FACULDADE DE ENGENHARIA DA UNIVERSIDADE DO PORTO

Co-creation of Multiplayer Serious Games: An Innovative Strategy for Cognitive and Psychosocial Rehabilitation

Carolina Figueira

Masters in Informatics and Computing Engineering

Supervisor: Eliana Silva

Supervisor: Luís Paulo Reis

September 30, 2024

Co-creation of Multiplayer Serious Games: An Innovative Strategy for Cognitive and Psychosocial Rehabilitation

Carolina Figueira

Masters in Informatics and Computing Engineering

September 30, 2024

Abstract

Rehabilitation is a set of interventions designed to retrieve, keep, or optimize abilities needed for daily life. Cognitive rehabilitation refers to various methods and approaches that aim to correct deficits in memory, concentration, attention, and learning, among other higher cognitive functions such as language, logic, and reasoning. There's an understanding that people who undergo traditional treatments for cognitive rehabilitation often lack motivation due to the repetitive and monotonous nature of the methods. In this context, innovative approaches are particularly important, such as serious games, which have been shown to be motivational and could complement their treatment. A serious game is a game designed for a primary purpose other than entertainment. Industries like education, science, and health care use them intensively. Incorporating serious games in cognitive rehabilitation has been widely studied with positive outcomes. This dissertation's main purpose was to develop a platform with various serious games that complements the existing resources for the cognitive and psychosocial rehabilitation process of people with Acquired Brain Injury (ABI). Some of the games are multiplayer and cooperative to help them improve social skills and feel connected to other people, while others are single-player to allow them to play at their own pace and in solitude. The development was supported by the methodology of co-design, which guided the study towards a platform that was within the patients' preferences and expectations, in order to be useful to them. The co-design had three phases with nine, three and eight participants, respectively, and included the perspectives of patients, professionals and family members. We created a well-designed, user-friendly computer platform that benefits patients recovering from an ABI in exercising memory, executive functions, language skills and mathematical reasoning, taking into account the suggestions of those who deal with this reality on a daily basis. The main achievement was to develop an application that could complement cognitive training with a collection of appropriate games that are valuable for the recovery of ABI patients. The usability and acceptability of the platform was validated through a usability study with Think-Aloud protocols and Remote Usability Testing.

Keywords — Co-Design, Cognitive Rehabilitation, Serious Games, Multiplayer Games, Human-Computer Interaction

Resumo

A reabilitação é um conjunto de intervenções destinadas a recuperar, manter ou otimizar as capacidades necessárias para a vida quotidiana. A reabilitação cognitiva refere-se a vários métodos e abordagens que visam corrigir défices de memória, concentração, atenção e aprendizagem, entre outras funções cognitivas superiores, como a linguagem, a lógica e o raciocínio. Existe o entendimento de que as pessoas que se submetem a tratamentos tradicionais de reabilitação cognitiva têm frequentemente falta de motivação devido à natureza repetitiva e monótona dos métodos. Neste contexto, as abordagens inovadoras são particularmente importantes, como os jogos sérios, que têm demonstrado ser motivadores e que se podem constituir como um complemento ao tratamento. Um jogo sério é um jogo concebido para um objetivo principal que não o entretenimento. Sectores como a educação, a ciência e os cuidados de saúde utilizam-nos largamente. A incorporação de jogos sérios na reabilitação cognitiva tem sido amplamente estudada com resultados positivos. O principal objetivo desta dissertação foi desenvolver uma plataforma com vários jogos sérios que complementem os recursos existentes no processo de reabilitação cognitiva e psicossocial de pessoas com Lesão Cerebral Adquirida (LCA). Alguns dos jogos são multijogador e cooperativos para os ajudar a melhorar as competências sociais e a sentirem-se ligados a outras pessoas, enquanto outros são de jogador único para lhes permitir jogar ao seu próprio ritmo e em solidão. O desenvolvimento foi apoiado pela metodologia de co-design, que orientou o estudo para uma plataforma que estivesse dentro dass preferências e expectativas dos pacientes, de modo a ser-lhes útil. O co-design teve três fases com nove, três e oito participantes, respectivamente, e incluiu as perspectivas dos pacientes, dos profissionais e dos familiares. Criámos uma plataforma para computador bem concebida e de fácil utilização que beneficia os pacientes em recuperação de um LCA no exercício da memória, das funções executivas, das capacidades linguísticas e do raciocínio matemático, tendo em conta as sugestões daqueles que lidam diariamente com esta realidade. O principal objetivo alcançado foi desenvolver uma aplicação que pudesse complementar o treino cognitivo com uma coleção de jogos apropriados que são valiosos para a recuperação dos doentes com LCA, tendo sido validada a usabilidade e aceitabilidade da plataforma através de um estudo de usabilidade com protocolos Think-Aloud e Teste de Usabilidade Remoto.

Keywords — Co-Design, Cognitive Rehabilitation, Serious Games, Multiplayer Games, Human-Computer Interaction

Acknowledgments

I would like to thank my supervisors, Eliana Silva, Professor Simão Reis, and Professor Luís Paulo Reis for supporting me throughout the entire dissertation process and showing me that there's no such thing as a stupid question. I would also like to thank all of the participants and consultants involved in this work, as their contributions were pivotal for the development of the study. Gratitude for my three parents will never be enough, as they are the greatest help I could ask for in moments of need and great friends of mine. They were always very present throughout my path in university and this dissertation was only possible due to their support and love. Thanks to the three sweetest brothers I could wish for and my lovely sister-in-law, the ones who always manage to make me laugh even in stressful times and who have always been there for me. A special thank you to the friends I made during my 5 years of university, the ones that stayed and the ones that left a positive mark on me. To Marta and Miguel, the biggest group hug, as they are the ones I cherish the most, and that played a crucial role in the development of this work. Thank you, friends, I hope to always have you in my life. To my other great friends, Sofi, Nó, and Bruno I thank you for being such good friends and for the opportunities to unwind and laugh during these 5 years of hard work and the course of this last great challenge in my academic career. Lastly, the biggest thank you to my incredible boyfriend, Robbie, the one who understands me better than anyone in the world and to whom I owe so much. Even from afar, he was always there for me, during stressful times and heartening ones, encouraging me when I needed it and celebrating my victories during this process.

