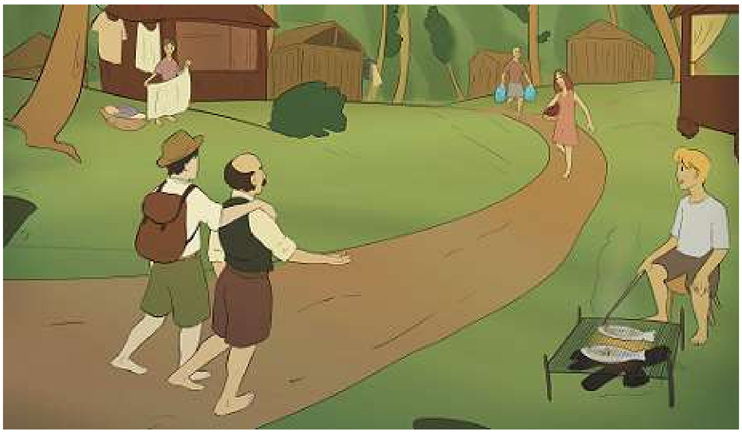

Narrative-based Gamification for Physical Therapy

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Abstract

With the ageing population and the longer life expectancy, more people will seek physical therapy to prevent and recover from physical decline and injuries. Although traditional therapy programs have proven their effectiveness, they can be painful and unappealing for some patients, as they have to perform repetitive and monotonous exercises. We developed a user-friendly and engaging system, *ARCADE-N*, to support upper-limb rehabilitation by leveraging gamification elements such as feedback mechanisms and a narrative that is progressively unlocked throughout the sessions. The system was deployed and tested in a rehabilitating clinic for three weeks. The results showed that *ARCADE-N* motivated and engaged patients, mainly due to the narrative. Our results also revealed that the gamified feedback elements, such as the voice assistant and the dummy, were relevant to give patients awareness about their body movements which is essential to the rehabilitation process.

Keywords

Gamification ; Physiotherapy ; Rehabilitation ; Narrative

Resumo

Com o envelhecimento da população e a expectativa de vida mais longa, mais pessoas procurarão atendimento médico para prevenir e recuperar de enfraquecimento físico e lesões. Embora esteja comprovada a eficácia dos programas de terapia tradicionais, eles podem ser dolorosos e pouco atraentes para alguns pacientes, que são submetidos a exercícios repetitivos e monótonos. Desenvolvemos um sistema acessível e atraente aos utilizadores que suporta a reabilitação de membros superiores, aproveitando elementos de gamificação, como mecanismos de feedback e uma narrativa que é progressivamente desbloqueada. O sistema foi instalado e testado numa clínica de reabilitação por três semanas. Os resultados mostraram que *ARCADE-N* motivou e envolveu os pacientes, principalmente devido à narrativa. Os nossos resultados também revelaram que os elementos de gamificação de feedback, como o assistente de voz e o manequim, foram relevantes para consciencializar os pacientes dos seus movimentos corporais, algo que é essencial no processo de reabilitação.

Palavras Chave

Gamificação; Fisioterapia; Reabilitação; Narrativa;

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1

Introduction

Contents

The overall ageing of the population and longer life expectancy will drive more people to seek medical care to improve age-related musculoskeletal decline, and injury [37]. These conditions affect not only the ageing population but also the individuals who suffer orthopedic trauma from sports, work, combat, and everyday life. Nowadays, advances in healthcare make it possible to prevent and treat such injuries [5]. However, survivors of such disorders often lose their motor mobility and become unable to carry out daily activities, losing their autonomy and quality of life [5]. For example, after suffering a stroke or dislocating a shoulder, patients may lose physical function while their body heals.

Physiotherapy is one measure in modern healthcare used to improve and restore physical function after injury or surgery [5] and, therefore, ways to improve rehabilitation processes, namely through the use of technology (new gadgets, software, and apps), have been explored. As varied as they come, these technologies can make therapy treatment more effective with advantages such as increasing patient motivation, increasing the intensity of the exercises, and an increase of the recovery speed [31]. Mainly, technologies focusing on rehabilitating the upper limbs can restore the autonomy needed to carry out everyday tasks like eating and dressing [3].

These tools are as helpful for the patient as for the physiotherapist who follows them, proving to be a support that underpins the entire clinical process. Another advantage is that patients can perform the exercises with less or full supervision from their therapists. They can access precise instructions regarding the exercises and instant *biofeedback* on their actions. *Biofeedback* is proven effective in improving exercise technique in musculoskeletal populations [17]. In addition, the *feedback* can provide the patient with motivation to continue their exercises [28]. Consequently, patients become more independent, which reduces their therapist's workload giving them more time to focus on other patients.

1.1 Problem

The traditional physical rehabilitation process can be slow, making progress sometimes invisible to patients and professionals [5]. For patients, this can affect their motivation and raise doubts about the benefits of physiotherapy [5]. For clinical professionals, it leads to inaccurate assessments of physical abilities and longer rehabilitation processes.

During physical rehabilitation, patients are taught several exercises to help restore strength, range of movement, and function [5]. Patients commonly report feeling pain during the movements and find the traditional rehabilitation tasks boring due to their repetitive nature.

In the clinical setting, physiotherapists reveal that the time they have to take care of each patient is short and needs to be maximized, making difficult the adoption of systems that imply their full supervision during its use, in addition to the setup time [15].

1.2 Proposed Solution

This project aims to increase patient engagement in their rehabilitation program by applying gamification and integrating a narrative in an upper-limb rehabilitation application. First, we applied the knowledge found in the related work to **develop a functional high-fidelity prototype**. We improved it through multiple iterations using the physiotherapists' input and testing its usability via Usability Tests. Then, we took our prototype and deployed it in a clinic for three weeks, where we **evaluated it** with the help of actual patients with upper-limb injuries. Lastly, we did a thematic analysis of the results to build our conclusions.

Our prototype was developed on top of a previous existing project, an application developed by Duarte S. et al. named *ARCADE* [15]. That version of *ARCADE* is designed for upper-limb rehabilitation and uses Kinect, a motion-capturing device, to track the users' movements during the exercises. It has three exercises and stores the data relative to user sessions. The main issue in *ARCADE* was the lack of patient adherence, so we aimed to fix that in our project. Our solution kept the previous settings but improved the patients' experience by reframing the therapy as a fun and gamified experience. To achieve that, we implemented *gamification elements* such as session scores and medals, a voice assistant that gives encouragement and corrections, and visual and auditory feedback that improved the "look and feel" of the exercises. Additionally, we wrote and integrated a 5-chapter visual story that the patients unravelled throughout their sessions. This story was framed as a rewarding element in every session.

This project had the partnership of "Egas Moniz Teaching Cooperative", a university dedicated to the area of health, which provided the professionals to collaborate with (the physiotherapists) and allowed us to use the clinic to conduct the evaluations, resulting in a user-centred design. To validate our functional prototype, we deployed it in the clinic and tested it with patients and physiotherapists over three weeks. We assessed the impact of our system on the daily routine of our users (the physiotherapists and their patients) through observation and interviewing techniques, which ultimately provided us with the results for our conclusions.

1.3 Contributions

The main contributions of this work are: (1) Development of a gamified Kinect-based rehabilitation system capable of supporting upper-limb therapy sessions; (2) Conducted a study with patients and professional physiotherapists that included a qualitative thematic analysis of their opinions about the implementation of our system in their therapies; (3) Results from a study on the use of narrative-based approaches in engaging patients in their physiotherapy sessions.

1.4 Organization of the Document

The rest of the document is organised as follows. In Chapter 2, we will provide the background context on the concept of gamification and the frameworks that use it. In Chapter 3, we present the literature review regarding gamification techniques in the rehabilitation context and describe the studies that developed such solutions for upper-limb recovery. After, in the same Chapter, we present and analyse commercial platforms that use gamification for physical therapy. Chapter 4 describes our narrative-based approach to developing a compelling story for the users and presents the final result of the story component. In Chapter 5, we explain the technical implementation of our system and its design process. Chapter 6 describes the process of validating our functional high-fidelity prototype through User Studies at the clinic. After, we present the results and review them via thematic analysis. Finally, in Chapter 7, we present our main remarks and suggestions to further improve *ARCADE*.

2

Background

Contents

In this chapter we describe the concept of **gamification** and introduce some **frameworks** that use it, as we intend to use gamification in our solution.

2.1 Gamification

Gamification is defined by the application of game mechanics to non-game contexts to engage audiences and inject some fun into dull activities in addition to producing motivational and cognitive benefits [36]. Gamification takes game mechanics such as leaderboards, points systems, badges and up-levelling in order to tap the natural human drive for competition and achievement. These game-like elements motivate its users to participate actively, increasing engagement.

Prior to the current definition, the term ”gamification” was heavily contested within the video game and digital media industry, and it could be used to refer to similar concepts, such as ”serious games”, ”playful interaction” or ”game-based techniques” [14]. **Serious games** are games that have been designed for a primary purpose other than pure entertainment, focusing on ”serious” areas such as education or health [34]. Serious games do not need gamification as they already follow the typical game structure and are designed to involve some form of training value in addition to pure entertainment. Like gamification, they offer benefits such as increased user enjoyment and retention of knowledge, and they help inspire and motivate users to participate and achieve a higher potential. The key difference is that gamification takes game-like mechanics and infuses them into traditional programs to increase participation and engagement. At the same time, serious games are full-blown games with typical game structures that also offer some form of educational value and not simply entertainment.

While many fields such as Business, Marketing and e-Learning have taken advantage of the potential of gamification, the digital healthcare domain has also started to exploit this emerging trend [36]. Literature [12,23,26,36] proves that such motivation and enjoyment can be highly beneficial in a rehabilitation context, where tasks are often mundane and repetitive by nature. Therefore, solutions that use game elements and user-centred design have been arising to target and improve therapeutic processes.

2.2 Gamification Frameworks in Healthcare

Here, some frameworks are presented that explain how gamification should be applied to a solution in healthcare. One of the goals that gamification aims to achieve is to drive the behaviour of users. However, influencing behaviour in healthcare is not an easy task [13]. To influence a user’s behaviour, one must understand how behaviour occurs and the factors that contribute to it.

2.2.1 The Fogg Behaviour Model

In 2009, B.J. Fogg [9] proposed a model that explains how behaviour occurs.

The Fogg Behaviour Model (FBM) asserts that for a person to perform a target behaviour, they must (1) be sufficiently **motivated**, (2) have the **ability** to perform the behaviour, and (3) be **triggered** to perform the behaviour. These three factors must occur simultaneously, or the behaviour will not happen. To explain the model, the authors use a website creator that aims to get users to register for a newsletter, which can be accomplished by typing their email into a text box. In the FBM, the target behaviour is ”typing the email address”, and for this simple task, users have a high ability because it is easy to type in an email address. When it comes to motivation, users may be motivated or not to perform the task, depending on their interest in the newsletter. With the proper trigger, those with high ability and motivation will likely perform the target behavior [9]. The third and last factor, the trigger, can take many forms - an alarm that rings, a pop-up message, a notification - and has three characteristics: (1) we notice the trigger, (2) we associate it with a target behaviour and (3) the trigger happens when we are both motivated and able to perform the behaviour. To succeed in its job, a trigger must have timing and feel appropriate to the target behaviour. If a design team or a physiotherapist notices that users are not performing the desired behaviour, they can use FBM to determine what is missing. It also works on prevention: if a patient is performing unwanted behaviour, one can focus on one of the three factors (reducing motivation, taking away the ability, or removing triggers).

2.2.2 The Wheel Of Sukr

In 2015, Marshedi et al. [27] proposed a conceptual framework named The Wheel Of Sukr to assist in the self-management of diabetes for young adults in Saudi Arabia (see Fig. 2.1).

The goal is to influence users to better self-manage their condition and motivate them towards healthy behaviours that are hard to start or maintain through gamification. The authors state that rewarding patients for taking their medication is much more effective than punishing them for not taking it regularly. However, some systems that rely solely on rewards like points and badges are not successful in the long term. To gain full advantage of specific gamification techniques, they need to be tailored to a specific environment [27]. The Wheel of Sukr provides the guidelines to design for diabetic users. However, we believe it is adaptable to the rehabilitation environment.

When looking at the Wheel, gamification can be applied by using *fun* elements, which include badges, points, challenges and competition. Levelling up on a leaderboard and having a reputation are elements that provide *esteem* to the users, aiming to boost their performance. Praising good actions and providing general feedback on test results and management habits have a significant impact on diabetic users [27], which is part of the *growth* aspect of the framework. As stated in literature [28],

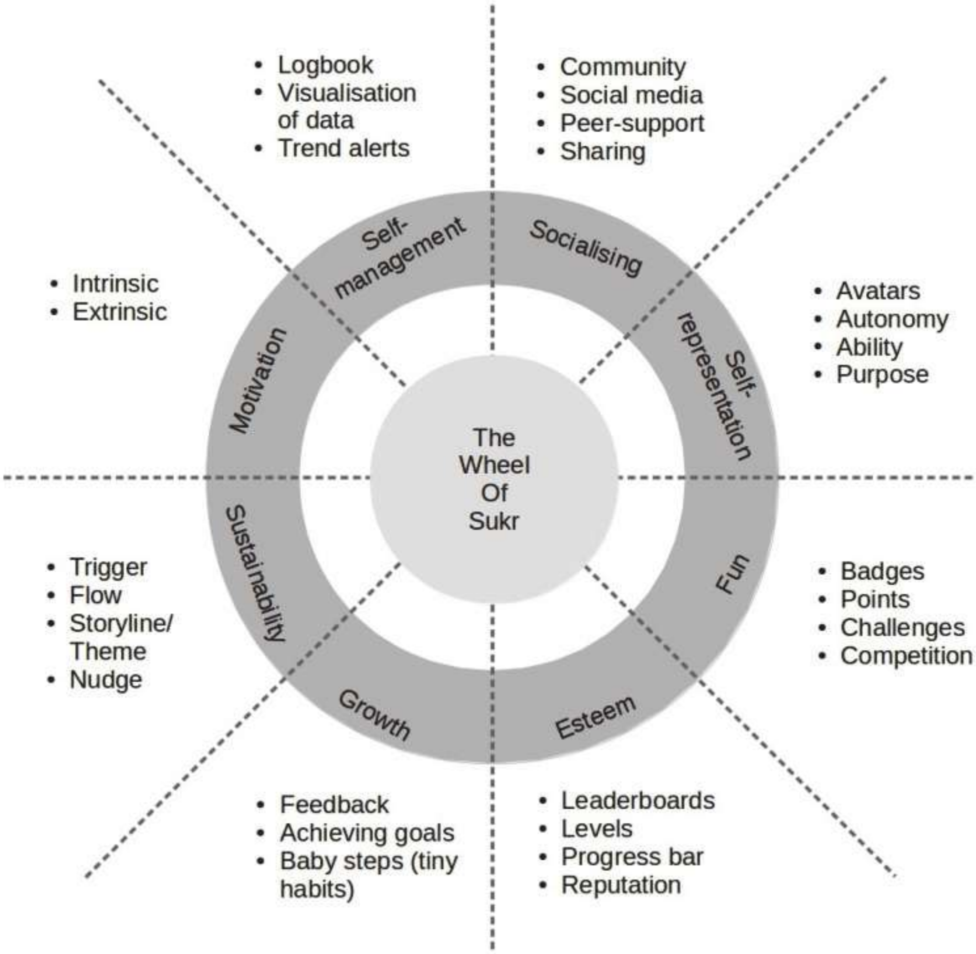


Figure 2.1: The Wheel of Sukr - a framework that uses gamification to design solutions in healthcare. Image taken from [27].

patients undergoing physical therapy programmes also respond positively to real-time feedback. On the other hand, *self-management* is essential for controlling the users' blood glucose test results and any information regarding their food intake. However, in physiotherapy, we could use these elements to save the users' progress, such as the duration of exercises or the number of repetitions. This data would be valuable for identifying patterns and monitoring progress. Furthermore, the *socialising* elements are an exciting aspect of the Wheel. For diabetic patients, social elements cover the psychological side of dealing with diabetes, as this condition can lead to clinical depression. In modern society, where social media, in general, are very popular, there is a lack of online spaces for diabetic people. Thus, providing an online community would help build a sense of belonging and increase social cohesion and acceptance.

