NOVA SCHOOL OF SCIENCE & TECHNOLOGY

DEPARTMENT OF COMPUTER SCIENCE

GONÇALO SIMÃO ROXO

Bachelor in Computer Science and Engineering

STUDYING SERIOUS GAMES FOR THE THERAPY OF CHILDREN WITH DISABILITIES FOLLOWING A CO-DESIGN PROCESS

MASTER IN COMPUTER SCIENCE AND ENGINEERING

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Advisers: Rui Miguel Neves Gonçalves Madeira
Assistant Professor, IPS Setúbal School of Technology
Rui Pedro da Silva Nóbrega
Assistant Professor, NOVA School of Science and Technology

Examination Committee:

Chair: Sérgio Duarte
Assistant Professor, NOVA School of Science and Technology

Rapporteur: Maria Beatriz Carmo
Assistant Professor, Faculty of Sciences of the University of Lisbon

Adviser: Rui Pedro da Silva Nóbrega
Assistant Professor, NOVA School of Science and Technology

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Acknowledgements

A special thank you to my parents for sponsoring this academic journey that took a bit more time than expected and for their support throughout every stage of life leading to this moment.

I would also like to thank my advisers, Professor Rui Nóbrega and Professor Rui Neves Madeira, for their patience and guidance and for pushing me to be better.

A final thank you to NOVA.ID.FCT for funding part of my research through the grant UIDB/04516/2020/TRA/BIL/29, and to the whole team at *Cresce com Amor* for their support and collaboration in this dissertation.

It has been an immense pleasure to have been part of this institution.

Abstract

Therapy can be a long and tedious process where progress is usually not immediately visible. This slow process can discourage younger patients, especially children who do not understand exactly what they are doing. *Serious Games* can help in these situations since they are games designed for a primary purpose other than pure entertainment. These games can be helpful as therapy tools because they promote engagement on the side of the patients, which in turn will make them feel more motivated to follow the therapeutic programme.

In order to develop a game with a meaningful experience for users, beyond the fun of playing it, which helps them in their therapy, experts in the area need to be involved through close collaboration throughout the whole research process. Therefore, we developed a game suite for the therapy of children with disabilities following a co-design process that included *Cresce com Amor* as the partner clinic. *Cresce com Amor* provided therapy expertise to the research team, collaborating in several phases of the process.

Furthermore, by developing a classification system for serious games, based on the International Classification of Functioning, Disability and Health (ICF), which matches each game with body functions and therapy areas, we intend to support the classification of serious games in order to make them more suitable for their ultimate purpose. An in-house developed platform, called PLAY, supports the games by acting as a repository for the data collected and giving the therapists an interface to interact with and adjust the game parameters.

The games use different interaction methods, other than the usual keyboard and mouse, to allow patients to seamlessly perform exercises that simulate the ones done in current traditional therapy sessions. By using off-the-shelf controllers, such as the balance board and dance mat, we can translate real-life movements more naturally into character movements in the virtual space.

Keywords: Co-Design, Serious Games, Therapy, Human–Computer Interaction, Natural User Interfaces, Design Thinking, Off-the-shelf Controllers

Resumo

A terapia pode ser um processo longo e tedioso onde o progresso geralmente não é imediatamente visível. Este processo lento pode desencorajar os pacientes mais jovens, especialmente as crianças que não entendem exatamente o que estão a fazer. *Jogos Sérios* podem ajudar nestas situações, uma vez que são jogos concebidos com um propósito principal que não seja apenas entretenimento. Estes jogos podem ser úteis como ferramentas terapêuticas porque promovem o envolvimento do lado dos pacientes, o que, por sua vez, fará com que se sintam mais motivados para seguir o programa terapêutico.

Para desenvolver um jogo com uma experiência significativa para os utilizadores, para além da diversão de jogar, que os ajude na sua terapia, os especialistas na área precisam de estar envolvidos através de uma estreita colaboração ao longo de todo o processo de investigação. Assim, desenvolvemos uma suite de jogos para a terapia de crianças com incapacidades seguindo um processo de co-criação que incluiu a *Cresce com Amor* como clínica parceira. A *Cresce com Amor* adicionou conhecimentos terapêuticos à equipa de investigação, colaborando em várias fases do processo.

Além disso, ao desenvolver um sistema de classificação para jogos sérios, baseado na Classificação Internacional de Funcionalidade, Incapacidade e Saúde (CIF), que combina cada jogo com funções corporais e áreas de terapia, pretendemos apoiar a classificação de jogos sérios, a fim de torná-los mais adequados ao seu propósito final. Uma plataforma desenvolvida internamente, chamada PLAY, suporta os jogos, agindo como um repositório para os dados coletados e dando aos terapeutas uma interface para interagir e ajustar os parâmetros do jogo.

Os jogos utilizam diferentes métodos de interação, além do habitual teclado e rato, para permitir que os pacientes realizem exercícios que simulam os que são feitos nas sessões de terapia tradicional atuais. Usando controladores comerciais, "prontos para uso", como a *balance board* e o *dance mat*, podemos traduzir de forma mais natural movimentos da vida real em movimentos de personagens no espaço virtual.

Palavras-chave: Co-Design, Jogos Sérios, Terapia, Interação Pessoa-Máquina, Interfaces de Interação Natural, Design Thinking, Controladores Off-the-shelf

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Acronyms

ASD	Autistic Spectrum Disorders 22, 23
AT	Assistive Technology 10, 11
CBT	Cognitive Behavioural Therapy 22, 23
CIF	Classificação Internacional de Funcionalidade, Incapacidade e Saúde vi
CNS	Central Nervous System 2
CoP	Center of Pressure 17
CP	Cerebral Palsy 1, 2, 6, 28
GDC	Game Device Controller 17
GMFCS	Gross Motor Function Classification System 28, 57
GS	Game Server 17
ICF	International Classification of Functioning, Disability and Health v, 46, 71
MD	Manhattan Distance 60, 61
WBB	Wii Balance Board 15, 16, 17, 29, 30, 32, 45, 46, 47, 48, 67, 68
WHO	World Health Organization 3, 9, 10

1

Introduction

The idea of serious games has existed since the dawn of video games, or even before. Its current definition has been used, to some extent, since 1970 when Clark Abt defined them, in his book "Serious Games" [1], as games that "have an explicit and carefully thought-out educational purpose and are not intended to be played primarily for amusement". Although nothing says they should not be entertaining [21], these types of games have been used in a variety of fields ranging from regular education to physiotherapy.

Physiotherapy for the rehabilitation of limb movement is a long process that often takes several weeks, or months, of continuous and repetitive exercises. For that reason, therapists are always in need of tools that can help them mask this repetitiveness. It is crucial to keep the patients motivated and invested in their rehabilitation when the results are not easily visible, especially in children with disabilities.

The advancement and increased accessibility of game development tools have made serious game development a more practical and engaging option for therapy. This approach adds an element of fun and enjoyment to the rehabilitation process while still retaining its serious objective of patient recovery.

Developing tools, namely games, which can be used in a therapeutic setting, must be done in a careful way to ensure they integrate the patient's therapy goals in a meaningful way. Exergames are the result of aligning physical activity with technology-based games, letting users manipulate the virtual environment by using body movements, allowing them to be more active. By using these tools, users can practice virtual sports, fitness, and/or other ludic and interactive physical activities, using movements that are similar to real-life tasks. Researchers believe exergames can help children and teenagers reach recommended levels of physical activity, which is a good way for them to acquire new motor skills and abilities [18].

1.1 Motivation

Cerebral Palsy (CP) is a group of disorders that affect a person's ability to move and maintain balance and posture because they lack control of their muscles. Caused by abnormal brain development or damage to the developing brain, CP is the most common motor disability in children. A cure for the majority of disorders linked to CP is currently unavailable, but physical therapy has been central in managing the symptoms of this disease. Children affected must be given support as soon as possible because the greatest potentiality for modification exists in the earliest stages of development of the Central Nervous System (CNS) [48, 17].

Patients require a long-term commitment to exercise in order to achieve and maintain an adequate level of physical condition [17]. Therefore, therapists need various and adaptable tools to keep their patients engaged. Serious games can have adjustable parameters to adapt their difficulty to the patient's needs, providing the versatility needed while also introducing the fun factor to keep them interested in continuing therapy. Our research also has several contact points with the work of André Antunes, who is working on the development of the PLAY platform. PLAY is intended to streamline the development of serious games and their integration in a complete therapy environment [4], being a support for the design of digital twins in this area.

We had a first-person view of the needs of patients with disabilities by visiting the clinic Cresce, whose therapists collaborated with us under a participatory design approach to increase the usefulness of this research project in a real-world setting. Cresce[1] focuses since its beginning on gathering the best tools and resources to be able to help families caring for children with special needs. They are one of the major specialized Therapy Centers at a national level in the pediatric intervention area, working with many families per year. At the clinic, they have experience working with several kinds of therapies, such as physiotherapy, speech therapy, occupational therapy, and sensory integration, among others. They have been contributing to the research of the PLAY platform since day one.

1.2 Objectives

This dissertation aspires to provide further evidence for the claims that serious games can have a valuable role in the healthcare sector, more specifically in the pediatric therapy of motor and cognitive disabilities, and how a collaboration between system developers and domain experts can be designed to provide benefits when creating tools for use in therapy sessions.

As such, the main objectives of this dissertation are the following:

- Definition of a conceptual framework for serious game development under a co-design approach.
- Creation of a classification system of serious games focused on the therapy of children with disabilities, mainly with CP.

[1] Cresce's website: http://www.cresce.pt/

- Use of current off-the-shelf controllers and sensors to help craft a more meaningful experience.
- Implementation of a suite of serious games.
- Validation of the work in a real clinical environment.

As mentioned in section 1.1, the disabilities focused on by this work require a long-term commitment to therapy, which may benefit from autonomous work at home. Therefore, as an additional aside objective, the games developed in the context of this thesis will continue to help validate the Ph.D. work of André Antunes behind the PLAY platform [4], which allows patients to play the games outside of the therapy clinic, and the way the platform interacts with third-party applications.

1.3 Implemented Solution

In this dissertation, we show a conceptual framework on how to co-design serious games with therapists to support the therapy of children with disabilities. As a case study, we implemented and tested a game suite (Figure 1.1) using such a framework. The games developed include balance and mobility exercises to help patients strengthen their muscles and improve their posture, but they also have symbol and position recognition elements to stimulate cognitive abilities. The games had to be funny and engaging, but the health factors remained the main focus. We also classify each of the developed games using a classification system created based on the Classification of Functioning, Disability and Health (ICF) [39] from the World Health Organization (WHO).

The games incorporate a point system that serves as a motivational tool, encouraging players to improve with each subsequent play. Additionally, the system tracks their performance upon successfully completing an exercise. The integration with the PLAY platform will allow therapists to adjust the difficulty and other game parameters according to the patient's needs. The data collected during gameplay is sent to the platform, and there, it will be easily accessible to the therapists for analysis.

1.4 Contributions

The main contributions of this thesis are:

- The systematic research process to co-design serious games as therapy tools, resulting in a conceptual framework.
- Proposal of a classification system for serious games focused on therapy of children with disabilities.
- A suite of serious games created to be used by therapists in their sessions with children in order to complement the traditional programme.

Figure 1.1: Game suite main menu where players choose which game to play.

- Human Factors Studies intended to assess the interaction of the end users with the implemented games suite to ensure the safety and effectiveness of that interaction and to improve human-device compatibility, including the user interface, instructions, and training programs to avoid use error, within a real environment of use and by the variety of potential users, the children and therapists.

- Publication of the paper "Dance Mat Fun - A Participatory Design of Exergames for Children with Disabilities" in Springer's Pervasive Computing Technologies for Healthcare [47], which was presented at the 16th EAI International Conference of Pervasive Health.

- Submission of an extended version of the previous paper, focused on the entire research work, to MDPI Sensors journal, Special Issue "Smart Sensing Technologies for Human-Centered Healthcare: Research and Applications".

By testing the proposed solution in a controlled environment of a clinic with healthcare professionals used to dealing with children's disabilities, we closed the design thinking-based process and brought the work closer to the patients that might benefit from it. This allowed us to draw some conclusions on what might work better when developing serious games for this particular audience.

1.5 Document Structure

This document is structured as follows:

- Chapter 1 - This chapter describes the motivation behind the development of this dissertation, its goals, and the contributions that were achieved by it. It also presents the structure of the document to guide the reader.

- Chapter 2 - This chapter shows some of the already existing games in the therapy field and some design principles for serious games. It presents an analysis of the methods they use to integrate health benefits in a serious game.
- Chapter 3 - Displays the design thinking-based methodology used to create the game suite.
- Chapter 4 - This chapter details the implementation and the games created as a solution for the problem presented throughout this document.
- Chapter 5 - Presents the evaluation of our solution through human factors studies.
- Chapter 6 - Reflects on the work done in this dissertation and proposes future work that can be done in the near future.

2

State of the Art

Studies have shown that even when traditional therapy programs attempt to stimulate the person with various rehabilitation exercises, people still feel they are often monotonous due to their repetitive nature [10]. The following chapter showcases the technologies that are commonly used when developing interesting games centered around health and the overall state of the art regarding the therapy of children with disabilities. The chapter starts by introducing some of the conventional therapy approaches and the concept of gamification. Then moves on to present some of the serious games already developed in the healthcare sector.

2.1 Therapy and Games

2.1.1 Conventional Therapy

When it comes to disabilities like Cerebral Palsy (CP), there are two issues to take into account: the treatment of the injured areas of the brain and the management of the disabilities that stem from the brain injury. These include muscle spasticity, muscle weakness, and uncontrolled muscle movements that cause impaired mobility and other obstacles to independence in daily life [25].

The interventions to tackle the first issue are much more complex and often require surgical procedures. The focus of our work will mainly be on the second issue, to alleviate the symptoms caused by the disabilities and help patients regain some control of their body movement, meaning it can be applied not only to patients with cerebral palsy but also to any other disability that requires physical therapy in the treatment regimens.

Research shows that programmed repetition as used in physical, occupational, and speech therapy can be a means to teach the brain to improve motor performance skills and create new brain pathways, and, to some extent, bypass damaged areas. In trials comparing different therapies, factors such as patient motivation and the intensity and duration of the treatment have shown to be more important than the details of the therapies themselves [25]. Traditional physiotherapy in children with CP has been shown to improve muscle strength, local muscular endurance, and overall joint range of motion.

Figure 2.1: Traditional reaching exercise. By Stacy Grieve, Cerebral Palsy News Today July 5, 2017

Different therapy programs have been used for different results. A program of progressive resistive exercises is used to improve muscle strength. A program that uses low resistance and more repetitions will enhance local muscle endurance. To maintain and improve joint mobility, patients need to repeat several passive range of motion exercises. To prevent joint contracture, patients also need to stretch.

Traditional occupational therapy has also been used to improve fine motor skills and the use of the upper limbs to increase the ability to perform daily living tasks. Occupational therapy also empowers children with the knowledge and skills they need for self-care and information processing [20].

Another important area on which we want the developed system to affect is the postural control and balance of the body. Having postural control is crucial if a patient is to have autonomous motor behavior. Physiotherapy in this area can be divided into three different categories of exercises [29]:

- Postural Orientation Exercises - these exercises will help patients control their body alignment concerning gravity and orientate themselves spatially.
- Neck, Back, and Upper-limb Musculature Exercises: these are the primal muscles involved in supporting the body. An increase in the strength of these muscles will allow better maintenance of body alignment, independent walking, or climbing stairs.
- Coordination Exercises: exercises to improve the relationship between the visual environment and the patient, and coordination between the eyes and limb movement.

Traditional therapy must be repeated for long periods, leading to patients becoming demotivated and losing focus on the therapy program [10]. So it is important to keep researching ways of keeping the patients motivated and engaged in the therapy because motivated patients spend more time and effort into promoting their recovery [22].

2.1.2 Gamification of Therapy

Gamification is the integration of game design elements and game thinking in activities that are not games. The premise for gamification was that the use of the game elements in a non-game context could bring about improvements in people's motivation to learn in formal and informal conditions and increase the engagement levels of users when interacting with a system.

It is important to point out that gamification is not the process of turning activities into games in itself, but more the use of game metaphors, game elements, and ideas in a context different from that of the games to increase motivation and commitment, and to influence user behavior. These game elements include things such as [32]:

- Challenges – tasks that users perform to progress towards defined objectives.
- Points – that are accumulated for completing tasks.
- Levels – that users pass depending on set conditions.
- Badges – given to users as rewards for certain actions or achievements.
- Ranking Systems – to classify users according to their achievements.

These principles applied to conventional therapy practices can help alleviate adherence problems by making them more interactive to patients. Especially by going one step deeper with gamification and creating serious videogames focused on therapy.

Adherence — defined as "the extent to which a person's behavior...corresponds with agreed recommendations from a healthcare provider" — remains one of the biggest challenges in the rehabilitation field. From a patient's perspective, physiotherapy can be frustrating and tedious while also imposing monetary and time constraints.

By combining video games with physiotherapy, therapy sessions can be more motivating and accessible without a significant increase in healthcare costs. Al-Nasri et al. [38] describe two main issues with physical therapy adherence: (1) the barriers patients face that lead to non-adherence; (2) the lack of adoption of new technologies that could encourage intrinsic motivation for adherence in patients.

In regards to the first issue, there are many variables to consider, from low levels of physical activity before physiotherapy to depression and poor social support. Patients need to feel like they understand the tasks in their treatment regimens. They can not be overcomplicated and must be stimulating because, ideally, the patient has to feel like they have some control over their treatment based on the recommendations made by the clinician.

As for issue number two, the lack of adoption of new technologies in the field of physical therapy is more apparent than in other health sectors. The nature of rehabilitation requires hands-on applications and clinicians need to be able to control parameters such as speed, duration, and difficulty. A multi-disciplinary approach to developing serious games is paramount. Computer scientists and engineers should always have the input of specialists in the field if the game being developed is to have a positive impact on the overall treatment plan.

Video games designed specifically for rehabilitation can battle these two issues without adding significant costs to both the healthcare system and patients.

2.2 Children with Special Needs

Developmental disabilities are a group of lifelong conditions caused by an impairment in the physical, learning, speech, or behavior areas. Children diagnosed with such disabilities typically require services to address behavioral and developmental challenges [55]. Therefore, there is always a need for continuous research in new tools to help those affected by limiting health conditions.

A global study [14] with data from 195 countries concluded that the global burden of developmental disabilities in children below the age of 5 has not significantly improved since 1990, particularly regarding cerebral palsy. These are worrying results that further indicate the need for research in this area and suggest that there has been a lack of investment from most countries in bettering the conditions of development for children with disabilities. In the following sections, we look deeper into these developmental disabilities.

2.2.1 Congenital Disorders

Congenital refers to the existence of something at or before birth. According to the World Health Organization (WHO), congenital disorders can be defined as structural or functional anomalies that occur during the child's development in the uterus and can be identified prenatally, at birth, or sometimes at a later stage of infancy [15].

Pregnancy, Birth and Baby is a national Australian Government service created to provide support and information for expecting parents and parents of children, from birth to 5 years of age. They list common congenital anomalies [54] as being, among others:

- Intellectual Disability — where a child's cognitive capacity is reduced, making it harder to learn and develop new skills.

- Down Syndrome — a common genetic condition, caused by having an extra copy of chromosome 21, that leads to intellectual disability.
- Cerebral Palsy — a physical disability that makes it hard for a child to control their body movement.
- Fragile X Syndrome — an inherited condition that causes intellectual disability and learning and behavior problems.

According to the WHO, despite approximately 50% of all congenital anomalies not being linked to any specific cause, there are some known causes and risk factors.

Genetic factors have an important role in many congenital anomalies. They can either appear by the inheritance of bad genes or from sudden changes in the genes known as mutations. When couples are related by blood the risk of having a child with some intellectual or other disability is even higher because of the higher chances of recessive genes being paired [6].

Socioeconomic and demographic factors also seem to have a role in the appearance of child disabilities. There is a higher occurrence of cases in low- and middle-income countries, this is usually attributed to the lack of access to sufficient, nutritious foods by pregnant women. Families living in worse conditions are also more vulnerable to the spread of infections and diseases, which may induce or increase the incidence of abnormal prenatal development [30]. Maternal exposure to certain chemicals, medication, tobacco, alcohol, and radiation during pregnancy may also harm fetus development. As such, women living near waste sites, smelters and mines have that added risk on the safety of the child development [15].

