive elements, high-contrast visuals and simplified navigation to enhance usability.

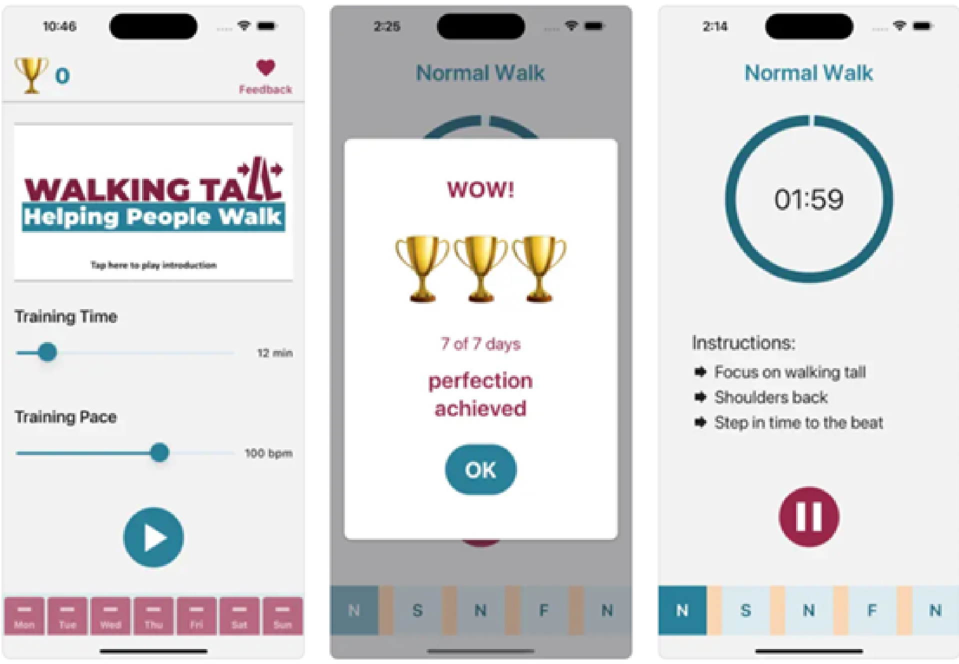

Figure 2.9: Screenshots showcasing the Walking Tall app

Screenshots showcasing the Walking Tall app can be seen in Figure 2.9. The images display features such as training time and pace settings, achievement notifications with trophies for walking consistency and an active session screen with a metronome tool and instructions for proper walking posture [58].

The app employs gamification techniques, including rewards and personalized goals, to motivate users to engage in regular walking exercises. These elements are designed to provide a sense of achievement and progress, supporting long-term user engagement and adherence to exercise routines.

Walking Tall utilizes built-in smartphone sensors such as accelerometers and gyroscopes to detect variations in gait and movement patterns. Real-time data collected by these sensors allows the app to provide immediate feedback and suggestions for gait improvement.

2.7.3 KinesiaU

KinesiaU is a mobile application designed to monitor and assess motor symptoms in patients with PD [59]. Utilizing the capabilities of modern smartphones, KinesiaU uses embedded sensors to provide real-time, objective data on motor function. The interface design of KinesiaU follows principles of user-centered design, ensuring ease of use for patients with PD. User Interface (UI) features such as large buttons, clear text and a minimalistic design help accommodate potential motor impairments and cognitive challenges common in PD patients, making the navigation structure intuitive. The main screen (Figure 2.10) provides immediate access to main functions like symptom tracking, data review and a calendar, with large, well-spaced icons to minimize the risk of mis-tapping [60].

Figure 2.10: The main screen of KinesiaU

KinesiaU also includes data visualization tools to help users and HCPs interpret symptom data. Charts display trends over time, allowing for quick assessment of disease progression or the effects of medication. These visualizations are designed to be easy to understand, with clear legends and color-coding to differentiate between various types of data. For instance, the symptom graph shown in the app (Figure 2.11) tracks tremor, slowness and dyskinesia severity levels using a color-coded system (Good, Mild, Moderate, Severe) to help users quickly assess their motor symptom severity [60].

Figure 2.11: The symptom graph screen of KinesiaU

KinesiaU primarily uses the accelerometers and gyroscopes embedded in smartphones to monitor motor symptoms. These sensors capture information about a user's movements, allowing the app to identify tremors, bradykinesia and other motor symptoms characteristic of PD. The raw data from the sensors is processed through algorithms to extract meaningful metrics, which are then used to generate scores that quantify the severity of symptoms.

KinesiaU is designed to boost patient engagement by providing tools for self-monitoring. This enhanced engagement can lead to improved adherence to treatment plans and better overall outcomes. Another objective of the app is to facilitate remote monitoring by HCPs. KinesiaU enables HCPs to remotely access detailed patient data, allowing for timely interventions and more personalized care. This data also offers insights into disease progression and treatment effectiveness.

2.7.4 Comparison of Parkinson's Disease Apps

In order to provide a clearer understanding of how these apps compare, their functionalities were examined and information was collected on key aspects such as user motivation, accessibility and sensor usage (see Table 2.2). However, it is important to note that information on user motivation is limited and the available insights were compiled to the best extent possible.

Solution	User Motivation	Accessibility	Sensor Usage
i-PROGNOSIS	It motivates users by emphasizing their role in early PD detection, benefiting themselves and the broader community through scientific research.	The app is accessible for users with disabilities and PD, designed to be user-friendly, particularly for older individuals.	The app utilizes smartphone and wearable device sensors to detect early signs of PD by monitoring movement, voice, typing patterns and facial expressions
Walking Tall	The app motivates users with personalized gait exercises and real-time feedback, making walking easier for PD patients. Gamified rewards like earning a "gold cup" further encourage consistent use.	Walking Tall is designed for individuals with PD, offering customizable training duration and pace to suit varying mobility levels. It has a simple interface and clear instructions that make it easy to use, even for those with limited tech experience.	The app uses smartphone sensors to monitor movements and provide feedback on gait. The metronome feature helps synchronize steps, enhancing coordination and reducing fall risk.
KinesiaU	It motivates users by giving them control over their symptom tracking, allowing them to monitor progress and make informed decisions about their care	It's designed for individuals with PD, offering a simple interface for those with mobility or cognitive challenges. The app supports remote monitoring, minimizing the need for frequent in-person visits	KinesiaU uses smartwatch and smartphone sensors to continuously monitor symptoms, including tremors and bradykinesia. The app generates reports for both users and HCPs, enhancing symptom tracking and disease management.

Table 2.2: Comparison of mHealth Solutions for PD

Chapter 3

The User Engagement Solution

This chapter explains the design and development of the user engagement solution for mobile health (mHealth) applications aimed at patients with Parkinson's Disease (PD). It describes the system architecture, integration of sensor technologies and how the solution addresses the specific needs of users, including accessibility, motivation and engagement.

3.1 ONParkinson System

The current ONParkinson mobile app prototype is the focus of this dissertation. The previous project and those derived from other dissertations are outlined to provide context for the current mHealth solution's role within the broader landscape of the ONParkinson project and how it interacts with these other components and initiatives.

The process of gathering functional requirements started by referencing the predecessor application [6], particularly focusing on the exercise component. In this component, Healthcare Professionals (HCPs) assign exercise programs to patients. Before starting, patients report their perceived effort, heart rate and blood pressure. Exercises are displayed sequentially according to the program phases: Warmup, Training and Relaxation (Figures 3.1, 3.2, 3.3). For each exercise, patients see an image, a description of how to perform it and a button to move to the next exercise. At the end of the session, patients again report their perceived effort, heart rate and blood pressure.

Figure 3.1: Warmup exercise screen

Figure 3.2: Training exercise screen

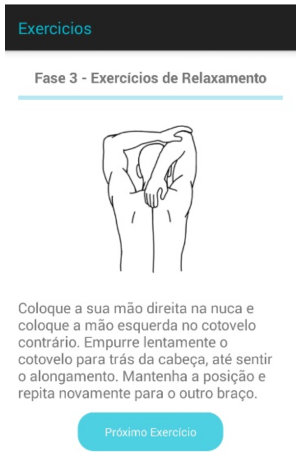

Figure 3.3: Relaxation exercise screen

The core functionality of the exercise component was enhanced in the new mobile app prototype, ONParkinson. In ONParkinson, patients with PD follow personalized exercise programs assigned by their HCPs. The app collects and shares data on patient adherence, progress and feedback with the web app, allowing HCPs to monitor and adjust exercise plans as needed. Two technological upgrades were implemented. One was developing ONParkinson using Flutter, an open-source User Interface (UI) toolkit from Google. Flutter allows for creating flexible UIs for both Android and iOS with a single codebase in Dart. It also uses Google's Material Design, which includes standardized components focused on accessibility for patients with PD.

To boost engagement, ONParkinson plans to include gamification elements like challenges and rewards in future updates. These updates will also integrate sensors to collect physiological data, allowing for more detailed observation of patient movements during exercises. Additionally, the app features Pandora, a conversational agent that helps users navigate the app, answers questions and improves the overall experience.

The other upgrade was to ensure that ONParkinson would integrate more effectively into the existing infrastructure, particularly by improving communication between the various project components and the database. The system architecture for the ONParkinson project is shown in Figure 3.4. This architecture consists of several modules, all of which are connected to a central server and database.

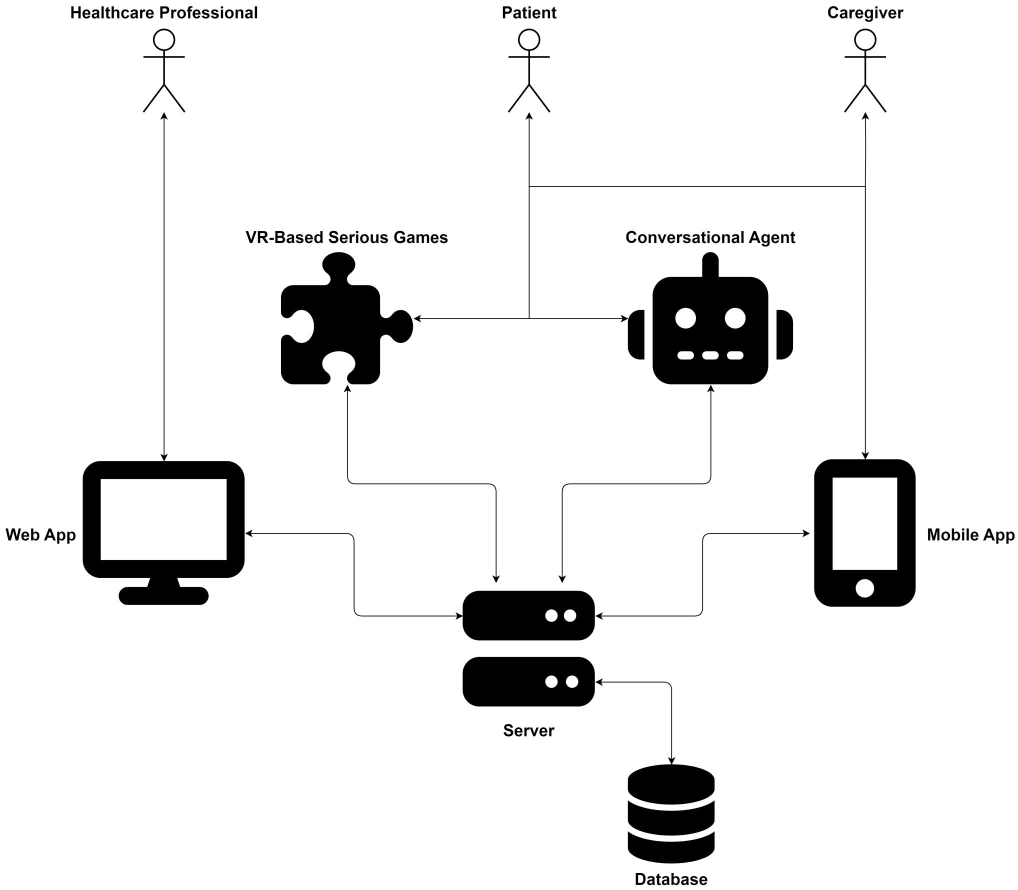

Figure 3.4: System architecture diagram

The users of the system are HCPs, patients and caregivers. HCPs use the web app to assign personalized exercise programs to patients, while patients use the mobile app to follow their prescribed exercise programs. Patients' interactions with the app—such as exercise adherence and feedback—are stored in a central database, where HCPs can track their patients' progress, adjust exercises and provide additional guidance through the system.

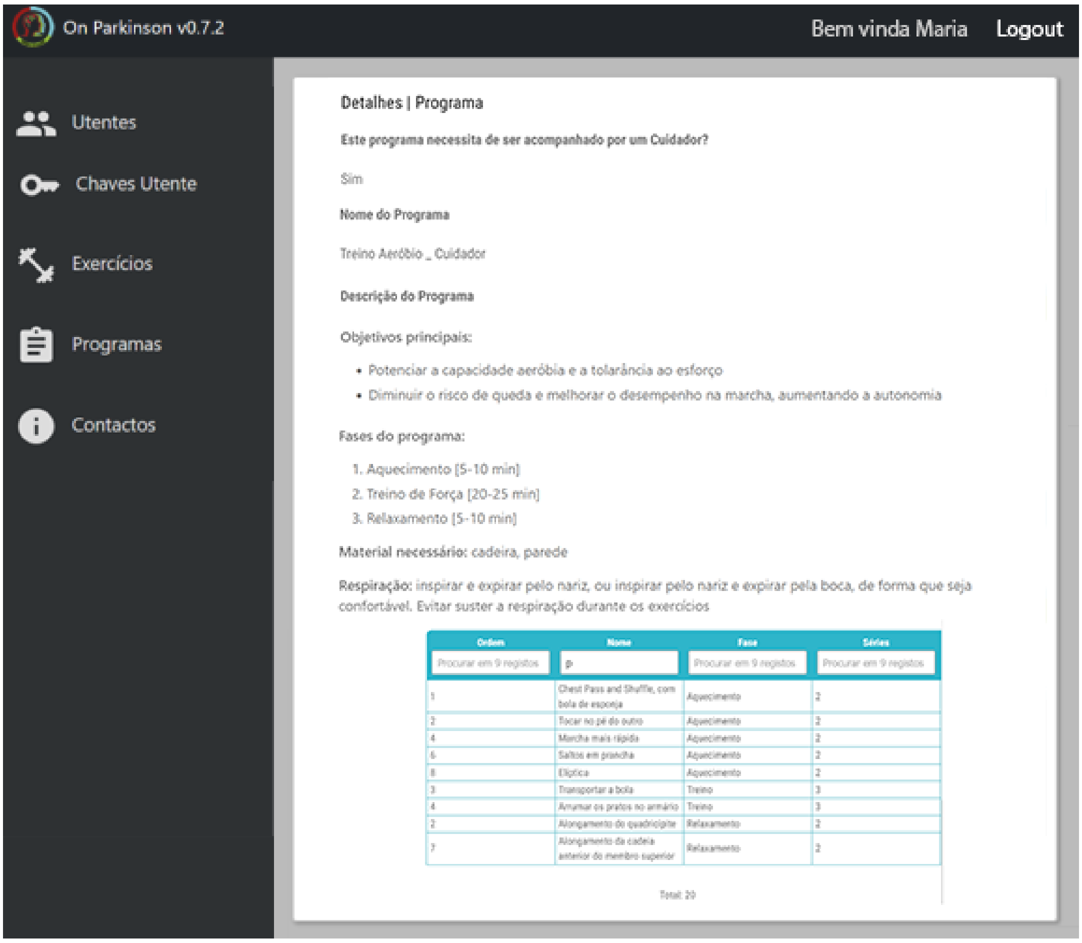

Figure 3.5: Web app program details

The web app (Figure 3.5) focuses on improving communication between HCPs and patients remotely [61]. It enables HCPs to assign exercise programs that patients can follow using the mobile app at home. The web app functions as a tool for monitoring patient adherence, tracking progress and gathering feedback, which provides HCPs with insights into the patients' rehabilitation process.