Moreover, *self-representation* through avatars and customised profiles increase the ability to relate to the system and tailor the experience to them.

2.2.3 Game design principles for rehabilitation

In 2009, Burke et al. [7] identified three aspects that are important for optimising engagement for gamified applications for physical rehabilitation: *meaningful play*, *challenge* and conservative *handling of failure*.

2.2.3.A Meaningful play

According to the authors, *meaningful play* emerges from a game in the relationship between the player's actions and the system's outcome. A well-designed game should provide clear, consistent and meaningful feedback in response to the player's actions. Feedback can be communicated aurally (speech, sound effects, music), visually (numbers, score bars, text messages, ability to see arm/hand in the game) or through haptic technology (vibrations). Meaningful play is necessary for users to know their goals, what actions they need to achieve them, and if they are achieving them.

2.2.3.B Challenge

Games for rehabilitation should be designed to dynamically adapt the difficulty or level of *challenge* depending on the player's performance. If the game is too difficult, the player could get frustrated and give up, or they can get bored if it is too easy.

2.2.3.C Handling of Failure

Finally, since some patients have poor motor control and a possible unfamiliarity with playing video games, the probability of them experiencing *failure* is high. It is less likely that players will feel discouraged when failure is positively handled by encouraging and rewarding them.

3

Related Work

Contents

In this chapter, we describe studies that use gamification techniques in the context of rehabilitation and then detail the studies that developed a solution specifically for upper limb recovery. Next, we present and analyse three commercial platforms that use gamification for physical therapy. Lastly, we highlight the motion-capture technology and gamification techniques on a table and assess the need for a therapist to be involved.

3.1 Gamification in Physical Rehabilitation

As suggested in the ”Background” section, rehabilitation programmes that use gamification can surpass the effectiveness of traditional programmes. In this project, we aim to apply gamification principles to an application with therapeutic purposes. Therefore, it is essential to understand the techniques used in rehabilitation programs that support gamification.

Natural Interaction is a Human-Computer Interaction technique that allows the user and the machine to communicate using actions commonly practised by human beings, such as facial expression, gestures, and voice [39]. Therefore, Natural Interaction presents itself as a promising approach in rehabilitation, as it allows the user to interact with an application using the actual therapy exercises. Another advantage of using Natural Interaction is that users do not need to learn how to handle new devices that they are unfamiliar with [33]. Some devices support the use of Natural Interaction, such as *Kinect*, *Nintendo Wii*, *Playstation Move* and *LeapMotion*, for their relatively low cost and its wide acceptance by users [2]. Although originally created for the video games industry, these motion-sensor-based devices can assist in physical therapy.

A study was conducted by Madeira et al. [25] in 2014 to understand the opinion of Portuguese physiotherapists regarding the use of Gamification and Kinect in rehabilitation. **Kinect** is a device that appears in many houses since it was used with commercial software from Xbox. Of 160 participants, 67% revealed that they did not know Kinect. Following this question, 43% considered their patients to be highly motivated with Kinect and only 7% claimed that their patients felt no motivation at all. When asked if and how the gamified software should allow interaction between multiple users, 35% said yes in a collaborative way and only 3% in a competitive way, being that the rest believes it is useful in any of these two modes or a blended mode. The results of this preliminary study are positive, revealing that patients and physiotherapists are receptive to this type of application and that it is a novelty, as a rehabilitation aid, to the Portuguese community.

McClincy et al. [28] developed *interACTION (iA)*, an interactive health technology to monitor knee-specific rehabilitation (see Fig. 3.1), using the principles of self-management found in the **Wheel of Sukr**. The authors conducted a user-centred design process with ten athletes aged 10-18 years with a history of *Anterior cruciate ligament* reconstruction (ACL-R). In the study's first phase, the subjects

Figure 3.1: *interACTION* platform components: (A) wireless motion sensors attached to the knee of a patient; (B) screenshots from the current version of the mobile app; (C) screenshot from the current version of the clinician portal. *iA* provides real-time exercise feedback to the patient and logs performance metrics for remote clinicians to allow home exercise program monitoring. Image taken from [28].

were interviewed regarding their recovery experience. All participants were prescribed home exercises by their physical therapists, and most of them never missed a day of exercise. Those who missed it said they ”did not feel like it, forgot, or were busy”. Participants said their physical therapist did not monitor their home exercises and instead had their parents do it. They added that it would be motivating to have their therapist monitor their progress because of (1) the fear of the professionals knowing their lack of commitment and that (2) they would help reach the goals faster. When asked the subjects their motivations for complying with the exercises, they mentioned their desire to improve their physical condition and get back to playing sports. These interviews show that it is highly beneficial having a device that tracks their progress when doing PT exercises.

In a second phase, participants were asked to use the method ”Think-Aloud” and rank cards representing the components of the **Wheel of Sukr** in order of interest. When using the mean, *motivation* was first, *self-management* was second, and *growth*, *esteem*, and *fun* tied for the third. The participants then suggested improvements, organised by categories: encouragement, rewards or congratulations for completion (*motivation*); visual progress or timeline (*self-management*); earning points or prizes for completion, selection of different games, bonus points and incentives for improvements (*fun*).

In the third phase, the patients reviewed the current version of *iA* and provided generally positive feedback on the device and app. One of the findings was that participants wanted a better sense of how their recovery progressed. A good approach would be to incorporate performance thresholds or milestones and allow users to interact with peers via avatars. This would also contribute to the *self-management* aspect and provide an extrinsic form of motivation.

Murnane et al. [29] evidenced a problem with the use of quantitative data representations (e.g., charts, graphs, and statistical reports) in most health tools. They suggest that such feedback can fail to motivate behaviour, harm self-integrity, and fuel negative mindsets about exercise, as these data representations can be hard to interpret and overwhelm users. To address this problem, the authors developed a smartphone application called *WhoIsZuki* that visualises physical activities and goals as components of a **multi-chapter quest**, where the main character's progress is tied to the user's.

WhoIsZuki uses Google Fit to automatically detect walking, running and cycling. Users can manually edit and delete recorded activities and set any number of weekly exercise goals across various subcategories (e.g. flexibility, walking, strength training). The fitness data is stored in a Firebase mobile development platform, which provides a real-time database. Two narrative chapters are fetched every time the platform syncs with Firebase cloud storage to improve the app's offline performance. The data is then visualised through a multi-chapter story on the phone's lock or home screen. This keeps the user aware of their progress throughout the day. Completing weekly goals unlocks the next chapter (13 chapters, each with five parts).

The construction of Zuki's narrative was achieved with the help of professional narratology experts. Zuki is an alien who ventures to Earth on a mission to collect biosamples to save his dying home planet and find his brother, who got lost on a prior voyage. Chapters 1–11 then deliver rising action as Zuki encounters diverse scenes, characters, and sub-challenges. The climax is reached in Chapter 12, falling action occurs in Chapter 13, and finally, an exit screen serves as the story ending, when Zuki rescues his brother as resolution. The writers framed the story as a mission to create an emotional connection between Zuki and the user, who also faces challenges (being physically active). The use of characterisation is used as well, such as the "helper characters" (monkeys, bunnies and fish) who offer assistance and hints to Zuki, and the "antagonist", a governmental agent trying to catch Zuki for experiments, which adds tension and uncertainty to increase engagement further. The story also fosters a sense of suspense by making information in early chapters relevant to solve problems later on.

Two studies were conducted to ensure the narratives were understandable and engaging. In the first study, 5 participants recruited via email and word-of-mouth visited their lab and were asked to review the initial versions of the story to provide feedback during a 60-minute session. In the second study, to confirm the narratives had been improved, was measured the engagement of 7 participants based on five dimensions from the Narrative Engagement Scale [8]: empathy, cognitive perspective taking, narrative involvement, ease of cognitive access, and narrative realism. All participants could successfully describe Zuki's goal. All but one participant claimed to empathise with the emotions Zuki was going through (feeling happiness, fear and worry in parallel with Zuki). Furthermore, nearly all participants thought that completing the last chapter provided insufficient fanfare and lacked a dramatic resolution.

There are **four types of real-time feedback** to reflect the completion of activities and progress towards goals (see in fig. 3.2). Each time a user logs a physical activity, a new **activity icon** appears on

Figure 3.2: A weekly storyline illustrating the incremental progress of the main character, Zuki, towards his goal for that chapter (here, climbing to escape his antagonist), which parallels the user's progress. The glanceable display uses visual elements to give feedback about tracked activities (e.g., birds – top of the screen) and progress towards weekly goals (e.g., carabiners – bottom right), accentuated with celebratory overlay (e.g., balloons) at 100%. Image taken from [29]

the top of the screen, encoded by different colours: blue for biking, red for running, yellow for walking, and purple for other user-logged types of activities. The icon size encodes the activity duration: activities lasting less than 30 minutes, 30–60 minutes, and over 60 minutes are represented by small, medium, and large icons, respectively.

A plotline-relevant **progress indicator** is used in the bottom right corner of the screen to indicate and celebrate the weekly goals. This indicator has milestones every 20% completion towards the goal. When the user reaches 100%, a **celebrating icon** is displayed (such as balloons, confetti, or fireworks) to celebrate goal attainment, unlocking the next chapter, which becomes available at the start of the following week. If users fail to achieve their goals by the end of the week, they return to the beginning of the same chapter. Finally, **notifications** are sent at every 20% milestone to complement the visual narratives and assist the transition between chapters.

The results led the authors to conclude that multi-chapter narratives can boost physical activity levels and engagement with both the system and its story.

3.2 Interactive Upper Limb Rehabilitation

In the previous section, we saw that gamification could be supported by techniques like Natural Interaction, User-centered design and Narratives. In this section, we will understand which and how gamification elements are used in serious games and gamified solutions that address Upper Limb Rehabilitation.

A study by Whittinghill [40] pretended to induce a behavioural change in the patients through positive

Figure 3.3: A patient using the serious game ”Burnie”. Image taken from [40].

reinforcement and reframing the therapy experience as a fun game. A Kinect-based serious game called ”Burnie” was developed that gamifies upper arm physical therapy for pediatric cerebral palsy (CP) patients by placing the player in the role of a bird navigating a nature-themed obstacle course. Cerebral palsy (CP) is a chronic movement and muscle disorder whose onset begins in childhood and persists for an individual’s life. It is proven that physical therapy, mainly when applied to the upper extremities, has been shown to ease some of the CP symptoms [40]. Even though the effects are visible, there is a noticeable lack of patient adherence to therapy, being even worse in pediatric CP patients. The player controls Burnie by flapping their arms and performing one of four poses that correspond directly to physical exercises defined by the medical professionals. The essence of Burnie’s gamification is the motivation to collect prizes, which earn points, and to avoid hazards, which subtract points if the user hits them. This study’s primary factor of interest was player satisfaction, measured along three dimensions: visual aesthetics, game controls, and overall enjoyment. A study was conducted with 21 subjects playing the game and then completing a post-game survey. On average, and using the Likert scale, subjects rated Burnie’s visual aesthetics as 7.65, controls as 5.4, and overall enjoyment as 6.75, which means that subjects found the game enjoyable on all dimensions, being unclear why the input mechanism was less satisfying than the other aspects of the game. The authors think the exercise-related discomfort may be the source of the lower ratings. Some interesting ideas that can be found in this successful project are to transform the exercise movements into the character controller, increasing the connection and engagement of the user with the game. Another is that the pleasing aesthetics and controls are responsible for high player satisfaction. Also, an excellent approach to player punishment is to give a humorous effect after hitting hazards (e.g., ”eating a hot pepper launches Burnie forcefully forward on a jet of burning hot gas”) instead of simply subtracting points.

A year after publishing the study on the **three game design principles** for designing healthcare

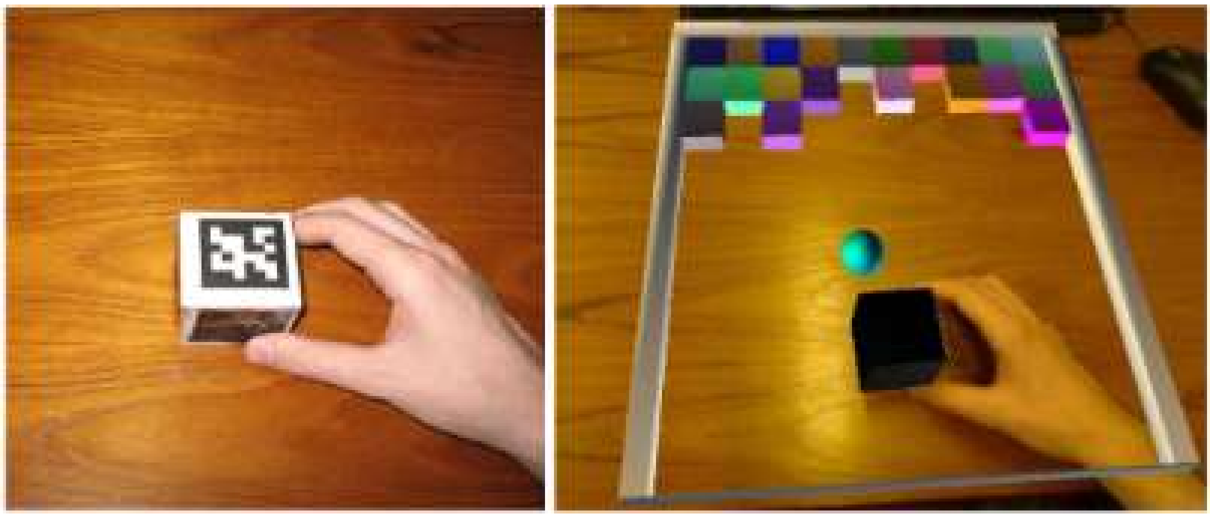


Figure 3.4: Brick'a'Break - A marker-based AR game. On the left, there is the marker. On the right is the augmented scenario. Image taken from [6]

solutions (introduced in the Background), Burke et al. developed two simple Augmented Reality (AR) based games [6].

AR typically refers to augmenting the real world with virtual (computer-generated) elements. In marker-based AR techniques, markers are attached to real objects, enabling the system to track their position and orientation as they move. The system can then augment the captured image of the environment with computer-generated graphics to create "scenarios" in which users have to complete tasks. In the first game, *Brick'a'Break*, players need to clear rows of bricks rebounding a ball with their paddle, which the user controls by moving a real-world object with a marker attached (see Fig. 3.4). Unlike in the original game, when the player misses the ball, he does not lose a life - instead, he has to wait a few seconds before the ball re-spawns. In line with the principle of handling *failure*, the user has no time limit to clear the bricks, but the exercise duration determines their score. In future versions, they want to build new levels suitable with the *challenge* aspect and forms of visual and auditory feedback, aiding to create *meaningful gameplay*. In the second game, the player can move real-world objects of different sizes and shapes with markers attached. Then, they must place these objects inside virtual rings that change colours when successfully used. After each correct action, a point is awarded, and additional points are depending on how fast the task was completed (*challenge* aspect). The player has to score as many points as possible within a designated time limit. This way, players will never *fail* and instead be encouraged to increase their scores over multiple sessions. By the time the paper was published in 2010, the games had not been tested by stroke patients, and there were found issues with AR that prevented it from providing an effective rehabilitation tool (e.g., occlusions are hard to detect). Nonetheless, the guidelines for optimising engagement in games for stroke rehabilitation are relevant and applicable to other technologies that are not AR, such as Kinect-based ones.

Peiris et al. implemented *SHRUG*, an interactive shoulder rehabilitation exerciser [32]. Traditional shoulder rehabilitation involves exercises that use both shoulders (the ”strong” shoulder can guide the ”weak” shoulder through the proper movements), such as placing a wooden pole into a pair of horizontal hooks. The main problems the authors found with these activities are that patients require supervision at all times (otherwise, they would perform the exercises wrong) and the lack of recording and saving data to build the user’s clinical history and progression. To solve the above limitations, the authors inserted LEDs on the pole and platform that give feedback to the user (indicating if they are doing the exercises wrong) and save their data after each use (completion time and accuracy - holding the pole horizontally being the desired position). It also has a built-in game with four different modes (difficulty levels), in which patients have to put the pole in the correct hooks following a random LED sequence with a continuously increasing pace. The prototype development involved the continuous participation of the therapists in interviews and focus group studies.