2.2.2 Disorders Developed After Birth

Some disorders can only be identified after birth once the child is more developed. These include hearing problems, heart and blood conditions, or metabolism and hormone disorders. It is important to try to detect any health complications as soon as possible to perform the necessary procedures to lessen the effects of the conditions [54]. Complex mental anomalies like autism can only be diagnosed after birth, but nowadays it is possible to diagnose it in children as young as 18 months of age. Children affected by disorders in the autism spectrum will usually have less social communication/interaction abilities and restrictive, repetitive patterns of behavior [28].

At later stages of development, disabilities can also be caused by head trauma that injures the brain or the lack of oxygen, caused by a stroke or almost drowning, for example.

As we have seen, multiple disabilities can affect children from a young age, both cognitive or motor/physical, and with various degrees of severity. People that suffer from health conditions, or simply old age, usually need Assistive Technology (AT) to carry on with their daily living. AT is any product or device designed to prevent, compensate, relieve, or neutralize impairment, disability, or handicap and improve the individual's autonomy and quality of life. In children, AT is a good way of improving functions and encourage learning [19, 36].

One of such AT products are serious games, and in the next section (2.3) their development process is described.

2.3 Serious Game Development

Burke et al. [10] consider two main principles of game design to be very important in the development of serious games: meaningful play and challenge. In this section those principles are detailed along with some of the desirable features and a recommended software process for serious game development.

2.3.1 Core Principles

Meaningful play stems from the relationship between players' actions and the system's outcome. Meaning that the actions players perform should not be arbitrary, and their impact on the game should be perceived by them. To give players the awareness they need of their choices, the actions must have feedback when performed.

Feedback is how the game responds to changes or choices made by the player, and it is the pillar of creating and maintaining meaningful play. Feedback can be visual, aural, and haptic. It helps players have a feeling of progression by indicating right and wrong decisions. There are many different ways to deliver feedback, and they vary depending on the game type.

In rehabilitation games, the feedback should take into account the difficulties patients playing the game might have. Therefore, failure should be handled more conservatively with an initial focus on increasing engagement and then rewarding players with success. Patients must not feel like they are being held back by their disabilities, or else they would not want to continue playing the game and their rehabilitation will suffer from it.

Challenge is closely related to the difficulty of the game objectives. Players expect a low challenge level when starting a new game, but as they continue getting more experience with the game, the challenge level must increase to keep players interested. If the challenge level is too low, players will get bored of the game and will not get much enjoyment out of it, but a steep challenge level increase can get frustrating and cause players to give up. Thus, the challenge level has to be monitored and gradually increased.

Games usually use soft progression barriers where players are only able to progress once they have mastered some game mechanic, each level builds upon the previous one requiring players to hone or acquire a new skill to progress.

Games for rehabilitation have to be prepared to adjust their parameters according to the patients' difficulties. After an evaluation from the therapist, the game speed could be adjusted to set its pace. The position of objects could also be adjusted to account for different ranges of motion, making the game's difficulty more appropriate for a specific patient. It is always better to have a conservative starting difficulty when the user is being introduced to the system to minimize the risks of failure. Once the user is engaged they will, eventually, welcome the challenge increase.

2.3.2 Desirable Features

With the previous core principles in mind, this subsection enumerates desirable features for motor rehabilitation as gathered by Alcover et al. in [3]:

1. Selecting an existing interaction mechanism – A serious game should be a new way of making the already tried and validated therapies more engaging. The validation of a serious game that tries to develop a new rehabilitation therapy would be very challenging.

2. Defining an interaction model adapted to patient capabilities – The part of the body where the therapy will be applied must be considered along with the patients' physical limitations. The correct controller for the system must also have these factors in consideration.

3. Incremental development – An incremental development process that supports communication should be considered because the technical engineering language is completely different from the therapy specialist language. This development method also accommodates the validation of the system very well.

4. Specialist validation – To be able to claim that a serious game has the desired effect, it must always be validated by a specialist at every stage of development.

5. Clinical evaluation – Clinical validation of the serious game will allow to determine its actual effects on a patient's health and compare the results with standard therapy methods. In the end, this is what determines if the game is appropriate for motor rehabilitation.

2.4 Collaborative Design Processes

Literature suggests that serious game development should have a more agile approach like Scrum, with variable length sprints [5, 3]. This design process offers flexibility that can be beneficial for projects that require close collaboration with stakeholders over continuous iterations of the evolving software. Scrum focuses on productivity through communication and planning and gives engineers the freedom to find more appropriate solutions. The development in small incremental stages also makes a project able to better deal with fundamental shifts in production, and it is also a great match for smaller teams [50]. Serious game development can benefit from this method because they should always be multidisciplinary projects, where experts in the area the game will be used to guide the system developers to the requirements needed to achieve the serious goals of the game [26].

2.4.1 What is Co-Design?

Co-design is the process of involving end-users in the design approach of a product, with the belief that the result of the said design approach will be more meaningful and innovative to the consumers. Having collaborative work between designers, service providers, and service users makes co-design person-centered by having everyone involved share their perspectives. Co-design has the goal of creating practical, real-world solutions to issues facing individuals, families, and communities. The use of prototypes and a variety of other media can make the ideas more visible and tangible to all participants, making it an inclusive process that draws on the many perspectives of people, experts, disciplines and sectors [11].

Contrary to other processes that use the prefix "co-", such as co-creation or co-production, co-design should involve a deeper relationship between everyone involved in the design. Participants should collaborate in the exploration and making of the solutions through active participation during the entire duration of the process instead of only being allowed to say what they want from the product being developed [52].

2.4.2 Co-Design Frameworks

Throughout the literature, a core concept of co-design that seems invaluable is understanding users' needs and behaviors before starting the development and testing of concepts though an iterative process [52]. In serious games for health, whether each stage of that iterative process is named or just explained, most seem to follow a similar structure [53, 46, 49]:

1. Discover - Uncover the scientific foundations. Define your target audience and study their needs. Through interviews and workshops with users you will learn their technical needs and empathize with them.

2. Define - Lay the design foundations. Define which problems your games try to solve. Are there similar games you can build upon, or will you build new ones?

3. Plan out the game mechanics and design requirements. In what context will games be played? What's the user profile?

4. Develop - Generate and prototype as many ideas as possible. Plan game content, visuals and themes.

5. Validation - Deliver your games to experts for validation through structured usability testing, ideally in a clinical environment.

6. Implementation - After the results of the validation and the refinement of games with the collected feedback, they can be released to wider audiences and the study findings disseminated in the research community.

2.5 Technology Overview

The explored literature usually indicates Unity as the software used to develop the games on which the studies are based. Unity is a game development engine that allows the creation of both 2D and 3D games and their deployment to multiple platforms ranging from computers to mobile devices.

The following subsections give a brief description of the controllers used in games of interest to this dissertation.

2.5.1 Vision Based Controllers

2.5.1.1 Microsoft's Kinect

Kinect uses an infrared depth-sensing camera to capture full-body movement in a 3D space allowing users to control the game using their bodies without any additional controllers. It also contains a color camera and a four-microphone array. The camera can be easily connected to a computer through a USB cable. On its first version (Figure 2.2a), released in 2010, Kinect's cameras had a resolution of 640x480 at 30FPS and were capable of tracking 20 individual joints of two users simultaneously. In 2013 an updated version was released for Xbox One (Figure 2.2b), with improved fidelity and higher resolution cameras and the ability to track up to six skeletons with 25 joints.

(a) Xbox 360 Kinect

(b) Xbox One Kinect

Figure 2.2: The available Kinect systems

Kinect's impact has extended far beyond the gaming industry. With its wide availability and low cost, this system has been used for varying tasks, from helping children with autism to assist doctors in operating rooms [56].

2.5.1.2 Leap Motion

The Leap Motion Controller consists of two cameras and three infrared LEDs that create an interactive area in the shape of an inverted pyramid limited to 60cm with a 120º angle on each side of the device (Figure 2.4) [12]. Inside this area, the Leap Motion Controller is capable of tracking the hand motion with great precision (Figure 2.3 [1]).

Therapists have found that a system using The Leap Motion Controller was useful in monitoring the patient's progress and help in the rehabilitation [2].

Figure 2.3: Leap Motion capturing and displaying hand skeleton.

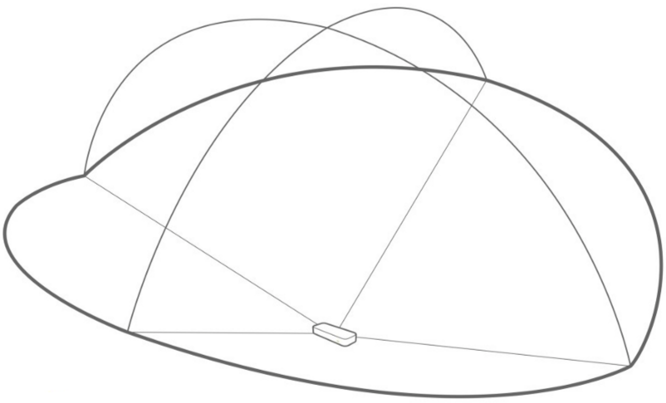


Figure 2.4: Leap Motion's interaction area [12].

2.5.2 Balance Based Controllers

2.5.2.1 Wii Balance Board

The Wii Balance Board (WBB) (Figure 2.5) contains four pressure sensors located in each corner of the board to assess force distribution and the resultant movements of the center of pressure [7]. Being inexpensive, portable, and readily available, the balance board

[1] https://www.ultraleap.com/tracking/#how-it-works

provides clinicians with a way to objectively assess biomechanical measures of postural stability. It can be connected to a computer through Bluetooth.

Studies suggest that the WBB is a valid tool for the quantification of postural stability and balance improvement [27, 23].

(a) Top View (b) Bottom View

Figure 2.5: Wii Balance Board

2.5.2.2 Dance Mat

The Dance Mat is a controller that has not been widely used in the therapy sector yet. Still, a study has shown, the Dance Mat can be a useful device in rehabilitation games. The preliminary results of this study showed balance improvements in patients with cerebral palsy after courses of stepping games. It consists of a flat mat, divided into a 3x3 matrix of square panels that are the buttons the user has to step on [34].

It can be connected to a computer using a USB cable.

Figure 2.6: A Dance Mat for Playstation.

2.6 Serious Games in Therapy

In this section we will present some of the existing projects that are considered relevant to the goals of this dissertation in greater detail. After that, a brief classification and a summary of those systems is presented.

2.6.1 The Home Rehabilitation Gaming System

The Home Rehabilitation Gaming System [35] was developed to provide game training at home under the supervision of a therapist and consists of two main parts: a) a patient-side application installed on a home computer - the Game Device Controller (GDC), and b) the Game Server (GS) on the Internet.

The GDC can interact with different input gaming devices through USB or Bluetooth and collect data from gameplay.

The GS is responsible for managing different types of users, game guides, usage statistics, and a messaging system between patients and therapists.

The games used balance training exercises that required patients to stand on the WBB and shift their body weight to the sides and forward and backward. These movements were also done in a sitting position, kneeling, or with just one foot on the board.

The system also includes a game called "Stabilometry."Stabilometry is used as a diagnostic tool to evaluate balance disorders. The child stands still on the balance board and the mean velocity of the Center of Pressure (CoP) displacement and the area of CoP displacement are calculated. These two parameters indicate how well the child can balance itself. Higher velocities and larger areas indicate poor balance.

The Home Rehabilitation Gaming System was tested on six patients, who went through daily training sessions for two weeks. At the end of the study, the results suggested that home gaming training is beneficial for improving balance function and all the parents and children were satisfied and interested in continuing using the game.

2.6.2 Gesture-based Games for Spine Physical Therapy

In their paper Pereira et al. [41], the authors developed a game using Kinect to track spine movement using 3 of the 25 joints that Kinect can track. To acquire the angles realized during spine movements, a C# software was developed that used the Kinect for Windows SDK (Software Development Kit) 2.0. This software was capable of gathering the position and orientation of the tracked joints.

The position is given in XYZ coordinates related to the Kinects coordinate system, where it sits at its center. The orientation is delivered as quaternions (W, X, Y, and Z) that provide a way to operate over rotations.

The angles of interest from the joints spatial position were obtained by projecting the joints in the YZ (sagittal) and XY (frontal) planes. After that, two lines are traced: one horizontally at the spine mid-point and another perpendicular to the spine line, through

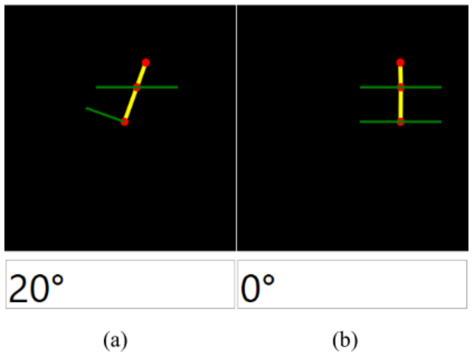


Figure 2.7: Developed software output to determination of the spine angles by the Kinect. (a) Angle of lateral inflection to the right of 20°; (b) 0° flexion-extension angle [41].

the spine base. The angle between these two lines represents the angle of the spine movement. Figure 2.7 shows the graphical representation of this method, obtained with the developed software.

With the previously obtained quaternions from the spatial orientation, the angles are obtained by converting them to Euler angles. Euler angles are the rotations of an entity concerning the X, Y, and Z axes and represent the orientation in a three-dimensional space.

The quaternion values of each joint were converted to rotation around X (R_x) and Z (R_z), representing the flexion-extension and the lateral inflection angles, respectively. This was done using (2.1) and (2.2), which return the angles in radians.

$$R_x = arctan((2(WX + YZ))/(1 - 2(X^2 + Y^2))) \tag{2.1}$$

$$R_z = arctan((2(WZ + XY))/(1 - 2(Y^2 + Z^2))) \tag{2.2}$$

To validate the measurements, the values were compared to a Miotec digital goniometer that was used at the same time they were testing the measurements with Kinect. The study states that there were no statistically significant differences between the methods of acquisition of flexion-extension and lateral inflection movements, meaning Kinect can be a reliable tool for measuring body movements.

After the validation, a game was developed where patients had to use spine movements to direct random dropping balls to the correct containers by controlling the middle platform. As seen in Figure 2.8.

2.6.3 Leapball and CatchAPet

Tarakci et al. [51] describe the development of two games that use the Leap Motion Controller, intending to improve patients' joint range of motion, muscle strength, coordination, and fine motor functions of the hand and wrist.

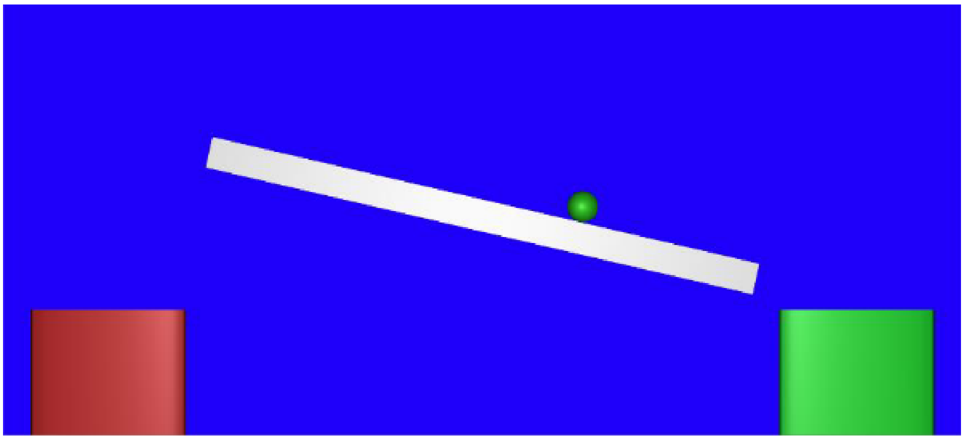


Figure 2.8: Spine movement controls the middle platform to direct the ball to correct color container.

"Leapball"was designed to focus on grasping and individuating motor skills of hand; the improvement of the dexterity and coordination of the digits; the improvement of the ability to flex and extend the hand, the increase in the joint range of motion of the wrist and digits; the improvement of the movement speed, muscle strength, and motor control. In this game, players need to grasp a virtual ball and throw it to a bucket of the same color. Figure 2.9 shows an image of the game [2].

Figure 2.9: Leapball game [51].

In "CatchAPet," the goal is for players to touch rabbits that come out of holes with repetitive flexion/extension movements of the wrist. The faster the player touches the rabbits, the more points they get. Figure 2.10 shows an image of the game [3].

The study of the article involved 92 participants over eight weeks of rehabilitation and showed that Leap Motion Controller-based training is feasible as an alternative training method for children and adolescents with physical disabilities. Video game-based training with Leap Motion Controller was deemed to be more enjoyable than conventional

[2] https://www.youtube.com/watch?v=3PMm57f5y40
[3] https://www.youtube.com/watch?v=sGAa3B7ZAME

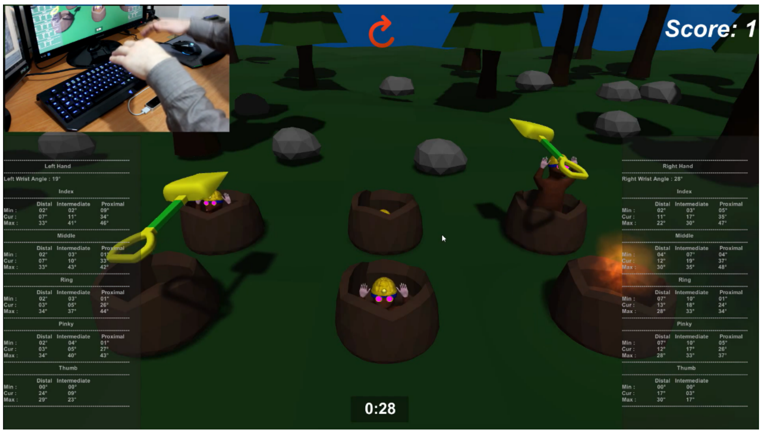


Figure 2.10: CatchAPet game [51].

therapy. The use of interactive games provides task-oriented practice with visual and auditory feedback, which further motivates and engages players to increase the rehabilitation intensity.

2.6.4 Thorough Approach to Upper Limb Rehabilitation

This study [16] was directed at the rehabilitation of the upper limbs, more specifically for patients affected by hemiplegia or hemiparesis. The goal was to use biofeedback analysis to evaluate patients' development and also highlight the benefits of having a multiplayer system.

Hemiplegia is a disorder that affects one lateral half of the body. This condition can leave the affected half partially or fully paralyzed, resulting in a loss of function. Hemiparesis is considered to be a less severe version of hemiplegia, where the effects are not as strong. Making a full recovery is a long process, so the purpose of the game was to increase the patient's range of motion to, hopefully, return them some independence.

To develop the game, the authors decided to use the Unity 3D engine along with Kinect SDK. Through the use of C# scripts, the data captured by the Kinect can be mapped onto a character skeleton which allows the creation of more realistic-looking characters where the character's limb movement matches the player's. The mapping of game objects to joints captured by the Kinect also enables the creation of different types of games that don't necessarily include 3D characters.

The plugin used included the ability to have an additional player. In general gaming, multiplayer has been found to increase the social presence of players [33, 43].

The authors also point out the existence of "mirror neurons." They explain the importance of these neurons by saying that when a patient observes an individual performing an action the same neural circuitries are activated as if they were acting themselves. [31] This supports that multiplayer or the use of an extra character similar to a human being can be beneficial.