In the future, the ONParkinson platform aims to integrate data from sensor-equipped devices, offering HCPs objective insights into the patient's physical condition. This data will allow for adjustments to exercise programs by analyzing metrics such as movement patterns and performance, resulting in more accurate and personalized care for each patient.

The ONParkinson project also incorporates serious games and Virtual Reality (VR) to enhance physiotherapy for patients with PD [62]. These games immerse users in virtual environments, using gamification techniques to sustain motivation throughout their treatment. In healthcare, such games promote patient participation, boost adherence to therapy and stimulate both physical and cognitive functions. By transforming tasks like physical therapy or educational exercises into engaging activities, they increase motivation and compliance. Features such as reward systems, gradual progression and interactive feedback ensure that users remain engaged in their therapeutic tasks.

This approach is useful for conditions like PD, where patients face motor challenges, apathy and reduced motivation for treatment. Serious games, combined with therapy, provide a structured environment that encourages patients to stay active and practice their exercises.

Figure 3.6: Serious game Hole in the Wall

The "Hole in the Wall" is a Kinect-based game designed for individuals with motor impairments, such as those related to PD. Players adjust their bodies to pass through virtual cutouts on a moving wall, promoting physical activity that aligns with physiotherapy goals such as improving balance, coordination, and flexibility. Using the Kinect sensor to track body movements, the game encourages full-body engagement and motor coordination as players adapt their posture to fit the cutouts. With simple mechanics and progressively challenging levels, it keeps users engaged by providing real-time feedback that reinforces correct movements and encourages repetition. Gamified elements like scoring and visual feedback help maintain motivation throughout therapy sessions.

3.2 Assessing User Needs and Perspectives

To build on the established requirements of the predecessor application, a study was conducted as part of another dissertation [63]. This study aimed to evaluate the exercise module of ONParkinson by testing the platform (Web App + an early version of the ONParkinson prototype) and exploring the needs and perspectives of PD patients, their informal caregivers and HCPs. This evaluation helped in identifying additional requirements from both HCPs and patients. Data collection was performed through semi-structured interviews conducted both in person and via Zoom. The recruitment process included 13 participants: 6 patients, 2 informal caregivers and 5 physiotherapists. Personal, sociodemographic and professional data from these participants are compiled in tables, which are available in an appendix of another document [63]. Three key themes from this study are relevant to the current dissertation:

Exercise

Within the theme of "Exercise" in the study, it became evident that physical activity plays a role in managing PD and enhancing patients' self-efficacy. The findings revealed that a perception of exercise improves its effectiveness. This attitude is driven by the understanding that exercise promotes well-being, helps preserve functional quality over time and contributes to control of PD symptoms.

The study also highlighted the role of physiotherapists in designing exercise programs. These HCP create a therapeutic experience that is not only personalized to the individual's stage of PD but also meaningful. This personalization is important in addressing the physical challenges of the disease while boosting the patient's motivation to participate in the exercise program.

The importance of setting goals was another factor identified in promoting adherence to exercise programs. Goal-setting gives patients a sense of accomplishment and progress, reinforcing their commitment to the treatment plan.

Motivation and adherence to physical exercise were further explored, with the study finding that preferences, interests and life stage influence patients' motivation to exercise. The involvement of caregivers and family members was recognized as an element in supporting the patient's exercise routine, providing both assistance and encouragement, which enhances motivation and adherence.

However, the study also identified barriers to motivation and exercise adherence, including a sedentary lifestyle, advancing age, disease progression and the physical, cognitive and psychological changes associated with PD. These barriers emphasize the need for adaptable exercise programs and support at each stage of the disease.

In-Person versus Remote Rehabilitation

In examining the theme of "In-Person versus Remote Rehabilitation", the study highlights that patient preferences for rehabilitation modes are influenced by their profiles, exercise history and preferences. For example, sedentary individuals may prefer exercising at home, while socially active individuals might favor in-person sessions in outdoor settings or gyms. This variation in preferences demonstrates that remote rehabilitation may not be suitable for everyone, particularly for those in the advanced stages of illness or with safety concerns.

Remote rehabilitation offers advantages, such as the convenience of exercising in a familiar home environment, which can enhance focus and minimize distractions. It also provides flexibility in scheduling and removes the need for travel, making it beneficial for individuals with mobility issues or time constraints.

However, the lack of real-time professional supervision in remote settings is a concern. Without proper oversight, there is a risk of incorrect exercise execution, which can lead to safety risks, particularly when there is no one available to assist the patient at home. Additionally, the absence of a dedicated exercise space and suitable equipment in the home can compromise the effectiveness of the exercises.

Another challenge with remote rehabilitation is the reduction in social interaction, which can affect patient motivation and adherence to the program.

HCPs also face difficulties in remote settings, especially when performing initial assessments, which are often more effective in person. Developing exercise programs for home practice can be complex and time-intensive, as HCPs must select appropriate demonstration videos, adapt exercises to the patient's home environment and take on a role in motivating the patient. This process requires effort in terms of preparation and follow-up, making it a task for HCPs.

Health Technologies

In addressing the third theme, "Health Technologies," the study highlights the value and accessibility of mHealth resources, highlighting these as benefits. However, it also emphasizes the need for these resources to be more interactive and to provide feedback to users. Enhancing interactivity and offering feedback are important for fostering a sense of human connection, which research suggests can motivate physical exercise in PD patients [64].

Participants expressed frustration with technologies that do not provide clear results or fail to give feedback on the information submitted. Such feedback is essential for informing users about their progress, helping maintain engagement and motivation.

Usability was identified as an important factor, with users valuing the convenience of having health resources readily available. This supports more autonomous and motivating exercise practices, enabling patients to continue therapy at home. Technology, particularly for PD patients, is viewed as a tool for providing motivation and enabling remote monitoring of intervention plans.

User Needs

The study identified the main needs of PD patients in managing their condition, particularly the importance of personalized and guided exercise programs. These needs are summarized in Table 3.1 and also include the need for exercise variety, safety, feedback and motivation.

ID	Patient Need	Description
PN1	**Variety in Exercise**	Patients need a variety of exercises personalised to their specific needs and disease stage
PN2	**Instructional Guidance**	Patients need video guidance to perform their exercises correctly
PN3	**Feedback Mechanism**	Patients need a way to provide feedback on their exercise experience
PN4	**Access to Exercise Information**	Patients need access to audio and visual information about their exercise programs
PN5	**Safety Instructions**	Patients need visual and audio guidance with warnings to safely perform exercises remotely
PN6	**Motivation and Engagement**	Patients need to feel motivated and engaged in managing their condition
PN7	**Goal Setting**	Patients need a way to set realistic, achievable goals and track their progress over time

Table 3.1: Patient needs

Similarly, HCPs have their own specific needs. These are contained in Table 3.2 and they focus on personalizing and adjusting exercise programs and tracking patient progress.

ID	HCP Need	Description
HCPN1	**Personalize Exercise Programs**	HCPs need the ability to create personalized exercise programs for each patient
HCPN2	**See Exercise Program Data**	HCPs need the to see data regarding the execution of exercise programs
HCPN3	**Adjust Exercise Programs**	HCPs need to be able to adjust exercise plans based on patient progress or feedback
HCPN4	**Writing Notes**	HCPs need to be able to write notes on exercises and programs and have these notes visible to patients

Table 3.2: HCP needs

3.3 User and System Requirements

Taking into account the previous sections, we can extract the set of requirements presented in Tables 3.3, 3.4 and 3.5. Given that the primary focus of this dissertation is on the exercise component, the requirements were prioritized around the needs of two key stakeholders: HCPs, who are responsible for creating and monitoring exercise plans and patients, who perform the exercises.

Parkinson's Disease Patient Requirements

The patient requirements are inherited from both the exercise module specifications of the predecessor application [6] and new functionalities. These include providing video guidance, detailed instructions and displaying the recommended number of sets, repetitions, duration and rest time for each exercise. The resulting interfaces from this implementation are presented in section 4.1.

The study in section 3.2 identified the importance of suporting patient motivation and engagement with their health and the mobile app. This required understanding motivation theories and their practical application in the current mHealth application design. Sections 2.6 and 3.5 address the research and integration. Functionalities such as enabling patients to set and track goals and sending reminders to encourage adherence to prescribed exercise programs are explored in section 4.2.

In the same effort to support patient motivation and engagement, a study was conducted on how the use of sensors could support this goal and enhance data collection, improving the overall effectiveness of exercise monitoring. This required understanding how such devices could be integrated, identifying the types of data they could collect and conducting a spike to test communication between the mobile app and a device with integrated sensors. The spike specifically tested communication with a Bluetooth-based device to assess the data it could transmit. This study is detailed in sections 2.4 and 3.6.

ID	Patient Need ID	Requirement
PR1	**PN1**	The mobile app must enable patients to access and complete their personalized exercise programs, which have been assigned by their HCP
PR2	**PN2**	The mobile app must enable patients to watch instructional videos that guide them through their exercises
PR3	**PN3**	The mobile app must collect patient feedback on their exercise experience
PR4	**PN3**	The mobile app must allow patients to provide their subjective perception of effort at the beginning and end of the exercise program
PR5	**PN3**	The mobile app must enable patients to input their vital signs at the beginning and end of the exercise program
PR6	**PN4**	The mobile app must display the current exercise being performed and indicate the phase of the exercise program the patient is in
PR7	**PN4**	The mobile app must display the recommended number of sets, repetitions, duration and rest time for each exercise
PR8	**PN4, PN5**	The mobile app must provide patients with both readable and audio instructions, along with safety instructions, to guide them in performing each exercise correctly and minimize the risks associated with remote exercises
PR9	**PN6, PN7**	The mobile app must send motivating reminders to patients to encourage user engagement
PR10	**PN6, PN7**	The mobile app must allow patients to set goals and monitor their progress

Table 3.3: Patient requirements

Healthcare professional Requirements

Similarly, the requirements for HCPs are based on the exercise module specifications from the predecessor application and further emphasized in the study discussed in section 3.2. A new feature allows HCPs to write patient-specific notes for assigned exercises or programs. These notes should be accessible to patients on the screens preceding the exercise program or individual exercises. The design of these screens is detailed in section 4.1.

Table 3.4 uses "The ONParkinson system" to emphasize that information flows between the web platform and the mobile app. Exercise programs created by HCPs, along with any updates or notes they make through the web platform, are visible to patients on the mobile app.

ID	HCP Need ID	Requirement
HCPR1	**HCPN1**	The ONParkinson system must enable HCP to create personalized exercise programs for each patient
HCPR2	**HCPN2**	The ONParkinson system must be able to exchange and display data related to the execution of exercise programs
HCPR3	**HCPN3**	The ONParkinson system must allow HCP to adjust exercise programs
HCPR4	**HCPN4**	The ONParkinson system must allow HCP to write notes specific to each patient regarding their exercises and exercise programs

Table 3.4: HCP requirements

System Requirements

As mentioned in section 3.1, there was a recognized need to update the technology used to build the mobile app, primarily to ensure compatibility across both Android and iOS devices. To meet this requirement, the Flutter software development kit was chosen for the development of the ONParkinson prototype, as it offers a unified solution for cross-platform development. Additionally, the new app needed to integrate within the ONParkinson system architecture. Since the mobile app is intended for use by Associação Portuguesa de Doentes de Parkinson (APDPk), it is also required to be available in Portuguese of Portugal.

To address the challenge of designing an eHealth solution that improves exercise adherence in self-management for PD patients, the ONParkinson prototype needed to be accessible to individuals with PD. This required understanding how the disease affects smartphone interaction and usability, as discussed in section 2.5 and incorporating a set of accessibility considerations for interface design, which are outlined in section 3.4.

ID	Requirement
SR1	The mobile app must be compatible with both Android and iOS platforms
SR2	The mobile app must be able to communicate with the current server
SR3	The mobile app must be available in Portuguese of Portugal
SR4	The mobile app must have accessible interfaces designed for patients with parkinsons-disease

Table 3.5: System requirements

3.4 Accessibility Considerations

Based on the discussion regarding how PD affects smartphone and app interactions, as detailed in section 2.5, the following guidelines offer solutions for designing more accessible user interfaces. PD introduces motor and cognitive challenges that can influence how individuals interact with digital devices, particularly touch-based systems like smartphones. These guidelines address common issues such as tremors, bradykinesia and memory deficits, with the goal of improving the user experience for individuals with PD [48, 65].

- Usage of tap targets with 14mm ($\approx$ 90 Device-Independent Pixels (DIP)) of side;

  The study recommends using tap targets with a minimum side length of 14mm, which was supported by accuracy rates (97.81%) in usability experiments. Targets of 17.5mm and 21mm also performed well, achieving accuracy rates of over 97%. While 10.5mm targets, which are useful in situations with limited screen space, reached 94% accuracy, smaller targets like 7mm resulted in lower accuracy, falling below 80%. Individuals with PD do not require larger targets than older adults, aligning with the design recommendations for the elderly.

- Usage of the swipe gesture without activation speed;

  Usability experiments revealed that participants could swipe accurately on the smartphone touchscreen under all test conditions. Approximately 95% of participants swiped at speeds of 24 mm/s or higher, indicating that this speed should be supported in smartphone user interfaces for individuals with PD. To accommodate these users, the activation speed of the swipe gesture can be eliminated. Individuals with PD do not have specific requirements for swipe gesture target size.

- Caution on implementing controls that use multiple taps;

  It was observed that participants were not significantly affected by bradykinesia in the multiple-tap test, up to the 10th tap. However, caution is advised when using this gesture, as successive taps may lead to user fatigue and discourage continued interaction with the interface.

- Avoid the usage of drag gestures;

  Participants successfully performed drag gestures on all sensitivity scales, indicating that drag gestures are viable in interfaces for individuals with PD. However, some participants reported frustration during the test, highlighting the importance of using drag gestures cautiously and sparingly to avoid user discomfort.

- Adapt interfaces to the momentary characteristics of the user;

  People with PD may experience fluctuations in their symptoms over time. To accommodate these changes, smartphones should monitor variations in touch performance, such as tracking selection errors or measuring the time between clicks. This would allow applications to adapt and optimize interactions based on the user's current condition, providing a more tailored and responsive experience.

- Usage of high contrasted and coloured elements;

  PD can affect vision, reducing the ability to discern low-contrast elements. Therefore, it is recommended to use high-contrast user interface elements to improve visibility and ease of use.

- Careful selection of information to display;

  PD often involves short-term memory loss, a symptom that can overwhelm users if too much information is displayed. Careful selection of displayed information is advised, considering the impact of memory loss.

- Provide clear information of current location at all times;

  Short-term memory loss and slowed cognitive processing in PD can hinder smartphone interactions. Displaying the user's current location within an app or interface can assist in recalling their goals, helping to prevent errors and improve navigation.

- Avoid controls that are time dependant;

  Movement speed reduction during the Off phase in individuals with PD can make time-sensitive tasks, such as responding to prompts within a few seconds challenging. Imposing time limits on controls may hinder interaction, cause frustration and potentially lead to the abandonment of the technology.