Ferreira et al. developed a smartphone application containing three games that use stroke rehabilitation exercises [16]. These games were designed to promote and evaluate different movements of the upper limbs, and their difficulty level is adaptable to each patient’s impairment level. The smartphone is placed in an armband attached to the upper limb of the user to collect movement data. A computer screen is a visual interface for the games, providing visual feedback that the smartphone alone could not achieve. The games are straightforward and are played using the extension and rotation of the wrists and forearms. Before each game, a calibration phase evaluates the user’s range of movement (in degrees), ensuring the games are always adapted to the patient’s recovery stage. The games finish after 1 minute and display the score and maximum rotation angles achieved by the player. This data is then sent to a therapist via email.

In a study [3] carried out by Aranha et al., a Kinect-based serious game called MoVEROffice was developed to induce paraplegic patients to perform tasks inside a Virtual Reality (VR) scenario using Natural Interaction. The proposed exercises involve organising a work table, inside a virtual environment, by picking up different objects and placing them in the correct places (see Fig. 3.5). The choice of this particular scenario is justified by the fact that such elements are present in many people’s daily routines, allowing not only the recovery of the affected limbs but also the transfer of skills from the virtual to the real environment. After each round of exercises, the supervisors recorded specific metrics such as the times of selecting and placing objects, total exercise time and distances between objects. This information allows the physiotherapist to keep track of the patient’s evolution and compare their performance on the same task inside Virtual Reality and the real world. To identify the main difficulties users encountered during a serious game with VR through natural interaction, two healthy subjects and two motor-impaired subjects played the game in a controlled environment supervised by two physiotherapists and two computer experts familiarised with the project. They were asked to repeat the proposed

Figure 3.5: MoVEROffice Interface - A Kinect-based serious game using a Virtual Reality environment. Image taken from [3].

exercises five consecutive times to verify the performance improvement. Despite the low number of participants, the results showed that all users have a learning curve to manipulate the objects. However, it can easily be overcome after a few sessions, proving that the difficulty relating to using Natural Interaction devices tends to be conquered after some uses.

Sergio et al. [1] modelled a 3D Virtual Environment (VE) and animations for a 3D avatar to assist in neurorehabilitation of the upper limb. Patients need to move their arms to simulate concrete daily actions while wearing a special garment that tracks the patient's shoulder, elbow and wrist orientation. In the VE, patients are represented by 3D avatars that, using the sensors' data, reproduce their arm movements in real-time. The game rules are to reach the "transition points" represented by yellow circles on the screen (see Fig. 3.6). The difficulty level is modified during the exercise according to the time the patient needs to reach the current goal. The score is displayed by two bars, one showing the progress of the current exercise and the other showing the total score of the exercise through the repetitions. The 3D avatars were modelled in Blender skeleton armatures, and their appearance was achieved by considering the therapists' opinions. The result is a visually pleasing model, not dull enough to distract the patient's attention. Although the system has not been tested on patients, the authors expect it will make rehabilitation more fun and effective. This study highlights the advantages of implementing a controllable character (not necessarily a 3D avatar), the adaptation of the difficulty during the execution of the exercises and the possibility of using two score visualisations instead of just one.

Figure 3.6: 3D virtual environment (VE) for neurorehabilitation of the upper limb. Image taken from [1].

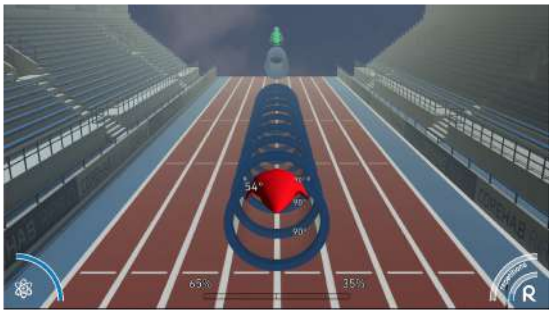
3.3 Commercial Platforms using Gamification

In this section, we describe three commercial platforms **that use gamification in healthcare**. This overview is based on commercial descriptions and online content, therefore not having peer reviews or efficiency reports supporting an exhaustive analysis.

Riablo [1] is a medical device composed of wearable sensors and a stabilometric platform. These devices transmit data via Bluetooth to a software that provides visual feedback through a TV screen to support physiotherapists' everyday work with patients (see Fig. 3.7(a)). The physiotherapists control the software that contains a pre-set library of exercises to create working sessions for the patients. The therapist can choose from more than 350 exercises that cover all body districts, including the upper-limbs, select the number of repetitions and resting times, or change the amplitudes of the movements they want to feature in the working session. When the program is ready, it can be assigned to a patient or saved in the favourite sequences to be used later. Once the patient starts to work out, each exercise is then transformed by the software into a simple video game that the patient must complete by performing the movements correctly. The games consist in controlling a character through an obstacle course using the movements from the exercises (see Fig. 3.7(b)). During the games is displayed a simple interface

[1] https://www.corehab.it/en/riablo-bf/

(a) Patient using Riablo during a therapy session



(b) Video-game played during the workout session using Riablo UI

Figure 3.7: Images taken from the Riablo website.

containing a progress bar. Once completed the exercises, all results are saved in the form of an intuitive report, both in terms of quantity (time and number of exercises) and quality (with simple indexes that show rotation, flexion-extension and prono-supination of the upper limb).

Jintronix [2] is a rehabilitation system to make training fun and interactive, which consists of a computer interfaced with a Microsoft Kinect camera to track upper body movement. The Jintronix software promotes movements like reaching, transporting and releasing virtual objects, moving the arm through a prescribed trajectory and performing a bilateral task using five games with fun 2D virtual environments [30]. The system can be used in the clinic or at home, as current televisions or computers are already equipped to work with telerehabilitation platforms. In the clinic, therapists control the degree of difficulty, duration and intensity level of the exercises (required speed, target number, repetitions) and make adjustments based on patient progress [30]. At the end of each session, the patient is presented with a score according to their performance level, and the clinician can view an overall performance report [30]. This system was designed to be combined with conventional therapy, being useful in quick assessments of the client's progress and reducing manual documentation.

SWORD Health [3] is a virtual musculoskeletal care provider that uses inertial sensors and a tablet to communicate with a physical therapist. The main goal of this product is to assist patients as they do the exercises at home, wearing the sensors and receiving live feedback from the professional through the tablet. The information from the sessions is generated by the sensors and sent to the application. The therapist will receive the data and adjust future sessions. The screen showing the results contains each session saved independently, and the highlighted metrics are the Duration, Performance, Pain and Fatigue (see Fig. 3.8). Additionally, a balance of global compliance, performance and therapy time is displayed on top of the menu.

[2] https://jintronix.com/
[3] https://swordhealth.com/

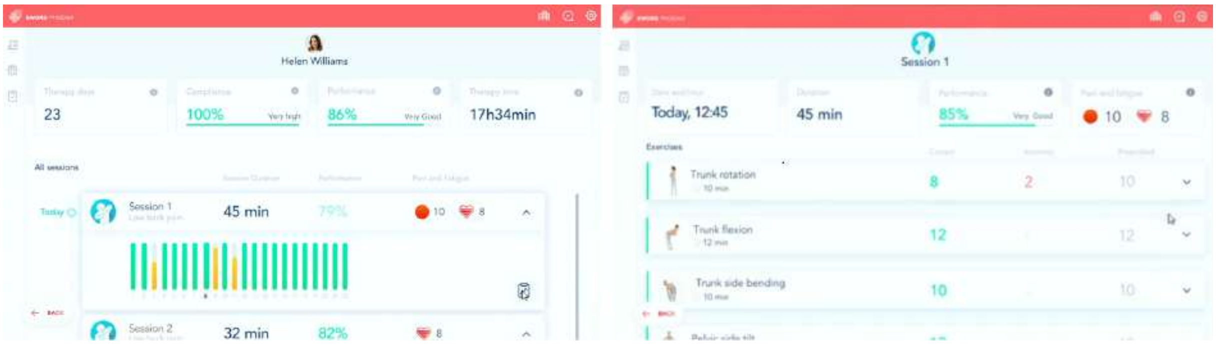


Figure 3.8: Interface for User Progression in SwordHealth. On the left, there is a user history of the sessions. On the right, there are the metrics from the previous session. Image adapted from a video on the site.

3.4 Discussion

In this section, we analysed the features of the solutions found in the related work. We created a table with the following parameters: Technology, Gamification, User-Centred Techniques, and Evaluation Techniques (see Table. 3.1).

3.4.1 Technology

As seen in the table, various technologies have been used to provide input to serious games or gamified apps in rehabilitation: Kinect [3,40], wearable motion sensors [28], inertial sensors [1], augmented reality markers [6], smartphones [16], and even augmented objects like a simple bar and platform [32]. These technologies capture motion differently and present advantages in their therapy contexts. Their main objective is to map the exercises performed by users in a virtual environment. Kinect is the most used technology, as it brings good value, particularly to upper-limb rehabilitation. The Kinect camera and software can recognize and generate data for most exercises in this type of therapy, with the downside of being unable to capture joint rotations. Additionally, unlike wearable motion sensors, it works without the patients using a wearable or markers, allowing them to move freely. Smartphones also have that constraint, on top of only registering the movements from the one body part they are attached to (in this case [16], the forearms).

3.4.2 Game elements

There are many game elements being used in the related work, each of them serving a unique purpose. The most common elements are Rewarding, visual and auditory Feedback, and elements that provide a sense of Progression.

	Technology	Gamification	User-Centred Techniques	Evalution Techniques
Aranha [3]	Kinect	Points Feedback visual Controlling a character	-	Observation Focus groups
McClincy [28]	Wearable motion sensors	[suggested for future versions] Avatars Leaderboards Rewards on each milestone	Initial Interview Card Sorting Think Aloud	Interviews
Whittinghill [40]	Kinect	Points Goals Encouraging sounds Controlling a character Hazards had funny outcomes	-	Survey
Sergio [1]	Inertial sensors	Points Score bars Controlling a 3D avatar Adaptable exercise difficulty during its execution	-	-
Burke [6]	AR markers	Points Visual and Aureal feedback Multiple levels Difficulty adaptation	-	-
Ferreira [16]	Smartphone app	Points Visual feedback Time constrained exercises	-	Observation Questionnaire
Peiris [32]	Bar and Platform	Points Visual Feedback (Leds) Different challenges	Interviews	-

Table 3.1: Results of the solutions described in the ”Interactive Upper-Limb Rehabilitation” section. The systems that can be used in the home environment are marked with orange.

3.4.2.A Rewarding

Rewarding is an excellent method to motivate users and can be implemented in multiple ways. The most known method for rewarding a player is ”Pointification”, which is the action of giving points at the end of each successful task. All but one solution [28] integrated a scoring system using points, as it creates in users the desire for completing the exercises and consequently gathering points and levelling up their Scores. Other Rewarding methods include giving badges when players achieve determined checkpoints or milestones. None of the solutions had badges, but it was suggested during a user study in [28]. In some cases [16, 40], there are used forms of punishment, such as subtracting points if the user made a mistake, but in most cases, this is not used because it can discourage them. Instead, if patients make a mistake, a form of Feedback should be a more appropriate approach, for example, a pop-up with a discrete message on screen, a subtle sound, or the use of a different colour (e.g., LEDs [32]). In the AR games proposed by [6], and in line with the *handling failure* principle, there is no time limit to complete the task, and when the player misses the ball, they do not lose a life but instead, have to wait a few seconds before the ball reappears. Even in the game ”Burnie” [40], which subtracts points, the punishment is satisfying because a humorous result would come out of that action (i.e., ”eating a hot pepper launches Burnie forcefully forward on a jet of burning hot gas”).

3.4.2.B Feedback

Providing real-time feedback has two objectives. Firstly, it is crucial during therapy sessions to reassure the users of the correct use of their bodies and not to harm themselves. Secondly, it serves the purpose of motivating and encouraging the user. Most papers described the use of at least one form of visual or auditory Feedback.

Visual Feedback The forms of visual Feedback found in the papers were: score bars [1], the ability to see their avatar moving in the game [1], the use of LEDs [32], colors and images [6, 16], and animations [40].

Auditory Feedback In papers, auditory feedback was found paired with visual feedback. After a successful task, a festive and encouraging sound would play in [6, 40].

3.4.2.C Progression

Usually, therapists need to save data from the sessions, track their patients' progression and build a clinical history. Therefore, a good application should provide a way of storing metrics such as duration, number of repetitions, amplitudes, and averages or statistics. Most papers and commercial platforms mention saving user data. The metrics can be registered in the form of reports (seen in all commercial platforms), emails to the therapist [16], in a memory card (SHRUG bar [32]), or in the software of the application [3]. Also, as users would benefit from understanding their progression, the app should provide that information in a friendly way. Instead of using charts and graphs, a paper [29] described in the ”Gamification in Rehabilitation” section used a narrative that would progress with the user's progression.

3.4.2.D Difficulty

In rehabilitation games, the use of levels and their complexity must be adapted to different players that may present additional difficulties and limitations, as they may not be able to overcome them like other players in advanced recovery stages. To solve this problem, in [1] the difficulty level is modified during the exercise execution according to the time the patient needs to reach the current goal. In [16], a calibration phase takes place before the workout, assuring the difficulty of the games is adjusted to the patient. In the commercial platforms, physiotherapists can choose the difficulty of the exercises when preparing the workout sessions by selecting the duration, desired amplitude of movements, number of targets, and number of repetitions of each exercise.

3.4.3 Ambient

The most common environments where the proposed systems were implemented are home [16, 28] and in the rehabilitation clinic [3, 40]. [1, 6] are not defined.

3.4.4 User-Centered Techniques

Only some systems are created with the involvement of their users. It is essential to hear from the patients and therapists to ensure their necessities are attained. The techniques found are Interviews [28, 32], Card Sorting [28] and Think Aloud [28].

3.4.5 Evaluation Techniques

To assess the viability of the systems, they were evaluated with patients and physiotherapists using the following techniques: Observation [3, 16], Focus groups comparing healthy and impaired subjects [3], Post-game Interview [28], Post-game Survey [40], and Questionnaire [16].

4

Designing a Narrative for Rehabilitation

Contents

4.1 Narrative-based Approach

We decided to integrate a narrative into our system due to its potential in engaging people to persist motivated in activities. Narratives are known to be immersive and mentally engaging. A rich body of literature suggests that such immersion is persuasive because beliefs, emotions, and intentions can change to reflect those presented in the story [18]. Besides being immersive, narratives could also lead to *transportation*. Transportation into a narrative world has been conceptualized as a distinct mental process [19]. The Narrative transportation theory [20] characterizes this *transportation* as a desired state sought by individuals on a daily basis. Book publishing, television, and film industries continue to thrive, supported by a mass audience eager to escape into alternate universes for at least a few hours each day. After an individual is transported, they are fully concentrated on the story. They often lose track of time or fail to notice events occurring around them because of their focused involvement in the world of the narrative [20].

In the context of health care, some narrative technologies have been used in the form of mobile applications. Instead of requiring the user to launch an application, some applications communicate health-related behaviours and goals through ambient smartphone wallpapers. These passive displays are often in tandem with visual metaphors such as flowers [10, 11] or sea life [22, 24] that reflect physical activity or other personal metrics. Research has found that these narrative-based strategies can successfully improve perceived happiness and self-esteem [21], make physical activity more enjoyable [41], and persuade behavioural changes. In particular, personalized narratives that positively frame exercise in terms of enticing and playful challenges presented through aesthetically pleasing interfaces may promote a more crave-worthy mindset and, in turn, more physical activity [29]. However, such interventions have not fully explored the use of narrative to instantiate effective and engaging storytelling techniques to motivate activity [4].

For all the reasons above, we decided to include a narrative to support our system to increase patients' motivation during their rehabilitation sessions. Aiming to get a deeper understanding of patients' preferences and narrative experiences, we decided to interview them.

4.2 Interviews on patient Narrative Experiences

We conducted 9 semi-interviews in the clinical facilities to gather insights and inspiration to create a suitable story that appeals to as many patients as possible.