The game developed was an apple picking game, used to verify the improvement in

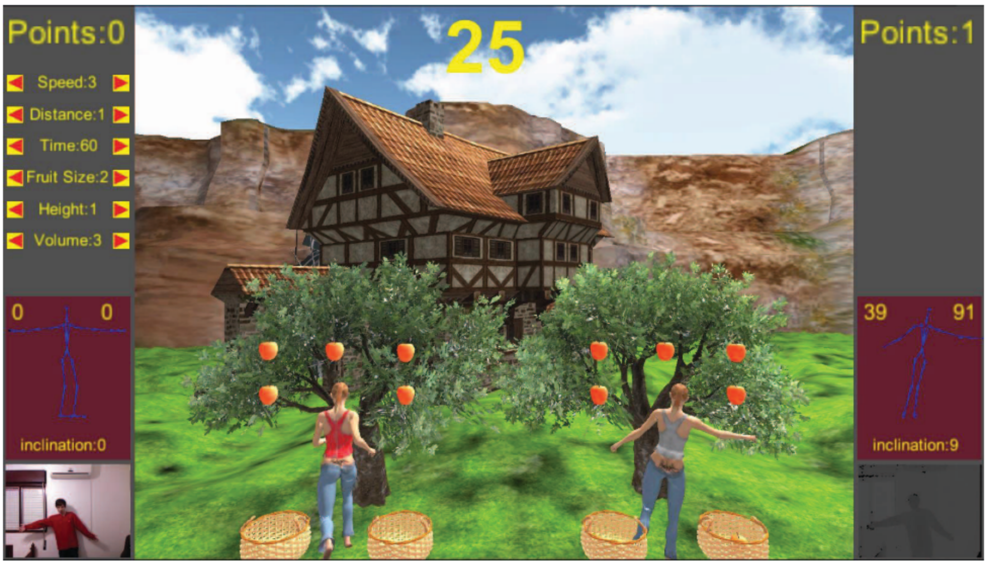


Figure 2.11: Apple picking game scenario [16].

abduction and adduction movements of the upper limbs. Patients must grab the apples that are placed randomly on the tree. Then they must place them on the baskets that are near the character. The objective is to collect as many apples as they can during a set period. An example of a game scenario can be seen in Figure 2.11.

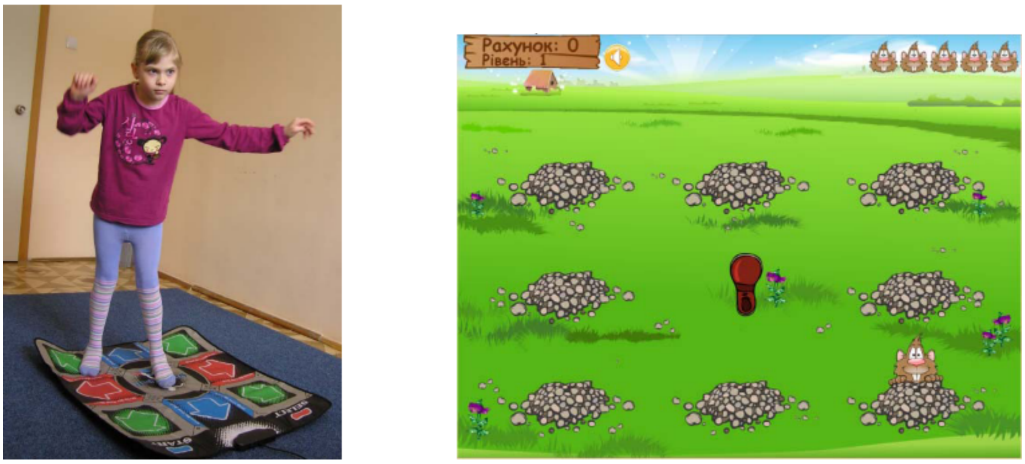
The therapist can adjust the game parameters on an in-game control panel. As mentioned, the game features a single-player mode where the patient plays alone trying to get as many fruits as possible and a multiplayer mode where both patients can compete to get the fruits or collaborate to catch the apples together.

2.6.5 Dance Mat for Motor Rehabilitation

Kozyavkin et al. [34] describe the use of two similar games called "Chase a Groundhog" and "Catch a Butterfly." Both games have the same gameplay, so here we will only reference the first one. The game is set on a lawn, and the screen shows the player's cursor, represented by a boot, at the center. There are eight holes arranged around the center position. These holes represent the eight buttons available in the dance mat which the patient needs to step on to try to catch the groundhog. The game has five difficulty levels where the response time is decreased in each one. On the third level, a female groundhog is introduced that players must not step on. Giving an extra layer of complexity to the game that makes players have to distinguish the target before stepping on it.

Preliminary tests were done on five patients with walking limitations. The patients performed daily home training sessions for two weeks, with each session lasting thirty minutes.

To evaluate the impact of the game on patients, four tests were performed before and after enrolling in the treatment:



(a) Player with cerebral palsy (b) Chase a Groundhog game scenario

Figure 2.12: A player and a screenshot of the Chase a Groundhog game [34].

1. Timed Up and Go (TUG) - the time it takes for the patient to stand up, walk three meters, turn around, and walk back to sit down again.

2. Pediatric Balance Scale (PBS) - a modification of Berg's Balance Scale, for children with mild to moderate motor impairments, it includes 14 tasks rated by a 3 point scale.

3. Four Square Step Test (FSST) - how long a patient takes to step on four different squares placed on the floor.

4. Stabilometry - the child is asked to stand still on a balance board for 15 seconds, and their area of the center of pressure displacement is calculated.

After the study period, a balance improvement was visible on four of the five patients. On average there was a TUG improvement of 2.2 seconds, and a PBS score increase of 1.6. The FSST reduced on average 1.8 seconds and the area of the center of pressure displacement decreased 4 points on average.

Despite the small sample and requiring further study, the results indicate the Dance Mat can be a useful gaming rehabilitation component.

2.6.6 Serious Game for Anxiety and Stress Reduction

Since anxiety and stress are common problems in children with Autistic Spectrum Disorders (ASD) the authors of this paper [13] decided to develop a serious game that incorporates Cognitive Behavioural Therapy (CBT) techniques taking the ASD modifications and guidelines into account. It was decided that biofeedback would not yet be collected because the use of wearables usually proves to be an extra obstacle for children with ASD.

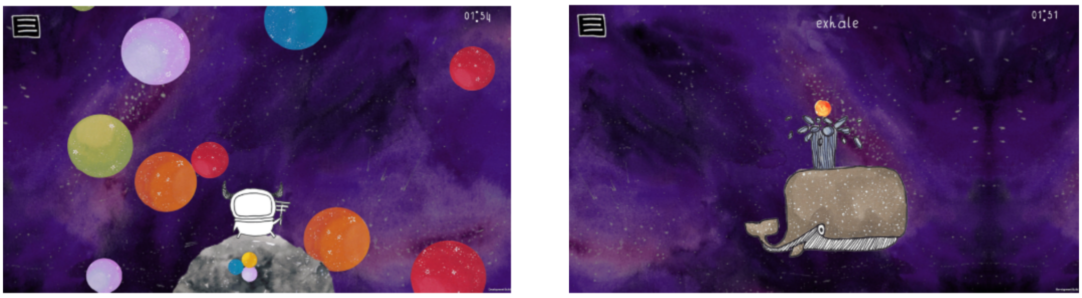
The game developed was called New Horizon (Figure 2.13), a 2D mobile exploration and puzzle game. The game is set in an infinite universe with an infinite amount of planets to discover. The player can travel around the universe by controlling the spaceship and landing on planets to complete puzzles and earn rewards. Within the game, the player can find two puzzles containing no CBT techniques:

- Memory Mini-Game (Figure 2.13b) – the player has to watch several starts light up in a specific order and then imitate that sequence before the time runs out.
- Platformer Mini-Game (Figure 2.13c) – the player needs to progress through a level by avoiding hazards in their way and jumping on platforms.

(a) The Universe (b) Memory Mini-Game (c) Platform Mini-Game

Figure 2.13: New Horizon game scenarios [13].

Two other games were created using relaxation techniques, such as the guided imagery relaxation technique and focused breathing. In the Senses mini-game, the objective is to pop bubbles of the same color within a time limit (Figure 2.14a). In the Breathing mini-game, the player has to focus on their breathing and inhale and exhale at the correct time (Figure 2.14b).



(a) Sense Mini-Game (b) Breathing Mini-Game

Figure 2.14: Relaxation Games from New Horizon [13].

The system developed also included the app SpaceControl, where parents can visualize information about the gaming behavior of their child and get some insight into their feelings. Several statistics can be accessed, such as the number of times the child plays a given game and how the child rates their mood after playing a game. This way, children can have an easy, communication-free option to express their moods.

Despite not having biofeedback measurements, the study showed some positive results that indicate that serious games could be a useful tool to empower ASD patients in their struggles with anxiety and stress.

2.6.7 Classification and Summary

In their work Rego et al. [45] gathered the main criteria that they considered relevant for classification and comparison of serious games based on the reviewed literature.

Those criteria are the following:

- Application Area - Normally, serious games have two main areas of application, Cognitive and Motor rehabilitation. The first being more related to mental faculties, and the second to physical disabilities.
- Interaction Technology - The technologies used by the patient to interact with the game. Includes cameras, controllers, and other sensors.
- Game Interface - The interface used by the game. Either two-dimensional (2D) or three-dimensional (3D).
- Number of Players - Number of players that the system handles. A game can be single-player (Single) or multi-player (Multi).
- Game Genre - Game genre can vary with the technology used. Examples found included: games to evaluate movement, simulations, strategy, or a combination of several (Assorted).
- Adaptability - Can the game increase/decrease difficulty based on the player's performance? While some games change the challenge level at set intervals or levels, others can adapt dynamically according to the players' abilities to maintain an adequate experience.
- Performance Feedback - As described in sub-section 2.3.1, this dimension indicates if a system is capable of providing adequate feedback to users.
- Progress Monitoring - This is the system's ability to save the gameplay data for analysis and to keep a record of the patient's progress with the game.
- Game Portability - Game portability relates to the capability of the system to be used in different locations.

For an easy and quick comparison of the serious games presented in Section 2.6, we will be using the previously described criteria to classify each of the games' features in Table 2.1.

The games studied in this document were focused on motor rehabilitation because those are more easily validated and the serious game developed in the context of this dissertation will also be more directed to physical rehabilitation.

We can see that there is a larger investment in single-player games, which makes sense since traditional therapies are often one-on-one as well and it is important for the patients to be focused on their treatment.

Table 2.1: Classification and Comparison of games in Section 2.6

	Kozyavkin et al. [35]	**Pereira et al.** [41]	**Leapball** [51]	**CatchAPet** [51]	**Apple Picker** [16]	**Chase a Groundhog** [34]	**New Horizon** [13]
Application Area	Motor	Motor	Motor	Motor	Motor	Motor	Cognitive
Interaction Technology	Balance Board + Kinect + Others	Kinect	Leap Motion	Leap Motion	Kinect	Dance Mat	Touch + Smart-phone
Game Interface	2D	2D	3D	3D	3D	2D	2D
No. of Players	Single	Single	Single	Single	Single/Multi	Single	Single
Game Genre	Assorted	Sorting	Arcade	Arcade	Simulation	Simulation	Puzzle and Exploration
Adaptability	No	–	No	No	No	No	No
Performance Feedback	Yes	–	Yes	Yes	Yes	–	Yes
Progress Monitoring	Yes	Yes	–	–	Yes	–	Yes
Game Portability	Yes	–	Yes	Yes	No	Yes	Yes

Adaptability in rehabilitation games can sometimes be hard to achieve. We need to constantly monitor the patient's performance and adjust the challenge level accordingly. Even when two different patients are affected by the same disability, how they are affected can vary greatly. Perhaps it is best to allow the therapist to manually adjust the game parameters in a manner they consider more valuable to a specific patient's condition.

It is crucial to record the patients' results and the progress they make during a game session. This data should always be accessible to the professional responsible for the treatment to keep a solid track of the patient's progress.

Game portability can be a valuable feature, depending on the condition of the patient. By allowing easy access to the system we may encourage patients to willingly give more hours to therapy while also saving traveling costs and time.

3

Co-Design of Games for Therapy

The exploration of Serious Games as tools for therapy is a field that is still in need of continuous research, especially when we're talking about children with disabilities. These children are usually forced to deal with their conditions throughout their whole life, making their therapy regimens repetitive, boring, and hard to maintain motivation. The investment in serious games can bring the inherent positive stimulants associated with the games to the therapy sector while also harvesting the health benefits of therapy that can help patients conquer more independence over their disabilities.

In order to create valuable experiences for patients, a multidisciplinary collaboration between engineers and experts in the field is imperative. Using a design thinking approach, which is intrinsically human-centered, allows developers to empathize with the end-users and create a more meaningful product by using their active engagement and participation [9]. The concept of design thinking also encourages an iterative development process where each stage doesn't necessarily follow a linear order and promotes early prototyping to help identify problems sooner, while the direction of a project can still change, rather than later.

With this dissertation, we built a framework for serious game development for the therapy of children with disabilities that will, hopefully, contribute to advancements in this area. We worked with the therapists from clinic Cresce and used their valuable input to help us design and plan the correct game mechanics for the patients we would approach. Together with what we have learned from the state of the art, their expertise allowed for more informed decisions at each stage of development to avoid working in the wrong direction.

This participatory design was based on a design thinking approach consisting of five different stages: Empathize, Define, Ideate, Prototype and Test, as described by the Hasso Plattner Institute of Design at Stanford [42, 24]. This approach is widely used, and we feel that each of these stages completely encompasses the processes and needs established in Section 2.4. Although the stages are represented sequentially, that only shows the general flow a project should follow and does not mean that a previous stage should not be revisited. In fact, design thinking is a non-linear process, and you are encouraged to go back to different stages at any point. Creating a prototype can generate new ideas, and by testing your system, you will inevitably learn more about your users and empathize with them. In our case, our process looked more like what is represented in Figure 3.1.

In this chapter, each section provides an overview of how each stage of design thinking was conducted. In Section 3.5 the testing stage and methodology are introduced, but we detail them further in Chapter 5.

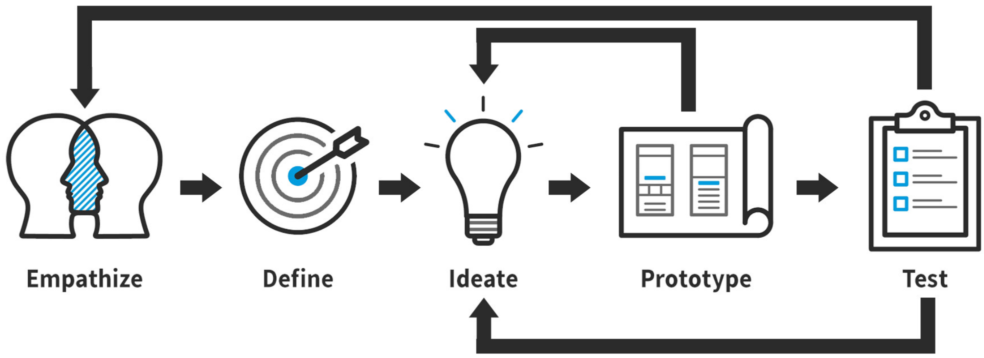


Figure 3.1: Design thinking stages diagram.

3.1 Empathize

When starting a project, the first thing to do is to research our user's needs. We must gain real insight into who the users are and the problem we want to solve. By creating an empathetic relationship with our users, not only will we be more connected to the problem we want to solve, but also, the users will be more comfortable in sharing their points of view. Part of the **Empathy** stage of the process was already completed through previous collaboration on different projects with the clinic "*Cresce com Amor*", mainly "just Physio kidding"[37], which is a solution based on the use of serious games with Kinect-based user interfaces and game personalization.

3.1.1 Clinic and Therapists

The Cresce clinic [1] has been operating since 2014 and, since then, has focused on gathering the best tools and resources to be able to help families caring for children with special needs. They are one of the major Specialized Therapy Centers on a national level in the pediatric intervention area, working with around 50 families per year.

The therapists at the clinic are qualified to perform several kinds of therapies, such as physiotherapy, speech therapy, occupational therapy, and sensory integration, among others. Recently, they have been contributing to the investigation of the PLAY platform

[1]Cresce clinic website, http://www.cresce.pt/ , accessed on February 2023

together with Setúbal's School of Technology, a project in which this dissertation also contributed.

The therapists, and some of the children, were already familiar with some members of the team. Even so, we visited the clinic often to get a better perception of the disabilities we would be working with and to create a sense of trust and companionship between us and the patients that could facilitate future work with them by having them be more comfortable with our presence.

3.1.2 Children and Disabilities

At the clinic we were able to observe and work with children affected by several different disabilities, from slight speech impediments to major physical and cognitive limitations. For our work, we wanted to focus mainly on the physical side with physiotherapy and, when possible, on providing some degree of cognitive stimulation.

Most of the children we interacted with were affected by Cerebral Palsy (CP), with varying Gross Motor Function Classification System (GMFCS) [40] levels. The GMFCS is a classification system for mobility, represented by a I to V scale where V means less mobility (Table 3.1).

Table 3.1: Gross Motor Classification System Levels and their description.

GMFCS Level	Description
I	Children walk at home, school, outdoors and in the community. They can climb stairs without the use of a railing. Children perform gross motor skills such as running and jumping, but speed, balance and coordination are limited.
II	Children walk in most settings and climb stairs holding onto a railing. They may experience difficulty walking long distances and balacing on uneven terrain, inclines, in crowded areas or confinedspaces. Children may walk with physical assistance, a hand-held mobility device or use wheeled mobility over long distances. Children only have minimal ability to perform gross motor skills such as running and jumping.
III	Children walk using hand-held mobility devices in most indoor settings. They may climb stairs holding onto a railing with supervision or assistance. Children use wheeled mobility when travelling long distances and may self-propel for shorter distances.
IV	Children use methods of mobility that require physical assistance or powered mobility in most settings. They may walk for short distances at home with physical assistance or use powered mobility or a body support walker when positioned. At school, outdoors and in the community children are transported in a manual wheelchair or use powered mobility
V	Children are transported in a manual wheelchair in all settings. Children are limited in their ability to maintain antigravity head and trunk postures and control leg and arm movements.

3.2 Define

In the **Define** stage, we take all the observations made during the Empathize stage (3.1) and identify the core problems to solve. The team focused on discussing and selecting the therapeutic exercises that needed motivational support to be executed by children, like repetitive reaching exercises or the ones that require moving to different positions to train mobility and balance while standing. We established that therapists sometimes used commercial games in their sessions, but they mentioned these were often hard to adapt to their patients' capabilities and did not allow them to collect relevant data to measure progress. Therefore, the therapists would like to see exergames where they could still use off-the-shelf controllers but have more control over the game parameters, and use games more targeted to a specific exercise. They considered the dance mat a great controller to explore due to its possibilities regarding different therapeutic exercises' dimensions, because of its ability to, not only, be used as a stepping mat, but also be folded or hung on a wall, for example. They had also worked with the Nintendo Wii before, mainly with the Wii Balance Board (WBB).

Because of the way the same disability can affect different people in different ways and degrees of severity, therapists would like to see games implemented in a way that, while having clear objectives, can also be used in different ways. Therapists mentioned that, more often than not, they don't have set treatment plans for a disability and plan things on a case-by-case basis. They want to be able to use the games in creative ways that can benefit different therapy types.

3.3 Ideate

Reaching the **Ideate** stage, we use the knowledge foundation created in the first two stages to generate ideas and look for alternative ways to tackle the problems defined. We had brainstorming sessions with the therapists to understand how we could build games that benefit the therapy of children followed by the clinic (Fig. 3.2). When possible, we also asked children what themes they enjoyed to make the games more appealing. We settled on a game suite where children would have to use body movements to control the games so it would be possible to train balance and mobility. The idea of having different games would also allow us to test which kind would be more suitable for the children at the clinic and their characteristics. If games had an element of symbol/pattern recognition, they could also be used to train focus and stimulate cognitive function.

3.3.1 Device Choice

While doing the research work during the preparation for the dissertation, we had access to a dance mat. This device had shown promise in literature (Subsection 2.6.5), so we created a simple endless runner prototype game (Fig. 3.3) to test the feasibility of developing games that use it as their interaction method. We believed the dance mat to be a

Figure 3.2: Workshop at "Cresce com Amor"to showcase games and discuss ideas.

great option for satisfying the gathered requirements while being very affordable, easy to use, and requiring no calibration, unlike other sensors like the Microsoft Kinect. For those reasons, we showed the dance mat and this previously made game at the clinic. The game was played by using the left and right arrow keys on the mat to make the character move to the respective side. They enjoyed using the dance mat to interact with the game and were interested in using it more in future work.