- Having multiple ways of interaction over a single one is preferable;

  The impact of PD on vision and speech can hinder smartphone interaction. To improve application usability for individuals with this condition, it's beneficial to incorporate multiple modalities for controls, such as combining visual elements with voice commands. This approach provides alternative ways to interact, accommodating various needs and abilities.

- Consider smartphone design guidelines for older adults.

  In 96% of the cases, people with PD are diagnosed after the age of 50 [66]. This means that besides PD symptoms, a percentage will also experience age-related changes. For this reason, when designing for people with PD, user interface design principles for older people should also be considered [67, 68].

3.5 Motivation Model Integration in eHealth Design

As discussed in section 2.6, user engagement refers to the level of interaction and involvement a user has with a product or service, reflecting their interest and continued use. Motivation is closely tied to engagement, as it drives users to initiate and sustain their interactions. In contexts like eHealth, motivated users are more likely to remain engaged with the system, which can lead to improved outcomes [50, 69].

To better understand how motivation can be promoted within eHealth applications, Table 3.6 outlines how the basic psychological needs of the Self-Determination Theory (SDT) and the principles of the Theory of Influence (ToI) are reflected in specific features within the current mobile app prototype. The goal is to enhance patient engagement, both with the app and with their own well-being.

SDT	**ToI**	**Feature within the mobile app**
Autonomy	Commitment	Patient-selected goals
		Commitments shared with HCPs and caretaker
		Remind patients of their commitments and encourage completion
Relatedness	Reciprocity	Personalized exercise plans designed by the HCP for the patient
		The caregiver can both assist and participate in the patient's exercises
	Liking	
Competence	Authority	Presenting the HCP as the primary authoritative figure
		Using the conversational agent as a means of communication
	Scarcity	Winning achievements, both standard and those with time or supply constraints
	Consensus	Providing the option to see and share earned achievements with others

Table 3.6: Mapping of Self-Determination Theory (SDT) and Theory of Influence (ToI) elements to mobile app features for patient engagement

- **Autonomy and Commitment:** The app enhances autonomy by allowing patients to select their own goals and share these commitments with HCPs and caregivers. This empowers users by giving them control over their health journey, increasing engagement;

- **Relatedness and Reciprocity/Liking:** The app improves relatedness by offering personalized exercise plans and involving caregivers in the patient's exercises. Interaction with HCPs and caregivers fosters a sense of belonging, encouraging the patient to stay engaged and motivated. Including caregivers builds trust, reinforcing commitment to the healthcare plan;

- **Competence and Authority/Scarcity/Consensus:** ONParkinson presents the HCP as an authority figure and uses a conversational agent to enhance user confidence in the app's guidance. Features like earning achievements under conditions of scarcity and sharing these achievements with others reinforce a sense of accomplishment, sustaining engagement and motivation over time.

Influence Awareness in computer-assisted rehabilitation refers to understanding how factors like feedback and motivation impact a patient's recovery. [50] emphasizes that recognizing these influences helps design rehabilitation tools that keep patients motivated and engaged, leading to more effective therapy. Guidelines for designing effective rehabilitation systems include:

- Avoid overwhelming the user with information, as too much detail can lead to information being ignored due to increased cognitive load;

  This is achieved by designing clear, straightforward interfaces that are easy to read, helping users navigate and absorb important information.

- Create challenging tasks while ensuring the complexity remains manageable for the patient;

  This is achieved by having HCPs create personalized exercise programs to the patient's abilities and progress. Challenges that patients can overcome, along with badges or rewards, further motivate them.

- Provide regular feedback on progress and achievements to enhance motivation;

  This is done by creating frequent, supportive interactions (Figure 3.7) that build connection and empathy. For PD patients, sharing exercise data and offering emotional support helps maintain enthusiasm for regular physical activity [70].

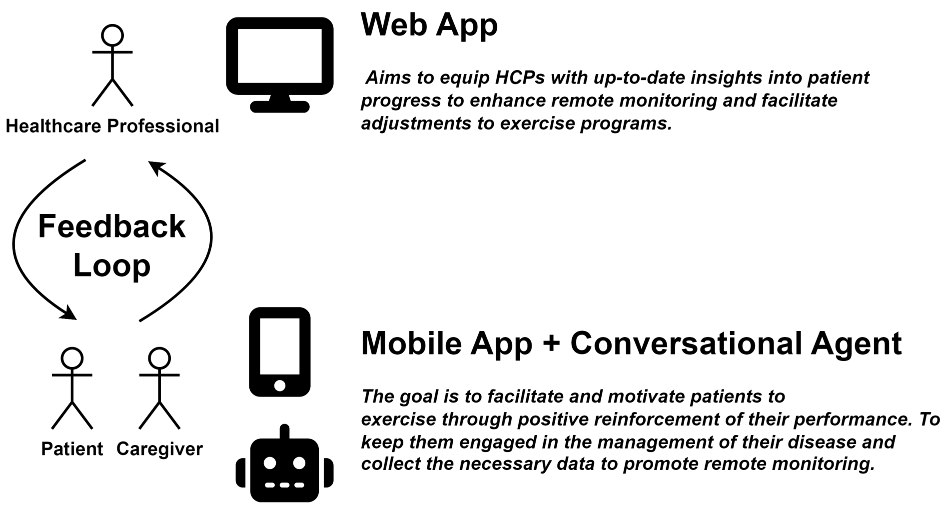

Figure 3.7: Feedback loop diagram

- Help them feel competent by reminding them of their achievements, both current and past, to reinforce their confidence in their abilities;

  This is accomplished by providing patients with access to a performance screen displaying personal records, current goals and earned badges. Support from HCPs and caregivers further enhances the patient's sense of competence and motivation.

- There are four stages in rehabilitation where motivation is necessary: before the exercise begins, motivation helps the patient start; during the exercise, it prevents stopping prematurely; after the exercise, it highlights achievements; and periodically, it encourages the patient to continue with more exercises;

  Motivating messages are delivered through notifications triggered by different metrics as outlined in Table 4.1. Notifications can be sent when an exercise program begins, ends, or at times when the patient is not currently performing an exercise program but has one assigned. However, no notifications are sent during the exercises themselves to avoid distractions or overload.

- Commitments and publicity are aimed at reinforcing the patient's dedication to performing exercises by reminding them of the commitments they have made and emphasizing that others are aware of these commitments.

  Notifications remind patients of their commitments. While HCPs and caregivers can be kept informed of the patient's progress, challenges and milestones, there is no plan to implement a broader sharing feature or social network for publicizing commitments to a wider audience.

3.6 Integration of Sensor Technologies

The study in section 3.2 emphasized the need for personalized feedback for exercises and highlighted the challenges of remote rehabilitation. To address these issues, one of the focuses of this dissertation was to investigate the integration of sensor technologies to enhance data collection and improve the effectiveness of remote exercise monitoring. This involved exploring how these devices could be integrated, identifying the types of data they could collect and conducting a spike to test communication between the mobile app and a Bluetooth-enabled device with integrated sensors.

Currently, data from both the mobile app and serious games can be captured and displayed on the web app. The mobile app provides details such as exercise program completion status, time and duration of exercises, subjective effort perception before and after the program and manually entered blood pressure and heart rate data. The serious games component offers game-specific metrics, like scores, bonus points, stars collected and obstacles cleared. Integrating sensor technologies aims to enhance data collection, giving more detailed insights to HCPs through the web app and to patients and caregivers through the mobile app. This integration can be further analyzed through a level-by-level approach.

Level 1 - Monitoring Patient Movement

The first level of implementing devices with integrated sensors is to monitor patient movement during exercise programs. The existing exercise module guides users through exercises and relies on self-reporting for completion. The primary objective at this stage is to validate patient movement to ensure the exercises are being performed.

An important factor in this step is the placement of the sensor on the patient's body. For example, in exercises involving leg movements while seated, the sensor should be placed on the leg to collect meaningful data that reflects actual movement. However, the placement may need to vary depending on the exercises, as a sensor on a non-moving body part won't provide useful information.

There are additional challenges to consider. Given the project's focus on supporting at-home exercise, it is important that attaching and repositioning the sensor is simple, especially for patients with PD, who may have limited autonomy. Additionally, the physical presence of the device, such as added weight, should not hinder the patient's ability to exercise, as this could affect performance data and possibly demotivate the patient.

Adapting devices to individual patients may involve offering different types or sets of devices, chosen by HCPs based on the specific exercise program and patient needs. These devices would differ mainly in their physical characteristics and placement methods to accommodate different situations.

However, using integrated sensors solely to verify patient movement during exercises may not be sufficient. The management of PD largely depends on the individual's commitment to managing their health, with exercise being part of this broader process. Using data from integrated sensors to verify exercise completion is an additional feature, but relying only on this data for monitoring may undermine patient confidence. Such an approach could be seen as intrusive, potentially demotivating patients rather than encouraging them.

Level 2 - Understanding Patient Motion

In the second level, the goal is to enhance the use of devices with integrated sensors by gaining a more detailed understanding of the specific motions patients perform during exercises. This involves deeper analysis of the data collected by these devices to identify the exact nature of movements. For instance, if a patient is moving a leg, the aim is to determine whether the movement is up-and-down or side-to-side, continuous or intermittent and whether it is performed smoothly or shakily, quickly or slowly. Essentially, this level seeks to replicate the observational capabilities of a HCP as if they were physically present with the patient.

It's important to recall the distinction between sensor data and processed data, as discussed in subsection 2.4.4. The raw data from sensors is not easily interpretable by humans and must be converted into a more understandable format. This process involves dealing with physics and its inherent complexities. To address this challenge, two main approaches are considered:

- Utilizing third-party software or devices;
- Developing custom physics-based algorithms.

Some devices previously discussed, such as the Biostamp RC, STAT-ON and Verisense, fall into the first category. These tools are advantageous because they pair with companion apps that process the data, simplifying the use of integrated sensors and ensuring medical applicability. However, two main limitations exist. First, since these devices come with their own apps, integrating them with this project's existing app is challenging. Ideally, there should be a way to merge or interoperate these apps to avoid the complexity of using separate applications, which could discourage exercise adherence.

Second, these devices offer a limited set of functions, such as gait analysis, sleep movement tracking and general activity monitoring. While these features are useful, they do not provide detailed insights into the specific movements patients perform during exercises. Additionally, using third-party software can lead to additional costs.

The alternative approach involves using devices that deliver raw data, placing the responsibility of data processing on ONParkinson. While this approach is more complex and requires specialized expertise, it offers an opportunity to collaborate with other departments within the Instituto Politécnico de Setúbal (IPS). It also opens the possibility of developing a prototype device adapted to the project's specific needs. A main advantage of in-house data processing is the flexibility to create and integrate a wider variety of exercises, including unconventional ones, into the exercise library. After assessing their benefits, these exercises could optionally be performed with the help of devices with integrated sensors.

The process of extracting meaningful data from patient movements requires converting raw sensor data from accelerometers and gyroscopes into a format that enables the understanding of specific motions. This transformation allows for the analysis of a wide range of movements. Although this stage is complex, it is not the final step. At this point, the information obtained is comparable to what a HCP could observe in person or via a video of the patient performing the exercise.

Level 3 - Evaluation of Patient's Exercise Execution

This third level builds on the previously collected data, aiming to provide feedback to the triad—healthcare professionals (HCPs), patients and caregivers. The focus is on comparing the patient's actual movements with a customizable expected movement profile. This profile must be adaptable to individual patients, as variations in disease progression and other factors can affect how an exercise is executed. A uniform standard of movement cannot be applied across all patients. Therefore, what constitutes correct and acceptable movement should be collaboratively established by the triad, with HCPs retaining the ability to adjust expectations when designing exercise programs. Feedback from this analysis falls into two categories:

- Feedback provided to the healthcare professional;
- Feedback presented to the patient and caregiver.

Feedback for HCPs will be delivered through the web application. The content of this feedback is the subject of a separate dissertation, but the general aim is to provide HCPs with clear, concise data on patient performance. This helps them make informed adjustments to exercise programs personalised to the patient's needs. The data will include detailed information about the patient's execution of exercise programs, collected via the mobile app and integrated sensor devices. The goal is to help HCPs maintain a current understanding of the patient's progress.

Feedback for the patient and caregiver should emphasize motivation, recognizing that engaging in exercise is inherently beneficial for managing PD. The feedback must balance positivity with constructive guidance, highlighting areas for improvement without being punitive or demotivating. The goal is to encourage continuous participation in the exercise program. It's also important to consider the timing of feedback delivery:

- Feedback during the exercise;
- Feedback after the exercise or at the conclusion of the exercise program.

The current system offers video demonstrations of exercises, but an enhanced feature could include a virtual assistant to guide the patient through the exercises. This could take the form of a human avatar or body part representation that mirrors the patient's movements and provides real-time guidance, similar to games like Wii Sports or Just Dance. The virtual assistant would offer interactive feedback, enhancing the exercise experience by making it more engaging and possibly gamifying it. Verbal guidance and encouragement from the assistant could further boost motivation. However, the system should be simple, clear and adaptable to the patient's pace to avoid overwhelming users, particularly those in more advanced stages of the disease.

Despite these features, real-time exercise guidance may not be suitable for everyone, depending on the individual's stage of the disease, so it would be an optional tool for HCPs to enable when appropriate.

From a technical standpoint, providing real-time feedback can be demanding on smartphone hardware, depending on the optimization of the algorithms involved. Minimizing delays in data collection, processing and display is crucial to avoid confusing the patient. The system should aim for low latency to ensure the feedback is in sync with the patient's movements.

An alternative approach involves providing feedback after the exercise or at the conclusion of the program. This method, which could complement real-time feedback, would deliver feedback during breaks or after the exercise session. One advantage of this is that without the need for real-time processing, more complex analyses can be handled by a server, reducing the burden on the smartphone.

In terms of feedback presentation, the focus shifts from real-time performance tracking to reviewing past performance. It's important to maintain a positive tone, acknowledging areas for improvement while celebrating successes and encouraging progress. Complex data should be avoided in favor of user-friendly formats like checkboxes, progress bars, or simple graphs, especially to illustrate positive trends. The information should be clear, easy to understand and motivational.

The goal of this third level is to provide actionable insights for the triad. For HCPs, the feedback is intended to simplify their responsibilities, enabling more effective remote monitoring and intervention strategies personalised to each patient. For patients and caregivers, the focus is on creating a more interactive, engaging exercise experience. Even if the primary function of sensor data is to count series and repetitions, the ability to track and visualize progress plays an important role in motivation. This visualization is not just about presenting data, it's about delivering it in a way that encourages adherence to the exercise program, ultimately improving treatment outcomes. The integration of devices with sensors and the analysis of the data they produce should be designed to enhance the exercise experience for patients and caregivers while providing helpful insights to HCPs.

3.7 The User Engagement Proposal

This chapter ends with the wrap-up of the user engagement model. As stated above, adherence to exercise and treatment programs is essential to improve health outcomes in people with PD. Therefore, Figure 3.8, the Motivational Model Diagram, highlights six pillars that should promote engagement: accessibility and usability, motivation theories, gamification, personalized exercise programs, positive reinforcement, and sensor technologies. Accessibility and usability ensure that solutions address diverse needs, while motivation theories guide strategies to maintain interest and commitment. Gamification introduces elements of play to enhance participation. Personalized exercise programs align activities with individual capabilities, promoting adherence. Positive reinforcement rewards progress and consistency, reinforcing healthy habits. Lastly, sensor technologies enable real-time monitoring and feedback, providing data-driven insights to refine interventions and maintain user engagement. These elements together form a robust framework to support sustained participation in exercise and treatment programs.