4.2.1 Participants

With the help and coordination of the physiotherapists from *Clínica Dentária Egas Moniz*, we arranged meetings with 9 participants. Some sessions were individual, but others were in group: meeting 1 (P1), meeting 2 (P2), meeting 3 (P3, P4, P5, P6, P7), and meeting 4 (P8, P9). The participants were regular patients in the clinic diagnosed with various injuries, and all of them were older adults or elders (60+ years). At this stage, it was not necessary to study patients with upper-limb injuries, meaning that these were not the same subjects of the User Studies in Chapter 6.

4.2.2 Method

The semi-structured interviews took place in the "Clínica Dentária Egas Moniz"- where we would eventually test our final prototype - and we started by introducing the team and explaining that the research session aimed to investigate which types and genres of stories are more appealing to the patients.

Throughout the different meetings, we used a TV showing a PowerPoint presentation to illustrate the questions and recorded the audio using a smartphone. The questions were prepared to allow the participants to explore their feelings and opinions regarding different genres of stories. For instance, our questions aimed to gather information about their favourite scenarios for the story 4.2 (i.e. farm, sea, western), types of plots (i.e. family story, hero adventure) and genres 4.1 (i.e. adventure, drama, mystery). All the questions and slides are listed on the Appendix B. Then, we transcribed and coded the audios to get the results.

4.2.3 Findings

The majority of patients **do not watch movies frequently**: *"I am a little tired of movies and series"* (P1), *"I have no patience for movies"* (P7); but enjoy a "good movie" when is on TV: *"[...] but sometimes [I watch] adventure movies"* (P1),*"[I like] a good movie and sometimes soap operas when my wife is watching"* (P5). Participants **enjoy classical movies and childhood movies**: *"I like movie classics, I know Indiana Jones, Casablanca"* (P8), *"When I was a kid I saw Snow White. Every now and then, at Christmas, I do not mind watching it"* (P6). **None of the participants enjoys science-fiction content**: *"I'm not a fan of science-fiction [...], and I love books based on real facts"* (P8); and **5 participants are entertained by documentaries**: *"I like Documentaries about the Environment and Real Facts"* (P2).

Then, to consolidate our knowledge of the genres that patients prefer, we asked for their **"most memorable story"**. We had 3 participants talking about the subject "War":*"The last movie I saw with my late wife was an action movie where the main character is an American paramedic during World War II [...] that healed the wounded from both sides."* (P9); other participants talked about family stories and childhood times.

Figure 4.1: "Types of entertainment" slide used to illustrate the first question of the auscultation.

To find which setting is more interesting for the unfolding of the story, we asked participants to pick **one of three scenarios** (see Fig. 4.2). Participants showed little interest in the desert scenario, despite watching western movies when it is on TV: *"When [Zorro movie] it is on TV, I always watch it."* (P5), *"In the desert, there is no good hope."* (P7). Three participants chose the countryside setting as it carries nostalgia for their childhoods, while the seaside setting represents the feeling of relaxation: *"For me it's the island, somewhere calm, facing the sea. The ocean is stress relieving"* (P9). In addition, as they live in Caparica, the participants visit the beach regularly *"I go practically every week to see the sea in Caparica"* (P1).

Figure 4.2: "Scenario" slide used to illustrate possible scenarios for the plot.

To help us define the plot, seven participants believed that a story following a set of **multiple characters** would be more interesting than a story with just one main character: *"a group of friends would be more interesting"* (P3); P2 thinks that we need a leader but also people to be lead. P1 believed that one main character is more interesting: *"Heroes no longer exist, only half-heroes. Someone always stands out and may not be the hero [...]. So, I would like to see the path of a character, a protagonist."*.

4.2.4 Discussion

As expected, there were a lot of diverging opinions and preferences in our results, and, therefore, it is impossible to extract a unique story that would suit every patient. Keeping this in mind, we used the results to exclude the least preferred features from our story while keeping the ones that received the most discussion.

Story genre. Participants spoke enthusiastically about old classics and childhood films and showed much interest in documentary films. Additionally, when asked their *most memorable story*, their answers were related to their ”childhood times” and ”family”. Even the ones who mentioned ”war” did so due to its impact on the affected families. Correlating the information received, we can infer that most patients would enjoy watching an adventure story with the classic style of old movies and featuring family members. Similar to documentaries and old stories, a good narrative should also contain teachings and morals.

Scenario and Main character. Participants showed more interest in the countryside or sea-related scenery, believing that natural landscapes transmit relaxation and relieve stress. Between these two, we believe that a story featuring the ocean would be more suitable for these patients, as they live in Caparica and visit the beach regularly, which makes patients naturally associate this scenario with their ”home”. Lastly, participants preferred following a group of main characters, such as a group of friends, to a single character.

4.3 The Narrative and Illustrations

This section describes the final version of the narrative and illustrations. We also connect the findings from the interviews to the related work to explain how they influenced our decisions during the writing process.

After receiving feedback from the interviews, we hired a writer with a Bachelor in Communication Sciences (in Universidade Nova de Lisboa) and a Postgraduate in Storytelling (in Instituto Politécnico de Lisboa). She has experience in writing fictional stories. One of our main goals was to elevate the narrative into a *memorable story* that the patients would remember and talk about afterwards. During the interviews, we learned that providing strong emotions, such as nostalgia, could be useful towards that goal. We decided that we were going to ”bring out” their childhood times through popular proverbs.

Proverbs contain common sense and humour, emotional expressiveness and the ability to express feelings and moods, national originality, and the depth of culture of the people [35]. By naming each chapter a different proverb, we are not only providing extra meaning to the story but also giving a fun touch that we believe the patients will recognize as an old teaching/moral. In addition, such expressions might evoke their childhood times, as proverbs were commonly used in the daily language (more than today) and as jokes among the population.

The final result was a five-chapter story named "An unexpected treasure" (PT: "Um tesouro inesperado"), and each chapter is composed of 4 or 5 illustrations (a total of 23 illustrations). We hired an illustrator, a Master's student with a Bachelor's degree in Drawing from the university "Faculdade de Belas-Artes da Universidade de Lisboa", to bring our story to life by illustrating the images that the patients would see during the sessions. The visual language of the story is a mix of "Asterix & Obelix" and "Tintin" - two comics whose style we believe to be suitable to our story. As a final detail, we decided that every chapter would be named after a Portuguese proverb.

(a) 1st Image: "It's been 10 years since Pedro last saw his grandfather."

(b) 5th Image: "Although he didn't know where to start, Pedro was sure that this was a dream to fulfill."

Figure 4.3: Chapter 1 - "The apple does not fall far from the tree" ([PT] "Filho de peixe sabe nadar")

4.3.1 Chapter 1: The apple does not fall far from the tree

Summary: *"The first chapter introduces the main character, Pedro, whose objective is to fulfil the old dream of his grandfather: to find the hidden treasure on an unknown island in Chile."* (see Fig. 4.3)

We decided to create an adventure story that features a grandson searching for the same treasure his grandfather once sought, as the "adventure" genre is enjoyable to most patients, and their *most memorable stories* usually mentioned "family". The setting takes place on an island because being near the ocean could relieve stress and reminds the patients' homes. The art-style and visual elements, such as the clothing and scenery, create the feeling of the story being set in the 20th century, where patients lived most of their lives—creating a similar environment to recall possible enjoyable memories.

The highlighted proverb *"The apple does not fall far from the tree"* means that a child usually has the same qualities and talents as their parents. In this case, the proverb refers to Pedro, that has the same courage and spirit of adventure as his grandfather.

The 1st chapter sets the plot and main character, the visual language, and the format of our story (i.e. every chapter has a proverb and 4 or 5 illustrations), and, in the end, Pedro is seen embarking on a journey to a mysterious island, leaving suspense in the air.

(a) 1st Image: "It was already dark when Pedro took his first steps on the island. He heard voices as soon as he disembarked and decided to follow their sound until he reached a clearing."

(b) 4th Image: "When they grabbed him, Pedro thought, for the first time, that his adventure could turn out to be more dangerous than he had imagined."

Figure 4.4: Chapter 2 - "Every jack to his trade" ([PT] "Cada macaco no seu galho")

4.3.2 Chapter 2: Every jack to his trade

Summary: *"Pedro arrives on the island, and shortly afterwards, he comes across a tribe of indigenous people who, at first glance, seem threatening. Without realizing it, Pedro is caught, getting himself into a sticky situation."* (see Fig.4.4)

To give depth to the story, Pedro meets a new character in our second chapter: the indigenous tribe. We chose a tribe because some participants love History documentaries. After some research, we decided to draw inspiration from the native Mesoamerican Tribes that usually had their faces painted red, their clothes made of straw and decorated with leaves from the island. Around their necks, each indigenous person carried several necklaces made of small stones. Their hair was pulled back (with elastic bands or ribbons also made of island vegetation), making their red face stand out even more. At first glance, we wanted them to look like enemies/antagonists by illustrating them with beefy bodies, angry faces and menacing looks.

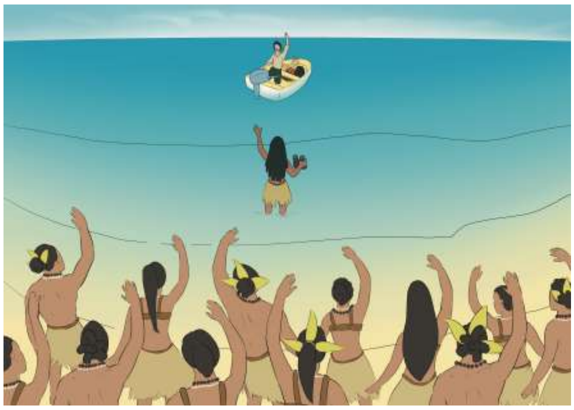
The proverb highlighted in the second chapter, "Every jack to his trade, " means that people should mind their business and recognize their place without meddling in other people's affairs. Like so, Pedro was intruding on an island that was not his and risking getting himself into a dangerous situation, as the tribe appeared to dislike his presence.

An engaging story should have moments of rising action/tension followed by a resolution [29]. At the end of the second chapter, Pedro will face his first challenging situation, leaving the users excited for the resolution in the next chapter.

(a) 1st Image: "Pedro was taken to Mara, the healer of the tribe."

(b) 3rd Image: "Around the fire, Pedro danced with the indigenous people as if he were part of the tribe. That was precisely what they wanted – for Peter to feel like one of them for one night."

(c) 4th Image: "The tribe chief's offerings were the ultimate gesture of friendship and respect."



(d) 5th Image: "We never know what hides behind a face. Pedro understood this as he said goodbye to his friends to head to the south coast of the island, where he hoped to find the long-awaited treasure."

Figure 4.5: Chapter 3 - "Don't judge a book by its cover" ([PT] "As aparências iludem")

4.3.3 Chapter 3: Don't judge a book by its cover

Summary: *"Pedro is taken to the healer of the tribe, who paints his face with red paint. His fear has slowly turned into curiosity. Then, around the fire pit, Pedro dances with the indigenous people as if he was part of the tribe. That was precisely what they wanted – for Pedro to feel like one of them for one night. At the end of the ritual, the chief gives offerings to demonstrate his friendship and respect for Pedro. Finally, Pedro says goodbye to his friends and heads to the south coast of the island, where he will find the long-awaited treasure."* (see Fig.4.5)

The 3rd chapter resolves the situation in the previous chapter - the indigenous people did not want to harm Pedro. Instead, they were friendly and welcomed him as if he was one of them. This plot twist is connected to the proverb *"Don't judge a book by its cover"*, which aims to convey the message of not judging other human beings based on their appearances and not being afraid to make connections with them. In this chapter, Pedro has made allies and learnt an important message. Now, he is more prepared to face the last challenge unfolding in the following two chapters.

(a) 1st Image: "After hours of walking through the forest to the south of the island, Pedro began to believe that the treasure was nothing more than his grandfather's invention... Until he found a strangely familiar hat."

(b) 4th Image: "Pedro did not want to believe what his eyes saw, while logic struggled with reality. He knew that his grandfather had died ten years ago. How could he be here, now, in front of him?"

Figure 4.6: Chapter 4 - "Long time no see" ([PT] "Quem é vivo sempre aparece")

4.3.4 Chapter 4: Long time no see

Summary: *"After hours of walking through the forest, Pedro finds a strangely familiar hat. Following his sixth sense, he starts digging and, to his surprise, finds small bags full of diamonds. Finally! Pedro had fulfilled his grandfather's dream! Then, a nearby presence shows up, revealing to be his grandfather."* (see Fig.4.6)

In the 4th chapter, Pedro finally finds the treasure, achieving his initial goal. However, the unexpected appearance of his grandfather brings a mix of emotions: joy, surprise and intrigue, as he was presumed dead after ten years of being missing. Suddenly, his journey gained a new purpose: to discover the mystery behind the disappearance of his grandfather - to be solved in the 5th and final chapter.

(a) 1st Image: "When Pedro's grandfather disappeared, everyone in the family thought him dead. But the reality was quite different: he had found the unknown island on his map and started a new community, far from the vices of consumer society."

(b) 2nd Image: "With admiration, Pedro heard new stories of adventures, friendships, cured illnesses, and dreams come true. His grandfather told him that diamonds were not the island's real treasure — that one, only a few were meant to see."

4.3.5 Chapter 5: You get what you give

Summary: *"Pedro follows his grandfather to his "house" - a village in the middle of the forest - where other adventurers, who also decided to stay on the island, live. The grandfather had founded a community that lived in harmony with the island and with the other tribe. The last challenge comes when his grandfather gives him a choice between staying on the island, away from consumerist vices or leaving with the diamonds and being rich. Upon reflection, Pedro chooses to return the diamonds to the island and stay."* (see Fig.4.7)

In the final chapter, Pedro solves the most recent mystery. There was a secret community on the island founded by his grandfather that had achieved perfect harmony with the island: people were happy and healthy, despite living with wore clothes and having a humble lifestyle. In the second and last images (see Fig. 4.7), we can also see that the previous tribe and this community cohabit on the island in harmony, which teaches the important lesson of respecting other cultures.

The dilemma arises when Pedro is faced with the ultimate decision: 1) Leave the island with the diamonds and become rich, or 2) stay on the island and have a happy but humble life in a community with others like him. This moment is the climax of our story, and it should induce the readers to put

(c) 3rd Image: ”*And you, can you see?* – the grandfather’s question echoed in Pedro’s mind as he faced the biggest dilemma of his life: leave with the diamonds or stay and make the island his home?

(d) 5th Image: ”*Because wealth is everything that cannot be bought*, Pedro understood this there, on an unnamed island more than 10 thousand kilometres from home. Far from everything he thought he needed, he found the true treasure that every man seeks. Freedom, peace, love... Life. And he had never felt so rich.”

Figure 4.7: Chapter 5 - ”You get what you give” ([PT] ”Dá se queres receber”)

themselves in this situation- *”What is more important: Family and health or bags full of diamonds?”*. It should be no surprise that our character Pedro chose to stay on the island, as we believe the first option is the **moral of the story**.

4.3.6 Conclusion

In conclusion, the story delivers an adventure featuring a family mystery, with some climatic moments and resolutions. There was a use of characterization: Pedro, the tribe, and grandfather. Every chapter is named after a proverb, which would be a fun and engaging element to wrap up the story. Two important messages/morals were taught: in the 3rd and final chapters. In the end, we chose to have a happy ending. The results are explored in Chapter 6.

5

ARCADE-N

Contents

5.1 Base-Prototype

ARCADE is a Kinect-based application developed by Duarte et al. [15] that supports physiotherapists and patients in upper-limbs physical rehabilitation (see Fig.5.1).

Duarte's research studied the physiotherapists' adoption process of markerless motion capture systems (technologies such as Kinect), using *ARCADE* during the evaluations. They concluded that these systems are useful and effective tools to improve therapist interventions, enabling constant feedback on the performance of the patients, even when they are alone performing the exercises. Although it was proved that systems like *ARCADE* are valuable to professionals, not all patients seemed to adhere to *ARCADE*, leaving some problems related to its adoption unsolved (i.e. motivating patients to use it).