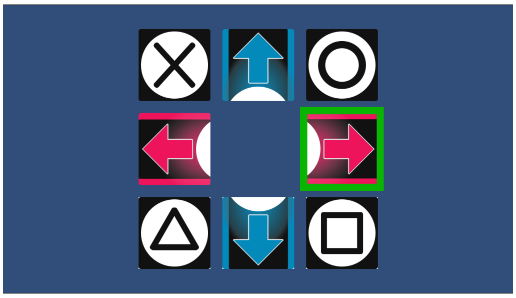
Since the clinic had used the WBB in the past, and believed it to be a useful device, we decided to create games for it as well while addressing the past problems they had with customization and data collection.

Figure 3.3: Game developed during the preparation phase of the dissertation.

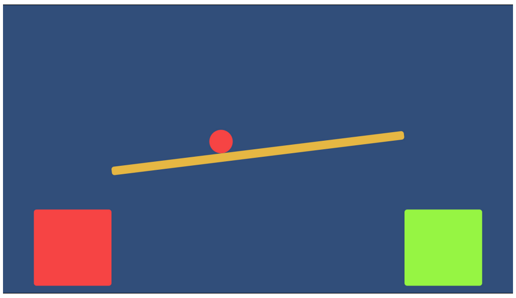
3.3.2 Early Mockups

After our discussions with the therapists we began bringing our ideas to life by creating mockups (Fig. 3.4) that could help us plan and visualize game mechanics that made use of the chosen controllers. On Figure 3.4a we can see concept for a game with the goal of matching the symbols you see on screen with the ones on the dance mat by pressing the correct button. The player would have to be able to recognize which button to press and then physically move to press it. Figure 3.4b shows a simple balancing game where the player would lean to either side, on top of the balance board, making the platform in middle rotate according to their center of balance. The goal of this game would be to sort a given number of balls by their color to the respective container.

After showing these mockups to the therapists, they were excited to move on to the prototype stage and left us with some more valuable feedback. Since the target audience would be primarily children, the games should be more visually appealing. We would have to add sounds and colorful imagery. Therapists approved the interaction method but would also like it if we could create variations of the games suggested in the mockups, either visually or with a slightly different goal, such as having to decide which foot to use to press a button.



(a) Symbol matching game.



(b) Balancing game.

Figure 3.4: 2D Mockup ideas for games using the dance mat and WBB.

3.4 Prototype

Reaching the **Prototype** stage, we start the actual development of the solutions. With the suggestions and ideas collected in the define and ideate stages, it is time to develop a quick, scaled-down version of the idealized system.

3.4.1 Dance Mat Prototypes

We developed four prototype games that use the dance mat as the interaction device. They were called *Matchmat*, *Left or Right?*, *Crazy Car* and *Fishing* (Fig. 3.5). With the dance mat being a simple interaction device, all games follow the same interaction principles with varying degrees of complexity. The dance mat forces patients to physically move to press a button, so we tried to integrate different game modes and input layouts that would allow the games to be more suited to a higher number of patients depending on their physical and cognitive strengths. In every game, it is also possible to adjust parameters, such as, speed and button and obstacle placement, as required by the therapists. *Matchmat*,*Left or Right?* and *Fishing* were directly created from the mockup presented at the clinic, while

Crazy Car was a re-skin of the game developed in preparation for the dissertation to make it look better.

The updated 3D graphics and better visual and audio feedback was now much more appropriate, making the games more captivating and preventing children from getting bored of them quickly.

3.4.2 Wii Balance Board Prototypes

For the WBB, we created a balancing game where the player needs to balance a ball on a platform that is controlled by their center of pressure in the real world (Fig. 3.6), measured by the balance board. This game was mostly done to evaluate the feasibility of games in Unity using the WBB and to learn how to read its input. Even so, we took this game to the clinic to get the therapist's feedback. They considered the interaction method very valuable, but the perspective and ball movement was hard to understand, so we moved on to the game envisioned in the mockup where the players must control the center platform by balancing on the board and rotating it to either side, making the balls fall into their respective colored container.

3.5 Test

After having the dance mat prototypes built, we conducted a user study at the clinic. The test focused on testing the usability of mat-controlled games and how children with different disabilities would be able to interact with them.

The Test phase is introduced in this section to keep it in the context of all the design thinking stages, but it is explored in greater detail in Chapter 5.

Figure 3.5: **Top Left:** Depiction of *Matchmat*; **Top Right:** Depiction of *Left or Right?*; **Bottom Left:** Depiction of *Crazy Car*; **Bottom Right:** Depiction of *Fishing*

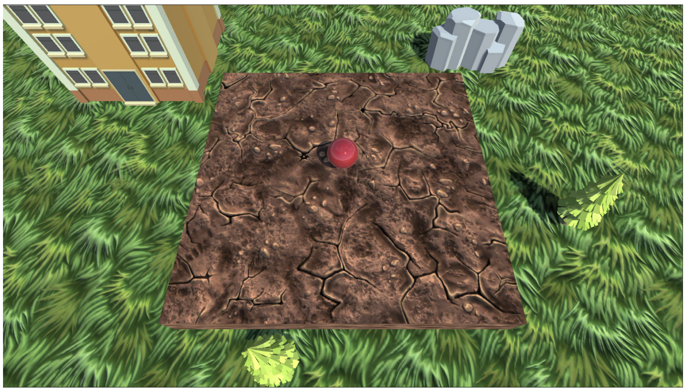


Figure 3.6: Screenshot of the balancing platform game.

3.5.1 User Selection

The testing phase is another development aspect greatly reinforced by a participatory design approach, especially when you know you will be working with target populations with particular characteristics. In our case, for the therapy of children with special needs, it would be challenging to gather adequate participants without having a partnership established with a clinic. Even with such partnerships, we were still limited by the number of patients available and their schedules.

The therapists did a pre-selection of children they considered able to use the system at the clinic. We achieved a sample size of ten participants with varied diagnostics and abilities, which allowed us to test the mat in different ways. A careful selection of participants is crucial to avoid unnecessary patient frustration. Patients must feel their disabilities are not holding them back if you want them to engage with the games and play them enough times to benefit from them.

3.5.2 Testing Procedure

Testing was done over the course of two weeks, and we only had limited time with each patient. Our testing sessions had to be done during small time windows that coincided with the time patients went to the clinic for their regular therapy sessions without disrupting their treatments. The tests had to be done either before their therapy or right after they were finished for the day. The goals of the test should be clear and discussed with the therapists beforehand to allow them to prepare everything to accomodate the test in a therapy session in a way that suits the patient.

For each test session we must:

- Obtain parental consent.
- Ask child if they feel like playing the game.
- Adjust game parameters or input method for that child.
- Let the therapist control the session.

- Record gameplay data through the game.
- Be ready to stop at any time if child shows signs of discomfort.
- Collect feedback from the therapists and, when possible, the children.

Questions done to children should be simplified. When asking questions that are answered by using a numbered scaled (like the System Usability Scale (SUS) [8]), it might be helpful to use a visual visual representation of the Likert scale [44] that is more easily identified by a younger audience. While not always possible, it's important to listen to children's feedback, not only because it will make them feel more involved in the whole collaboration process but also because the games are meant to benefit them, and only by making sure they like them can we develop a product that they get excited to use wether when they go to the clinic or even at home.

Because of their expertise, the therapists' feedback is even more crucial. They are the ones capable of determining if and how a serious game can be integrated into the therapy regime of a patient.

One of the things we quickly found during our tests was that not every child could, nor should, play every game, but therapists had no way of rapidly choosing a game just by looking at the list of available ones.

3.6 Classification of Games for Therapy

As development went on, our number of games kept increasing. Together with the therapists, we felt that it would be helpful to have some classification system for games related to therapy that would help them choose the more appropriate one for their patient. From our first discussions, a problem we found was that when therapists work with games or other devices, they can not always classify the exercises they perform in a standardized way. Much of their work is finding creative solutions to achieve the therapeutic goals of a patient using the tools available to them at the time. They mentioned that different therapists with access to the same game would probably be able to use it differently depending on the patient and their creativity.

The therapists suggested that a good approach would be to associate each game with general functions of the body and types of skills used during the game instead of describing a specific exercise that the game tries to promote. They proposed the creation of a classification system based on the International Classification of Functioning, Disability and Health (ICF) [39] from the World Health Organization.

The therapists compiled a list of the sections and chapters from the book that would be most useful as the dimensions in the classification of a therapy game and its areas of effect. The sections and chapters selected where:

- Body Functions:

- **Mental functions**: refers to functions of the brain that include global mental functions, such as consciousness and energy, and specific mental functions, such as memory, language and calculation.
- **Sensory functions and pain**: refers both to functions of the six senses and the sensation of pain.
- **Voice and speech functions**: refers to functions of producing sounds and speech.
- **Neuromusculoskeletal and movement-related functions**: refers to functions related to movement and mobility, which include the functions of joints, bones, reflexes and muscles.

• Activities and Participation:

- **Learning and applying knowledge**: is about the application of knowledge that is learned, thinking, problem solving, and decision making.
- **General tasks and demands**: is about performing variable tasks, the organization of routines and handling stress. These components can be used with specific tasks to help identify the fundamental characteristics of executing tasks under different circumstances.
- **Communication**: is the features of communicating by language, signs, and symbols. These include receiving and sending messages, ability to have conversations, and using communications devices and techniques.
- **Mobility**: is about changing the position or location of the body. It can be by moving or manipulating objects, by walking, running or climbing, and by using various forms of transportation.

Inside each of these chapters, there is still another level of depth that can be used in case we want to classify each game in a more specific way, but in the scope of this dissertation, and according to the observation made by the therapists that they would often have to be creative in the way they employ the games with each patient, we felt that it would be beneficial to keep the classification with dimensions that are vague enough to avoid closing the games in boxes, but also provide enough information for the therapist to gauge the impact the game can have in each of the classified areas.

We propose a classification framework that takes the previously listed body functions and activities and scores them in a range of 1-10. We can then create a visualization of this classification using a radar chart (Fig. 3.7). The radar chart is an easy way of displaying multivariate data in a chart and allows therapists to quickly compare different games and the areas they can impact if used by their patients. When planning the position of each dimension of the graph, we tried to position them in a way that would keep activities more related to physical and tangible things on the right side and the ones more abstract

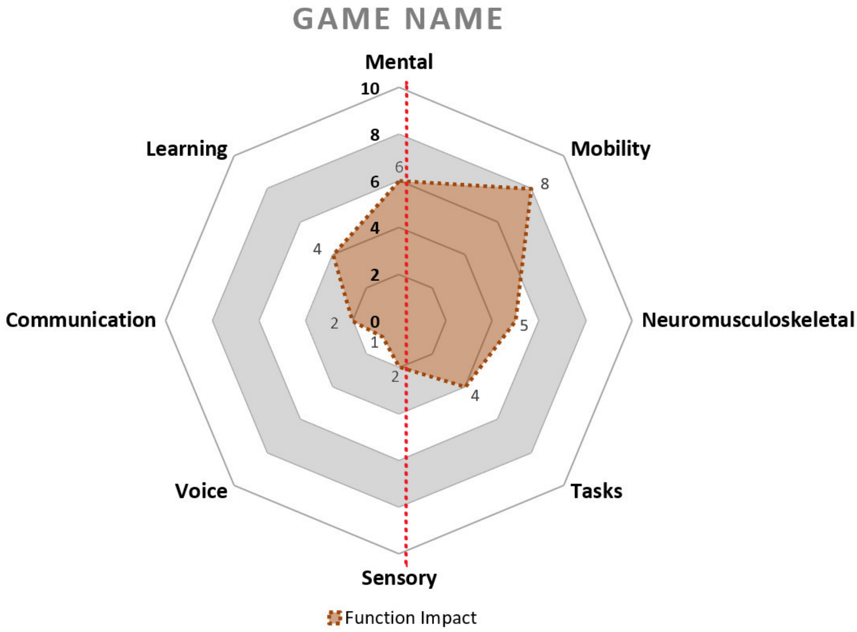


Figure 3.7: Example radar chart for the classification of a therapy game.

and related to cognitive abilities on the left. We believe this helps with the visualization by allowing to see at first glance if a game is more demanding in a physical and more tangible way, or the in more cognitive or abstractive functions.

4

Implementation

In this chapter, the developed solution is presented in more detail. We start by explaining the system and its requirements, the PLAY platform, and the system's architecture. We then move on to describe the games that were implemented in the context of this dissertation.

4.1 Solution

We developed a system with a primary focus on the physical rehabilitation of patients with cerebral palsy or similar conditions that affect balance, posture, and muscle strength. We used readily available game controllers/sensors to simulate the exercises done in conventional therapy. Conventional therapy includes exercises, such as several spine movements (rotational, flexion, and extension), balancing, and image recognition to improve the coordination between the eyes and body movements.

For the targeted type of patients, the therapy needs to be intensive and repetitive. Therefore, patients must feel motivated while using our system to complete their assigned exercises. To keep a high engagement level the developed games include some stimulating features such as points and rewards to allow players to have some sense of progression, and a cartoony 3D art style and sounds to make it more appealing to younger audiences.

As far as gameplay, we used the controllers to translate real-life movements into character movement in the virtual space, allowing the patient to get real-time feedback of their actions. For example, if a player leans or steps left, the game character will also move left or do an action associated with that specific movement. The parameters for triggering these game actions can be defined by the therapists and vary from patient to patient, making it a customizable experience that can be adjusted according to the patient's capabilities.

To play the game, the patient only needs access to a computer, the respective controllers, and login into their PLAY account before starting to play. In case there is no connection to the internet, or if a new user just wants to test the games quickly, there is an option to create a local profile on the device that is running the games. Game results can then be saved locally and sent to the platform at a later date if the user wishes to do so.

By having our games integrated with the PLAY platform, game session results and the patient performance, such as the center of balance position or time it took to complete a given task, can be sent to the server for later analysis. Having the data stored non-locally means that the game can be played autonomously by the patients at home, for example, and the therapist will have almost immediate access to the data collected to evaluate how they performed. As long as a patient has a PLAY account, they will be able to use the system on different devices without losing their progress.

The platform communicates with the games through a series of HTTP REST requests, which allow therapists to use the platform's interface to adjust the game parameters at any given time if they feel the game is either too hard or too easy for the patient. All the parameters and game session results are stored individually for each player that has an account on the platform making it easy to keep track of each patient's progress.

In short, to run our system, either at the clinic or at home, the only things needed are access to a computer to install the game and the required controllers (a balance board or dance mat, for example) to interact with it. For everything to work as expected, it is also important to have an internet connection. If the game is not connected to the internet therapists lose the ability to adjust the game in real-time and easy access to patient data, although, if an internet connection cannot be established, the game parameters can be adjusted in the game menu and the data recorded during the game session can be sent to the platform later once the system has access to the internet. Since we are dealing with children, the patient should always be accompanied by a responsible caregiver that can ensure the therapist's directions are followed or by the therapists themselves.

4.2 PLAY Platform

The PLAY platform is being developed by a colleague as a tool to collect and analyze data from user interactions with serious games. It is a web-based platform with multi-user support (patients, therapists, and clinics) and can be used in clinical or home environments. The platform recognizes patients by their profiles, which can be managed and monitored by the therapists. Therapists can also plan out which exercises their patients should be doing and the parameters for the goals the patients need to achieve.

PLAY offers a web services API that allows the expansion of the platform to third-party games that follow the framework, and this is going to be the means of communication from our game to the platform. The API allows for authentication, requesting game parameters, sending gameplay data, receiving notifications, and sending session results. The platform aims to provide:

- A model for a patient profile.
- A flexible model for games.

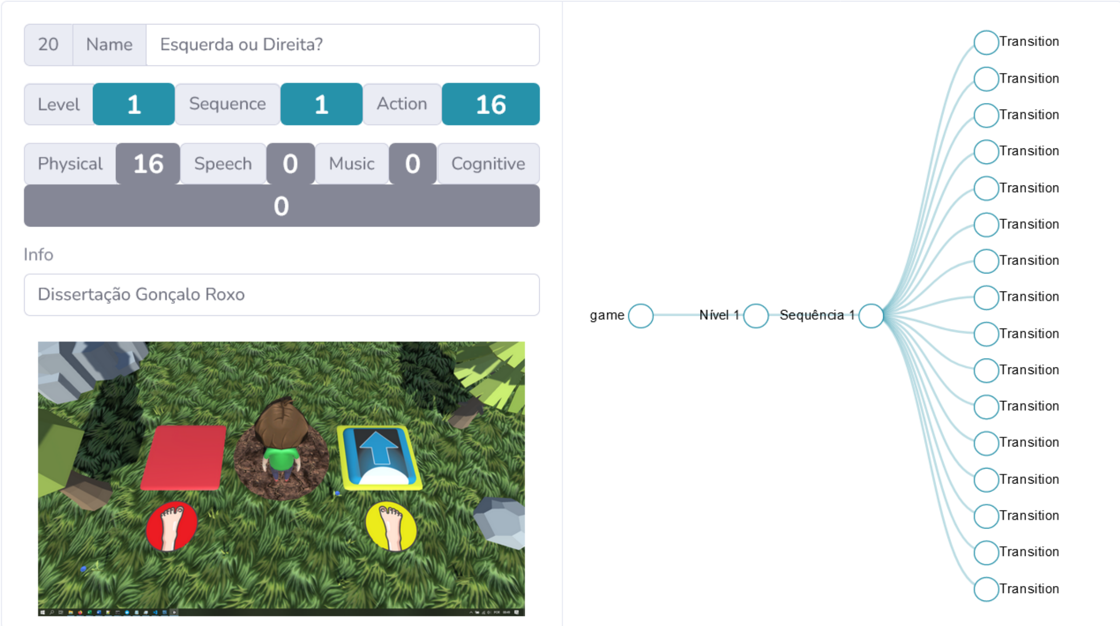


Figure 4.1: "Left or Right?"game overview inside the PLAY Platform. The game has one level, consisting of one sequence of sixteen actions of type "Transition".

- Recommendation of games based on user profile.
- Repository of game related statistics.
- Data for machine learning algorithms and knowledge obtaining tools.
- Abstraction of devices.
- Easy access to data and tools using internet.

To fit our games with the platform some abstract guidelines were followed. The therapeutic exercises should be created based on actions and parameters, where each action can have its own set of parameters. Therefore, games are built with sequences of actions, that can be called levels (Fig. 4.1), and each of those actions has parameters to define their variable parts, such as the angle of movement the player must perform, distance to reach, or a time and score limit. As such, a game cycle must fullfill a set of requirements in order for the game data to be correctly recorded using the PLAY API (Table 4.1). This game structure can be completely configured inside the platform's web interface, making the option to add new levels, sequences, and actions available at any time. The first request is done once the player opens a game and returns the game structure of that game, i.e., the actions the patient must perform. The second request happens when a patient starts playing a game and records the time the game was played on the patient's profile. The 'executed' parameter is the date the game was played, 'gameid' identifies the game played, and 'userid' identifies the patient that played the game.

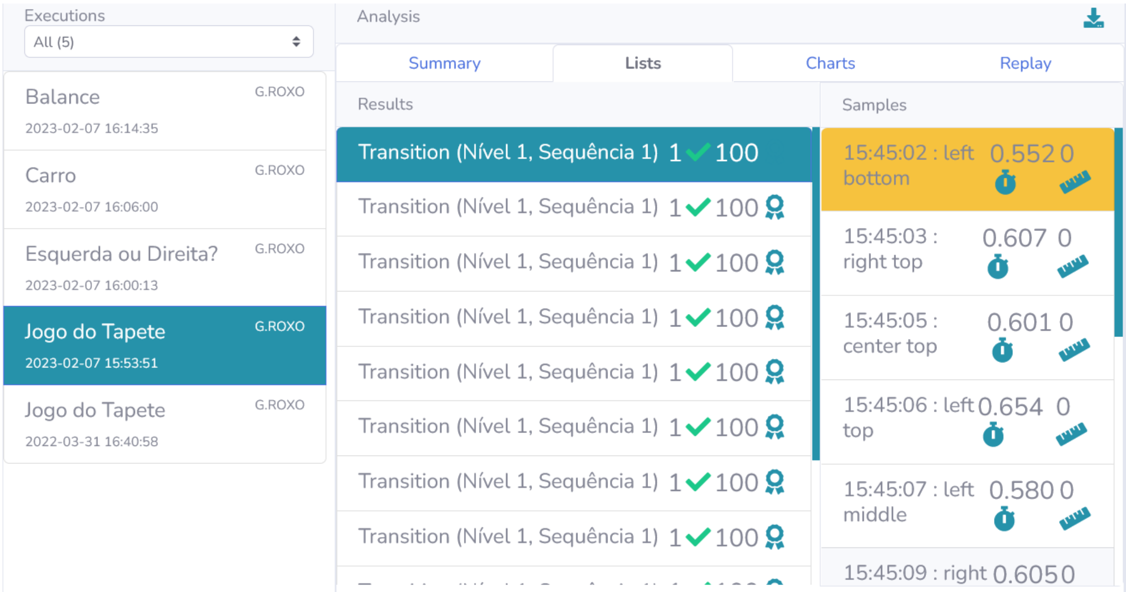


Figure 4.2: On the web interface for the PLAY platform, we can see the recorded samples for each completed/failed action (result) highlighted in yellow when a result is selected.