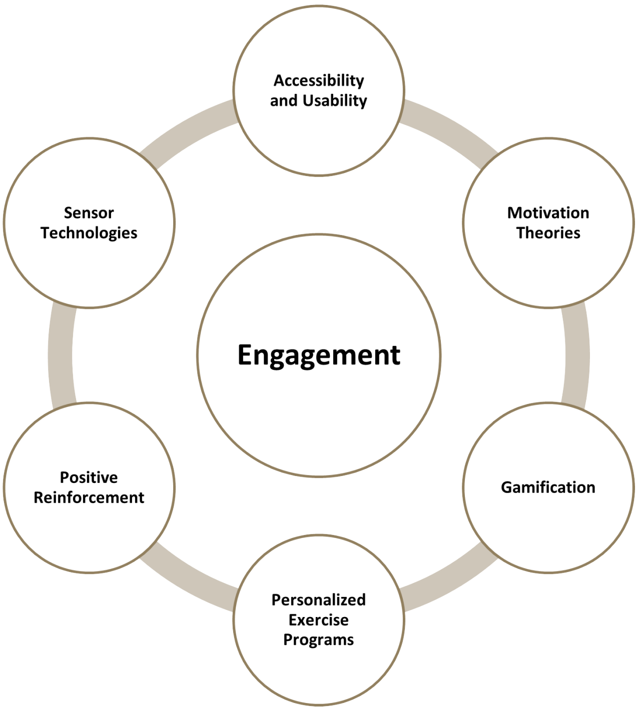

Figure 3.8: Motivational Model Diagram

Chapter 4

Results and Evaluation

This chapter presents the results and evaluation of the user engagement solution developed. It covers the user experience design, user motivation aspects and the integration of sensor technologies. The chapter also discusses the feedback collected from users through preliminary tests, including their experiences with the ONParkinson mobile app and usability.

4.1 User Experience Design

This section provides an overview of how the exercise module is incorporated into ONParkinson. Once users log in, they are directed to the main menu (Figure 4.1), where they can explore a list of Frequently Asked Questionss (FAQs) about Parkinson's Disease (PD), curated by Healthcare Professionals (HCPs). The app also offers a calendar function, helping both patients and caregivers keep track of exercise program schedules. This project primarily focuses on the implementation and management of these exercise programs.

The exercises menu in the mobile app (Figure 4.2) offers access to four distinct screens: "Desempenho" (Performance), "Desafios" (Challenges) and "Passos Diários" (Daily Steps), which are further discussed in section 4.2. These screens are designed to enhance user motivation and app engagement by setting goals and rewards for task completion or milestone achievement, incorporating elements of gamification and persuasive technology.

Figure 4.1: Main menu screen

Figure 4.2: Exercises menu screen

The "Programas" (Programs) button in the mobile app directs users to a screen (Figure 4.3), where patients can view their assigned exercise programs. These programs are organized into categories, such as "Atividades Vida Diária" (Daily Life Activities), which focuses on exercises designed to improve tasks like standing up from a seated position or getting out of bed.

The "Equilíbrio" (Balance Training) category targets reducing postural instability and enhancing postural control. This category includes exercises aimed at improving motor coordination and walking, while lowering the risk of falls.

The "Força" (Strength Training) programs are geared toward promoting muscle hypertrophy and increasing muscular strength in the torso, upper and lower limbs. These programs seek to improve walking, reduce fall risk and counteract sedentary behavior.

"Aeróbio" (Aerobic Training) is focused on cardiovascular health and overall fitness. For PD patients, aerobic training helps improve endurance and supports cognitive function.

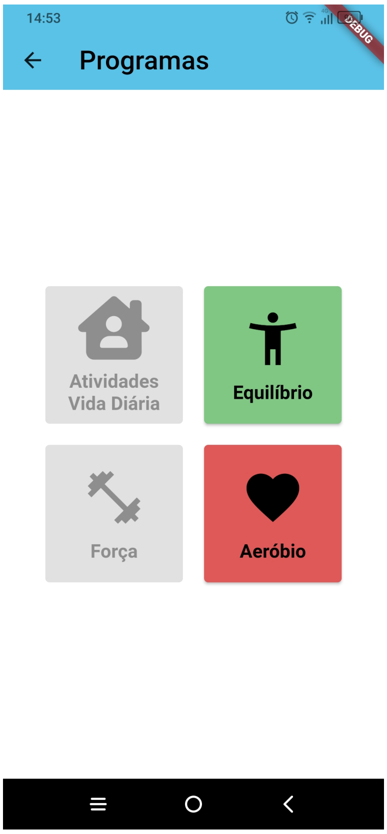

Figure 4.3: Programs screen

After selecting an exercise program, such as aerobic training, the user is presented with an overview (Figure 4.4). This overview outlines the program's objectives, includes any notes from the HCP for guidance and provides a breakdown of the workout session, required equipment and instructions on breathing techniques. Each program is divided into phases with designated durations, ensuring that patients begin with a warm-up, move on to the main exercises and finish with a cooldown. The exercise list (Figure 4.5) shows the exercises that will be performed during the session.

The speaker button at the bottom center of the screen activates the text-to-speech feature, allowing the app's conversational agent to read the text aloud for users with visual impairments or those who prefer listening. Navigation buttons at the bottom allow users to move to the next or previous step in the exercise program.

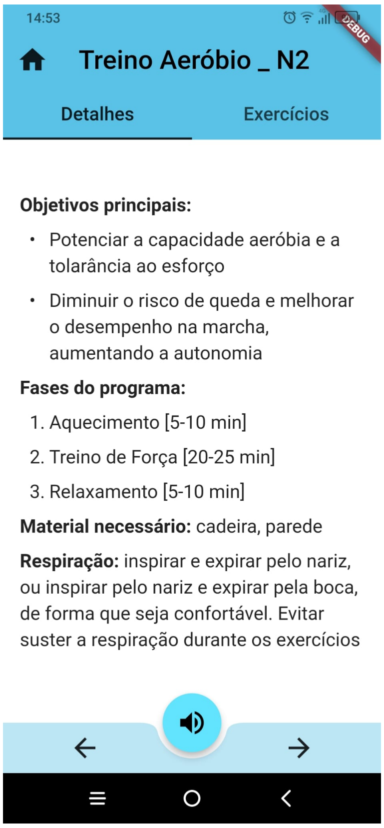

Figure 4.4: Program details screen

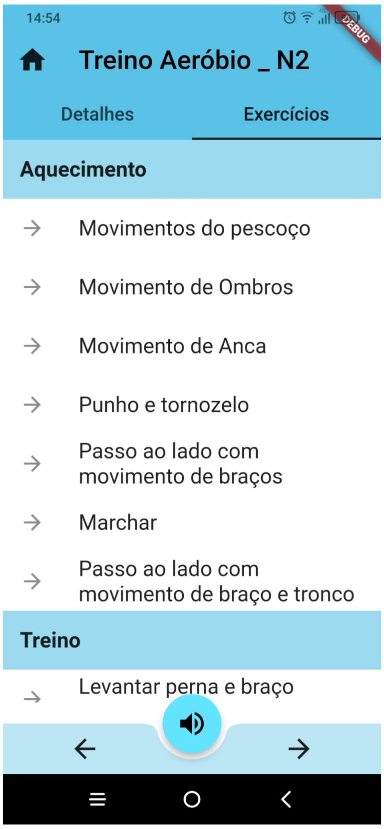

Figure 4.5: Program exercise list screen

The exercise details screen (Figure 4.6) provides users with step-by-step instructions for the next exercise in their program. It explains the required starting posture, includes notes from the HCP for personalized guidance, details the movements to be performed and lists safety precautions to ensure exercises are done safely.

The next screen (Figure 4.7) features an interactive instructional component for performing exercises. It includes a video demonstration to help users with proper form and technique, shows the prescribed repetitions and sets from the HCP and allows adjustments based on the user's performance.

The screen also includes a help button that activates Pandora, the app's conversational agent [71]. Pandora offers interaction options, such as dictation, typing questions, or selecting preset options like exercise assistance, reporting discomfort, skipping an exercise, or resuming the program. When the user asks for help, Pandora requests details and provides relevant information, offering further assistance or allowing the user to continue the program.

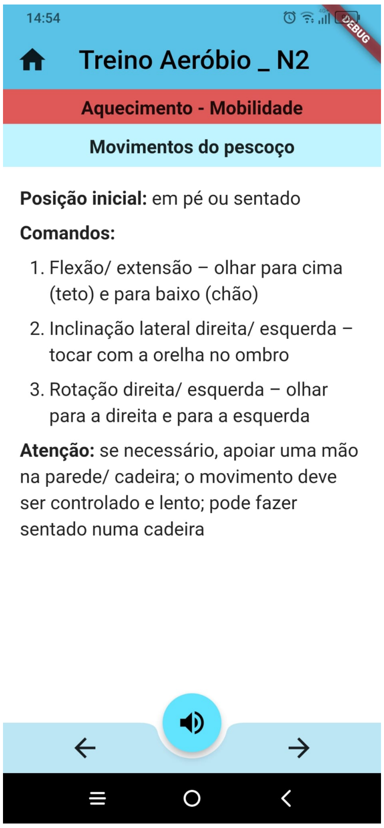

Figure 4.6: Exercise details screen

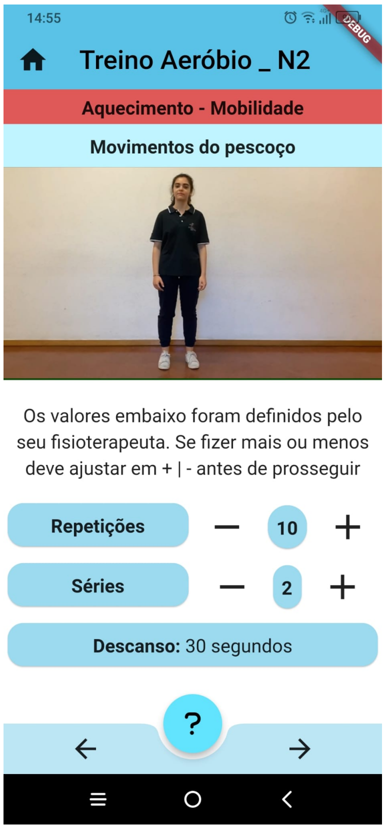

Figure 4.7: Exercise execution screen

The mobile app includes two screens for monitoring patient engagement and response to the exercise program. The vital signs measurement screen (Figure 4.8) records physiological data, such as blood pressure and heart rate, both at the start and end of each exercise session. This feature provides insights into how the exercises are impacting the user's physical condition.

The perceived exertion screen (Figure 4.9) is used before and after the exercise program. It employs a modified Borg Rating of Perceived Exertion (RPE) scale to measure the user's subjective perception of exertion and fatigue, allowing HCPs to track changes in fitness levels over time and assess the effectiveness of the exercise program.

Figure 4.8: Vital signs measurement screen

Figure 4.9: Perceived exertion screen

The final screen in the exercise program (Figure 4.10) is designed to collect feedback on the patient's experience. It presents the user with questions about their most recent exercise session, with responses recorded on a color-coded scale featuring emoticons ranging from sad to happy. This feedback helps maintain an ongoing feedback loop between the patient and the HCP, ensuring that exercise programs are regularly updated and personalized to better match the patient's needs and preferences.

Figure 4.10: Collect feedback screen

The mobile app interfaces were designed in accordance with the principles discussed in sections 3.4 and 3.5, aiming to enhance the user experience for patients with PD. Large, clear User Interface (UI) elements are consistently used throughout the app. In the main menu and program selection screens, buttons are spaced apart with clear labels and tap areas are appropriately sized to assist users with tremors or limited fine motor skills, reducing the likelihood of accidental selections.

Simplifying navigation was another focus. The menu layout is streamlined with a few large buttons, a design approach that is also reflected in other sections, such as the program details screen, where tabs allow easy switching between "Detalhes" (Details) and "Exercícios" (Exercises). The exercise list screen presents a simple, easy-to-read list, helping users stay oriented.

High-contrast colors are used to assist users with visual impairments or color blindness. Different colors clearly distinguish sections and options, with blue used for active selections and red or green for program types. Black text on white or light blue backgrounds improves readability. Clear instructions and feedback are also integrated: the program and exercise details screens provide objectives, required materials and step-by-step guidance. Text-to-speech functionality is available for users with reading difficulties, with audio buttons on the program details screen and the conversational agent button on the exercise execution screen to read instructions aloud. The exercise execution screen further includes video and audio instructions, as well as adjustable exercise parameters, ensuring that users can effectively follow their exercise programs.

4.2 User Motivation Aspects

Providing regular feedback on progress and achievements is important for maintaining motivation, as it keeps users engaged and informed about their improvements. Additionally, reinforcing a sense of competence by reminding users of their past and current accomplishments helps build confidence in their abilities. Persuasive technology applies these concepts, using psychological principles to guide and encourage users toward desired behaviors. By using notifications, the mobile app delivers timely feedback and reminders, helping to sustain patient motivation and confidence.

The following two images (Figures 4.11 and 4.12) illustrate the motivation cases that trigger notifications from four areas of the mobile app: daily steps, challenges, performance and exercise programs. They also provide examples of the messages sent to the patient.

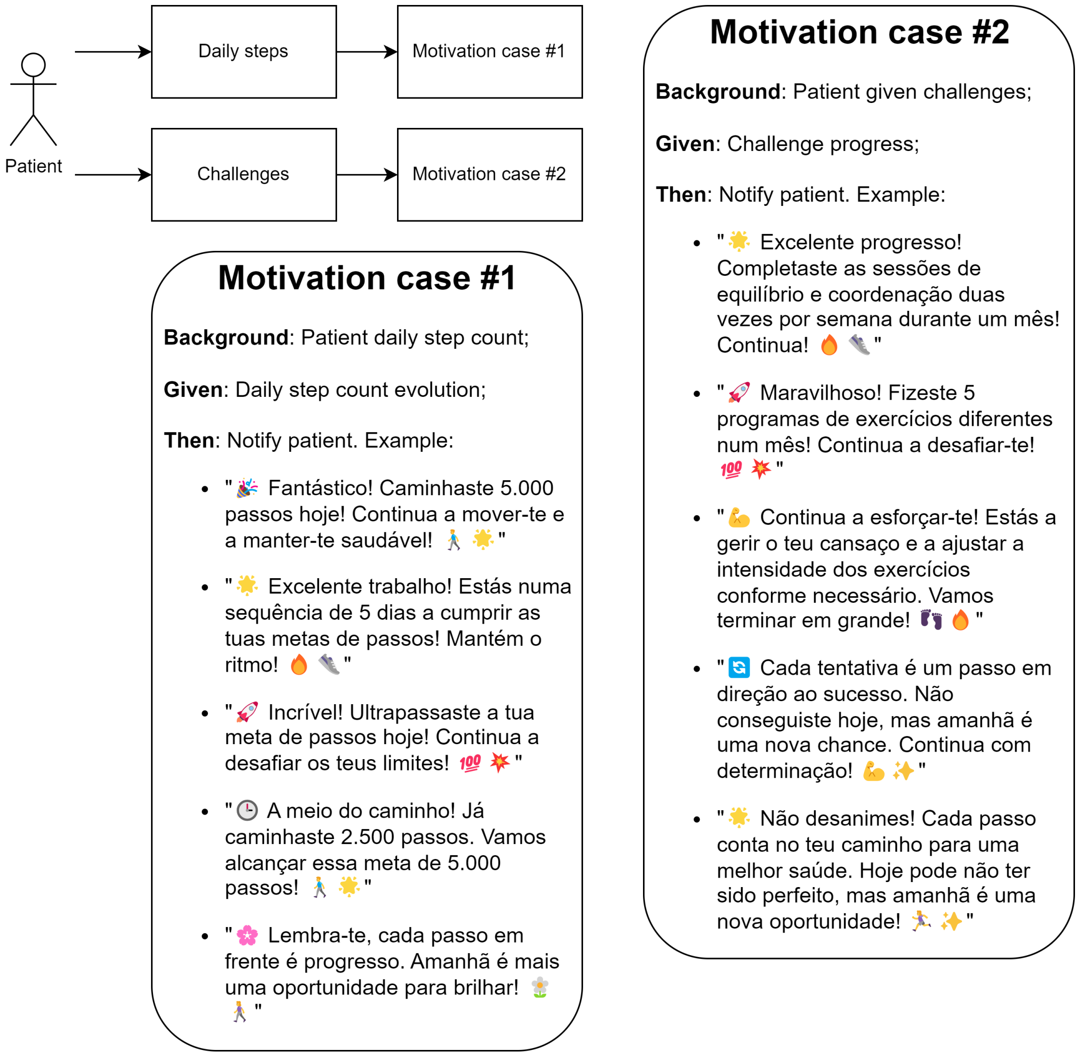

Figure 4.11: Diagram of motivation cases (part 1 of 2)

- Motivation Case #1 focuses on increasing the patients' daily step counts. The system tracks daily steps, evaluates progress over time and sends notifications. These messages recognize milestones, encourage consistency and remind the patient of the significance of each step.