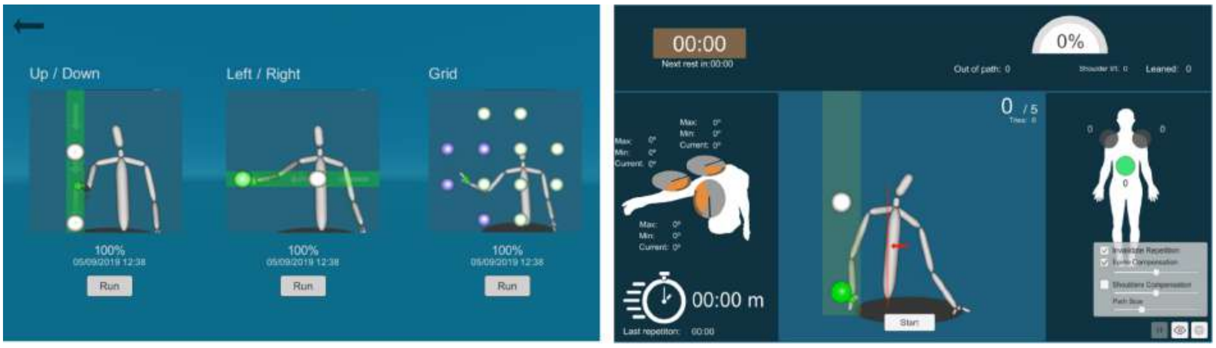


Figure 5.1: Screenshots of the base-prototype *ARCADE* developed by Duarte [15].

Our project, *ARCADE-N*[1], focused on the patients and their needs/preferences as we aimed to develop a more personalized and fun experience for them. The main goals of our project were to implement gamification and a narrative to motivate patients to enjoy our system, and to explore if it is a viable tool in assisting physiotherapists in creating engaging sessions.

To **improve user enjoyment**, we used gamification during the exercises and created a narrative to be unravelled throughout the sessions. These elements aimed to encourage the patients to perform the proposed exercises and work on their rehabilitation plans. In particular, the narrative gives extra meaning and a sense of reward to their rehabilitation process because it advances simultaneously with their progress.

To **improve the usability and readability of the system** and provide a better workflow for the physiotherapists, we redesigned the whole user interface. We did so by updating the look and feel of existing screens, adding new screens and features, and rethinking the flow between screens. Particularly, we want to provide more clarity to the screens responsible for creating the exercises, a key feature to be used by physiotherapists.

[1] N stands for narrative

5.2 Architecture

Similarly to the architecture of the base prototype, the movement data is captured by the Kinect and processed by the application developed in Unity3D, a computer runs the application, and a touchscreen TV serves as the interface to receive commands (see Fig. 5.2).

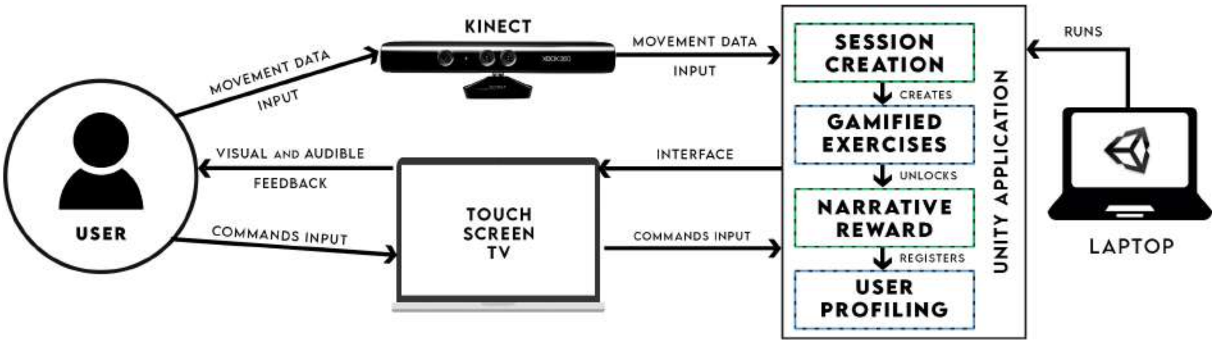


Figure 5.2: *ARCADE-N* architecture. We can divide the application into four key modules: in blue are the modules extended from existing features, and in green are the modules created from scratch. The developed modules belong to the Unity application, with the rest of the architecture similar to the base prototype.

The motion capture is performed by the Kinect V2 camera, which was originally developed for *Xbox 360*. However, Microsoft makes available the Kinect SDK for anyone to create applications with the data generated by Kinect.

The television needs to be big enough for the patient to see and comprehend the feedback during the exercises, so we used a conventional 55 inches LCD television with a touchscreen. Therefore, the LCD TV is the interface responsible for providing visual and auditory feedback and receiving the commands to control the application.

Our contribution focuses on the Unity application, which we can divide into four main modules: session creation, gamified exercises, narrative reward, and user profiling.

The ***session creation*** module was created from scratch to accommodate in one screen all the necessary parameters to create the exercises. The therapists indicated the set of parameters: exercise type, arm, number of series, number of repetitions, and resting duration. The base version did not allow creating sessions, only repetitions of one exercise type. So, we added the parameter *series* and the ability to create multiple sequences of different exercises to create one session.

The ***gamified exercises*** module was extended by adding the gamification elements and improving the exercise screen UI. We reutilize the three exercises from the base prototype, as they were already programmed and integrated with Kinect (including the dummy controlled by the patient). We changed the amount of information on the screen to the point where it is not overwhelming to patients but has the important parameters for the physiotherapist. Then, we added the following gamified elements:

- *Progress bar*, which increments with every successful movement and unlocks the narrative illustrations at every checkpoint (0%, 25%, 50%, 75% and 100% for chapters with 5 illustrations). The progress bar was chosen because it visually represents the user's progress, motivating the patient to complete the session.

- *Voice assistant*, which delivers pre-recorded voice lines that encourage and correct the user during the workout. This feature helps to keep the users entertained and creates the feeling of monitoring their performance because it gives auditory feedback.

- *Colors, sounds and music*. In the exercises, we use green and red colours associated with ”beeps” and ”warning sounds” to indicate success or failure. These are simple but effective elements that help produce responsive exercises. We play upbeat background music to create a sporty and vibrant atmosphere.

- *Performance score and Medals*, which are displayed at the end of every session. The performance score is calculated by $\frac{CorrectRepetitions}{TotalRepetitions}$ and the medals are golden, silver or bronze depending on the performance (0-49% bronze, 50-79% silver, 80-100% gold).

The ***narrative*** component is triggered during the exercises after reaching checkpoints on the score bar, causing the illustrations to show on the screen. The illustrations are meant to be a reward and only appear during resting times or between sequences to not break the exercise flow.

The ***user profiling*** module saves the data from the exercises to build the user profile (e.g., the duration of exercises and the number of compensatory movements during each session). After a session, the data is saved locally on the PC, avoiding needing a database or Internet connection.

5.3 *ARCADE-N*: The Final version

In this section, we describe our work: the gamified version of *ARCADE*, which we called *ARCADE-N*. In the next section 5.4, we explain the design process and some of the iterations the system went through.

5.3.1 Adding a new Patient

When the physiotherapists log in to the application, they must use the patient's name (see Fig. 5.3(a)). An account must be created first on the Register Menu if it is the patient's first time using the system (see Fig. 5.3(b)).

(a) Login Menu

(b) Register Menu

Figure 5.3: Adding a new Patient.

(a) Creating the first Sequence: choosing the exercise type (the gray overlay helps highlighting the correct area)

(b) Multiple Sequences created

Figure 5.4: Creating the Session.

5.3.2 Creating the Session

To create the session, the physiotherapists must log in with the patient profile and then choose "Create Session" in the Main Menu. In the "Create Session" screen (see Fig. 5.4, physiotherapists can choose to Add, Delete or Edit **Sequences** of exercises to the session. Each Sequence has the following parameters:

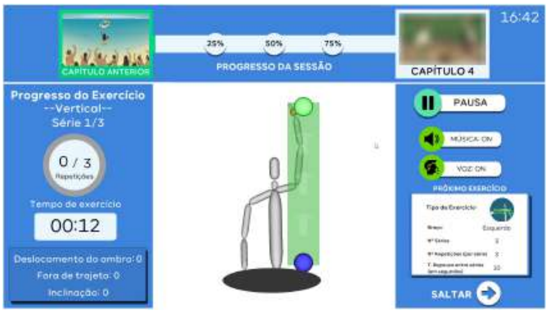
- Exercise type: *Vertical*, *Horizontal* or *Grid*
- Arm: *Left* or *Right*
- Number of Series
- Number of Repetitions (per Series)
- Rest time (between Series)

Essentially, creating a session is equal to creating a list of Sequences, in which every Sequence is a given Exercise repeated *S x R* times, with a given Arm (*S* is the number of Series, and *R* the number of Repetitions).

5.3.3 Exercise-Types

After creating the session, the application jumps to the "Exercise" screen, where the patient will perform the planned exercises. There are three different *exercise types*:

- **Vertical Raise.** The patient raises and lowers the arm forward in a line.
- **Horizontal Sweep.** The patient elevates the arm forward to shoulder level and then moves the arm sideways in a line.
- **Grid.** The patient uses their arm to go through multiple points on the screen, following one of four patterns.



(a) Vertical Raise exercise

(b) Horizontal Sweep exercise

(c) Grid exercise

Figure 5.5: Exercise types.

On the **left side**, we can see the progress of the current Sequence (number of *Series*, number of *Repetitions*, total time, and number of incorrect movements - which is the number of times the patient left the boundaries of the green box with their hand). On the **right side**, we can see the Pause, Voice assistant and Sound Buttons (that mute the voice assistant and the background music, respectively), a panel containing information about the following Sequence with the button to jump to that Sequence. On the **top side**, we can see a progress bar that fills up whenever the patient performs a correct repetition. Each checkpoint on the bar corresponds to an illustration of the narrative. Finally, in the **middle of the screen**, we have the *exercise space* and the dummy that represents and mimics our patient in real-time. The figure works as an "avatar", controlled by the patient, and is essential to completing the exercises. It expresses self-representation and helps to use a correct body posture.

(a) Setup of the Vertical exercise: adjusting the path

(b) Setup of the Grid exercise: picking the pattern

Figure 5.6: Pre-Exercise setup.

5.3.4 Calibrating the Exercises

At the beginning of the first Sequence of every exercise type, the physiotherapist has to adjust it to each patient. This setup can be done at any time by pressing the PAUSE button.

For the vertical and horizontal exercises, the physiotherapy should adjust the position, height and width of the **green box** to match the desired range of movement (see Fig.5.6(a)). The purpose of the green box is to work as a container for the patient's movements and prevent any compensatory movements[2] that would further increase their injury. This setup allows the adjustment of the exercise difficulty for patients with different arm amplitudes and injury degrees.

For the grid exercise, this step is more simple, as there is no green box to adjust, and it only requires the physiotherapist to choose between four different patterns: *spiral-left*, *spiral-right*, *S-horizontal* and *S-vertical* (see Fig. 5.6(b)).

[2]Compensatory Movement: compensation comes from weakness or inability of a muscle to perform its role in movement (e.g. lateral trunk flexion and exaggerated weight shift to substitute for incomplete shoulder flexion) Definition taken from: *https://medical-dictionary.thefreedictionary.com/compensatory+movement*

5.3.5 Gamified Exercises

During the exercises, we implemented several gamification elements: Voice Assistant, Colors, sounds and music, Progress bar, Unlocking the narrative, Performance score and medal.

5.3.5.A Voice Assistant

The voice assistant is a feature that speaks personalized voice lines during the exercises. There is a 50% chance that the voice assistant generates one of these lines whenever the patient completes or fails an exercise repetition. The auditory feedback differs depending on patients' correct or incorrect movements (see Fig. 5.7). Some examples of audio feedback for correct movements were: *"Keep going! You can do it!"*, *"Good job! You're almost there!"*; whereas for incorrect movements were: *"Oops, you got off track"*, *"Oh-oh, the movement did not follow the line"*.

(a) After correct repetition: "Don't give up! You're almost there."

(b) After patient leaves the green box (incomplete repetition): "You are a little off track."

Figure 5.7: Examples of the Voice Assistant. The voice lines go along text popups.

5.3.5.B Colors, sounds and Music

There are multiple visual and sound cues that provide feedback on the exercise. When the patient makes a mistake and leaves the green box, it turns red and makes a "warning sound". When the user touches a ball, it shakes and makes a "beep" sound. A cheerful animation is played if a checkpoint on the bar is reached. We play upbeat background music to create a sporty and vibrant atmosphere.

5.3.5.C Progress bar and Unlocking the Narrative

As our main gamification element, the narrative is unlocked and seen during the session. On the top part of the exercise screen, there is a progress bar that fills with every successful movement. When the patient performs a given number of exercises, they reach checkpoints on the bar and are rewarded

(a) Story screen: Cap 2, Images 2 and 3

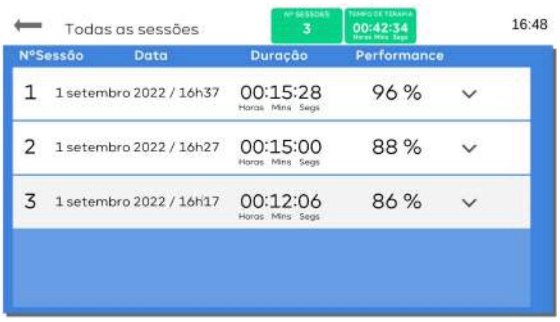
(b) Session Results screen

Figure 5.8: Gamification "Rewarding" elements: the Story and the Medal.

with a piece of the narrative: in form of illustrations. Then, whenever there is a rest time, the application shows the illustrations and respective captions in a different screen, the *Story screen* (see Fig.5.8(a)). To increase the immersion, we have a narrator, played by the same voice used in the voice assistant, that reads the captions aloud.

5.3.5.D Performance score and medal

After finishing the planned exercises, the application recaps the whole unlocked chapter and then shows the *Session Results screen* (see Fig.5.8(b)). There, the patients can see their end of session results: the duration of the session, the performance score (calculated by $\frac{CorrectRepetitions}{TotalRepetitions}$) and a (virtual) medal according to their score (0-49% bronze, 50-79% silver, 80-100% gold).



(a) List of all sessions

(b) **Session 1** results

Figure 5.9: Results screen.

5.3.6 Ending the session

The application then returns to the *Main Menu* and saves the session's results (using text files). These metrics can be consulted by going to the *Results Menu* (see Fig.5.9). For each session, the following data is saved: type of exercises, number of correct and incorrect repetitions (named *out-of-paths*), performance, and total duration.

5.4 Design Process

This section describes the design process behind developing *ARCADE-N*. The design process includes **Usability Tests** of a low-fidelity prototype and a **Focus Group** with the physiotherapists.

5.4.1 Usability Tests

We made a low-fidelity paper prototype using A4 sheets representing each one of the screens. To evaluate the prototype, we asked 4 participants (who are Computer Science Master students) to complete four tasks. These tasks were the same actions of the physiotherapists creating the session for their patients. The "Wizard-of-Oz" and "Think-Aloud" methods were used. We recorded the audio and took notes during the tests. Afterwards, we transcribed and analysed them to reach the main conclusions. Next, we enunciate and describe the tasks and our findings:

Task 1: Add a new patient and login.

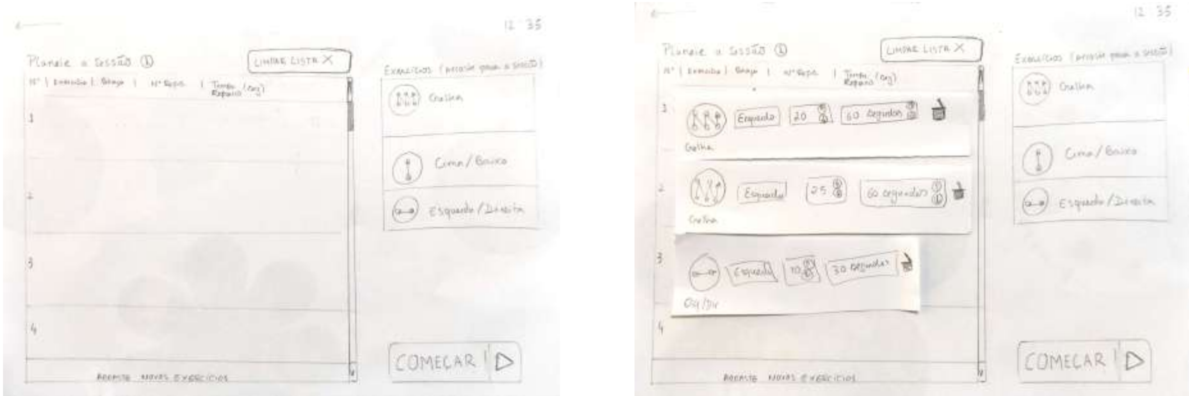
Description: On the Login screen, select "Create User" and type in the input boxes to fill in their personal information. In the end, select the "Save" button.