Each time the player executes an action (pressing a button, for example), a "game sample"is sent to the platform recording which movement was done. The 'data' parameter in a sample is a JSON object, this allows the request to remain generic and for each game to send the data gathered from different input devices used in different games. Once the correct action is performed (or failed) a "game result"is sent, we then move to the next action and the cycle repeats until the the last action is performed. The information is stored and can be consulted at any time (Fig. 4.2).

	Endpoint	Parameters
GET	/game/:id/structure	id: int
POST	/gameexecution	executed: string gameid: int userid: int
POST	/gamesample	data: JSON gameactionid: int gameexecutionid: id
POST	/gameresult	status: int score: int gameaction: int gameexecutionid: int

Table 4.1: API calls used to connect the prototype games with the PLAY platform.

4.3 System Architecture

We can say our system is divided into two parts that we can call the client and server. A diagram of the system's architecture can be seen in Figure 4.3. On the client part, we

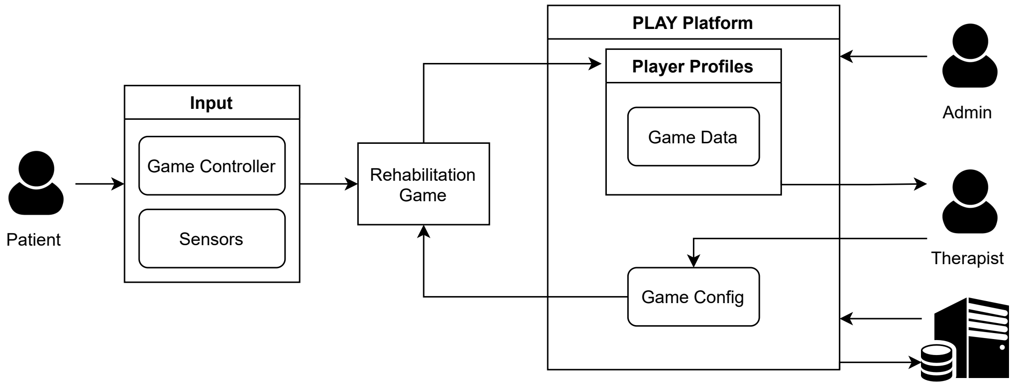


Figure 4.3: Diagram representing the system's architecture.

have the patient that interacts with the game by using the appropriate input readers (controllers and sensors). The game is then able to send the data it collects during a game session to the PLAY platform, which is on the server part. The data collected by the platform is stored and associated with each patient through their profiles. The therapists can then access the platform and have access to their patient's profiles to evaluate the data collected and analyze it. They can also use the platform to configure the game according to their patients' needs. The admin has power over all the features of the PLAY platform and is responsible for maintaining it. The platform is hosted on a server with a database to store the data from the games and patients.

4.4 Developed Games

The game suite presented in this thesis was developed using the Unity game engine. The game ideas were all generated during our visits to the clinic at various iterations of the Define and Ideate stages of the participatory design process. For each game in this section, we show how therapists classified them using the classification system explained in Section 3.6. In a later section (5.2), we show how we asked therapists to make that classification.

4.4.1 Matchmat (G1)

Matchmat was the first game we developed. It shows a representation of the dance mat on-screen with a human character in the middle that the children can recognize as a reference. The game structure in PLAY consists of one level, with a sequence of several actions (the buttons the patient has to press). Buttons will show up on the screen for a limited time, with their virtual positioning matching the one in the real world. There are two modes in this game, one where only the correct button is displayed (Fig. 4.4a) and another where all the buttons are always shown on the screen, with the correct one being highlighted with a red animated square (Fig. 4.4b). The second version was designed to help children have an easier time identifying which button to press by using the adjacent

(a) Version where only the target button is shown. (b) Version with all buttons allways visible.

Figure 4.4: Screenshots of the two game modes for Matchmat.

symbols as additional reference points. With this game, patients can train the matching between real-world positioning and the visual representation of the buttons, as well as having to use real-life movements to reach each button.

Besides allowing therapists to define which buttons to press and the time the patient has to press them, the game also supports changing the images displayed on each button. This customization offers variety to the game and makes it possible to help children learn about different concepts, such as animals or numbers.

During gameplay, we capture and send to PLAY every button that a patient presses. For each of those button presses we record the total time the button is held down and the Manhattan distance between that button and the target one. A patient is allowed to press any number of incorrect buttons until they find the correct one, the Manhattan distance between each button pressed and the target button will be summed for each action. At end of the game, a lower total Manhattan distance indicates a better patient performance during the game, along with the total amount of time it took to complete the game. The reason we also record the time each button is held down is because the goal of the game is to press the button shown on screen and then return to the middle to receive another action. This means that an efficient player will spend less time on top of each button, and it can also be used as a metric for success or evaluating improvements. An action is only considered failed if the patient is not able to find the target button within the time limit.

Goals: Improve equilibrium, Real-virtual visual matching, Mobility.

Matchmat can be used to train mental capacity to a certain extent, by training symbol recognition and matching. The game requires high mobility and changing the body position frequently to reach each button. While there are no exercises requiring intense muscle strength, the patient should try to stand on its own during gameplay and there will be a lot of joint movement to reach buttons. Depending on the time that is defined to press a given button, the patient's reflexes can be tested. The objectives are not fundamentally linked to a specific task. The game provides some audible feedback on actions, especially on the number and animal modes. There are no voice or communication exercises, but the patient can learn about symbols, animals, and numbers.

Table 4.2: Scores that therapists have attributed to the game Matchmat in each dimension of the classification.

Body Functions		Activities & Participation	
Mental	6	Mobility	8
Neuromusculoskeletal	10	Tasks	3
Sensory	5	Communication	1
Voice	1	Learning	4

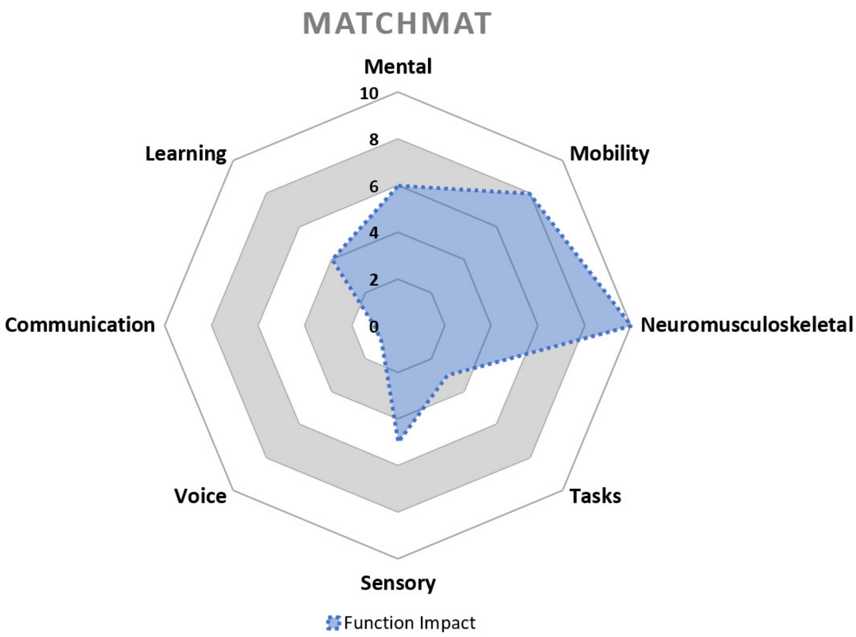


Figure 4.5: Visualization of the classification for the game Matchmat.

As such, applying our classification system to this game (Fig. 4.5), therapists gave it the scores seen in Table 4.2.

4.4.2 Left or Right? (G2)

Left or Right? Is a more complex variation of Matchmat. There are two colored squares on the screen with a symbol representing the left and right feet below them (Fig. 4.6). The game structure in PLAY consists of one level, with a sequence of several actions (the buttons the patient has to press). When a button appears on the red square, the patient must press it using their left foot. When it appears on the yellow button, it must be pressed with the right foot. In this game, the children no longer see the whole representation of the mat in the virtual space. They must not only recognize the symbol and find its position on the mat but also decide which is the correct foot to use.

The dance mat can only detect which buttons are being pressed at any given time, meaning that while we can detect if the correct button is pressed to complete the action, the game depends on the therapist, or caregiver, to make sure that the correct foot is used to press each button. The game offers the same configuration options as Matchmat and

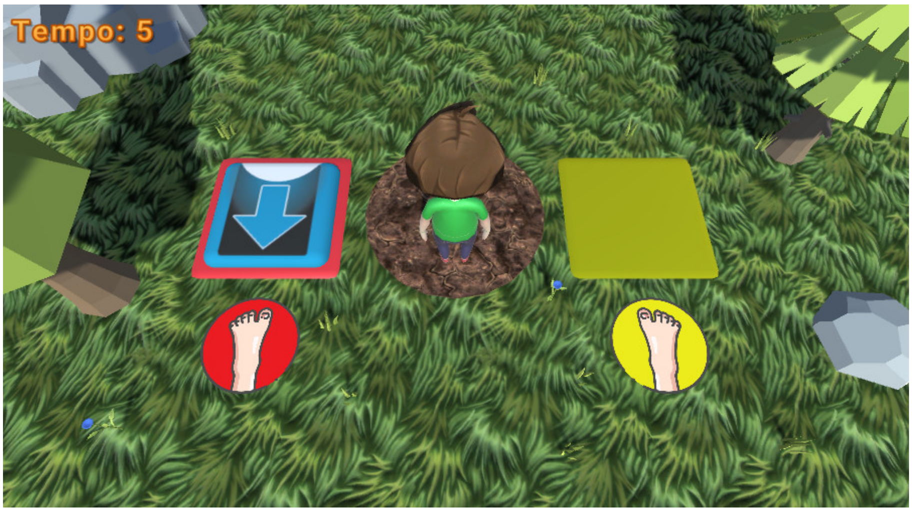


Figure 4.6: Left or Right? game.

Table 4.3: Scores that therapists have attributed to the game Left or Right? in each dimension of the classification.

Body Functions		Activities & Participation	
Mental	8	Mobility	8
Neuromusculoskeletal	10	Tasks	4
Sensory	5	Communication	1
Voice	1	Learning	5

the data being collected is also the same as the one mentioned in the previous subsection.

Goal: Improve Equilibrium, Real-virtual visual matching, Mobility, Limb laterality recognition.

Left or Right? has a similar classification to Matchmat (4.4.1), as it follows similar interaction methods and goals. By adding the decision of which foot to use to press each button, the game's overall complexity increases in some areas. There is a bigger mental effort involved when playing this game, and the game scores a point higher in the Tasks and Learning dimensions for the same reason of having to learn to distinguish the left and right sides.

Applying our classification system to this game (Fig. 4.7), therapists gave it the scores seen in Table 4.3.

4.4.3 Crazy Car (G3)

Instead of having to match symbols shown on the screen, this game is an "endless runner"style game where a car continuously moves forward (Fig. 4.8). Since the game doesn't follow a fixed structure and the patients are allowed to play until they lose, the game structure in PLAY consists of one level, with a sequence of a single action. This action is called "Free"and serves the purpose of storing every button press (or center of pressure,

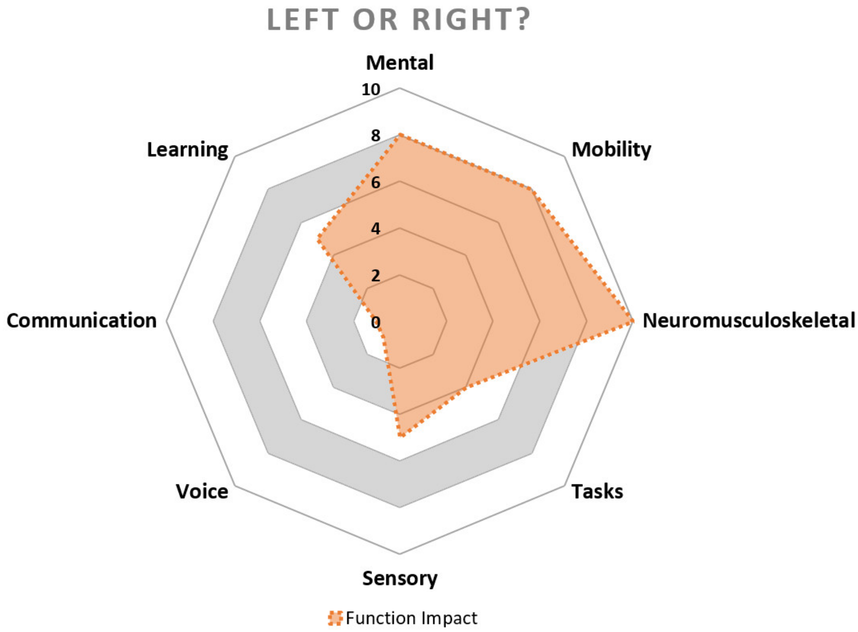


Figure 4.7: Visualization of the classification for the game Left or Right?.

when using the WBB) during the game. The patients must use the buttons on the mat to dodge obstacles placed on the road. For more adaptability, this game offers four controller layouts that allow the game to be played while standing, sitting, or possibly, laying down. The control layouts (Fig. 4.9) use button presses to make the car switch lanes, with variations V1, V2, and V4 using the buttons on the left and right sides of their layout to move the car in the respective direction. Variation V3 matches each button from the first row of the mat to each of the three lanes the car can occupy, allowing to move instantly between lanes by pressing each of the corresponding buttons.

Crazy Car also has the option of being played using the WBB, choosing this option makes the game more difficult. The player has to constantly shift their center of balance from side to side to be able to dodge obstacles.

To offer some variation, the game cycles between two different environments, the city, and the forest, each composed of seven distinct tiles. The player can also use the coins caught during the game to unlock additional cars to play with (Fig. 4.10). By default, the car speed increases gradually as time passes, but there are controls to lower or increase the speed manually.

As mentioned already, the data we send to PLAY during this game is every button press and the position of the center of pressure at each frame. These can be useful to see if the patient has preferences in dodging to one side or the other, for example. As performance metrics we also record the total time played and a final score, consisting of the distance traveled plus the number of coins collected.

Goals: Improve Equilibrium, Real-virtual visual matching, Mobility, Reflexes, Decision making.

Figure 4.8: Crazy Car game.

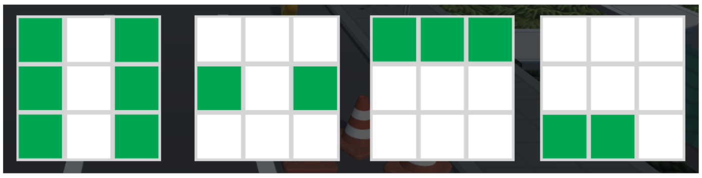


Figure 4.9: Dance mat controller layout options for *Crazy Car*. Highlighted squares represent the buttons used to play the game (from left to right: V1, V2, V3, V4).

Figure 4.10: Car selection screen in the Crazy Car game. Coins collected can be used to unlock a new car.

Crazy Car requires focus and decision making to decide when and where to turn. Both functions are related to the Mental and Learning chapters of the International Classification of Functioning, Disability and Health (ICF). Patients have to press the buttons very often, or shift their body weight when using the WBB. The game can be very mobility intensive and patient's reflexes will be tested, especially at higher speeds. This game connects to the real life situation of driving, patients are encouraged to think and make decisions to correctly avoid obstacles on the road. The patient must visually process the action happening in the game and be able to gauge the distance between the obstacles

Table 4.4: Scores that therapists have attributed to the game Crazy Car in each dimension of the classification.

Body Functions		Activities & Participation	
Mental	8	Mobility	9
Neuromusculoskeletal	9	Tasks	8
Sensory	6	Communication	2
Voice	1	Learning	8

and the car.

Applying our classification system to this game (Fig. 4.11), therapists gave it the scores seen in Table 4.4.

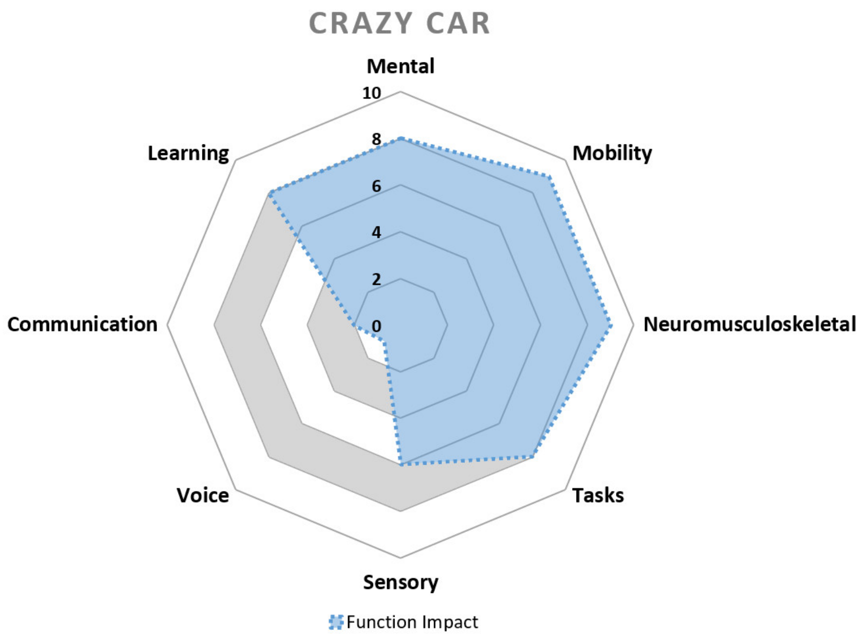


Figure 4.11: Visualization of the classification for the game Crazy Car.

4.4.4 Balance (G4)

This game was designed to be played with the WBB. The player should be standing on top of the board, and by leaning left or right, they are able to rotate the middle platform in that respective direction. By doing this, the player has to sort the balls that spawn over the platform into the container with the correct color placed on edges of the screen. The game structure in PLAY consists of one level, with a sequence of several actions (the red and yellow balls that must be sorted to their respective sides). While balancing to keep the platform steady, the player must recognize the color of the ball that spawns and decide to which side it should be sent. In Balance, the therapists can decide the number and color of balls that will spawn during the game, and also the amount of time that the player has to sort each one. The WBB is constantly measuring the patient's center of balance. For this reason, at each frame, a sample containing the position of the center of balance is sent to the PLAY platform. Grouping these samples allows the creation of a diagram that shows how the patients balance themselves on the board during gameplay (Fig. 4.13).

Goals: Improve Equilibrium, Color matching/recognition, Decision making.