- Motivation Case #2 aims to motivate patients to complete various challenges. The system monitors progress in these challenges and provides notifications based on performance, encouraging patients to stay engaged and complete them.

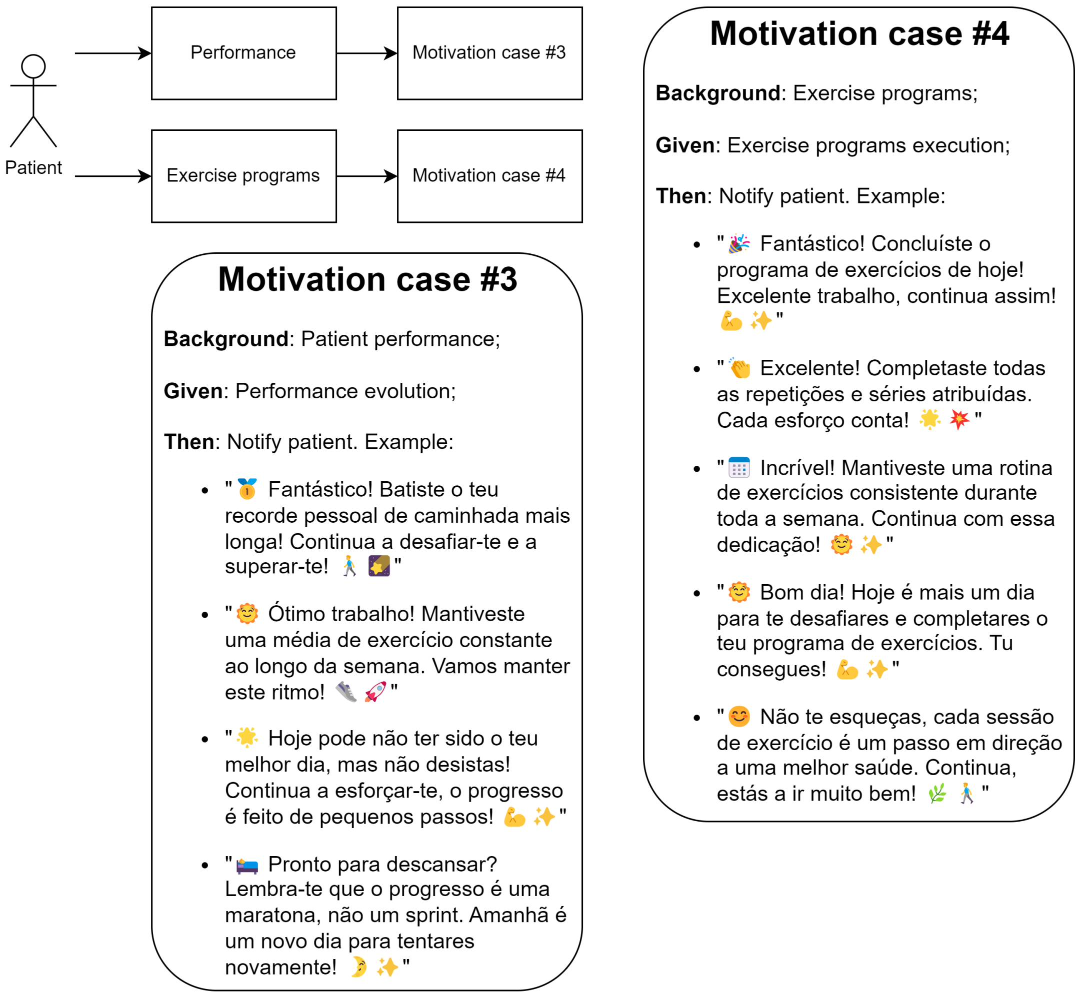

Figure 4.12: Diagram of motivation cases (part 2 of 2)

- Motivation Case #3 is aimed at improving patient performance by tracking performance metrics and assessing progress over time. Notifications highlight personal records and encourage patients to continue pushing through challenges.

- Motivation Case #4 supports patients in completing their exercise programs. Notifications acknowledge the completion of exercise routines, motivate patients to maintain their activities and stress the importance of each exercise session.

The metrics required to generate and trigger the motivation cases, such as step count, can originate from sensors in smartphones or other devices with integrated sensors. In more advanced cases, these metrics can be derived by reaching at least Level 2 of the Integration of Sensor Technologies (Section 3.6), where patient movement can be measured and interpreted. Additionally, metrics can come from user input, such as subjective perceived exertion, or be calculated and recorded by the system, such as time spent exercising or the longest streak of a specific activity. Examples of motivation case metrics and their data origins are listed in Table 4.1.

Area	**Metric**	**Origin of data**
Daily steps	Step count	Sensor
Challenges	Personal records (e.g., longest walk)	System
	Consistency metrics (e.g., number of consecutive days of activity)	
Performance	Personal records (e.g., most repetitions in a session, number of programs completed)	System
	Consistency metrics (e.g., number of consecutive assigned programs completed)	
Exercise programs	Number of repetitions completed	Sensor or User
	Number of sets completed	
	Exercise program status (Started, Completed or Not Started)	System
	Duration	
	Tiredness Level	User

Table 4.1: Motivation case metrics

The motivational cases include both a dedicated screen and notifications for each case. When specific criteria are met, notifications are triggered to send messages to the patient, highlighting progress and providing motivation through positive reinforcement. These notifications use emojis and icons to make them more visually engaging. Examples of notifications for each motivational case are shown in Figure 4.13.

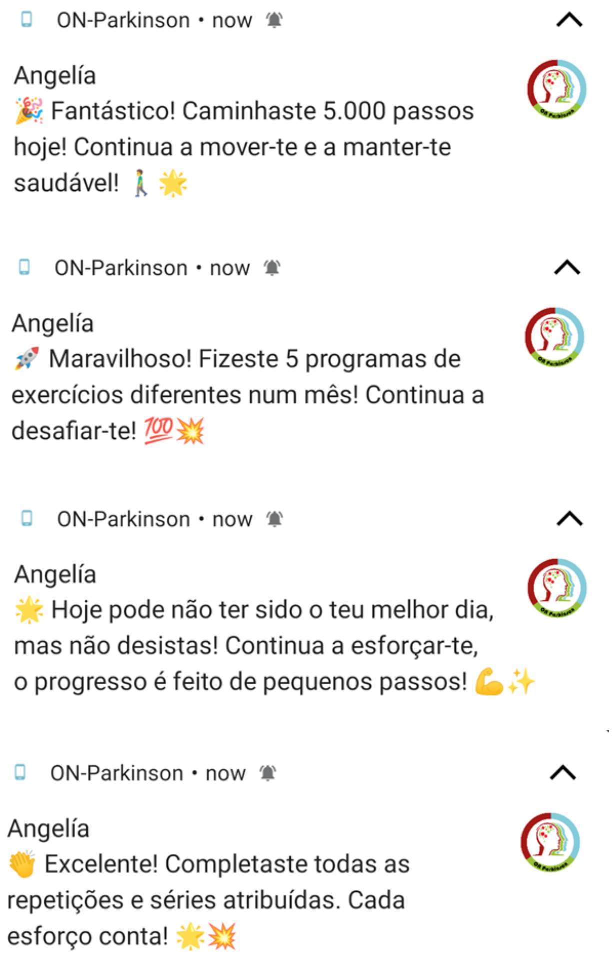

Figure 4.13: Notifications for each motivation case

Gamification incorporates game-like elements such as rewards, challenges and progress tracking into non-game contexts to make activities more engaging. This approach can include setting personalized goals, providing achievement notifications and using virtual badges to mark milestones. These elements create a sense of accomplishment and encourage user engagement in health-related activities.

The following mockups of mobile app screens demonstrate this concept. The screen in Figure 4.14 displays performance data like total steps and exercise duration, allowing users to monitor their progress over time. Personal records, such as the longest walk or exercise session, are shown to motivate users to exceed past performance. The reward system incorporates badges and achievements to encourage users to reach new goals, adding a competitive dynamic to the experience.

Figure 4.14: Mockup of the performance screen

The screen in Figure 4.15 displays a list of challenges, along with the current progress percentage for each and the rewards earned so far. These challenges can be set by the patients or by HCPs and can be customized to meet individual needs. Challenges offer clear, manageable goals that help PD patients stay focused and improve their self-efficacy. Rewards and recognition for completing challenges reinforce positive behaviors and encourage continued engagement in physical activities.

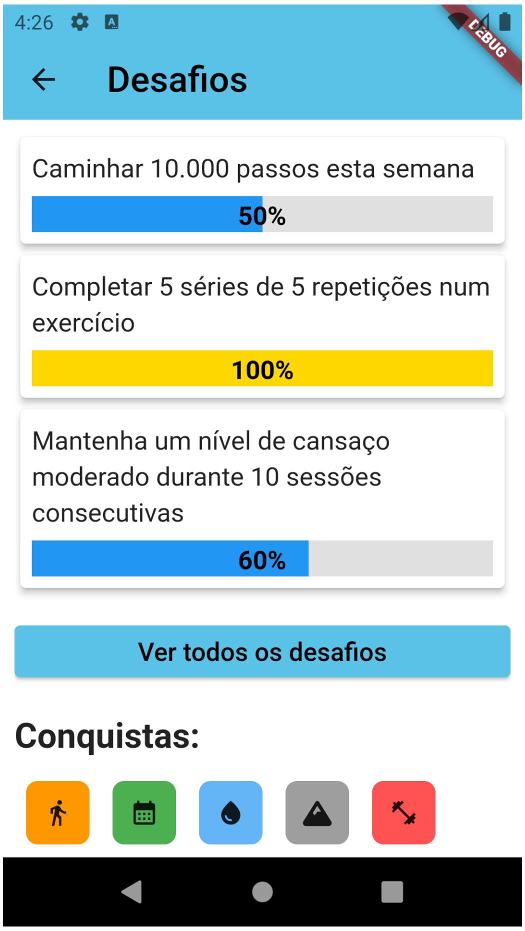

Figure 4.15: Mockup of the challenges screen

The screen in Figure 4.16 tracks daily steps and encourages physical activity. It shows the number of steps taken today, the step goal and progress towards that goal. It also tracks the current streak of consecutive days in which the step goal has been met. Users can adjust their daily step goals to set personalized targets. Walking is essential for individuals with PD, as it helps maintain mobility, reduce symptoms and improve quality of life. Regular walking also enhances cardiovascular health, muscle strength and coordination, which are often impacted in PD patients [72].

Figure 4.16: Mockup of the daily steps screen

The screen in Figure 4.17 displays earned badges along with their completion dates. This feature tracks accomplishments, promotes engagement by highlighting achievements and reinforces positive behaviors.

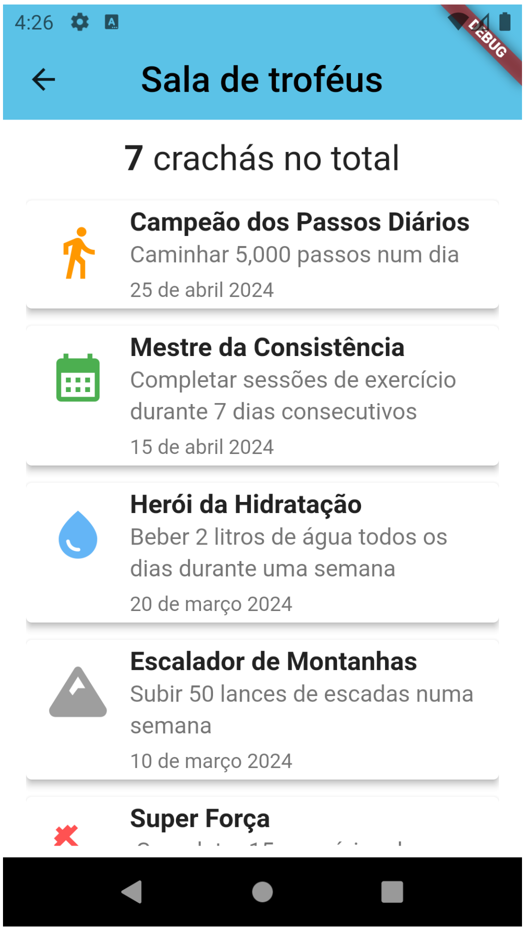

Figure 4.17: Mockup of the reward screen

4.3 Overview on Devices with Integrated Sensors

Incorporating devices with integrated sensors that provide raw sensor data and managing the transformation into processed data internally offers greater flexibility and allows any exercise in the exercise library to be enhanced with the support of these devices. From a cost-effectiveness perspective, this approach is more viable, as it only requires the initial acquisition of the devices, eliminating the need for ongoing expenses related to companion apps and their infrastructure.

Figure 4.18: WitMotion WT901BLECL BLE5.0

As a proof of concept, a device with integrated sensors (Figure 4.18) was acquired and tested to evaluate its connectivity and the data it could provide. The device connects via Bluetooth and has a default data output frequency of 10 Hz, meaning it transmits the array of information listed in Table 4.2 ten times per second.

Byte Detail	**Description**
0x55	Packet header
0x61	Flag bit
axL	X Acceleration low 8 byte
axH	X Acceleration high 8 byte
ayL	Y Acceleration low 8 byte
ayH	Y Acceleration high 8 byte
azL	Z Acceleration low 8 byte
azH	Z Acceleration high 8 byte
wxL	X Angular velocity low 8 byte
wxH	X Angular velocity high 8 byte
wyL	Y Angular velocity low 8 byte
wyH	Y Angular velocity high 8 byte
wzL	Z Angular velocity low 8 byte
wzH	Z Angular velocity high 8 byte
RollL	X Angle low 8 byte
RollH	X Angle high 8 byte
PitchL	Y Angle low 8 byte
PitchH	Y Angle high 8 byte
YawL	Z Angle low 8 byte
YawH	Z Angle high 8 byte

Table 4.2: WitMotion WT901BLECL BLE5.0 data format

To convert raw sensor data into practical values representing acceleration, inclination and orientation (roll, pitch and yaw), specific calculations are applied to the data acquired from the sensor. For this device, sensor data is received in bytes, which are 8-bit units. These bytes must be translated into signed integers (values that can be either positive or negative) to be used. If a byte is less than or equal to 127, it represents a positive number and is used in its existing form. If a byte exceeds 127, it needs to be converted into the corresponding negative integer.