Findings: From the start, participants were meticulous with the UI of our lo-fi. They pointed out the importance of filtering the search bar using the patients' names alphabetically, shortcuts such as TAB to traverse between text boxes, and ENTER to complete the signing-up process. Also, in case the fields have not all been filled in, they suggested using error messages and, in case the BACK button is pressed, a message saying *"Are you sure you want to go back? Your progress will be lost!"*.

Task 2: Create the Session with two grid exercises and one horizontal sweep.

Description: Participants had to create a Session and add the respective exercises by dragging them from the right to the list on the left. Then, press "Start" on the bottom right (see Fig.5.10).

Findings: The participants started by questioning the functionality of planning a session on the go: "wouldn't it make more sense to plan the whole session beforehand and when the patient arrives there would be several plannings to choose from and select one?" and "isn't planning at the moment taking



(a) Empty List

(b) List with 2 Grid exercises and 1 Horizontal sweep exercise

Figure 5.10: Lo-fi: Create Session screen.

time from the session?". Throughout the Usability tests, several questions like these were noted and later discussed with the physiotherapists in the Focus Group.

Some participants found this screen intuitive, but others took a minute to realize how to work with the List. It was then suggested to add the "Helping Context" feature, a tutorial with animations (or .GIFs) to teach the user during their first time creating a session. In this animation, the screen would be partially dark (using a semi-transparent layer) except for the highlighted area that shows how to drag exercises to the List.

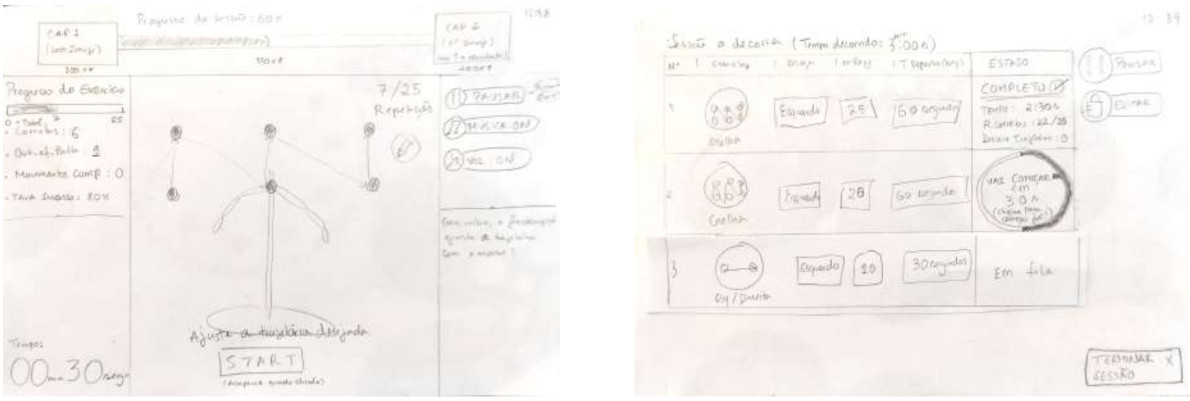
After dragging the correct exercises to the List, participants focused on the exercise metrics. One question was related to the "resting time" - the time between the end of an exercise and the next one - and they suggested adding information icons (i) for the user to hover with the mouse to read the information regarding that metric.

Task 3: End the session after completing the first exercise.

Description: In the "Exercise screen", the therapist will see the current exercise progress on the left, settings on the right, and the session progress bar on the top (see Fig.5.11(a)). After an exercise is completed, during the resting time, the lo-fi changes to the "On-going Session" screen (see Fig.5.11), which has the planned exercises, the options to reorder the remaining exercises (by dragging up-down), and END the session - which should be pressed to complete the task.

Findings: The first comment was that maybe patients would not like to see certain pieces of information during the exercises, such as the number of incorrect movements (Out-of-path) or total session duration. A solution would be to implement a button to SHOW/HIDE undesired information.

On the "On-going Session" screen, it was pointed out that if the therapist wants to JUMP to a given



(a) Exercise screen

(b) On-going Session screen

Figure 5.11: Lo-fi: Exercise screen flow.

exercise, they have to rearrange the order or eliminate multiple exercises to reach the one he wants. The solution would be to add a "JUMP to this exercise" button, which would skip the jumped ones (in the end, on the session report, it would be explicit which exercises were skipped). Relatively to the task, we found the "End Session" button easy to understand and see.

Back at the "Exercise" screen, we talked about the **unlocking of the narrative** and explained that the progress bar on top has two images: the Last image of the Last chapter on the left; and the First image of the Current chapter on the right. The image on the left recalls the last chapter, and the one on the right teases the upcoming chapter. One participant suggested recapping the last chapter in every session: *"I think it would be nice to start the session with the last chapter that was unlocked, like a "previously on Game of Thrones", as this will hype the patient to know what will happen next!".*

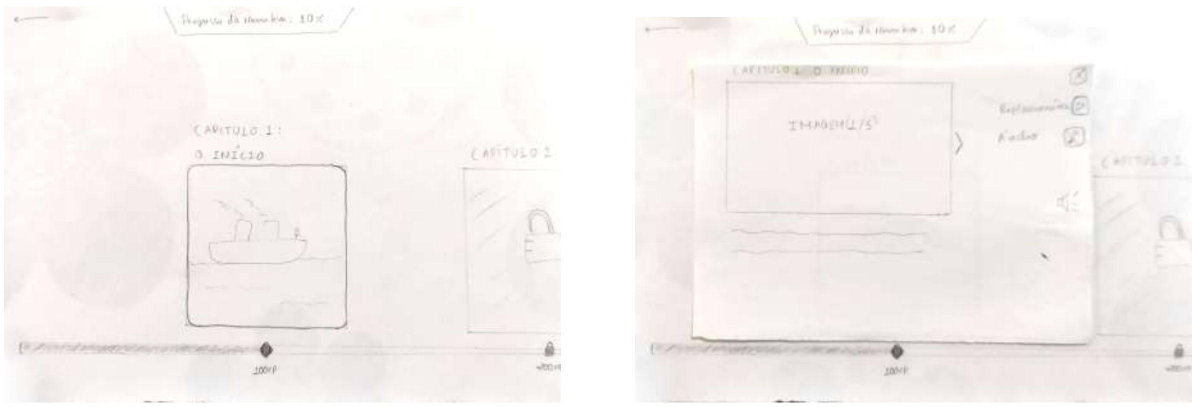
The moment with the most discussion in the Usability Tests was not related to the system's usability but to designing the narrative component. Towards the end of the session, there is a *"Well Done!"* message followed by a popup that asks ***"Do you want to give the chapter to the patient?"***. This popup allows the physiotherapist to reward or penalize the patient if they underperform during the session. First and foremost, participants disliked asking that question in front of the participant: *"I feel that someone who is seeing their doctor pressing "No" is demotivating. I find it hard for the patient to see their XP progressing and then not receive it"*. Next, we discussed the situation where the patient could not complete all the proposed exercises, therefore not gathering enough XP to unlock an entire chapter. This situation could happen if the physiotherapists over-planned the exercises or the patient did not work hard enough.

One solution was not to show the narrative, and, in the following session, there would be an "All or Nothing" exercise that allows the patient to earn all the missing XP to unlock the entire chapter. Otherwise, if they fail to complete that exercise, they lose all the previously accumulated XP and must restart the chapter. This and other ideas were rejected based on the argument that when patients underperform by doing a low number of repetitions or making compensatory movements is because they are tired and/or in pain. Therefore we should not take away their reward.

Later, we decided to organize a focus group with physiotherapists to deepen this topic and clear some other doubts that came to us.

Task 4: Play and listen to the unlocked Chapter.

Description: The lo-fi shows the ”Narrative” screen at the end of a successful session. By clicking on the image, the chapter is played alongside the audio reading its text (see Fig.5.12).



(a) All Chapters overview

(b) Chapter 1

Figure 5.12: Lo-fi: Narrative screen.

Findings: The participants appreciated the simplicity of the design and the idea of having the story in audio, as some patients may have difficulty reading the text. They also noticed the buttons to MUTE the audio and STOP/START the automatic play of the images. The MUTE button should be used if the physiotherapists prefer to read the story themselves or if the patient prefers to read the story in silence. Participants think that this button will probably never be used. The second button stops the automatic play in case the patients want to replay a given image manually, and the participants pointed out that the audio should be MUTED if the automatic play is OFF (the first button is redundant if the second one is OFF).

5.4.2 Discussion of Usability Tests

The low-fidelity prototype was particularly useful for exploring designs for the ”Session Creation” and” Exercise” screens. We gathered helpful feedback regarding the UI, such as showing and hiding information that potentially overwhelms the patients in the Exercise screen. However, we found that we still needed some input from the physiotherapists to implement the narrative and the exercise flow. Namely, questions related to the narrative were ”Should the patient always get rewarded?” and ”Should the story only be displayed at the end of the session?”. Questions related to the exercise flow were ”Should the patient take a rest after N repetitions or after T seconds?”, ”Is it ok to create the session on the go, or do you prefer to plan it beforehand?” and ”How can we improve the existing exercises?”.

5.4.3 Focus Group with the Physiotherapists

After the Usability Tests, we developed most of our application and then had one meeting with three physiotherapists (P1, P2, P3) at the clinic to ask for their feedback on the current version at the time and to clarify some critical questions mentioned in the last subsection. We recorded the audio and later transcribed and analysed it to form our conclusions.

The first key question we discussed was related to ”resting time”. P1 said that patients usually take rests after completing N repetitions unless they are neurodivergent[3] patients, which could take rests based on execution time instead.

In the ”setup phase” (calibrating the green box), P1 suggested that changing the margin of error during the exercise and not only at the start could be relevant. P2 explained that: *”in the 3rd session the person already understood the exercise and the musculoskeletal part much more, and therefore by the 3rd series the person already needs a much smaller margin of error, so it makes sense have the possibility to edit whenever necessary”*.

On the Exercise screen, P1 suggested using graphs to show the Out-of-paths. We explained the feature ”Voice Assistant”, and they found it relevant to have encouragement throughout the session, as long as the expressions were appropriate to the moment: *”[in case of a bad session] Don’t say ”GREAT!” but it should have a positive reinforcement anyway because there was an effort.”* (P2). Sometimes, they leave the patients working on their own: *”Not with neurodivergent patients, but we sometimes leave others alone for a few moments”* (P2), and this feature could be especially useful in those situations.

Then, we discussed another critical question related to the unlocking of the story. P3 started by saying that: *”it’s a good thing to show [the images] throughout the exercise”*; but P2 pointed out that: *”there is the problem of [the images] being able to interrupt the flow of the exercise. There is also the problem of the noise in the room, as the person might not hear well”*. We addressed the situation in which the session was not completed due to lack of time or the patient being tired (e.g. unlocked 3 of a total of 5 images). In this case, participants recognized that there are two options: 1) we give the entire chapter regardless of the performance; 2) we reset the progress, and in the next session, the patient has to start the chapter from the beginning. P3 suggested another solution: *”I think it’s motivating to give a*

[3] A neurodivergent person is defined as one whose neurological development and state are atypical, usually viewed as abnormal or extreme. Some examples are people with autism, ADHD, dyslexia and dyspraxia.

reward like gold medals based on performance rather than depriving the person of the story".

Finally, to improve the *Grid* exercise, the physiotherapists told us that it is useful to have different patterns to complete. They suggested the spiral, S-patterns and a personalized mode that allows the creation of the desired sequence.

5.4.4 Discussion of Focus Group

The findings of the focus group helped us make design decisions. We decided to implement rests between series because our users will not be part of the neurodivergent spectrum, so we did not consider a design that would encompass their unique needs. After learning the importance of adjusting the difficulty during the exercises, we implemented the possibility of calibrating the green box at any time by pressing the "PAUSE" button. To solve the noise problem, the physiotherapists reserved a separate and quiet room to make the User Study, allowing the patients to hear the story during the session more effortlessly.

Instead of using forms of punishment, such as taking away the narrative reward, we decided to give medals based on their performance score (from 0 to 100%). If the patients make an effort, they should be rewarded even if the session objectives were not met. If the patient underperforms, giving the entire chapter is the right option. However, the narrative should always be displayed during the session disregarding their performance. Then, we decided that giving the story piece-by-piece as they complete exercises made more sense than giving the whole chapter only at the end because the narrative aims to encourage patients during the sessions and not after.

Additionally, in line with the *handling failure* principle seen in the Background chapter, we decided to have no time limit to complete the exercises. We added the voice assistant as an incentive to keep working. Lastly, due to lack of time, we implemented the spiral and S pattern for the *Grid* exercise but not the personalized mode.

6

User Study

Contents

6.1 Research Questions

The User Study aimed to test our prototype with real patients with upper limb injuries and their therapists. The results of this study gave us the data required to answer the following research questions:

1. What is the potential of this gamified application in improving the patient experience during their upper-limbs rehabilitation process?

2. What are the barriers and facilitators of this application?

3. Does *ARCADE-N* help physiotherapists in their daily activities?

6.2 Participants

The evaluation was carried out with 8 patients (P1 to P8) and the help of 3 physiotherapists (F1 to F3) from the rehabilitation clinic ”Clínca Dentária Egas Moniz”.

Different patients have different treatments and routines. One example of treatment is to relieve pain by applying *local heat* and *massaging* in the injured area. Then the patient is mobilized to do some *exercises*. The order of these three components can vary, as sometimes the heat and massage may come after the exercise or not come at all. We aim to enhance the treatment by using *ARCADE-N* during the exercise component, which has specific exercises for upper-limb rehabilitation. Therefore, the participants needed to be familiar with upper-limb recovery and shoulder mobility exercises similar to the ones *ARCADE-N* provides.

The eight patients (P1 to P8) had two to three sessions weekly in the clinic. Five were women, and three were men (see Fig. 6.1). During the evaluations, each participant was assisted by their physiotherapist, who was responsible for creating the exercises in *ARCADE-N*. All the participants showed great interest in collaborating with our team by providing as much information and detailed opinions as possible.

ID	Gender	Age	Injury Descriptions
P1	F	55	pain and low mobility on left arm
P2	F	73	neck and right shoulder pain
P3	F	74	weak left shoulder joint range
P4	M	80	poor muscle strength in both shoulders
P5	M	59	functionality loss in both arms, weak range in both shoulder joints
P6	M	?	complete tear of the supraspinatus tissue (shoulder muscle)
P7	F	73	supraspinatus tendinopathy (shoulder pain)
P8	F	?	rotator cuff tendinopathy (shoulder pain)

Table 6.1: Participants in the study. Table indicates the ID, age, gender, and a description of their injury.

6.3 Methodology

The experiment was conducted over three weeks, during the morning time, inside an isolated room at the clinic. We conducted an exploratory study in which each patient used *ARCADE-N* for four sessions. The experiment was comprised of the following stages: 1) Briefing, 2) Procedure, 3) Patient Post-Interview, and 4) Physiotherapists Post-Interview.

6.3.1 Briefing

In their first session, before the experiment began, all participants were given consent forms. These forms outlined the purpose and goals of the study and the information regarding the privacy and safety of their personal data. The participants' names and images are not used to protect their privacy. Participants were also informed that the audio and video from the sessions was being recorded for posterior transcription and analysis. In short, we informed all participants that they participated by their own will and were free to withdraw at any time during the experiment. The consent forms can be consulted in Appendix C.