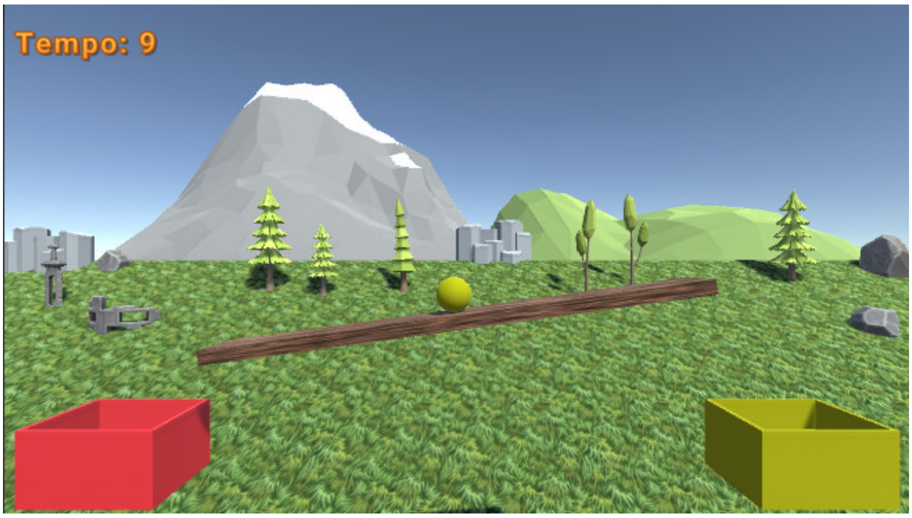


Figure 4.12: Balance game.

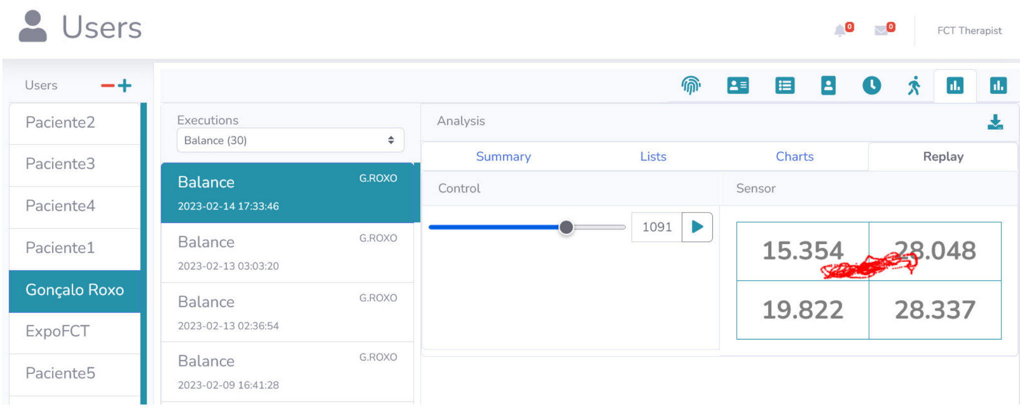


Figure 4.13: PLAY records the weight distribution in each of the WBB sensors and shows the CoB at each frame as a red point.

Patients must be able to recognize the two colors and decide which box they belong to. They are also required to stand on top of the WBB, constantly balancing their weight and lean to the sides to make the platform rotate. The game can help patients learn to differentiate colors and is connected sorting tasks. Sensory wise we maintain the audio feedback on actions to indicate correct and wrong decisions. Voice and Communication remain with a low impact, the child can eventually communicate the colors better, but it's outside of the focus of the game and not something the game would be used for.

Table 4.5: Scores that therapists have attributed to the game Balance in each dimension of the classification.

Body Functions		Activities & Participation	
Mental	7	Mobility	8
Neuromusculoskeletal	8	Tasks	7
Sensory	5	Communication	2
Voice	1	Learning	7

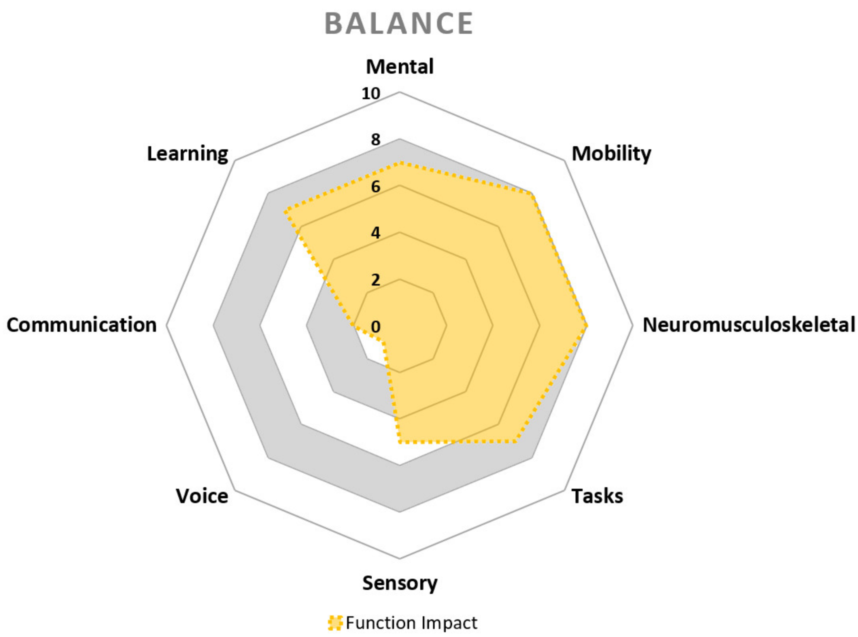


Figure 4.14: Visualization of the classification for the game Balance.

Applying our classification system to this game (Fig. 4.14), therapists gave it the scores seen in Table 4.5.

4.4.5 Bubble (G5)

The idea for the Bubble game came from a game that one of the therapists had used before, which has a similar objective of using one's center of balance to roll a ball through an obstacle course and reach the end in the least amount of time possible. With this game, we tried to answer the complaint that games designed for the general market usually do not store valuable data that can be used in future evaluations of the patient's condition. The game structure in PLAY consists of one level, with a sequence of a single "Free"action. Like in Balance, the center of pressure is constantly being measured allowing it to be mapped in a graph a assess how the patients balance themselves during the whole game.

Goals: Improve Equilibrium, Understanding direction.

Bubble is slightly more demanding than Balance (4.4.4), mobility wise, and in the way muscles are used. This game requires changing body positions more often and in every

Figure 4.15: Screenshot of Bubble game.

Table 4.6: Scores that therapists have attributed to the game Bubble in each dimension of the classification.

Body Functions		Activities & Participation	
Mental	7	Mobility	9
Neuromusculoskeletal	9	Tasks	8
Sensory	6	Communication	2
Voice	1	Learning	8

direction. A connection can be made to navigation tasks, as patients must make their way through the river avoiding obstacles trying to make the optimal route to be as fast as possible. Sensory wise there is also more happening on screen with multiple moving obstacles like boats and floating barrels.

Applying our classification system to this game (Fig. 4.16), therapists gave it the scores seen in Table 4.6.

4.4.6 Balloon Party (G6)

With Balloon Party, our initial plan was to develop a very simplistic game with the sole goal of blowing up balloons with the press of a button. The intent was to stimulate children with lower cognitive abilities by having them make the connection between the action they take and the reaction of the balloon blowing up. The first version was a game that had three balloons displayed horizontally (Fig. 4.17). By pressing each button in the lowest row of the dance mat, the respective balloon fills up with air until blowing up.

After showing the first game in the clinic, the therapists came up with two new ideas for games that would be appropriate for their patients. One of them was a game where several balloons rotated around a center point, and the player must press a button when the yellow balloons entered the target area (red box) in order to blow them up (Fig. 4.18a).

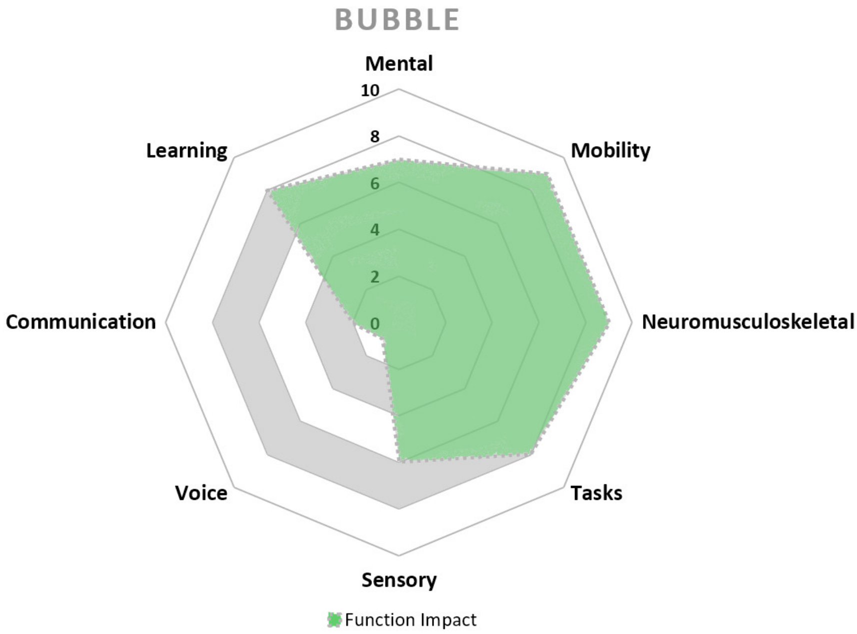


Figure 4.16: Visualization of the classification for the game Bubble.

Figure 4.17: Screenshot of the basic Balloon Party game.

In this game, the therapists can adjust the speed at which the balloons rotate and the number of balloons. The other game had the balloons displayed in a grid (Fig. 4.18b), and the player could make the target box move to the next balloon by clicking the lower left button on the dance mat. Once the target is over a yellow balloon, the player can press the lower middle button a single time to blow it up. Therapists can adjust the number of yellow balloons that show up. These version are more complex and the player must make the distinction between the pink and yellow balloons to make the decision of blowing them up.

This last game was initially developed to also be played with a single-button interaction, patient's would have to double click said button to move the target, and press

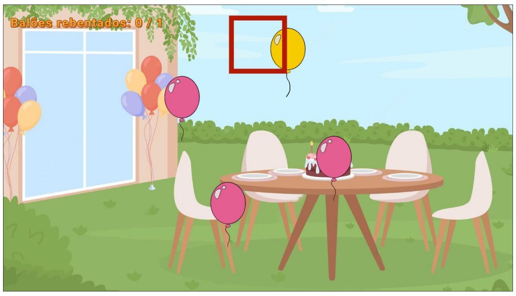
Table 4.7: Scores that therapists have attributed to the game Balloon Party in each dimension of the classification.

Body Functions		Activities & Participation	
Mental	3	Mobility	9
Neuromusculoskeletal	7	Tasks	3
Sensory	4	Communication	1
Voice	1	Learning	2

it a single time to blow up a balloon. It was noted that it was very hard for them to perform the double click action quickly enough, and so, the interaction was changed to two buttons.

The configuration of the number of balloons the patient has to blow up or their speed, when applicable, is set be adjusted only in-game, meaning that the game structure in PLAY also consists of one level, with a sequence of a single "Free"action. We still record every button pressed on the dance mat, and the time the button is held down each time it is pressed.

Goals: Stimulate reaction processing, Understanding color, Decision making.



(a) Rotating balloons version.

(b) Grid of balloons version.

Figure 4.18: Screenshots of the two additional game modes for Balloon Party.

Balloon party was designed to be simple and accessible to patients more limited cognitive abilities. The games still require mobility to press the buttons, especially in the rotating level. Even with the party scenery, there is not much relation to an actual meaningful task or learning opportunities. Sensory stimulation is mainly related to just the balloons exploding.

Applying our classification system to this game (Fig. 4.19), therapists gave it the scores seen in Table 4.7.

4.4.7 Music (G7)

The Music game is by far the simplest of the games developed. It only serves the purpose of stimulating a small reaction from the patient by having a music play when a button is held down and stopping when the button is released. Its target audience is children with

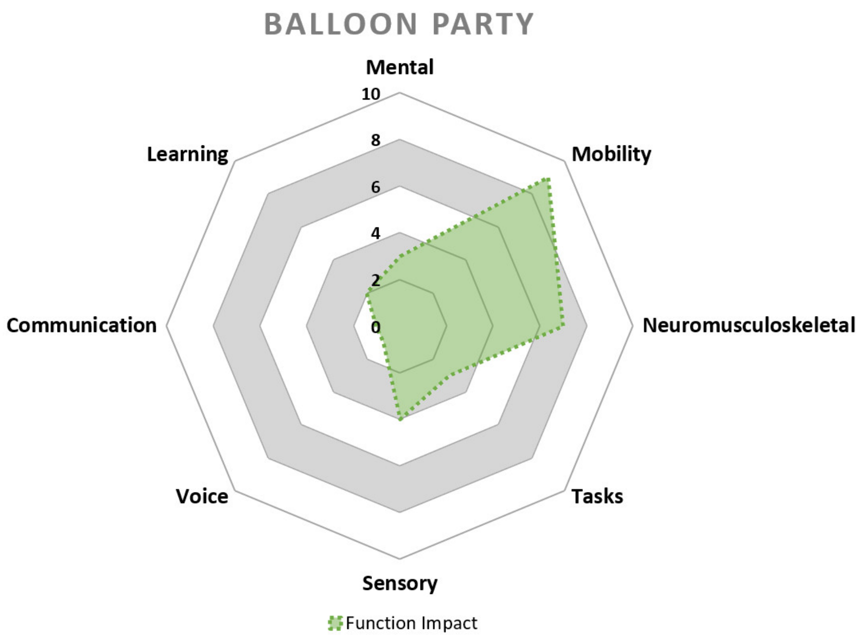


Figure 4.19: Visualization of the classification for the game Balloon Party.

limited cognitive and slightly above average physical abilities. This game also follows the structure of the single "Free"action and records only the number of times the button to play music is pressed and the time it is held down each time.

Goals: Stimulate reaction processing.

Figure 4.20: Screenshot of the game Music.

Music would really only have an effect in encouraging the patient to perform the action of pressing the button to listen to the music. The game is very simple in terms of interaction and cognitive capacities. Applying our classification system to this game (Fig. 4.21), therapists gave it the scores seen in Table 4.8.

Table 4.8: Scores that therapists have attributed to the game Music in each dimension of the classification.

Body Functions		Activities & Participation	
Mental	3	Mobility	7
Neuromusculoskeletal	6	Tasks	3
Sensory	4	Communication	2
Voice	1	Learning	2

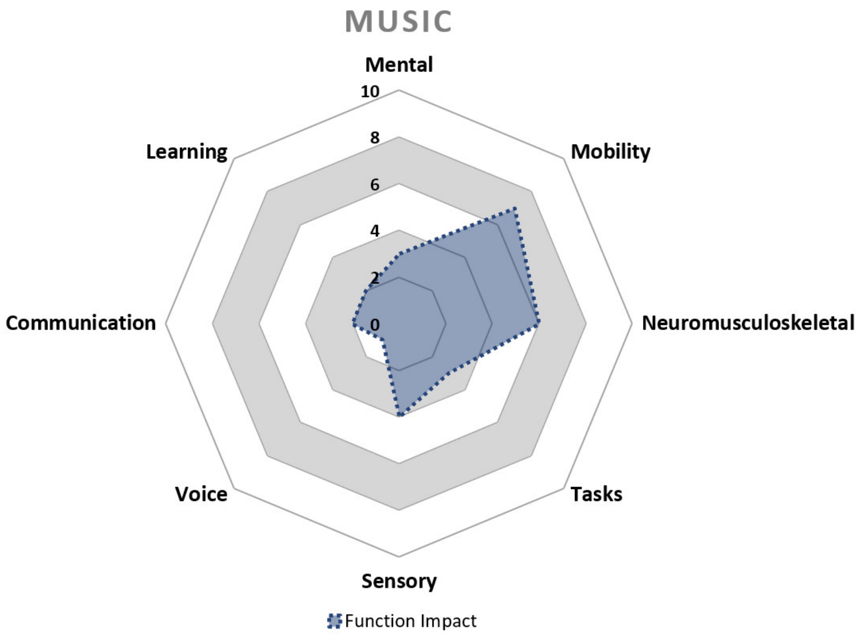


Figure 4.21: Visualization of the classification for the game Music.

4.4.8 Fishing (G8)

The fishing game was abandoned early on into the usability testing phase (Sec. 5.1), and so we will not classify but it still deserves a mention in this chapter.

The game was developed as an even more complex version of the games "Matchmat"and "Left or Right?". It had the same physical requirements as Left or Right? while being more demanding at a cognitive level. Instead of a clear representation of the dance mat using the same symbols, we would see the player at the center, on a boat, surrounded by water (Fig. 4.22). Fish would then appear around the player character in positions corresponding to the button on the dance mat. Once the player presses the correct button, a mini-game is triggered where the player must press the left and right buttons to reel in the fish (Fig. 4.23). The idea was to force repetitive left and right movements to workout the balancing muscles. The game proved to be too complex for the patients we worked with as they did not understand the purpose of the game, which could turn out to be frustrating.

Figure 4.22: Screenshot of fishing game. The fish can randomly appear around the player and they must understand which button to press by relating the position of the fish on screen with their own position on the dance mat.

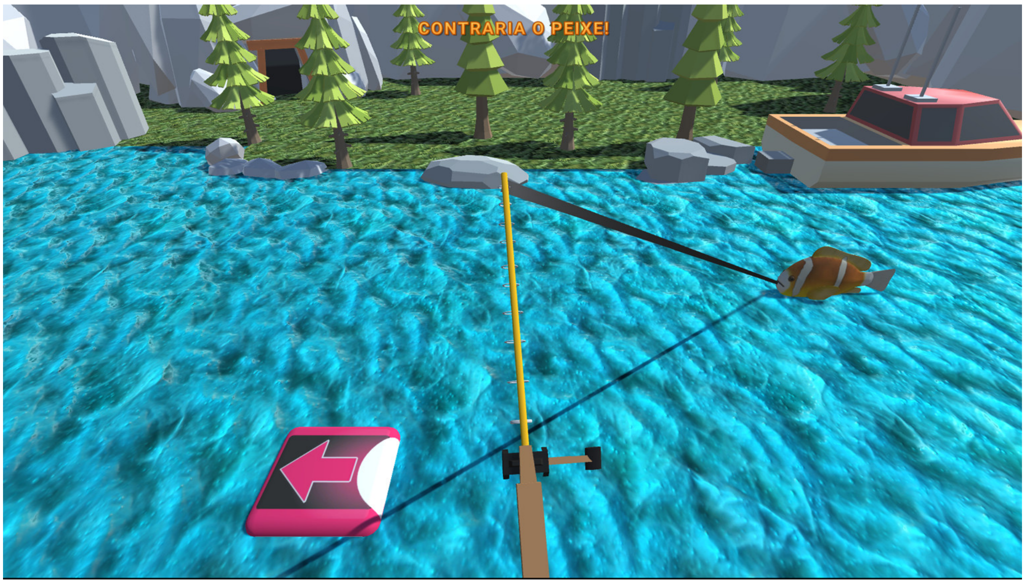


Figure 4.23: Screenshot of the side to side fishing mini-game that is triggered once a player presses the correct button.

5

Evaluation

We installed the game suite in the controlled environment of the partner clinic in order to evaluate the system's usability, but also its value as a tool that can support therapists in making their patients, children with disabilities, to be more engaged in the context of therapy. Given the nature of our target audience, this is an important step for validation because the professional expertise of the therapists will be able to translate behaviors and reactions that the children have towards the games that otherwise we wouldn't be able to identify, helping us validate more subjective parameters such as the motivation, for example. By testing the game in an experienced clinic, we also got a better idea if the games developed using the design thinking approach could deliver on the serious goals they were designed to do, because we have access to the therapists' knowledge and data from years of experience working with children with disabilities.

We felt that dividing the Evaluating stage into two different phases would be beneficial to have a first one more focused on the user acceptance of the system and another one where therapists could classify each game once they were more familiar with the system as a whole.

This chapter details the test protocols and session structures of both of our evaluation phases. Section 5.1 presents a usability study, while Section 5.2 presents the way we asked therapists to classify each game. Each of these sections describe how data was gathered and its purpose in each of their relevant subsections, followed by the results obtained and their discussion.

5.1 Usability Study

Our first **Test** phase, introduced in Section 3.5, happened at the end of the first cycle through all the Design Thinking stages after having developed the prototypes for the dance mat. The test allowed us to get our first insights into the usability and value of games for therapy co-designed with a team of experts.

At this stage, our main concern was to assess the children's acceptance of the system and the therapists' enthusiasm for using it in their therapy sessions. Due to the many

Table 5.1: Patient Gender Distribution.

Gender	Participants
Female	1
Male	9

Table 5.2: Patient Age.