To calculate the acceleration for each axis, the signed data bytes for each axis are combined. This involves taking the low and high byte for an axis, like X and merging them to form a 16-bit number. This is achieved by shifting the high byte and applying a bitwise OR with the low byte, forming a 16-bit integer. This integer initially represents acceleration in a raw form. To convert it into a measurement unit like meters per second squared (m/s^2), the 16-bit integer is scaled down using a specific factor, depending on the sensor's technical specifications.

For calculating the acceleration norm, a common approach is to take the square root of the sum of the squares of the X, Y and Z accelerations. This gives the total acceleration magnitude, independent of its direction. When the sensor is stationary, this value is approximately $9.8\,m/s^2$, reflecting Earth's gravity.

To determine the inclination angles along the X, Y and Z axes, the acceleration values on these axes are initially normalized within a range of -1 to 1, indicating the direction of acceleration. The arc cosine function is then applied to these normalized values to calculate the angles expressed in radians, which can be converted to degrees. These angles show the sensor's orientation, indicating which axis is more vertical or horizontal compared to the ground. For determining orientation values such as roll, pitch and yaw, the calculations are generally more complex. However, this device simplifies the process by providing the low and high byte for each axis and including a formula for these calculations in its documentation.

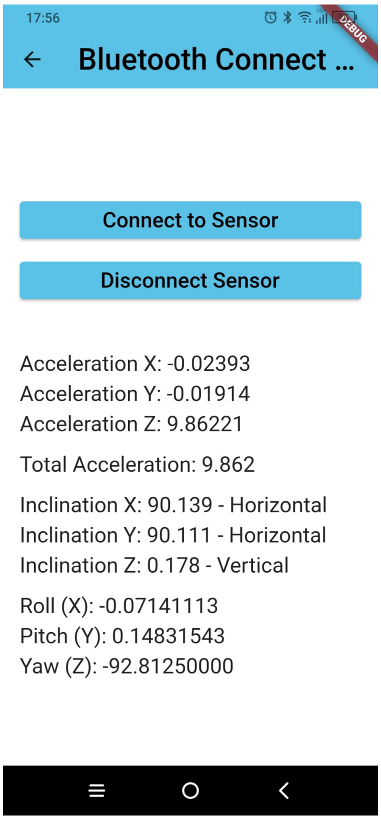

Figure 4.19: Mobile app sensor testing screen

These measurements were incorporated into the interface shown in Figure 4.19. They provide an overview of the device's movement and orientation. In the context of the milestones outlined in section 3.6, these values correspond to Level 1, serving as the foundational data for monitoring patient movement.

Regarding the analysis of processed data from third-party software or devices, information such as gait analysis, sleep movement tracking and overall daily activity levels provide insights beyond exercise program execution. This continuous monitoring highlights the importance of device comfort, unobtrusiveness and data privacy, as patients would wear the devices for extended periods, including during their daily routines. Developing long-term monitoring in ONParkinson could lead to a better understanding of PD progression in patients and capture information that might only emerge outside exercise sessions.

At this stage of the ONParkinson project, recommending a specific device brand or model is not feasible. The study of devices with integrated sensors in subsection 2.4.3 examines various devices for their features and potential integration. Research and experience gained from the ONParkinson project have revealed several important findings and future directions. One significant finding is the need for a device-agnostic data transformation system, illustrated in Figure 4.20.

To ensure integration, each device with integrated sensors would require an adaptor for interfacing with the system. This adaptor standardizes communication between the device and the mobile app by calibrating and converting data formats to follow a unified protocol. Once transformed into this standardized format, the data is processed by physics-based algorithms, which interpret the sensor data and convert it into practical insights. These insights are then made available to patients, caregivers and HCPs.

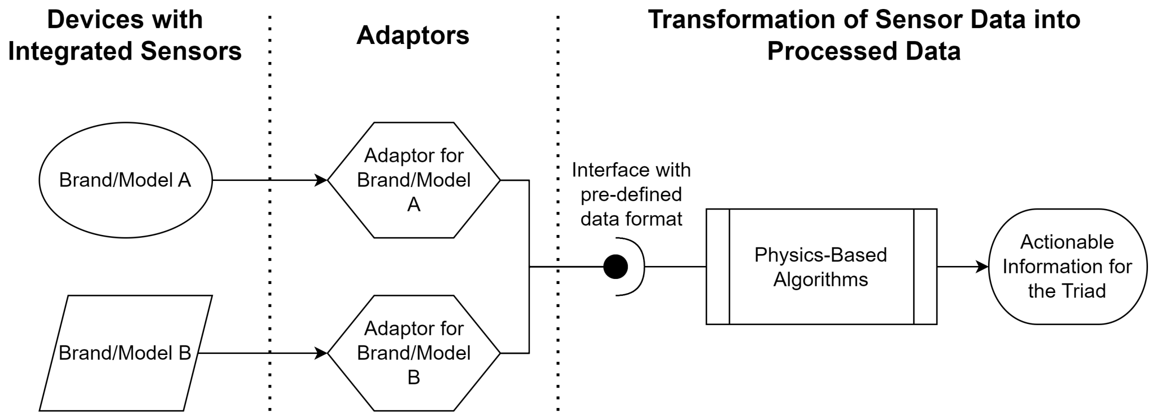

Figure 4.20: Device connection diagram

4.4 Assessment of the ONParkinson Mobile App

This study assessed how patients with PD interact with the ONParkinson mobile app, focusing on its usability and user engagement without using sensor-integrated devices. The goal was to evaluate the app's functionality and overall user experience.

The study's questionnaire, as detailed in Appendix A, mainly consists of yes/no questions but allows for open-ended responses. This study was conducted in a controlled environment over a single day, following a pre-established screenplay (Appendix B). The primary objectives were to identify any usability issues in the ONParkinson mobile application and evaluate the patients' interaction and engagement with its features. The study design is illustrated in Figure 4.21.

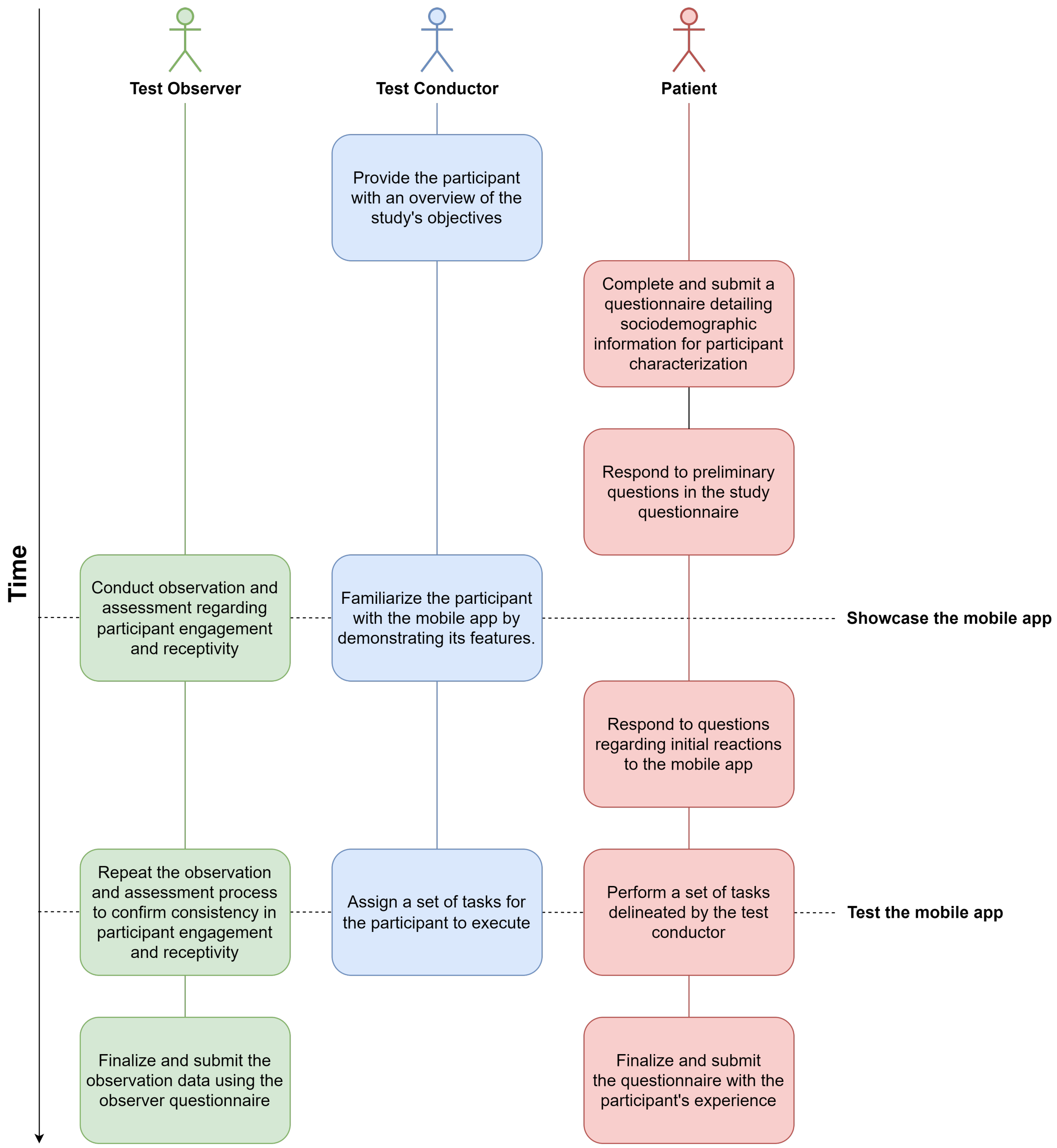

Figure 4.21: Flowchart of the assessment of the mobile app

Initially, participants were given a briefing that outlined the study's objectives, ensuring they understood its purpose. They then completed a socio-demographic questionnaire (Appendix C) for characterization and answered preliminary questions from the study questionnaire.

After these initial steps, participants were introduced to the application through a demonstration of its features. The test observer documented the participants' initial reactions and completed a specific questionnaire (Appendix D). Following the demonstration, participants answered additional questions in the study questionnaire, focusing on their first impressions and reactions to the application.

Next, the test conductor assigned tasks for the participants to explore the application's functionalities. During this phase, the conductor refrained from intervening unless the participant appeared confused or lost. Meanwhile, the observer continued to monitor the participant's behavior and filled out a separate questionnaire. This observer's questionnaire was designed to collect data on whether the participant's responses in the study questionnaire aligned with their verbal expressions or body language. After completing the assigned tasks, the participant answered the remaining questions in their questionnaire.

4.4.1 Characterisation of the Participants

The participant group, consisting of 8 individuals diagnosed with PD, was recruited from Associação Portuguesa de Doentes de Parkinson (APDPk), Saudis Clinic and Escola Superior de Saúde - Cruz Vermelha Portuguesa (ESSCVP). Within this group, 62.5% (5 individuals) are male and 37.5% (3 individuals) are female. Regarding the stage of PD, according to the Hoehn and Yahr scale, 50% of participants are at stage 2, 25% are at stage 3 and the remaining 25% are at stage 1. A majority, 87.5%, are currently attending physiotherapy sessions and 62.5% engage in exercise outside of their physiotherapy sessions.

Participant 1: A 67-year-old male, retired bookbinder, in a partnership, living with family. He has an education level of 6th grade, exercises outside of physical therapy, owns a non-smartphone mobile and computer, uses the internet and uses technology for activities, including internet searches. He has PD at stage 2, diagnosed 13 years ago and has been attending physiotherapy twice a week for 4 months.

Participant 2: A 74-year-old female, retired, married, living with her spouse. She has an education level of 11th grade, exercises outside of physical therapy, owns a smartphone, uses the internet and engages in technological activities. She has PD at stage 1, diagnosed 5 years ago and has been attending physiotherapy three times a week for 3 years.

Participant 3: A 68-year-old female, retired hairdresser, married, living with her spouse. She has an education level of 9th grade, exercises outside of physical therapy, owns a smartphone and computer, uses the internet and engages in technological activities. She has PD at stage 3, diagnosed 12 years ago and has been participating in physiotherapy three times a week for 1 year.

Participant 4: A 71-year-old male, retired mechanic, single, living with family. He has an education level of 5th grade, does not exercise outside of physical therapy, owns a non-smartphone mobile, does not use the internet and mainly uses technology for calls and messages. He is at stage 2 of PD, diagnosed 17 years ago and is engaged in physiotherapy three times a week for 6 months.

Participant 5: A 59-year-old male, retired from medical sales, married, living with his spouse. He has an education level of 10th grade, exercises outside of physical therapy, owns multiple devices including a smartphone and tablet, uses the internet but is not comfortable with technology. He was diagnosed with PD 21 years ago, is at stage 2 and has been receiving physiotherapy three times a week for 12 years.

Participant 6: A 75-year-old male, retired, with a profession in administration, married and living with his spouse. He has an education level of 11th grade, does not exercise outside of physical therapy, owns a smartphone and computer, uses the internet and mainly uses technology for phone calls. He has PD at stage 3, diagnosed 9 years ago and currently attends physiotherapy twice a week.

Participant 7: A 63-year-old female teacher, not retired, single, living alone. She has a doctorate, does not exercise outside of physical therapy, owns a smartphone and computer, uses the internet and her technology use includes various activities. She has recently been diagnosed with PD at stage 1 and attends physiotherapy sessions twice a week.

Participant 8: A 49-year-old male, retired tax technician, single, living with others. He has an education level of 12th grade, exercises outside of physical therapy, owns a smartphone, uses the internet and is active in technological activities. He has PD at stage 2, diagnosed 16 years ago, but currently does not attend physiotherapy.

4.4.2 Findings and Analysis

Regarding the question about prior usage of a similar application (MA1, Table 4.3), the majority of participants indicated they had not used such an application. However, two participants reported differing experiences, one did previously use a similar application, while the other had utilized an application exclusively for prescribing exercises. The initial reactions of the participants towards the mobile app (MA2, Table 4.4) were positive.

Patient	Answer
P1	No
P2	No
P3	Yes
P4	No
P5	No
P6	No
P7	No
P8	Similar no, but of exercise prescription yes

Table 4.3: Answers to **MA1**: Have you ever used a similar application?

Patient	Answer
P1	Very interesting
P2	It's great, very well thought out and the menu is well designed
P3	Liked
P4	Positive
P5	Usable, easy, informative, positive
P6	Positive, useful
P7	Good
P8	Positive

Table 4.4: Answers to **MA2**: What is your (first) impression of this application?

In response to the question about whether any aspect of the application was frustrating to use (MA3, Table 4.5), only one participant reported experiencing frustration. This frustration was specifically associated with interacting with the conversational agent, particularly the "other questions" feature. The participant found the necessity to write and send a text message, instead of using buttons with pre-written questions, to be difficult.

Patient	Answer
P1	No
P2	No
P3	No
P4	No
P5	No
P6	No
P7	The "other questions" option on the conversational agent
P8	No

Table 4.5: Answers to **MA3**: Is there any interaction with the application that is frustrating to use?