6.3.2 Procedure

We started every session by greeting the participant and setting up the system. We taught the physiotherapists how to use the system on their first use. To prepare for the experience, we would: (1) connect the Kinect to the PC and PC to the TV via HDMI; (2) run *ARCADE-N*; (3) login using the patient account; (4) turn on the phone camera and audio recorder; (5) the physiotherapist creates the session by adding the desired exercises; (6) start the exercises and adjust the green box.

As mentioned in Chapter 5, there is a calibration phase at the start of the exercises to adjust the difficulty for each patient. To do this, the physiotherapist would ask the patient to perform one or two repetitions to adjust the green box to the desired movement amplitude.

During the exercises, the patients were placed in front of the TV. We were seated behind or on the side, taking notes. Both the patient and the therapists were encouraged to make comments.

After the proposed exercises were completed, the patients would see the story, performance and medal, and greet us before leaving the room. Then, we would log out and wait for the next participant. On average, every session lasted 10 to 15 minutes, depending on the specific planning done by the professionals.

6.3.3 Patient Post-Interview

At the end of four sessions, each patient will have unlocked the five chapters of our story and will be prepared to answer a semi-structured interview (see Appendix A), which is composed by two different sets of questions: *the narrative-engagement questions* and *experience using ARCADE-N*.

The first set of questions aims to measure the patient's engagement with the narrative based on the five dimensions of the Narrative Engagement Scale [8] found in the related work: empathy, cognitive perspective taking, narrative involvement, ease of cognitive access, and narrative realism. The second set of questions is used to understand the barriers and facilitators of the system from the patients' perspective and if it was enjoyable to use.

6.3.4 Physiotherapists Post-Interview

At the end of the study, we interviewed the 3 physiotherapists that used *ARCADE-N*. The questions aimed to clarify the potential of our system in the context of their daily routines and the application's positive and negative aspects (barriers and facilitators). The interview was audio-recorded for further analysis.

6.4 Results

In this section, we present a thematic analysis of the sessions and post-interviews collected during the user study at the clinic.

6.4.1 Thematic Analysis

First, we transcribed the audio/video recordings from each session and read them several times to have a broad understanding of the results as a whole. Then, we did the same for the patient interviews (which lasted, on average, 10-15 minutes) and physiotherapists' interview (which lasted 25 minutes). In the second stage, we use the thematic analysis technique [38]. Through an inductive and deductive approach, we identified and labelled **92 codes** on the transcripts. We then organized the codes into four themes:

1. Exercises: Potentialities and Patient's Adaptation

2. Voice assistant: a motivational feature

3. Narrative: a rewarding element

4. Adoption of the system by the physiotherapists

6.4.2 Theme 1 - Exercises: Potentialities and Patient's Adaptation

This theme focuses on how the patients perceived the *ARCADE-N* exercises and their potentialities. The relevant codes to form this theme are related to patient reactions and adaptation to the exercises and setup, performance progression over multiple sessions, signs of pain, difficulties, use of dumbbells, patient autonomy, dummy, and technical problems found in the system.

We carried out the planned procedure: all sessions started with the patient in front of the TV and Kinect, watching the physiotherapist creating the exercises for them, and then watching the recap of the last chapter before starting the exercises. When editing the exercises in the exercise screen, the physiotherapist asks the patients to raise the respective arm to the maximum amplitude and then adjusts the targets and margin of error (green box). The setup became a routine that all patients accepted well, as we observed that they had no difficulties following the therapist's instructions.

However, for the older participants, the first session had a learning curve related to the execution of the exercises. We observed that all three exercises had a period of familiarization, especially the horizontal/vertical ones, of 20 to 30 repetitions. Most patients started slowly, carefully trying to reach the blinking targets without leaving the green box: *"You see why I go very carefully? I don't want to exit out [of the box]!"* (P7). However, some patients struggled to accurately hit the targets and stay inside the box due to pain or low mobility. In these situations, the patients showed a tendency to make compensatory movements to complete the exercises (e.g. P2 leans forward to hit the bottom target), so we increased the margin of error ("the green box") to prevent such movements. Additionally, we noticed a technical feature that caused a problem in these situations: incomplete exercise repetitions (when the patient fails to stay inside the green box) do not count as a repetition, and the counter did not advance, making it difficult to proceed to further exercises. In the vertical/horizontal exercises, an exercise repetition is programmed as follows: start in target A, reach target B, and then make the way back to target A. If the patient leaves the path during this time, they have to restart from point A. It was annoying to go back to the starting target after failing mid-repetition, resulting in patients doing, for example, 15 movements to complete a series of only five repetitions (this problem occurred frequently to P2, P4, and P7).

As the various sessions progressed, the patients desired to achieve better performances and acted as if the exercises were a challenge, which indicates an increase in their motivation. At the end of each session, we would show the results screen with the performance and medal. During the sessions, participants would mention their performance score and work to improve it. However, none of the participants seemed to notice the medals. During the interviews, we were sure: *"I did not pay attention. You could have said I would win a gold medal, so I tried harder!"* (P7), *"I noticed the performances but not the medals"* (P6), *"Receiving medals does not mean anything to me. The performance is what I paid attention to"* (P5).

In general, we recorded increasing performance scores, as they lowered execution times and did more repetitions in less time. One example of this was P6, who, in his 3rd session, was already practising the exercises with a minimal margin of error. A physiotherapist even commented: *"You look like a rocket!"*. It is important to note that P6 felt shoulder pain and made compensatory movements in the first two sessions. The general improvement was particularly noticeable in the grid exercises, where the patients have a pattern to follow, and once they memorize the sequence, it becomes much faster. To increase the difficulty and the gains, the physiotherapists decided to increase the workload by creating more series and made three patients start using a dumbbell in the working hand. As a result, one of the patients, P5, decided to "cheat" and started using the dumbbell to reach the points on the grid that the hand could not get - the Kinect could not tell the difference between the hand and the dumbbell.

All participants recognized the dummy in the screen as a representation of their body and its benefits: *"It's great that it's there. I looked more at its hand and the target"* (P5), *"It was good to keep your back straight"* (P3). The dummy, rigged based on the input data from Kinect, revealed a second advantage besides the visual feedback, as it disappears from the screen whenever the Kinect detects two or more people. Due to this programming bug, we learnt that our program is not prepared to work when the device captures more than one person, which limits the physiotherapists to providing verbal input to the patients. Another issue that came up during the experiment was also related to the Kinect, specifically during the horizontal exercise. We noticed that the dummy wobbles when the arm/hand is directly in front of the body, resulting in failed repetitions due to the system. This issue happened a lot to P4, but he soon realized that the trick was to do the movement slowly.

When we asked patients about a possible adoption of the system, three of them (P5, P6, P8) stated that they would use the system at home if they had the proper setup and sessions created for them: *"It would be great to have this system at home because I would do it many more times."* (P5). The remaining participants (P1, P2, P3, P4, P7) would not use the system on their own because they like the company of the therapists and their assistance in error prevention: *"Maybe I wouldn't be able to do it alone. The physiotherapists help to correct me, the dummy helps keep the back straight, but so does [the physiotherapist]"* (P3).

6.4.3 Theme 2 - Voice assistant: a motivational feature

This theme focuses on the patients' perception of the voice assistant feature and how it affected their experience using *ARCADE-N*. Relevant codes for this theme are related to the voice assistant, motivation and fun.

During the whole process, the feature that was always present was the voice assistant, and its reviews were predominantly positive. Some of the first impressions were that two patients (P3, P8) reacted to the voice by replying to it as if it was a real person: P3 replied back to "Good morning!" and P8 thanked after hearing the line "Keep going, you can do it!". As participants completed repetitions, the voice would congratulate them and probably make them feel good: *"This is fun, to hear the voice praise and encourage me. I love it! I think it is cute and a spectacular idea. We are old, we need cheer!"* (P7), *"I thought it was great, it gives us encouragement when we complete the exercise and strength to try to do better"* (P6). The voice assistant would also say encouraging expressions for the failed repetitions but with a corrective tone. We saw that these lines were adequate for most patients. P4 and P6 thought the voice lines were funny and laughed with them, and P2 said at the final interview: *"Oh yes, I remember the "Oops, you got out of line" (...) I was not upset but encouraged!"*. The patients appreciated the voice chosen for the assistant: *"You chose the voice well! It is a very smooth voice"* (P7).

An exception was P1, who got a bad first impression of the voice assistant. When P1 started the first exercise, she came out of the green box twice, and both times the voice assistant randomly generated "ohoh, the movement didn't follow the line", making P1 visibly annoyed. When P1 missed a third time, another voice line was generated: "Oops, you got out of the way", making her comment: *"Oh, that is annoying. You have to put on a nicer voice"*. At that moment, we suggested clicking the button to turn off the voice assistant, but F1 decided that the voice should stay ON because it was a good incentive. In the following moments, P1 started to get all repetitions correct, which made the voice assistant generate lots of expressions in a short period: "Wow", "Perfect", "You can do it", and "It is almost there". This moment was frustrating to P1 because, to her, the voices were "irritating", as she explained during the interviews: *"I thought [the voice assistant] was motivating because you get to a point where you want to do more than 50% and reach the 100% [performance]. The voices helped with that but emphasized certain phrases that irritated me"*. The physiotherapist F1 recognized the same issue: *"The voice is pleasant, but sometimes the lines seemed to be making fun of the patient and could be improved in frequency and selection"*. She explained*: "Listening to a "Sensational" on the second repetition is weird. It could be better calibrated"*.

6.4.4 Theme 3 - Narrative: a rewarding element

This theme explores how the narrative impacted patients' experience in terms of it being a rewarding and motivating element of *ARCADE-N*. All codes related to the story and proverbs, such as the provoked emotions, were used to form this theme.

During the sessions, all participants except for P1 paid attention to the story and wanted to know the ending. They showed different postures during the visualization of the narrative. Five participants stood quiet and were visibly focused on *ARCADE-N*: *"I completely isolated myself from the people in the room. I focused on the story completely"* (P7) and *"I personally focused 100% on the story"* (P5). In particular, P2 nodded her head while she attentively heard the story. However, the remaining three participants sometimes looked distracted from *ARCADE-N* and tried to start conversations.

In the first chapter, our participants felt emotions like excitement and nostalgia: *"When [Pedro] got* *on the boat, and his eagerness to find the treasure made me feel excited"* (P7); and *"Reminds me of we were 15 years old and played football on S.Paulo [...] There was the island, lakes and waterfalls"* (P4).

In the second chapter, when Pedro got caught by the indigenous tribe, two patients said that they were worried for him: *"This part was very nice, and in that situation, I was a little distressed"* (P7), *"When the natives caught him, I was apprehensive"* (P6).

In the fourth chapter, Pedro finds the treasure and his grandpa. The mystery involving a family member, particularly a grandfather, kept the participants engaged and triggered their curiosity to guess the possible solutions. During the transition between the last image and the one before, we would playfully ask the participants who they thought was the "strange presence". They all correctly answered "the grandfather", proving that the patients were paying attention since the first chapter (the only chapter that mentions Pedro's grandfather). P7 was deeply engaged with the story and was thrilled after giving the correct answer: *"So what about my prize? I figured out the story!"*, revealing the desire to be rewarded additionally to the story. The participants felt happy to see both characters reunited: *"I was very happy when he found his grandfather. I found it so tender"* (P2). Three participants had the theory that Pedro imagined his grandfather: *"The story is fantastic. I would not change anything because I loved that he found his grandfather. I even thought Pedro was imagining his grandfather!"* (P7).

In the last chapter, Pedro has to choose between the diamonds or staying on the island, eventually choosing to remain on the island. All eight participants expressed their own opinion regarding this moment. The majority would do the same as Pedro: *"I was worried that he would make the wrong decision, looking at all those diamonds. But then he made the right decision."* (P8) and *"I would do the same if my grandmother told me to"* (P2). However, others would act more creatively: *"I would take the diamonds but stay on the island for a few days"* (P5). During the interviews, several patients talked about valuing having health and a place to call home over money and being rich. This plot moment was effective in engaging the patients in the story.

The effect of the narrative was not limited to the sessions. For instance, P2 would think about the story on her way home: *"When I went home [in the last session], I thought that this story is nice to remember the good times!"*. P6 would talk about the story with other people before the sessions: *"I was in the other room commenting with [the physiotherapist] that I think that the treasure and the grandfather are a dream of Pedro"*.

P1, age 55, was the only participant that showed little interest in the story: *"I think it is very childish. I wanted a story about the basics of finance. At least, people would learn something they do not know"*. She asked us to skip the story parts so that she could do just the exercises. P1 suggested integrating the story into the exercises, for example, making gestures such as ironing clothes or rowing to match the storyline. The same suggestion was made by F1, P3 and P6, as it would create a connection between both things: *"I had no trouble following the story, but I was trying to see the connection between the story* *and the exercises. I thought there might be a parallelism between the two things"* (P3).

Patients found the proverbs a fun touch, and in particular, three of them were mentioned several times during the study: "Every jack to his trade" made three participants smile: *"I have heard this since I was a baby!"* (P7); "Appearances can be deceiving"; and "Long time no see" was recognized by P7 as an expression that *"has been around since the time of D. Afonso Henriques [the first king of Portugal]"* meaning that he considered the proverb as very old.

Lastly, some participants made noteworthy observations. P5 and P6 claimed that the story was a great "accessory" to the exercises: *"My attention was on the exercise and the story simultaneously. I think it completes the exercises"* (P6). P8 thought that the story would be interesting to her seven-year-old granddaughter: *"I thought a lot about my granddaughter while I was reading the story. I want to tell her the story and listen to her opinion [...] The story is very simple but has rich content!"*. F1 commented that the illustration style and the story format would appeal to children.

6.4.5 Theme 4 - Adoption of the system by the physiotherapists

The last theme focuses on what the physiotherapists think of *ARCADE-N* as a tool capable of creating motivating and fun sessions for their patients. Additionally, we explored its pros and cons in the working practice of physiotherapists.

All three physiotherapists considered that *ARCADE-N* is a tool that motivates patients into doing the prescribed exercises: *"The use of technology motivates the users. They have a goal to achieve if it looks like a game, so I found it interesting"* (F3). The following example further shows how it could have motivated patients. F2 told us that when P6 did a set of exercises moments before using *ARCADE-N*, he showed signs of pain. Then, he used the system to do the same set of exercises and did it without complaining: *"He was doing the same exercise inside [in the gym] feeling pain and here [using ARCADE] he was so excited that he did not complain!"* (F2). The therapists think that the motivation relies on the enjoyable experience *ARCADE-N* gives the patients: *"The fun part and the enthusiasm with the game's feedback is much more interesting than doing the movement without any objective!"* (F2).

We discussed the possibility of leaving the patients using the system alone. To make this idea work, F1 said that the system had to be assembled in the gym, the common room where the other patients are. There, the therapists could manage their patients closely: *"If [the system] were in a gym, it would be perfectly doable. We would be able to correct and give feedback to the patient"* (F2). However, it would not work if *ARCADE-N* was in a separate room like in the User Study. F3 added that it could be used at home with the proper follow-up: *"I think it even has potential for them to use [ARCADE-N] at home if they had the necessary equipment, and as long as we create the sessions for them"*.

F3 found it useful to adjust the margin of error (green box) and compare the performance scores throughout the sessions. F1 said that the most valuable aspect of the system is the vast number of options: *"The ability to select many parameters for different users, have several options, and be able to work not just one thing [...] I liked the possibility of choosing different exercises, increasing margins of error, etc. and being able to adapt it to the patient"*. F1 reinforced: *"there could be even more [parameters] in my opinion. For me, this is the most important feature, and it should be improved even further"*. F3 added that it would be interesting to have exercises explicitly targeted to the inferior members (legs).

During the interview, F1 enumerated a few suggestions that could be improved during the exercises. Time is one of the factors to consider when planning the session. One suggestion is related to the time that watching the narrative illustrations consumes in the planned session. In this case, therapists had to consider the execution time and the time to view the narrative. The suggestion was to be able to skip the illustrations when time is short, especially the recaps. Another suggestion was to have the option of adding more repetitions/exercises during the session in case they made a mistake during the creation: *"It is normal to make mistakes, so it would be good to interrupt and add four more repetitions"* (F1). Despite that, the therapists liked the option to skip exercises in case of over-planning, and F2 used it once. Additionally, they brought up previously mentioned suggestions, such as calibrating the voice assistant, counting failed repetitions, and not being able to stand in front of the Kinect with their patient.