Age	Participants
3-6	4
7-10	5
10+	1

different ways in which the children at the clinic were affected by their respective disabilities, the studies can not be as standardized as when working with neurotypical children with normal motor function. We decided our approach with this study would be to test the usability of mat-controlled games and how children with different symptoms would be able to interact with them. We also wanted to assess the degree of success they would have in their interactions and if we could establish some kind of patient profile that could benefit more from these games.

5.1.1 Participants

For this study, the therapists carefully selected patients whom they believed could benefit from the system, taking into account their diverse diagnoses and abilities. We managed to get ten participants. In Table 5.3, we can see a complete list of the participants along with their diagnoses and characteristics. For the patients with cerebral palsy, we include their GMFCS level. Participant P6 was a female, and the other nine were male (Table 5.2). The ages ranged between 3 and 11 years old (Table 5.2), with a median of 7.5, and every patient performed the tests under parental consent.

5.1.2 Protocol

Each test session was independent and intended to evaluate the ability of children with disabilities to use the games developed and how the same disabilities limit the use of the games.

The context of the thesis was explained to the parents and caregivers by the therapists so that they could give informed consent for their child's participation. The therapists collected all relevant demographic and health data before the testing sessions started. An account was created on the PLAY platform for each patient that was going to test the system to be able to collect and store game performance data during gameplay. No personal information is stored, and each user is identified by a generic participant username.

For this study, all participants attempted to play every game accompanied by their usual therapist. The interaction of a given patient with every game is what we considered a test session, and each session took no longer than twenty minutes. In this phase, the games tested were:

- **Matchmat** - The patient had to correctly press the buttons corresponding to a sequence of 10 symbols. For each button pressed, the Manhattan Distance to the

Table 5.3: Diagnosis and Characteristics of the patients that tested our system in the usability test.

ID	Diagnosis	Characteristics
P1	Spinal Muscular Atrophy - Type I	General muscle weakness. Restricted amplitude of movement (mainly elbows, knees, and hip).
P2	Articulation and Phonological Disorders	Neurotypical development.
P3	CP - Spastic Diplegia	GMFCS II. Able to walk, run, and climb stairs with the support of a railing. Difficulty jumping and balancing on one foot.
P4	CP- Spastic Tetraparesis	GMFCS IV. Higher function with the upper left limb. Limited amplitude of movement of knees and hip. Able to roll independently. Slight cognitive deficit.
P5	CP- Spastic Tetraparesis	GMFCS IV. Able to roll with assistance and remain seated with the support of the upper limbs. Difficulty dissociating lower limbs. Cognitive deficit.
P6	CP - Spastic Diplegia	GMFCS III. Lower limb constraints and difficulty maintaining balance while standing without support. Can perform all posture transfers but with a higher risk of falling. Prefers to stand with flexed knees and hip. Slight cognitive deficit.
P7	CP - Left Hemiparesis	GMFCS I. Bigger upper limb constraints and difficulty maintaining balance while standing on one foot. Able to walk, run and climb stairs without assistance.
P8	Global Developmental Delay	Lack of motor coordination and planning.
P9	Autism Spectrum Disorder	Difficulties with information processing and motor planning. Difficulty performing the same activity for long periods.
P10	Autism Spectrum Disorder	Difficulty focusing and managing frustration. Slight trouble with motor planning.

correct button was calculated. At the end, a lower average distance meant the player had a good performance.

- **Left or Right?** - The patient had to correctly press the buttons corresponding to a sequence of 10 symbols. For each button pressed, the Manhattan Distance to the correct button was calculated. The therapist had to encourage the patient to use the correct foot. At the end, a lower average distance meant the player had a good performance.

- **Crazy Car** - The patient had to use the buttons to dodge obstacles for as long as they could, trying to get as far as possible. At the end, a greater score (longer distance achieved) reflected a good performance.

- **Fishing** - The patient had to catch five fish by pressing the button corresponding to the position they had shown up on-screen. For each button pressed, the Manhattan Distance to the correct button was calculated. At the end, a lower average distance meant the player had a good performance.

The order in which games were played wasn't taken into account because, at the time of testing, we were only interested in evaluating the usability of mat-controlled games and how children with different disabilities would be able to interact with them.

Testing sessions were spread over the course of two weeks, and we only had limited time with each patient. Our testing sessions had to be done during small time windows that coincided with the time patients went to the clinic for their regular therapy sessions without disrupting their treatments.

5.1.3 Test Session Structure

Before each session, we asked the children if they wanted to participate, and the therapist assessed how comfortable they were in the process. On a few occasions, parents asked if they could be present for the session, which we allowed as it would also be interesting to get some subjective feedback from them. While the therapist prepared the patient and gathered equipment needed to help them play the games, we would prepare the game suite by logging in the patient's PLAY account.

During the session, we explained the goal of each game to the children together with the therapist and would let them get familiarized with both the game and the dance mat. We would then stand back while the therapist helped the child play through the game to avoid being an unnecessary distraction. After each game, the therapist assessed if the child would like to continue playing and decided if we were ok to proceed.

At the end of the test session the therapists would answer a questionnaire with questions directed specifically to the interaction of that patient with the system. When possible, an adapted questionnaire was given to the children as well.

5.1.4 Data Gathering

Early on, we found that the Fishing game was not adequate to use with the children because it was hard for them to recognize the place of the fish and press the correct button. Also, in some cases, since the character used for reference, at the center of the screen, always turns to face the fish, some children were inclined to always press the button representing the "front"position. For these reasons, no data was recorded for this game and we focused only on the games "Matchmat"(G1), "Left or Right?"(G2) and "Crazy Car"(G3) when moving forward with testing.

We gathered data from every test session to help us validate the work done. Data related to game executions and performance, like total playtime and number of correct actions, was sent and recorded in each of the patient's profiles in the PLAY platform (detailed next in 5.1.4.1 Game Data). We also collected the opinions of patients and therapists on the usability of the system through questionnaires at the end of each session.

For games that used the dance mat and had a clear target button, such as G1 and G2, we treated the dance mat as a 3x3 grid where each button has a value of one, and calculated the Manhattan Distance (MD), which is the distance between two points measured along axes at right angles, between each button that was pressed and the current target button (Fig. 5.1). This distance could then be used to reinforce performance measurements by adding an extra layer of "error distance"to otherwise binary hits or misses.

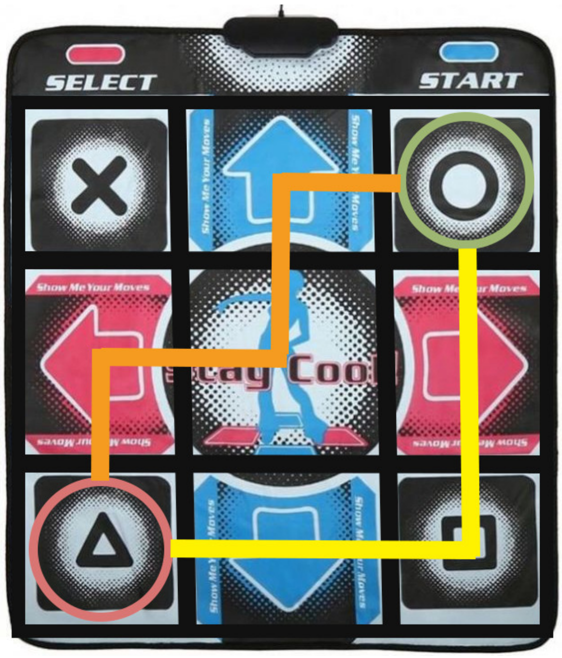


Figure 5.1: Representation of a Manhattan Distance of 4 between a pressed button, bottom left, and a target button, top right. Any path between the two points, measured along the axes at right angles, will return the same distance.

5.1.4.1 Game Data

Each time a patient plays a game, we record the time that game execution occurred in the patient's profile. During the game's execution, we can then send a sample to the platform each time the user performs an action, i.e., pressing a button, that gets stored associated with that same game execution. In games such as G1 or G2, where we import the game structure from PLAY, we can use that structure to compare if the button pressed was correct and calculate the total error MD, as mentioned previously. For these games we store:

- Date and time the game was played - useful for keeping track of, and organize, the activity a patient has on the platform.

- Each button press together with a timestamp - these timestamps can be used to create a virtual "Replay"feature on PLAY for therapists to see when and which buttons were pressed.
- Total error MD - during an action, if a patient presses wrong buttons several times before reaching the target one, the error MD of each button press for that action is summed. At the end of the game the error distances of all actions is also summed, reflecting how accurate a patient was with their button presses.
- Number of actions completed or failed - an action is completed when the patient finds the target button within the time limit, otherwise it is considered a fail.
- Total time patient stood on buttons - useful to analyze what is the reaction time of patients returning to the center position after each button press. A lower total value means that patients were quick to return to the center position after moving to press a button.
- Final score - the sum of all the action scores. An action is worth 100 points, but pressing the wrong buttons subtracts points from the action score until it reaches zero.
- Total game duration - in general a faster time would mean a better ability to play the game, but a better score is more important.

For G3 we store the same data, excluding the error MD, because it is played without following a predefined structure imported from PLAY. The final score is also calculated differently. In G3, the final score is the sum of the distance the car traveled without crashing and the number of coins collected (each coin is worth 10 points).

Our goal is for this data to be stored in PLAY to have it easily accessible to therapists for posterior analysis and comparison. At this stage we also wanted to get as much data as we could from the used devices to help us understand which metrics for measuring patient progress would be the most useful.

5.1.4.2 Usability Questionnaire

A two-part questionnaire was set up to be answered by both the therapists, and, when possible, by the children after each session to assess their thoughts and suggestions about the proposed solution. The first set of questions was directed at the children, using a simplified System Usability Scale (SUS) [8] where the questions were adapted to a younger audience [44] to get their direct opinion about the games and their overall experience with the system using the support of a visual representation of the Likert scale (Fig. 5.2).

The second set of questions, also using SUS, was directed at the therapist that accompanied the child during the game session. The SUS questions were directed to the specific interaction of each child with the system from the therapist's point of view. Since the

Figure 5.2: Visual Likert scale used to help children answer the questions.

therapists were always involved in the development process of the system and given the many variable patient characteristics, our goal with this questionnaire was not necessarily to attain a high score with the SUS. Our interest was in using the SUS structure to understand how children with different disabilities would interact with the mat and their motivation to do so. Then, on the side of the therapists, we wanted to see if exergames designed to be controlled with a dance mat could have a role in the therapy regimes of their patients.

5.1.5 Study Results

For each game we collected data that was considered to be relevant to evaluate patient performance along with the total time they took on each try of the game (Table 5.4). For "Matchmat"(G1) and "Left or Right?"(G2), for each button that the child presses we save which button was pressed and the timestamp for that action, how much time the button was held and the total amount of time the patient spent on top of a button, the number of actions completed, the final score, and we also calculate the Manhattan Distance (MD) of the button pressed to the target button. For the purpose of this study we focused on the last stat as our success measure, the shorter the total Manhattan distance is, the better the child performed at the game. For the "Crazy Car"(G3) game, since the goal is to dodge obstacles for as long as possible the metric for success is the game play Time (s), the longer the better, but we also save each button pressed with an associated timestamp. Using those success measures we were able to get a better idea which patients were able to have a more positive relation with games according to their characteristics and also group them how by frequently a therapist believed they would use the games with their respective patients (Table 5.5). Despite being more interested in assessing the acceptance of the system by both the patients and the therapists, we tried to collect as much data as possible from the dance mat in case it could prove useful for comparisons in the future and to understand its full potential has the means of interaction in a game developed for therapy by uploading all the previously mentioned game data to the PLAY platform, there it will be accessible for inspection and use even beyond this work.

Table 5.4: Table displaying the averages of the rest of the game data collected for each patient. Score represents the final score, Duration is the total time taken to finish the game, Reaction is the total time patients kept pressing the buttons, and Actions are the number of completed actions, c, and the number of total actions, t.

ID	Matchmat (G1)				Left or Right (G2)				Crazy Car (G3)	
	Score #	Duration (s)	Reaction (s)	Actions c/t	Score #	Duration (s)	Reaction (s)	Actions c/t	Score #	Reaction (s)
P1	-	-	-	-	-	-	-	-	200	9.34
P2	1078.3	39.7	12.27	11/11	870	32	5.51	9/10	259.5	10.72
P3	1085	18.5	5.32	11/11	900	15	7.03	10/10	176.3	2.03
P4	-	-	-	-	-	-	-	-	163.2	11.99
P5	-	-	-	-	-	-	-	-	62.2	4.32
P6	560	114	34.28	8/11	-	-	-	-	108.5	1.80
P7	1090	77.5	29.94	11/11	970	44	13.91	10/10	124.6	9.00
P8	725	102	31.55	9/11	-	-	-	-	92.1	4.05
P9	717.5	117	42.68	8/11	-	-	-	-	105.9	7.02
P10	1045	65.5	35.71	10/11	800	42	13.83	8/10	236.8	4.6
#	900 ± 224.6	76.3 ± 37.7	27.4 ± 13.5	9.7 ± 1.4	885 ± 70.5	33.3 ± 13.3	10 ± 4.4	9.3 ± 1	153 ± 65.1	6.5 ± 3.6

Table 5.5: Expected usage of the system by each patient in their therapy sessions with their respective game results. Total error Manhattan Distance (MD) for game G1 and G2, and play time for G3.

Expected Usage	ID	Main Constraints	GMFCS	Needs Support ?	G1 MD #	G2 MD #	G3 Time (s)
Frequent	P6	Lower limb movement & balance	III	Yes	80	-	26
	P7	Balance & right upper limb	I	No	2	4	17.6
	P8	Motor coordination & planning	-	Yes	44	-	12.3
	P10	Autism Spectrum Disorder	-	No	0.5	8	29
Occasional	P3	Balancing & jumping	II	No	3	4	27
	P9	Autism Spectrum Disorder	-	Yes	49	-	18.5
Unlikely	P1	General weakness & joint movement	V	Yes	-	-	53.25
	P2	Neurotypical development	-	No	2.6	6	42.8
	P4	Severe lower limb limitations	IV	Yes	-	-	54.2
	P5	Severe lower limb limitations	IV	Yes	-	-	25.3

5.1.6 Result Discussion

Starting with the questionnaire results, out of the ten children, only two didn't manage to answer the questions at all. We had SUS scores ranging from 25 to 100, averaging 68.75. It makes sense that the children that were not able to play the games as intended or didn't understand them produced a lower score on the questionnaire. But we were optimistic when seeing that the children that can play gave the system very high scores. Although it is important to note that in their enthusiasm, most children tended to rate every question with the highest score, we believe that same enthusiasm shows that they were motivated to use the system and wanted to keep playing the games (Table 5.6).

On the therapist side the system got an average SUS score of 77.5 (Table 5.7). But we would like to focus on the statement: "I think that I would like to use this system frequently with this patient."In the context of this study, the answer to this question is the most important since even when a therapist understood the system and the child had no trouble playing the games, the therapist can consider that the system does not meet

Table 5.6: Modified SUS questionnaire answered by the patients with the help of the visual Likert scale. For each question, the table showcases the Median, Quartile 1, and Quartile 3 results.

	Median	Q1	Q3
I would like to play many more times.	5	4.5	5
The games were too difficult to play.	1	1	3.5
I thought the games were easy to play.	3.5	2.5	5
I need help to be able to play the games.	5	1.5	5
I knew what I had to do to play the games.	5	1.5	5
Some things did not make sense in the games.	3	1	4
I think my friends could learn to play the games.	5	4	5
The games need a lot of effort to play.	2.5	1	4
I think I played the games well.	4	3	5
I had to learn many things to play the games.	2.5	1.5	4.5
I thought the games were fun.	4.5	4	5
If I had more time, I would like to keep playing.	4.5	4	5
I will tell my friends about the games I played.	4.5	3.5	5

Table 5.7: SUS questionnaire answered by the therapists directed at the specific interaction of a patient with the system. For each question, the table showcases the Median, Quartile 1, and Quartile 3 results.

	Median	Q1	Q3
I think I would like to use the dance mat with this patient frequently.	3	2	5
I found the interaction with the mat unnecessarily complex	1	1	1
I tought the dance mat was easy to use	2	3	5
I think I need technical support to be able to use this system	2	1	2
I found the various functions in this system were well integrated.	4.5	4	5
I thought there was too much inconsistency in this system.	1	1	2
I would imagine that most people would learn to use this system very quickly.	5	5	5
I found the system very cumbersome to use with this patient.	1.5	1	3
I felt very confident using the system with this patient.	5	3	5
I needed to learn a lot of things before I could get going with this system.	3	2	4

the therapy goals set for a given patient, as happened with patient P2. P2 is only enrolled in speech therapy and does not need to practice the kind of movements required by our games, so their expected usage in therapy sessions was "Unlikely", as seen in Table 5.5, where we grouped every child based on the therapist's answer to that statement. If the therapist answered the question with a score of 1 or 2, we considered that it would be unlikely a therapist used the games with that patient. A score of 3 meant they would play the games with a patient occasionally, and a score of 4 or 5 meant that therapists would consider using the games with that patient frequently. The table also shows each child's main constraints, GMFCS level, when applicable, if they needed support to play the game, and the results for each game played.

We observed that children with a higher GMFCS level and, therefore, less mobility are less likely to be able to play the games using the dance mat and, as expected, require more active support from the therapists. Especially when they also suffer from cognitive disabilities. For the patients on the autism spectrum, the bigger challenges were having them interested in the games for long periods and the abstract perception of the connection between the button pressed on the mat and the movement of the car, but the therapist accompanying them believed these were all aspects that could improve in subsequent sessions as the children got more used to the games, and that the style of the games developed could be useful to train their focus.

Because of the size of our sample, it is hard to make general assumptions about the collected data. Even so, taking another look at Table 5.5, we can see the average results each patient got in the games they played. In the column for Manhattan Distance (G1 MD#) of the "Matchmat", we can see that the values vary greatly from patient to patient and that the ones with more mobility constraints could not play it. Each of the abnormally high values are justified for a different reason for each patient. For P6 it was her slight cognitive deficit and even when she recognized the correct button, since she was playing while laying on a Pilates ball, she preferred to press the buttons closer to her because she didn't feel like stretching to reach buttons further away - this was one the aspects of her condition that therapist felt could be improved with the games. When his session started, Patient P8 was not very interested in playing the games and wanted to be held by the therapist leading to poor cooperation in the "Matchmat"game. Patient P9 was someone who had trouble processing new information and had trouble making the connection between the mat and computer screen. He was also much more interested in playing with the computer.

Only the four patients that managed to play "Matchmat"correctly were able to play "Left or Right?". We can see in the G2 MD# column that the Manhattan distance remained within understandable values, despite raising slightly. This was the result we expected since the interaction method is practically the same but the visual representation is a little more complex.

Finally, the last column of Table 5.5 (G3 Time (s)) present the time each patient managed to play the "Crazy Car"game without hitting an obstacle. The reason we see some patients with less mobility achieving better results is because the patients with less mobility were playing the games, sitting down, with excessive help from the therapists accompanying them, which to a certain degree would nullify the benefits of having the child play the game. That is also one of the big reasons therapists said it is unlikely that they would be interested in integrating the games in the therapy sessions of these patients. Regardless of that, both the development and the expert teams were optimistic with the obtained results and look forward to continue exploring this co-design process.

Analyzing patients P6, P7, P8, and P10, we observe the system was more suited for children that retained some mobility in at least one group of limbs. These children can harness more potential from the mat because they do not require a level of assistance that

Figure 5.3: **Left:** The mat can be folded to allow children with very limited mobility to play using elbows; **Right:** Child using Pilates ball to play a game while laying down.

would essentially have therapists playing the games for them. It is obvious that children with typical cognitive development understand the games faster and better, but patient P6 shows that having a slight cognitive deficit is not an obstacle to interacting with the games, as long as they can understand and recognize shapes, which is something they might even train while playing by having to recognize the symbols on screen repeatedly.

The different ways the children interacted with the dance mat (Fig. 5.3) also showed us it is a versatile game controller capable of adapting to the different needs of patients. The dance mat can act as a very flexible controller that can be used in a myriad of ways at a very affordable price, which would allow the parents to easily get one and help their children play the games at home. This expands the places where the system can be used, which can only benefit the end-user.