Regarding the question of whether the information within the application was legible and understandable (MA4, Table 4.6), all participants affirmed it was. However, one participant noted that some text required review for its Portuguese. In response to the question of whether any screen in the application contained an excessive amount of information (MA5, Table 4.7), all participants indicated that this was not the case.

Patient	Answer
P1	Yes
P2	Yes
P3	Yes
P4	Yes
P5	Yes
P6	Yes
P7	Yes, but the Portuguese needs to be revised
P8	Yes

Table 4.6: Answers to **MA4**: Do you find the information in the application legible and understandable?

Patient	Answer
P1	No
P2	No
P3	No
P4	No
P5	No
P6	No
P7	No
P8	No

Table 4.7: Answers to **MA5**: Is there a screen with too much information?

When questioned about whether they found the mobile application suitable for individuals with PD (MA6, Table 4.8), all responded affirmatively. Additionally, one participant noted that further enhancements could be made to address questions regarding the exercises more effectively. In response to the question regarding their interest in frequent use of the application (MA7, Table 4.9), all participants provided a positive reply. Similarly, when questioned about the ease of use of the application (MA8, Table 4.10), the response was affirmative, with one participant adding that they anticipated it would become easier over time.

Patient	Answer
P1	I think so, I was able to use it
P2	Yes
P3	Yes
P4	Yes
P5	Yes
P6	Yes
P7	Yes, but it should answer to more questions about the exercises
P8	Yes

Table 4.8: Answers to **MA6**: Do you feel the app is adapted for you (Person with Parkinson's Disease)?

Patient	Answer
P1	I could use
P2	Yes
P3	Yes
P4	Yes
P5	Yes, especially as the disease progresses
P6	Yes
P7	Yes, every day
P8	Yes

Table 4.9: Answers to **MA7**: Do you think you'd like to use this application often?

Patient	Answer
P1	Yes
P2	Yes
P3	Yes
P4	Over time, yes
P5	Yes
P6	Yes
P7	Yes
P8	Yes

Table 4.10: Answers to **MA8**: Did you find the application easy to use?

Despite the limited number of participants in this study, the mobile app was well-received. Participants found the app neither overwhelming nor complex, describing it as understandable and user-friendly. A noteworthy outcome was the strong willingness among participants to use the app more frequently, indicating that they see it as a valuable tool for managing PD and integrating it into their daily lives.

Chapter 5

Conclusions and Future Work

This chapter summarizes the findings of the research study, the contributions made throughout the study and the limitations encountered. It also makes recommendations for further research, such as expanding sensor technology, broadening participant demographics and investigating the long-term impact of mobile health (mHealth) applications in managing Parkinson's Disease (PD).

5.1 Conclusions

This dissertation focused on supporting individuals with PD by improving their engagement and motivation in managing their condition through mHealth solutions. The study aimed to establish design principles addressing the usability and accessibility challenges often faced by PD patients when using such applications. ONParkinson was developed according to these principles to accommodate the motor and cognitive difficulties associated with PD, ensuring effective user interaction.

The study explored how user engagement and motivation are interconnected, drawing on theoretical frameworks to encourage sustained adherence to exercise programs. A motivational model, built around the Self-Determination Theory (SDT) and the Theory of Influence (ToI), was developed to keep users engaged by fulfilling their psychological needs and fostering commitment. Mockups were created to illustrate app interfaces offering feedback on users' progress and achievements, aiming to enhance their sense of competence by showcasing past accomplishments and current progress. Additionally, ONParkinson integrates persuasive technology, utilizing notifications to provide feedback and reminders, helping users remain focused on their health goals.

This research also evaluated sensor technologies to promote user engagement and support objective remote monitoring. It explored how integrating devices with sensors to monitor physical activity could provide feedback to both Healthcare Professionals (HCPs) and patients. For HCPs, this feedback helps keep track of patient progress and needs, while for patients, the combination of sensor data with motivational strategies promotes adherence to assigned exercise programs.

Given the focus on the exercise component of ONParkinson, the study mainly addressed motor symptoms, limiting the exploration of sensor technologies for broader symptom monitoring, such as cognitive and emotional issues. Although technologies like smartwatches and wearable devices can monitor emotional responses or track stress via heart rate variability, these aspects were not thoroughly investigated in this work.

A major challenge in integrating sensor technologies for monitoring and analyzing human movement in PD is the complexity involved. While the goal was not to develop a complete system, the research aimed to create a proof of concept capable of tracking and displaying user movement in a simple format. Initially, a sensor like Kinect was considered, which tracks skeletal data, but its incompatibility with smartphone operating systems necessitated an intermediary computer to run its software. This increased infrastructure complexity conflicted with the research's aim of promoting exercise outside of a clinical setting. As with serious games, Kinect was better suited for use in a controlled clinical setting, where patients could come.

Following the study of devices with integrated sensors in subsection 2.4.3, it became clear that most commercially available devices fell into two categories: those with companion apps that process the collected raw data into processed data and those that provide only raw motion data. Devices offering raw data are more suitable for integration into the ONParkinson solution, as they incur no additional cost beyond the device and allow greater flexibility in creating a library of exercises supported by these devices.

To explore this further, a small sensor device called WitMotion WT901BLECL BLE5.0 (Figure 4.18) was used to test how raw data could be collected and processed. Although primary orientation data was successfully extracted, the broader goal of creating a proof of concept to track and display user movement was not realized. Limited knowledge in areas such as biomechanics and data science presented significant challenges, hindering deeper exploration.

The app was tested in a controlled environment with PD patients, showing positive results in terms of usability and the potential for frequent use. However, the small sample size limited the robustness of the findings during the assessment of the ONParkinson mobile app (section 4.4). Since participants were individuals with PD, the recruitment pool was inherently limited, despite efforts to coordinate with the Associação Portuguesa de Doentes de Parkinson (APDPk). Much of the study needed to rely on the goodwill of participants, many of whom volunteered their time after routine sessions at the APDPk.

While this study provided a cross-sectional view of user interaction with the mobile app, long-term studies are necessary to evaluate adherence to ONParkinson in real-life settings.

Although not all envisioned features were implemented, this work provides a foundation for future research on long-term user engagement and motivation, as well as the effectiveness of sensor-integrated devices in managing PD. The ONParkinson application shows promise as a tool for managing PD, but the proposed motivational model will need validation through long-term studies.

5.2 Recommendations for Future Research

Based on the findings, several topics for future research can improve the use of the mHealth application in managing PD. These recommendations include increasing participant diversity, exploring new sensor technologies, leveraging AI for personalized experiences and conducting longer-term studies to evaluate the impact of the app and sensors.

- Expand the Participant Base;

  Expanding the participant base in future studies is important for improving the reliability of the findings. Including a larger and more diverse group, such as individuals at different stages of PD, various age groups and varying levels of technological literacy, would provide a broader understanding of how different populations engage with the mHealth application.

- Explore Sensors for Broader Symptom Monitoring;

  The study's focus on the exercise component limited the exploration of more diverse sensor technologies, especially those that could address non-motor symptoms like cognitive or emotional issues. For example, wearable sensors that track physiological data, such as heart rate fluctuations or sweat levels, could be used to monitor stress or emotional states in PD. Future research should explore how such sensors can monitor non-motor symptoms.

- AI-Driven Personalized Notifications;

  In the future, AI may improve notifications by creating personalized messages based on user preferences, activity levels and progress. For instance, AI could generate more engaging and motivating notifications using natural language processing to create a tone that feels personal and encouraging to the end user according to her/his profile.

  AI-driven messages could celebrate user achievements, delivering positive reinforcement upon task or challenge completion. By varying tone and style, these messages would create a more dynamic and engaging experience, making interactions feel personalized and human, which keeps the experience fresh and relatable.

- Long-Term Effectiveness Studies for App and Sensor Use.

  Long-term studies are needed to evaluate adherence to the mobile app and devices with integrated sensors. These longitudinal studies involve repeated observations of the same variables over an extended period, providing insights into how users interact with technology in everyday environments. This approach reveals behaviors, preferences and challenges that may not surface in shorter studies.

Initially, these studies are proposed to span three months. This duration allows observation of usage patterns and how users incorporate the app into their routines. While longer studies could be pursued, this medium-term approach helps understand user adherence and address emerging issues before moving to longer tests. However, some impact can already be assessed.

These longitudinal studies are not part of this dissertation but should be incorporated into the broader ONParkinson project. The studies can be divided into two categories:

- Studies focusing solely on the mobile app;
- Studies involving both the mobile app and devices with integrated sensors.

Patients and caregivers will be invited to participate, with informed consent obtained after a full briefing on the study's objectives. The initial tests will assess how patients and caregivers adopt the mobile app and its impact on managing PD. Participants must have access, understand and be able to use the mobile app in daily routines. Involvement of the corresponding HCPs is also essential to replicate the feedback loop between the mobile app and the web app, simulating communication between patients, caregivers and HCPs.

All data gathered during the study will be accessible through the web app. A logging feature could be added to the mobile app to track how patients and caregivers interact with it.

The evaluation phases will include surveys to assess the impact of the app on PD management, structured as follows:

- **Pre-Test Phase:** An initial survey before the test to establish a baseline without the influence of the mobile app;
- **Mid-Test Phase:** A survey halfway through the test to track any changes in behavior or perception since the introduction of the mobile app;
- **Post-Test Phase:** A survey at the end of the test period to assess user satisfaction, changes in PD management and any technical issues;
- **One-Month Follow-Up Phase:** A final survey one month after the test to assess whether the mobile app had a lasting impact.

In the second category, involving the mobile app with devices that have integrated sensors, the objective is to evaluate how these sensors influence PD management. This study will focus on the interaction between patients, caregivers and the devices, assessing the user-friendliness of the devices, how well they integrate into daily routines and any challenges or resistance encountered. The effectiveness of the feedback loop enhanced by these sensors will also be evaluated, specifically looking at how the data impacts patient care and decision-making.

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Appendix A: Questionnaire Mobile Application + Conversation Agent

Questionário Aplicação Móvel + Agente de Conversação

*Obrigatório

1. Declaração de Consentimento Informado *

   Aceito contribuir para o desenvolvimento deste projeto. Foi-me explicada a importância e finalidade da minha participação no projeto, tendo compreendido o meu papel como participante. Depois de me ter sido explicado e ter compreendido esta informação, aceito em baixo, compreendendo que tenho o direito, a qualquer momento, de recusar ou interromper a minha participação no projeto. Fui também informado que, caso necessário, poderei contactar um dos membros responsáveis para responder a qualquer dúvida que tenha relativamente à minha participação. Aceito participar neste estudo e permito a utilização dos dados que de forma voluntária forneço, tendo garantias da sua confidencialidade e anonimato, bem como de que serão utilizados unicamente para este fim.

   Marcar apenas uma oval.

   - Aceito
   - Não aceito

1ª Ronda de perguntas

ANTES DE MOSTRAR A APLICAÇÃO MÓVEL + AGENTE DE CONVERSAÇÃO AO UTENTE

2. Número do Participante *

   Realizar previamente caracterização o utente, caso não exista

   ____

3. Fora da Fisioterapia, em casa ou na rua, pratica atividade física? *

   Marcar apenas uma oval.

   - Sim *Avançar para a pergunta 4*
   - Não *Avançar para a pergunta 7*

SIM - Fora da Fisioterapia, em casa ou na rua, pratica atividade física?

4. Por iniciativa própria ou prescrito pelo profissional de saúde? *

Marcar apenas uma oval.

- ◯ Iniciativa própria
- ◯ Prescrito pelo profissional de saúde

5. Como sabe quais os exercícios que deverá fazer? E como os deverá fazer? *

6. Há alguma parte frustrante relativamente à prática de exercício físico fora das sessões de fisioterapia? *

Avançar para a pergunta 9

NÃO - Fora da Fisioterapia, em casa ou na rua, pratica atividade física?

7. Há alguma coisa que o/a iniba de praticar exercício físico fora das sessões de fisioterapia? *

8. Acha que seria útil se houvesse uma ferramenta que o/a ajudasse na prática do exercício físico fora das sessões de fisioterapia? *

Avançar para a pergunta 9

2ª Ronda de perguntas

DEPOIS DE MOSTRAR A APLICAÇÃO MÓVEL + AGENTE DE CONVERSAÇÃO AO UTENTE

9. Já utilizou alguma aplicação similar? *

10. Qual é a sua (primeira) impressão sobre esta aplicação? *

3ª Ronda de perguntas

DEPOIS DO UTENTE TESTAR A APLICAÇÃO MÓVEL + AGENTE DE CONVERSAÇÃO / FINAL

Eficácia do sistema (AGENTE DE CONVERSAÇÃO)

11. Fui capaz de pedir ajuda ao Agente de Conversação. *

Marcar apenas uma oval.

	1	2	3	4	5	
Discordo plenamente						Concordo plenamente

12. O Agente de Conversação reconhece perfeitamente a minha voz. *

Marcar apenas uma oval.

	1	2	3	4	5	
Discordo plenamente						Concordo plenamente

13. Entendo perfeitamente a voz do Agente de Conversação. *

Marcar apenas uma oval.

	1	2	3	4	5	
Discordo plenamente						Concordo plenamente

14. O Agente de Conversação reconhece o que escrevo. *

Marcar apenas uma oval.

	1	2	3	4	5	
Discordo plenamente						Concordo plenamente

15. Entendo as respostas do Agente de Conversação. *

Marcar apenas uma oval.

	1	2	3	4	5	
Discordo plenamente	⬭	⬭	⬭	⬭	⬭	Concordo plenamente

16. Entendo as minhas opções do que posso perguntar ao Agente de Conversação. *

Marcar apenas uma oval.

	1	2	3	4	5	
Discordo plenamente	⬭	⬭	⬭	⬭	⬭	Concordo plenamente

17. O Agente de Conversação reconhece as perguntas nas quais toquei. *

Marcar apenas uma oval.

	1	2	3	4	5	
Discordo plenamente	⬭	⬭	⬭	⬭	⬭	Concordo plenamente

18. O Agente de Conversação esclareceu as minhas dúvidas relativamente ao exercício. *

Marcar apenas uma oval.

	1	2	3	4	5	
Discordo plenamente	⬭	⬭	⬭	⬭	⬭	Concordo plenamente

19. O Agente de Conversação ajudou-me a entender em que fase do programa de exercícios me encontro. *

Marcar apenas uma oval.

	1	2	3	4	5	
Discordo plenamente	◯	◯	◯	◯	◯	Concordo plenamente

20. Fui capaz de continuar o programa de exercícios depois de falar com o Agente de Conversação. *

Marcar apenas uma oval.

	1	2	3	4	5	
Discordo plenamente	◯	◯	◯	◯	◯	Concordo plenamente

21. O Agente de Conversação ajudou-me a saltar para o próximo exercício quando lhe pedi. *

Marcar apenas uma oval.

	1	2	3	4	5	
Discordo plenamente	◯	◯	◯	◯	◯	Concordo plenamente

22. O Agente de Conversação entendeu perfeitamente quando lhe disse que não me sentia bem, aconselhando-me de imediato. *

Marcar apenas uma oval.

	1	2	3	4	5	
Discordo plenamente	◯	◯	◯	◯	◯	Concordo plenamente

23. Sugestão de melhoria ou comentários que gostaria de fazer

Feedback Final

SE NECESSÁRIO VOLTAR A MOSTRAR A APLICAÇÃO AO UTENTE. PARA RELEMBAR ECRÃS, ETC...