All therapists could see the benefits and potentialities of *ARCADE-N* as it complements and improves the rehabilitation of their patients by transforming the regular dull exercises into a motivating experience.

6.5 Discussion

The first and main research question we posed was: "What is the potential of this gamified application in improving the patient experience during their upper-limbs rehabilitation process?". When we analyse the effects of the **gamification**, in themes 1 to 3, it becomes clear that they had a relevant role in providing positive experiences.

First, we observed a growing self-improvement and self-challenging feeling that led the patients to achieve better results in each session. During the interviews, they confirmed that looking at their performance scores **(gamification element: "pointification")** at the end of a session was motivating, but not the medals. Using pointification is not always a good practice in rehabilitation environments. Still, in this case, using the performance score functioned as a motivational factor because they did not get frustrated after failing a repetition (unless it was a Kinect problem), but instead, they concentrated more on improving their results. Secondly, as seen in theme 2, patient motivation also came from the voice-assistant **(gamification element: auditory feedback)** that praised and steered them.

The RQ2: "What are the barriers and facilitators of this application?" can be answered by analysing the application's features individually, and the voice assistant had both barriers and facilitators. In theme

2, participants claimed that the voice was kind, motivating, helpful in correcting their movements, and a facilitator in their adaptation to the exercises. The voice assistant was realistic enough that two patients replied to it as if it was a real person, which added to their positive experience. However, we found a barrier when the voice assistant became frustrating for one patient. For users that complete the exercises at a fast pace, this feature may result in a constant ”avalanche of voice lines” as they are programmed to play on a 50% chance at every exercise repetition. A solution would be to have a ”cooldown or timer” between two voice lines. Additionally, this feature could be improved by better adjusting the lines to the specific moments.

Correlating themes 1 and 2, we conclude that the combination of voice-assistant and dummy **(gamification element: visual feedback)** proved to be a great help during the exercises. These two facilitators contributed the most to giving an enjoyable experience to the patients. However, they needed to provide more feedback to make physiotherapist supervision expendable. Only 3 out of 8 patients felt comfortable enough to use *ARCADE-N* without the supervision of a therapist, as the majority of patients think that they could aggravate their injuries during the exercises. Despite that, we observed that most patients kept exercising whenever the therapist left the room for a few moments, proving that *ARCADE-N* can provide partial autonomy to some patients.

To answer the RQ3: ”Does *ARCADE-N* help physiotherapists in their daily activities?” we can start by saying that, according to the last paragraph, the system does not possess the advantage of substituting the professionals and their time in a consistent way. To better answer the question, we must analyse how physiotherapists dealt with ”creating sessions”, as this was the main feature used by them. We observed in theme 1 that creating exercises was easy and intuitive. However, one barrier was not being able to add more exercises after the session started, which would help to mend any human errors during the creation phase. Theme 4 suggests that physiotherapists admit a lot of benefits in using this system. From quick setups to being able to compare results from previous sessions, therapists can improve their daily practices by using *ARCADE-N*. In the same theme, we found that the large variety of options was a huge facilitator, which allowed them to personalise the exercises to different patients. The therapists recognised that *ARCADE-N* was giving motivation to their patients and possibly making them ignore their pain. All things considered, it is reasonable to assume that physiotherapists would have the usage intent to apply *ARCADE-N* in their daily practises.

Lastly, and still regarding RQ1, we constructed theme 3, which talked about the narrative, to explore how it affected the patient experience. We cannot ensure that the narrative **(gamification element: rewarding)** was responsible for motivating patients to complete the proposed exercises because we did not have a control group to compare with (using *ARCADE-N* with and without the narrative). However, considering the results and positive feedback, we can assume that it may have improved the experience of all but one patient. Patients remembered some of the proverbs that made them feel nostalgic for old happy times. They were enthusiastic about the story during and after the sessions.

In summary, patients that used *ARCADE-N* felt motivated and interested in doing more sessions with the system, manifesting that it was an enjoyable experience. Also, the physiotherapists seemed very interested in utilizing the prototype as a rehabilitation option.

7

Conclusion

Contents

7.1 Conclusions

The main goal of this project was to improve the rehabilitation experience of patients with upper-limb injuries by developing a narrative-based gamified application that uses Kinect motion capture technology. Although traditional therapy programs have proven their effectiveness, they can be painful and unappealing for some patients, as they have to perform repetitive and monotonous exercises [5]. To face this issue, we partnered with professional physiotherapists and engaged with patients in a user-centred design process to build a system that could be deployed in the clinic environment to support upper-limb rehabilitation.

The development process started with interviews with patients to gather their preferences regarding different narrative styles. The results indicated by the patients led us to create a narrative composed of an adventure story that features Portuguese proverbs as the names of each chapter. The proverbs represent the moral lesson in each chapter to increase the participants' curiosity about them. Next, we developed a low-fidelity paper prototype and evaluated its usability. The usability tests were essential to design the "session creation" screen and the flow between screens. Then, we conducted a focus group with professional physiotherapists to consolidate our previous findings regarding the features of our application. The main results helped us decide to always present the narrative to the patients disregarding their performance, and to reward their performance score by giving medals. The final result was *ARCADE-N*, a Unity3D application that uses a markerless motion capture camera, KinectV2 for Xbox 360, gamification elements such as feedback mechanisms and a narrative that is progressively unlocked throughout the sessions.

The system was evaluated in a physiotherapy clinic over three weeks. We conducted an exploratory study in which each patient used *ARCADE-N* for four sessions with the assistance of their therapist. At the end of the study, we interviewed all the patients and physiotherapists involved. We analysed the data using a qualitative thematic analysis of the collected observations, opinions, commentaries and interview responses. The thematic analysis resulted in four themes: "1) Exercises: Potentialities and Patient's Adaptation", "2) Voice assistant: a motivational feature", "3) Narrative: a rewarding element", and "4) Adoption of the system by the physiotherapists".

We posed three research questions relative to the whole project: 1) "What is the potential of this gamified application in improving the patient experience during their upper-limbs rehabilitation process?", 2) "What are the barriers and facilitators of this application?" and 3) "Does ARCADE-N help physiotherapists in their daily activities?". The first and most important question relates to the patient's experience using our system. We found that the narrative was engaging for most patients. We observed that one of the patients was prone to ignore pain when doing our exercises due to the effect of the gamification elements. Particularly, the voice assistant achieved excellent feedback from the patients and therapists, even though it needs some adjustments. We can confidently assume that the answer to the research question is that *ARCADE-N* could facilitate motivating and engaging experiences. The second research question aimed to assess the barriers and facilitators of our system. In summary, the main facilitators were the feedback mechanisms and the wide variety of options that helped personalise sessions for different patients. The main barrier was the physiotherapist's inability to stand in front of the Kinect to help the patients from a close distance. This is solvable through programming. Our third and last research question aimed to explore the physiotherapist's adoption of our system. We found that the physiotherapists seemed enthusiastic about the solution as they recognised many benefits of using this system, such as quick setups and comparing results from previous sessions. All things considered, we can assume that therapists could improve their daily practices by using *ARCADE-N*, a statement that they supported.

Ultimately, we learned that *ARCADE-N* could have a positive impact as a rehabilitation tool. The system may not substitute a physiotherapist but has the advantage of supporting the patients to understand their own movements through the dummy feedback, which complements the verbal input of an external observer. The system takes the traditional simple exercises and improves them through the motivational component, which is achieved not only through the different forms of feedback but also through the narrative and score system.

We believe this research contributes to establishing narrative-based gamified applications as a potential rehabilitation technology to boost patients' motivation, optimise intervention processes and improve overall physiotherapy rehabilitation.

7.2 Limitations and Future Work

As future work, we propose fixing the main barriers found during the user study, which include: 1) adjusting the frequency and selection of the voice assistant lines; 2) implementing the possibility of adding new exercises during the session run-time; 3) modifying the program to enable two or more people to stand in front of the Kinect; 4) counting incomplete exercise repetitions. The first barrier could be solved by adding a timer between each voice line and ”hardcoding” the sentences to the proper moments (e.g. only playing the line ”Perfect!” after 10 successful exercise repetitions; not playing the line ”Keep going! You are almost there.” at the last exercise before the rest time). The second barrier could be solved by adding the option to return from the ”exercise” to the ”session creation” screen and adding new exercises. The third barrier is solvable by programming the Kinect to recognize the closest person to be the patient and ignore everyone at a further distance. To solve the last barrier, each exercise repetition needs to be reprogrammed to not reset if the patient leaves the green box.

Physiotherapists provided helpful suggestions for future development and adoption of *ARCADE-N* in physiotherapy. To make the exercises more meaningful, they suggested transforming them into daily activities and trying to match them with the story (e.g. waving goodbye to the indigenous tribe as a pattern to the grid exercise, moving diamonds from a pile to a bag as the horizontal exercise). Moreover, implementing new exercises, specifically for the inferior members (legs and knees), would provide more flexibility to the solution. They also suggested making the tests in a shared room with other patients to see if the physiotherapists can manage multiple patients simultaneously. This will allow understanding if the system is helpful in a more realistic scenario instead of doing it in a separate room.

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A

User-Study Interviews

A.1 Patient Interview

A.1.1 Narrative-Engagement scale questions

- Empathy - At some point during the story did you feel what Pedro could be feeling?
- Cognitive perspective taking - Did the story ever remind you of an episode in your life?
- Loss of time - At some point during the sessions did you lost track of the time?
- Loss of self-awareness - At some point during the sessions did [you felt like] you forgot you were in the physical therapy session?
- Sympathy - At some point during the story were you worried about Pedro?
- Cognitive perspective taking - Did the story ever remind you of an episode in your life?
- Loss of time - At some point during the sessions did you lost track of the time?

- Loss of self-awareness - At some point during the sessions did [you felt like] you forgot you were in the physical therapy session?
- Narrative presence - When you were listening to the story, was your attention focused more on what was happening around you than on the story itself?
- Narrative involvement - Were you interested in knowing how the story ended?
- Distraction - While using the app, did you ever find yourself thinking about other things?
- Ease of cognitive access - Did you have difficulty following the story?
- Narrative realism - Did you notice any moral of the story?

A.1.2 ARCADE experience-related questions

- Did you notice that each of the 5 chapters had associated a popular saying? What did you think of it? Do you remember any sayings?
- Do you think the history motivated you more or less to perform the exercises? Why?
- Did you notice that there were some expressions during the exercises? What do you think?
- Did you notice you received medals? Did you think it was important or was it not relevant to you? Why?
- If you could change the history, what story would you like to tell?
- What did you think of the puppet (”boneco”) on screen?
- Do you think you could do the exercises alone or do you prefer with the presence of your therapist? Why?
- What did you like the most on ARCADE? Why?
- What did you like the least on ARCADE? Why?
- What would you like to improve on ARCADE?

A.2 Physiotherapists Interview

- Do you believe that ARCADE facilitates your work? If yes, in what aspects?
- In what aspects or situations does the system creates barriers or harms the physical therapy session?

- Do you believe that ARCADE can improve patient follow-up and progression? If so, in what way? If not, why?
- What is the potential for ARCADE to be used by patients without supervision? (eg. If the application were part of the daily routine at the clinic, at some point in the rehabilitation would allow the user to be alone in contact with the application?)
- Given the opportunity, would you use ARCADE in your daily routine?
- What did you like most about ARCADE?
- What did you like least about ARCADE?

B

Narrative Preferences Interview Script

Figure B.1: Genres of entertainment.

1. What are your favorite genres of stories? (e.g. action, adventure, mystery, romance, family)

2. What entertaining formats do you usually watch? (e.g. soap operas, series, movies, documentaries, books)

3. How often? (e.g. every day, almost every day, once a week, on weekends)

Figure B.2: Most memorable story.

4. What is the most memorable story?

Figure B.3: Scenarios: countryside, island/ocean, desert/western

5. From the following scenarios: countryside, island, desert; which one is the most attractive to unfold a story?

Figure B.4: One main character or multiple main characters.

6. Do you think you would enjoy more a story following one protagonist (i.e. hero, adventurer looking for a treasure / mystery) or several characters (i.e.family, group of friends)?

C

Consent Form - User Study

O meu nome é Francisco Cecílio e faço parte de uma equipa de investigação associada ao Instituto Superior Técnico (IST-ID), constituída por mim, aluno de Mestrado em Engenharia Informática e de Computadores, pela investigadora Ana Pires e pelo Professor Hugo Nicolau. A minha tese foca-se no desenvolvimento de uma aplicação de fisioterapia cujo objetivo é melhorar a experiência de reabilitação de utentes com lesões nos membros superiores da Clínica Dentária Egas Moniz. Venho assim por este meio solicitar a sua participação neste estudo no âmbito da minha tese. Solicito que faça uma leitura deste documento cuidadosamente e que procure esclarecer quaisquer questões que possa ter. Para quaisquer questões que possa ter e caso solicite a eliminação dos seus dados a qualquer altura, poderá fazê-lo através do email ou telemóvel indicados: email - franciscocecilio@tecnico.ulisboa.pt e telemóvel - 917282233.

C.0.1 Em que consiste o estudo?

Este estudo foca-se na utilização de uma aplicação de fisioterapia. Este estudo será feito ao longo de várias sessões, com previsão de 4 a 8 sessões, entre as datas de 11 a 29 de Julho de 2022. A duração de cada uma das sessões dependerá do planeamento do fisioterapeuta responsável.

C.0.2 O que vai ser pedido ao participante?

A cada participante será pedido que complete da melhor forma possível os exercícios propostos pelos fisioterapeutas. Para completar cada exercício basta seguir as instruções na televisão e usar os membros superiores para atingir os alvos, indicados pela cor verde. Em caso de qualquer dúvida não hesitem em perguntar ao fisioterapeuta ou aos membros da equipa de investigação. No final das 8 sessões, será feita uma entrevista aos participantes de modo a melhor compreender a sua experiência com a utilização da aplicação.

A atividade será realizada tendo em conta todas as precauções necessárias e impostas relativamente às normas de segurança e higiene associadas ao COVID-19. O anonimato dos participantes será sempre garantido pela equipa de investigação.

C.0.3 Riscos e benefícios

Não existe nenhum potencial risco nem benefício para os participantes.

C.0.4 Confidencialidade dos dados

Todos os dados captados relativamente à experiência com a aplicação, tais como os resultados das sessões, serão mantidos em sigilo e apenas serão analisados pela equipa de investigação associada a este projeto. Os dados poderão ser utilizados em contexto científico devidamente anonimizados e serão arquivados em repositórios privados protegidos, os quais apenas poderão ser acedidos pela equipa de investigação associada. Todos os dados serão apagados 5 anos após o término do estudo de acordo com a legislação em vigor (Lei de Proteção de Dados Portuguesa).

Caso necessite de entrar em contacto com o Encarregado de Proteção de Dados da ULisboa, poderá fazê-lo através de comunicação escrita dirigida a: Encarregado de Proteção de Dados (DPO, Data Protection Officer) para rgpd@ulisboa.pt. Tem direito de retificação, remoção, limitação e oposição do tratamento, incluindo o direito de retirar consentimento em qualquer altura, sem prejuízo da licitude do tratamento eventual e previamente consentido. Adicionalmente, tem também o direito de apresentar uma reclamação à Comissão Nacional de Proteção de Dados.

Importa reiterar que a sua participação é voluntária e poderá sempre optar por não responder ou mesmo desistir a qualquer momento sem qualquer penalização ou consequência.

C.0.5 Declaração de consentimento

Eu, ____________________, participante deste estudo, declaro que li a informação acima e que recebi resposta a todas as questões que coloquei. Ao assinar este documento autorizo a minha participação e consequente gravação.

O participante

____

Data: ___________/___________/___________

Investigador condutor do estudo

____

Data: ___________/___________/___________

Investigador responsável:

Hugo Nicolau

Professor Auxiliar do Departamento de Eng. Informática do Instituto Superior Técnico, Universidade de Lisboa

Investigador do ITI/LARSyS

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Este documento será guardado pelo investigador por pelo menos três anos após o final do estudo.