Therapists showed interest in the system from the start and looked forward to seeing the potential of its integration into the children's therapy sessions and doing longer testing periods.

5.2 Game Classification

To allow therapists to use the system in a more realistic setting, we left the game suite and the rest of the necessary equipment at the clinic, with instructions, for them to use autonomously and integrate the games into their therapy sessions as they see fit. After around 3 weeks, we collected their feedback once more to help us figure out more definitely in what areas the games fit best and how therapists would use them in a typical therapy session with their patients.

We wanted this study to be as organic as possible; therapists were taught everything needed for the games to work and how to connect each device, and we told them they could have an exploratory test approach to each game. This approach allowed us to understand more naturally in which settings the therapists would gravitate more towards using the games instead of feeling pressured to use them under our supervision.

In the end, after therapists had more experience using the game suite with their patients, we also wanted to validate the classification system we created together with them and give a more accurate score to the games in each of the classified areas.

5.2.1 Participant Profile Overview

This study was targeted at the therapists in the clinic and their relationship with the game suit as a tool for therapy. We got the direct opinion of two therapists that used the system more frequently with some of their patients (Table 5.8) during the period of this test, via a questionnaire. We also got input from the rest of the Cresce clinic's experts, as a team, who classified the games based on their observations and experimentation with the games at the clinic. The therapists are specialized in different areas such as physiotherapy and occupational therapy.

Table 5.8: Diagnosis and Characteristics of the patients that tested our system in the game classification tests.

ID	Diagnosis	Characteristics	Therapist
P1	Spinal Muscular Atrophy - Type I	General muscle weakness. Restricted amplitude of movement (mainly elbows, knees, and hip).	T2
P2	Articulation and Phonological Disorders	Neurotypical development.	T2
P5	CP- Spastic Tetraparesis	GMFCS IV. Able to roll with assistance and remain seated with the support of the upper limbs. Difficulty dissociating lower limbs. Cognitive deficit.	T1, T2
P6	CP - Spastic Diplegia	GMFCS III. Lower limb constraints and difficulty maintaining balance while standing without support. Can perform all posture transfers but with a higher isk of falling. Prefers to stand with flexed knees and hip. Slight cognitive deficit.	T2
P11	Pompe Disease	Balancing difficulties.	T1

5.2.2 Protocol

Each test session doesn't necessarily follow a strict protocol. Therapists are encouraged to use the games with the patients in their therapy sessions, but it is ultimately up to them when and how to do it (whether they replace a whole session with game practice or use it at specific points in the session). Therapists should provide relevant information about them and the patients they choose to use the game suite with. To make the process easier and faster for therapists, we created multiple placeholder accounts for their patients that they can select on the login page of the game suite. Similarly to the tests done in Section 5.1, no personal information is stored.

In addition to the games mentioned in the previous section (section 5.1) the game suit also offered four new games, two of them still used the dance mat and the other two used the WBB:

- **Balance** - The patient must stand on the WBB and sort a sequence of 13 balls into their respective containers, within a time limit, by leaning to the left or right to tilt the middle platform in the correct direction and make the balls roll off of it into the container. At the end, the number of correct ball sorted is used as a performance metric.

- **Bubble** - The patient must stand on the WBB and lean in the direction they want the bubble to roll. The goal is too follow the path and reach the end of the level in the least amount of time. At the end, a lower time taken means a good performance.
- **Balloon Party** - Using the dance mat to play all versions of the game, there is no time limit and the patient only needs to blow up all the balloons by clicking the button when the red cursor is over them, or by holding a button to fill up the balloons with air until they explode.
- **Music** - The patient only needs to push a single button on the dance mat. The music plays while the button is held down, and the game ends when the music finishes.

When a therapist decides to use the game suite in a session, they should take note of the patient's characteristics and which game was played, and at which point in the session did they decide to play it.

5.2.3 Test Session Structure

A typical session would start by having the therapists prepare the room for the session of their patient. If they had planned to use the game suite in that session, the game suit and respective interaction devices should be turned on and connected before the session starts to ensure everything is working as expected when the patient arrives.

When the therapist wants to start using the game suit, they select one of the placeholder users from the login screen. If the patient has never played with the game suite, a new user must be selected, if they have, then the same user account should be used. The therapist must then teach the patient how to play the game and ensure they are comfortable doing so by helping them when necessary. We asked therapists to fill out a form after each test session to help us understand how they integrated the game suite in a real world therapeutic context.

5.2.4 Data Gathering

Once again, each time a game is played, that game execution is recorded on the PLAY platform. We keep recording game samples during gameplay in case they might be valuable for comparisons in the future.

A new questionnaire was designed to collect the final opinions of the therapists regarding the game suite as a tool and how they would score each game in the dimensions discussed after having more time to experiment with the system. The first section asked the therapists general questions about the games and their use, while the other sections asked them to classify each game individually according to their experience when using the games alone or with patients.

5.2.5 Study Results

The first question of the questionnaire asked therapists which time they believed to be the more appropriate to use the games in a therapy session. The therapists told us that would be in the middle of the patient's therapy session, or at the end. The rest of the questions in the first section, with their respective answers, can be seen in Table 5.9. Table 5.10, shows the final scores that the therapists gave to each dimension of the classification system we proposed. The classifications can be seen illustrated in Figure 5.4, to have visual support to the numbers table. The figure helps us show how the games we developed lean more on the side of physical therapy.

Table 5.9: Answers that both therapists gave to the first section of the classification questionnaire (scale of 1-5).

	T1	T2
I felt that the patients were excited while playing the games.	4	4
The games are able to motivate children to continue their therapy, both at the clinic and at home.	3	3
The games are capable of helping patients achieve their therapeutic goals.	3	4
The games can be a good tool to support traditional therapy.	3	5
The games can be capable of replacing some exercises typically performed in traditional therapy.	3	2
I feel that the created classification can help me choose the appropriate game for different patients.	4	4

Table 5.10: Compilation of all the game classifications. Scores were obtained by averaging the responses obtained from the therapists.

Dimension	Matchmat	Left or Right?	Crazy Car	Balance	Bubble	Balloon Party	Music
Mental	6	8	8	7	7	3	3
Mobility	8	8	9	8	9	9	7
Neuromusculoskeletal	10	10	9	8	9	7	6
Tasks	3	4	8	7	8	3	3
Sensory	5	5	6	5	6	4	4
Voice	1	1	1	1	1	1	1
Communication	1	1	2	2	2	1	2
Learning	4	5	8	7	8	2	2

5.2.6 Result Discussion

Given the small sample size we would have to be careful making general assumptions based on the obtained results. Instead, these results should be seen for what they were, the collaboration between game developers and researchers, and a clinic specialized in children with disabilities to explore new ideas while creating some proof of concepts that could help similar work in the future.

Our therapy expert team seemed to agree that patients have a good time while playing

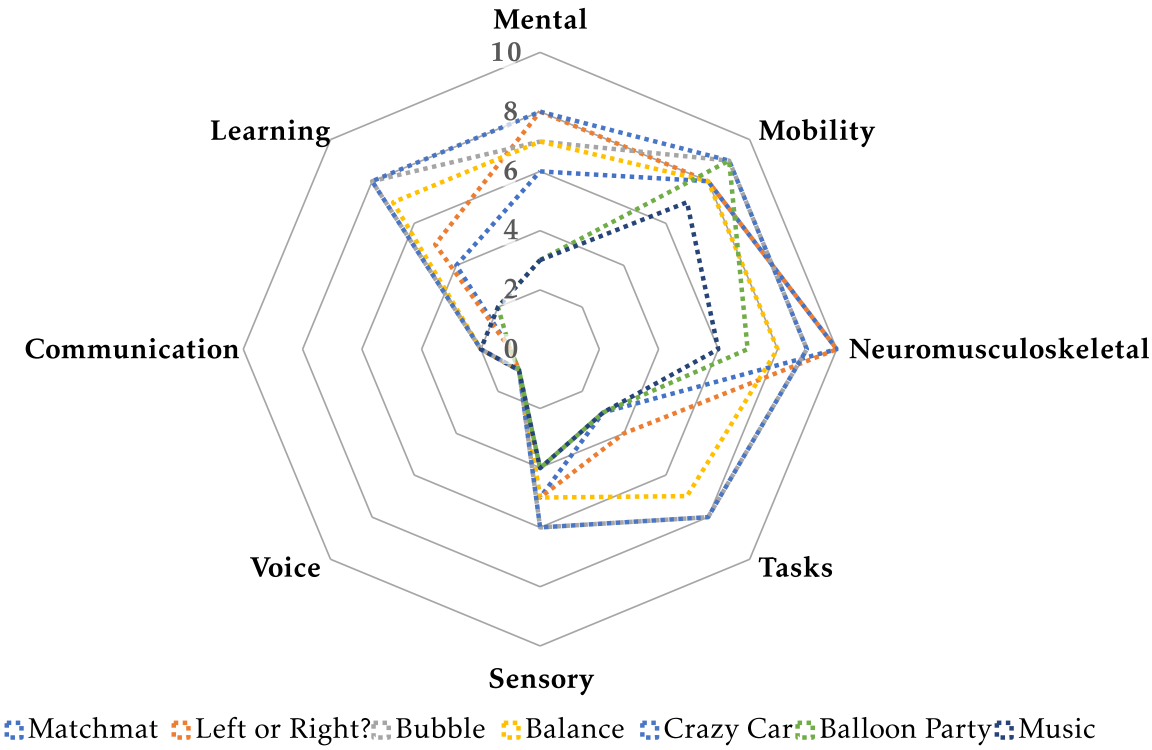


Figure 5.4: Radar graph showcasing all of the game classifications superimposed, showing how they differ from game to game. We can observe that the games developed lean much more towards side of physical abilities.

games developed specifically for them, and that the existence of a standardized classification system for games for therapy can be beneficial when deciding which game is more appropriate for a given patient. When asked if games are capable of helping patients achieve their therapy goals, or if they can be good support tools for traditional therapy, there were some divergent opinions. While not divergent enough to discourage future work, they highlight how hard it is to make a "one size fits all"solution and the importance of adaptability in games.

Regarding the classification of the games, looking at the scores in each category (and the radar charts in Section 4.4), we can see our games lean much more towards the side of physical therapy, which was our focus from the start. Yet, when creating our classification system, together with the therapists at "Cresce com Amor", we tried to make something that included other areas of expertise and functions of the body, so that it could be applied in the classification of games for other therapy settings. We believe the classification created can be a good starting point for future research and validation, and has room to expand should researchers find the need to include more functions of the body or activities.

As an exercise, before seeing the results of the therapists' classification of each game we did our own classification to see how it would compare to the opinion of the experts. We tried judging our games not only according to our perception of the body parts used and abilities needed to play the game, but also according to the definitions given in

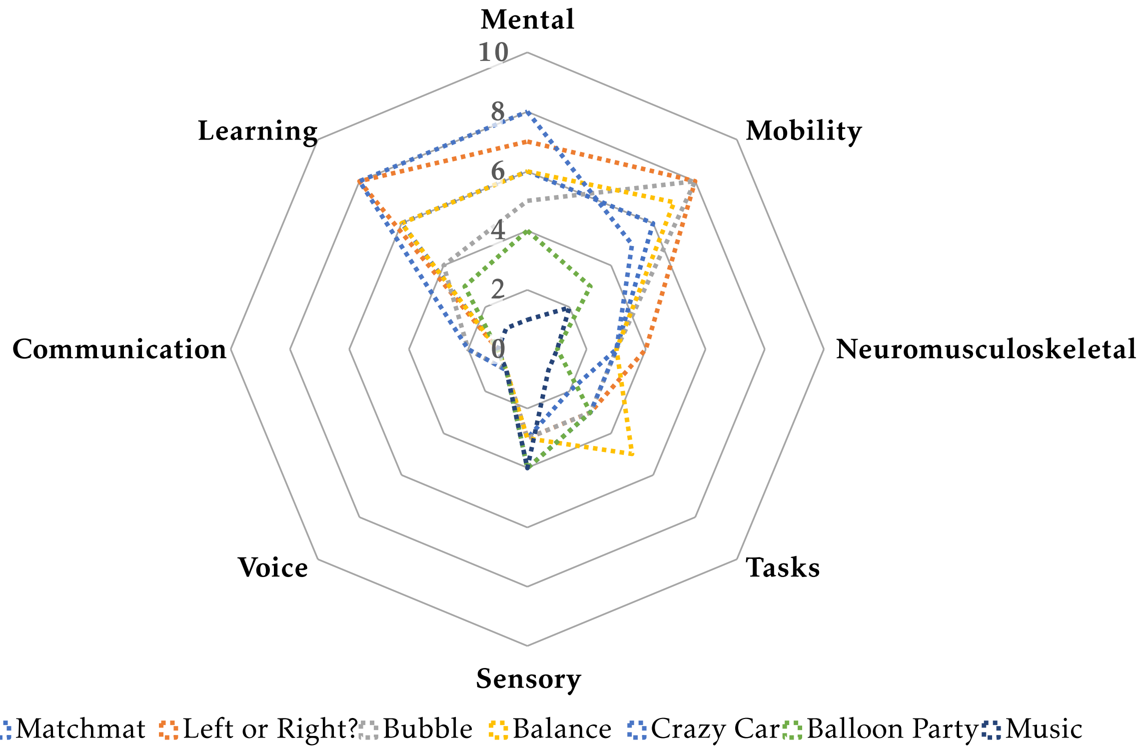


Figure 5.5: Radar graph showcasing all of the older game classifications, done by us without the help of the therapists, superimposed. We can observe that the classification varies greatly from the one done by professionals, with both over and underestimations regarding the impact a game can have on a given body function.

the International Classification of Functioning (ICF) for each body function, and the experiences we had with the patients at the clinic. Looking at Figure 5.5, it is clear that we, as developers, were often too cautious when rating each function. We were afraid of overestimating how much impact a game could have on a patient because we are not experienced in working with children with disabilities. This was just another way to show how important it is to collaborate and integrate experts in our team because even if we have all the knowledge about the inner workings of the games developed we lack a broader perspective on how to correctly apply them to the target audience.

6

Conclusions

The development of games for the therapy of children with special needs is definitely an area that benefits from the use of co-design strategies. Working with partners that are experts in the areas where the games will be deployed will ensure the project keeps following the correct direction, ultimately saving time and costs by preventing errors that would otherwise only be found after the project was near completion. From the very start, therapists were very eager to collaborate with us in the development of serious games as tools for their therapy sessions. They feel a need to modernize therapy methods in a way that allows them to gather valuable data from their patients. The children we interacted with have also shown to be very accepting of the system, as long as they were able to play it well enough to feel like they could make some progress and understand the actions they were taking.

If we were to create this system without our partnership with the clinic "Cresce com Amor"all of the games would have been created using guesswork. It would be hard to define realistic goals and expectations without having first hand contact with the patients we want to help and the therapists that care for them.

In short, the benefits of a design thinking approach are:

- Easy access to the knowledge of experts.
- Maintaining expectations at a realistic level.
- Valuable feedback at every stage of the project.
- Ability to validate the system closer the final user.

Having simple off-the-shelf controllers as the interaction method for therapy games is very viable and will enable a lower barrier of access to the games developed. Therapy can be expensive, expanding the tools therapists and caregivers have to help those in their care is important. By using games (that can possibly even be played at home) in a therapy context will not only make therapy more fun and engaging for children, but also unlock new ways for patients to follow their therapy regimes, which are often very repetitive and must be done for long periods of time.

We believe the classifications used in the comparisons of games in the literature review, while functional to make high-level feature correlations, are not specific enough to help a therapist quickly choose a game that could be useful for their patient at a given time according to the demands of their treatment needs. We hope that the classification framework we present in this dissertation is a step in the right direction for creating a solid classification system that can be extrapolated to games used in various areas of therapy.

As more serious games for therapy are created, there needs to be a standardized way of classifying them in a way that is easily understandable by therapists and can help them select the appropriate game for their patient at any given stage of their treatment. We hope the classification system detailed in this thesis can serve as a starting point to move in that direction.

In the end we believe to have achieved the objectives set in section 1.2, by detailing the process we used to create a game suite suitable for use in a therapy environment. We assessed the children's acceptance of the system in a first usability test, and later, created a classification system, together with the therapists from *Cresce*, that can be used as a tool to better visualize which areas of body functions a therapy game approaches more to facilitate choosing which game to play with a patient. Throughout the whole process we worked in close collaboration with the therapists at *Cresce* and the tests we did at their clinic allowed us to validate the work presented.

6.1 Challenges

It is fundamental to maintain focus on the therapy for children. While we, as developers, may often lack relevant ideas to create interesting games for therapy, the therapists would approach us with new ones each time we visited the clinic. With a small team you should try focus on the more relevant ideas before trying to implement all of them.

We tried to have every child play every game to understand to which extent the dance mat and the games we developed could adapt to the child's needs. If we could go back, we would have liked to make a more rigorous patient selection to avoid one or two cases where patients with high cognitive function, but very low mobility, did not enjoy playing the games because it made them feel like they were being held back by their mobility.

While working with a clinic has all the advantages we already mentioned, it is important to note that sometimes you will be limited by the availability of both the therapists and patients. Both teams must try to coordinate their schedules to make the most of the partnership. If a patient that can test the system is unavailable, you will have to wait until there is another, or look elsewhere. Testing plans must be done in advance to prevent having "dead"time between development stages because of schedule incompatibilities.

6.2 Future Work

Something that was not possible in the context of this dissertation was a deep evaluation of the impact games could have on the health of children with disabilities in the long future. After creating a tool like this, it would be interesting to research if playing the games for long periods could effectively result in a visible improvement of the patient's condition. Another direction in which the project could be expanded is adding more ways to customize the games and adjust their parameters to make them fit a patient profile more accurately. The exploration of machine learning algorithms that analyze the patient's condition and game history and then make necessary difficulty adjustments could be beneficial.

We would also like to see the classification method we present in this dissertation applied to other serious games, ideally developed by people outside of our project team, to understand how it would fare in more areas of therapy and, should it need them, which improvements can be built upon it.

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I

Questionnaires

I.1 Usability Questionnaires

Playmat Fun - Conjunto de Jogos para Auxiliar a Terapia Motora

Na primeira secção deste questionário, depois da caracterização da criança, as perguntas deverão ser respondidas, sempre que possível, pelas crianças que utilizaram o sistema. No caso de ser necessária a assistência de um terapeuta, as respostas devem sempre ser dadas pensando no ponto de vista da criança.

Para que as crianças possam responder mais facilmente, a escala de imagens apresentada em baixo deve ser mostrada para que elas escolham a emoção mais próxima do que sentiram.

1. Identificador do Paciente
2. Idade
3. Modos de Interação (Escolha Múltipla):
    - Joga em pé
    - Sentada
    - Deitada
    - Com arnez
    - Com apoio
    - Outra (Qual?)

Adapted System Usability Scale

- Eu gostava de jogar muitas mais vezes
- Os jogos eram muito difíceis de jogar
- Achei os jogos fáceis de jogar

- Preciso de ajuda para conseguir jogar os jogos
- Eu sabia o que tinha de fazer para jogar os jogos
- Algumas coisas nos jogos não faziam sentido
- Eu acho que os meus amigos conseguiam aprender a jogar os jogos
- É preciso muito esforço para jogar
- Eu acho que joguei bem os jogos
- Tive de aprender muitas coisas para jogar os jogos
- Eu achei os jogos divertidos
- Se tivesse mais tempo, gostava de continuar a jogar
- Vou contar aos meus amigos sobre os jogos que joguei

Therapist's Perspective - System Usability Scale

- Penso que gostaria de usar o tapete com esta criança frequentemente.
- Considero a interação com o tapete desnecessariamente complexa.
- Considero o tapete fácil de usar com esta criança.
- Considero que necessitaria de apoio técnico para conseguir utilizar o tapete com esta criança.
- Considero que as funcionalidades do sistema estejam bem integradas.
- Acho que existem demasiadas inconsistências neste sistema.
- Acredito que a maioria das pessoas seria capaz de aprender a utilizar este sistema rapidamente.
- Considero o sistema aborrecido e demasiado pesado para usar com esta criança.
- Acredito que utilizaria este sistema com confiança nas sessões desta criança.
- Preciso de aprender mais antes de começar a utilizar este sistema.