24. Há alguma interação com a aplicação que seja frustrante de utilizar? *

25. Acha a informação existente na aplicação legível e compreensível? *

26. Existe algum ecrã com demasiada informação? *

27. Sente que a aplicação está adaptada para si (Pessoa com Parkinson)? Porquê ou porque não? *

28. Se pudesse mudar uma coisa sobre a aplicação de modo a melhorá-la, o que seria? *

29. Há algo que gostaria de ver acrescentado à aplicação no futuro? *

30. Acha que gostaria de utilizar esta aplicação com frequência? *

31. Acha a aplicação fácil de utilizar. *

Ecrãs Alternativos

Mostrar os ecrãs alternativos

Definições > Ligar o Debug Mode e gravar > Clicar no botão Debug Mode Menu > Leitura de Sinais Vitais – Alt [1..3]

Alt 1 - seria o ideal, com dados recolhidos automaticamente via sensores
Alt 2, 3 - as alternativas nas quais os utentes têm de manualmente inserir os valores

32. Qual o melhor modo alternativo de inserir a informação? *

Marcar apenas uma oval.

- Alt 2
- Alt 3

33. Porquê?

Appendix B: Test planning - Handguide

PREPARAÇÃO PARA OS TESTES

Pessoal Necessário: **1-2** (sem contar com o/a utente). **É necessário conhecimento e familiarização prévia** com a Aplicação Móvel + Agente de Conversação, de modo a entender o funcionamento e propósito de ambas as partes.

Condutor/a do Teste – Tem de haver pelo menos uma pessoa para conduzir os testes. Terá também de realizar o trabalho de Observador/a, caso não haja uma segunda pessoa disponível. É importante que o/a Condutor/a do Teste tenha conhecimento sobre e seja capaz de lidar com Pessoas com Parkinson (utente).

Observador/a - Se possível, haverá mais uma outra pessoa para servir de observador/a e auxiliar quem conduzir os testes. Este/a observador/a deverá também ir preenchendo ao longo do teste um questionário, próprio para si, com as suas observações.

Material Necessário:

- **Um smartphone** com a Aplicação Móvel + Agente de Conversação instalada;
  - Usar um tamanho de fonte entre ***Large*** – ***Extra Large***
- **Pelo menos um portátil (ou outro dispositivo)** para poder preencher os questionários online.

Tempo Estimado para a Realização do Teste:

- Utente sem caracterização prévia ≈ 40 minutos
- Utente com caracterização prévia ≈ 30 minutos

Texto Introdutório à Aplicação Móvel + Agente de Conversação:

O projeto ONParkinson surgiu de uma parceria entre a Escola Superior de Saúde e Escola Superior de Tecnologia do Instituto Politécnico de Setúbal, e visa desenvolver projetos sem fins lucrativos focados na terapia da Doença de Parkinson.

Este projeto visa aproveitar o crescimento e vantagens das Tecnologias da Informação e Comunicação, e aplicá-las na área da saúde em benefício de todos.

Para tal, o foco é proporcionar a tríade "Paciente - Cuidador - Profissional de Saúde" com ferramentas que a apoie na gestão da Doença de Parkinson de uma forma mais eficaz

Esta Aplicação Móvel + Agente de Conversação é uma parte deste projeto e tem como objetivo ser uma ferramenta acessível para Pessoas com Parkinson e os seus Cuidadores e que potencie a prática do exercício físico à distância.

ANTES DE MOSTRAR A APLICAÇÃO MÓVEL + AGENTE DE CONVERSAÇÃO AO UTENTE

1. Preencher e submeter o questionário "**Caracterização Socio-demográfica – Utente"**, caso não tenha sido previamente feita a caracterização do/a utente. Anotar o número do utente para uso nos restantes questionários.

2. Aceder ao "**Questionário do Observador**" e ir preenchendo conforme a situação.

3. Aceder ao "**Questionário Aplicação Móvel + Agente de Conversação**".

    a. Preencher **até chegar** à "2ª Ronda de perguntas", **exclusive**.

MOSTRAR A APLICAÇÃO MÓVEL + AGENTE DE CONVERSAÇÃO AO UTENTE

1. Introduzir a Aplicação Móvel + Agente de Conversação.

2. O utente tem capacidade para interagir com a Aplicação Móvel + Agente de Conversação?

    a. Se Sim:

        i. O/A Condutor/a do Teste deverá **disponibilizar o smartphone** ao utente para este/a poder interagir com a Aplicação Móvel + Agente de Conversação.

        ii. O/A Condutor/a do Teste deverá guiar o/a utente numa simulação **SIMPLIFICADA DO PROTOCOLO DE TESTES** descrito mais abaixo, de modo que o/a utente tenha um contacto introdutório com a Aplicação Móvel + Agente de Conversação.

        iii. O/A Condutor/a do Teste deverá explicar ao utente como funciona a interação com a Aplicação Móvel + Agente de Conversação.

    b. Se Não:

        i. O/A Condutor/a do Teste deverá **ele/a próprio/a** realizar uma simulação **SIMPLIFICADA DO PROTOCOLO DE TESTES** descrito mais abaixo, de modo que o/a utente tenha um contacto introdutório com a Aplicação Móvel + Agente de Conversação.

        ii. O/A Condutor/a do Teste deverá explicar ao utente como funciona a interação com a Aplicação Móvel + Agente de Conversação.

<u>DEPOIS DE MOSTRAR A APLICAÇÃO MÓVEL + AGENTE DE CONVERSAÇÃO AO UTENTE</u>

1. No "**Questionário Aplicação Móvel + Agente de Conversação**".
    a. Preencher **até chegar** à "3ª Ronda de perguntas", **exclusive**.

<u>TESTAR A APLICAÇÃO MÓVEL + AGENTE DE CONVERSAÇÃO COM O UTENTE</u>

1. O utente tem capacidade para interagir com a Aplicação Móvel + Agente de Conversação?
    a. Se Sim:
        i. O/A Condutor/a do Teste deverá **disponibilizar o smartphone** ao utente para este/a realizar o **PROTOCOLO DE TESTES**.
        ii. O/A Condutor/a do Teste deverá guiar o/a utente durante a realização do **PROTOCOLO DE TESTES** descrito abaixo, passo a passo.
    b. Se Não:
        i. O/A Condutor/a do Teste deverá **disponibilizar o smartphone** ao utente para este/a realizar uma versão **SIMPLIFICADA DO PROTOCOLO DE TESTES**.
        ii. O/A Condutor/a do Teste deverá guiar o/a utente durante a realização **SIMPLIFICADA** do **PROTOCOLO DE TESTES** descrito abaixo, passo a passo.

<u>DEPOIS DO UTENTE TESTAR A APLICAÇÃO MÓVEL + AGENTE DE CONVERSAÇÃO / FINAL</u>

1. Terminar de preencher o "**Questionário do Observador**" e submeter.
2. Terminar de preencher o "**Questionário Aplicação Móvel + Agente de Conversação**" e submeter.
    a. Ter a atenção de mostrar os ecrãs alternativos e responder às questões relacionadas antes de submeter.
        i. Definições > Ligar o *Debug Mode* e **gravar** > Clicar no *botão Debug Mode Menu* > Leitura de Sinais Vitais – Alt [1..3]

<u>PROTOCOLO DE TESTES</u>

Pré-requisitos:

1. Abrir a aplicação móvel "**ON-Parkinson**"
2. Entrar em Exercícios
3. Entrar em Programas
4. Escolher o programa de exercícios "**Força**"

Protocolo:

1. Clicar no botão de som na introdução do programa
    a. Passar para o próximo ecrã
2. Clicar no botão de som na perceção de esforço
    a. Selecionar a perceção de esforço e passar para o próximo ecrã
3. Clicar no botão de som nos sinais vitais
    a. Aguardar a leitura dos sinais vitais e passar para o próximo ecrã
4. Clicar no botão de som na introdução do exercício
5. Clicar no botão de parar som na introdução do exercício
    a. Passar para o próximo ecrã
6. No primeiro exercício (ecrã com o vídeo):
    a. Interagir com a "individualização e ajuste da prescrição de exercício" (+ e -)
    b. Carregar no botão de ajuda (símbolo de ?)
    c. Tocar "Preciso de ajuda sobre o exercício"
    d. Carregar no botão do microfone
    e. Falar "Quantas vezes repito o exercício?" e enviar
    f. Tocar na opção "Outra duvida"
    g. Tocar "Preciso de ajuda sobre o exercício"
    h. Escrever "Quantas séries?" e enviar
    i. Tocar na opção "Outra duvida"
    j. Tocar "Preciso de ajuda sobre o exercício"
    k. Carregar no botão do microfone
    l. Falar "Qual a fase?" e enviar
    m. Escrever "Continuar exercício" e enviar
7. No seguinte exercício (ecrã com o vídeo):
    a. Carregar no botão de ajuda (símbolo de ?)
    b. Tocar na opção "Preciso de ajuda sobre o exercício"
    c. Tocar na opção "Quais as instruções?"

d. Tocar na opção “Outra dúvida”

e. Tocar na opção “Saltar exercício”

8. Prosseguir normalmente
9. No segundo exercício da fase de treino:
   a. Carregar no botão de ajuda (símbolo de ?)
   b. Tocar na opção “Não me sinto bem”
   c. Escrever “Sim” e enviar
   d. Tocar na opção “SIM”
10. TERMINA O PROGRAMA

PROTOCOLO DE TESTES SIMPLIFICADO

Pré-requisitos:

1. Abrir a aplicação móvel "**ON-Parkinson**"
2. Entrar em Exercícios
3. Entrar em Programas
4. Escolher o programa de exercícios "**Força**"

Protocolo:

1. Clicar no botão de som na introdução do programa
   a. Passar para o próximo ecrã
2. Clicar no botão de som na perceção de esforço
   a. Selecionar a perceção de esforço e passar para o próximo ecrã
3. Clicar no botão de som nos sinais vitais
   a. Aguardar a leitura dos sinais vitais e passar para o próximo ecrã
4. Clicar no botão de som na introdução do exercício
   a. Passar para o próximo ecrã, mesmo se estiver a falar
5. No primeiro exercício (ecrã com o vídeo):
   a. Interagir com a "individualização e ajuste da prescrição de exercício" (+ e -)
   b. Carregar no botão de ajuda (símbolo de ?)
   c. Tocar "Preciso de ajuda sobre o exercício"
   d. Carregar no botão do microfone
   e. Falar "Quantas vezes repito o exercício?" e enviar
   f. Escrever "Continuar exercício" e enviar
6. No próximo exercício (ecrã com o vídeo):
   a. Carregar no botão de ajuda (símbolo de ?)
   b. Tocar na opção "Não me sinto bem"
   c. Escrever "Sim" e enviar
   d. Tocar na opção "SIM"
7. TERMINA O PROGRAMA

Appendix C: Socio-demographic Characterisation - Patient

Identificação

*Obrigatório

1. Nome da Instituição

2. Número do Participante

1. Dados Pessoais

3. Nome *

4. Sexo *

Marcar apenas uma oval.

- Masculino
- Feminino
- Não responde

5. Idade *

6. Profissão *

7. Reformado? *

Marcar apenas uma oval.

- Sim
- Não

8. Estado Civil *

Marcar apenas uma oval.

- Solteiro(a)
- Casado(a)
- Viúvo(a)
- Companheiro(a)

9. Nível de escolaridade *

____

10. Com quem reside? *

Marcar apenas uma oval.

- Esposo(a)
- Sozinho(a)
- Família
- Outro

11. Se reside com alguém que não é familiar , indique qual a relação

____

12. Se reside com um familiar, indique que familiar

____

2. Doença de Parkinson

13. Há quanto tempo foi diagnosticado com DP (em anos)? *

____

14. Qual o estadio H&Y em que se encontra? *

Marcar apenas uma oval.

- ( ) 1
- ( ) 1.5
- ( ) 2
- ( ) 2.5
- ( ) 3
- ( ) 4
- ( ) 5

15. Medicação atual *

____
____
____
____
____

16. Outros problemas de saúde? *

Marcar apenas uma oval.

- ( ) Sim
- ( ) Não

17. Se sim, indique quais

___

3. Fisioterapia

18. Realiza Fisioterapia atualmente? *

Marcar apenas uma oval.

- ( ) Sim
- ( ) Não

19. Se sim, quantas vezes por semana?

Marcar apenas uma oval.

- ( ) 1
- ( ) 2
- ( ) 3
- ( ) 4
- ( ) 5
- ( ) 6
- ( ) 7

20. Se sim, há quanto tempo?

___

21. Se sim, pratica exercício terapêutico na Fisioterapia?

Marcar apenas uma oval.

- Sim
- Não

22. Fora da Fisioterapia, em casa ou na rua, pratica atividade física? *

Marcar apenas uma oval.

- Sim
- Não

23. Se sim, qual a frequência semanal (x/semana)?

Marcar apenas uma oval.

- 1
- 2
- 3
- 4
- 5
- 6
- 7

24. Se sim, há quanto tempo?

____

25. Se sim, qual o tipo de atividade física que pratica?

____

4. Tecnologias

26. Possui algum destes tipos de tecnologias?

Marcar tudo o que for aplicável.

- [ ] Telemóvel (não smartphone)
- [ ] Smartphone (touchscreen)
- [ ] Tablet
- [ ] Computador

27. Se posssui smartphone e/ou tablet, qual o sistema operativo?

Marcar apenas uma oval.

- ( ) Android
- ( ) IOS

28. Se posssui smartphone e/ou tablet, tem facilidade em funcionar com o mesmo?

Marcar apenas uma oval.

- ( ) Sim
- ( ) Não

29. Se não tem facilidade em funcionar com o smartphone e/ou tablet, quais as dificuldades?

30. O que mais faz com este tipo de tecnologias?

Marcar tudo o que for aplicável.

- [ ] Entrar em contacto com as pessoas
- [ ] Telefonar
- [ ] Mandar mensagens
- [ ] Tirar fotografias / gravar vídeos
- [ ] Jogar
- [ ] Redes sociais
- [ ] Pesquisar na internet
- [ ] Outra: ______________________

31. Utiliza regularmente a Internet?

Marcar apenas uma oval.

- ( ) Sim
- ( ) Não

Appendix D: Observer Questionnaire

Questionário do Observador

Assinalar a reação percetível do utente

*Obrigatório

1. Número do Participante *

   Realizar previamente caracterização o utente, caso não exista

   ____

2. Reação inicial à aplicação *

   Marcar apenas uma oval.

	1	2	3	4	5	
Muito Mau	◯	◯	◯	◯	◯	Excelente

3. Observação

   ____
   ____
   ____
   ____
   ____

4. Entendeu como proceder *

   Marcar apenas uma oval.

	1	2	3	4	5	
Discordo Plenamente	◯	◯	◯	◯	◯	Concordo Plenamente

5. Observação

6. Mostrou-se motivado/interessado *

Marcar apenas uma oval.

	1	2	3	4	5	
Discordo Plenamente						Concordo Plenamente

7. Observação

8. Os sintomas da doença de Parkinson não dificultaram a interação *

Marcar apenas uma oval.

	1	2	3	4	5	
Discordo Plenamente						Concordo Plenamente

9. Observação

____

____

____

____

____

10. Concluiu a tarefa sem problemas *

Marcar apenas uma oval.

	1	2	3	4	5	
Discordo Plenamente	◯	◯	◯	◯	◯	Concordo Plenamente

11. Observação

____

____

____

____

____

12. Reação final *

Marcar apenas uma oval.

	1	2	3	4	5	
Muito Mau	◯	◯	◯	◯	◯	Excelente

13. Observação

14. Observações extra