To all of you, thank you for being here and believing in me.

Carolina Figueira

"In the depth of winter, I finally learned that within me there lay an invincible summer."

Albert Camus

Contents

List of Figures

List of Tables

Abbreviations and Symbols

ABI	Acquired Brain Injury
SG	Serious Game
TBI	Traumatic Brain Injury
Non-TBI	Non-Traumatic Brain Injury
DALYs	Disability-Adjusted Life Years
YLLs	Years of Lost Life
GBL	Global Burden of Diseases, Injuries, and Risk Factors
CVA	Cerebral Vascular Accident
EF	Executive Function
SC	Social Cognition
ToM	Theory of Mind
AAT	Animal-Assisted Therapy
VR	Virtual Reality
VR-SG	Virtual Reality Serious Game
AI	Artificial Intelligence
ML	Machine Learning
DDA	Dynamic Difficulty Adjustment
CNS	Central Nervous System
ADL	Activities of Daily Life
GG	Game Genre
GN	Game Nature
GDS	Game Development Strategy
co-op	Cooperative
PvP	Player vs Player
PvE	Player vs Environment
MVC	Model-View-Controller
UI/UX	User Experience and User Interface
PSSUQ	Post-Study System Usability Questionnaire
GEQ	Game Experience Questionnaire

Chapter 1

Introduction

In this chapter, you will find a brief introduction to the subject of this thesis. There's a section that explains the context in which this project was conceptualized; the next section briefly presents the motivation for its development; and one section explains the goals set for this implementation to be successful. And finally, an overview of the structure of the document.

1.1 Context

Rehabilitation services are needed by people who have lost the ability to function normally, often because of an injury or trauma, a stroke, an infection, a tumor, surgery, or a progressive disorder. Its design is thought out mainly to help people who have lost important faculties and consequently their independence. Furthermore, cognitive rehabilitation is a specialized treatment procedure to retrain partially or completely lost cognitive functions through various methods and approaches. The main focus is to correct deficits in memory, concentration and attention, perception, learning, planning, sequencing, and judgment.

An Acquired Brain Injury can cause brain damage that compromises the normal brain functions of patients, so their integration back into the community can be challenging. Given those impacts, it is crucial to evaluate the effectiveness of the currently available treatments. The classical techniques depend on therapists and the dislocation of the patients to clinics, which can be an inconvenience for financial or mobility reasons. Another difficulty faced by patients relates to the repetitive nature of the tasks involved in the recovery process, which can be seen as tedious and monotonous. That discouragement can often lead to the abandonment of treatment.

This project was proposed by and has had the help from LIACC (Laboratório de Inteligência Artificial e Ciências da Computação), a research unit created in 1988 by 5 PhDs in Computer Science and Artificial Intelligence from the University of Porto. Their mission is to produce both software algorithms and prototype systems backed by relevant publications while assisting young researchers in developing their theses. Regarding this dissertation, LIACC had previously worked on papers and projects that will help ground the research for this one. Some of their previous works included the usage of multi-player Serious Games (SG) as an additional part of

the cognitive rehabilitation of patients with Acquired Brain Injury (ABI). This project will focus on both the cognitive and psychosocial perspective of the therapy, as the rehabilitation games will be multi-player and will create the opportunity for the patients to interact with each other, friends, or family. However, the innovative aspect of this project is its co-creation design process, which will ensure the users' needs and a better understanding of the expectations of the final product.

1.2 Motivation and Goals

There's a need for innovation in the treatment process for ABI patients. SGs can be a good way for patients to feel invested in their recovery through a playful and social perspective while not replacing the traditional rehabilitation treatment. The idea is to create a platform that patients can use to play games and interact with each other while exercising their cognitive abilities including memory, concentration, reasoning, and problem-solving. In addition, SGs have been proven to be very beneficial to physical and cognitive rehabilitation for motivational and focus reasons.

The motivation for this study is to give the patients a platform of mini-games in which they can interact with other patients, as well as family or caretakers while playing games that will improve their cognitive capacities. There is a high necessity for innovative approaches in this field due to the monotonous nature of the traditional rehabilitation process. Through a co-design approach involving the stakeholders of the product, we hope that this thesis works as a bridge between game development and the lived experiences of this community while creating a tool that motivates patients of ABI and is appealing and adjusted to their needs and preferences.

The main goal of this Dissertation is to create an alternative way to support a complex process such as cognitive and psychosocial rehabilitation. We hope to create a well-built and accessible platform that gives patients an adequate and useful tool to assist them in their journey to recovery. The platform has to cover cooperative game models while letting patients play and collaborate with other patients, caretakers, and family members. The games will incorporate tasks that deal with different areas of cognition, to better suit different patients.

1.3 Question and Requirements

To achieve the goals described in Section 1.2, the research will focus on answering the following research question:

Is it possible to develop a useful and accessible multiplayer serious game for cognitive and psychosocial rehabilitation of patients with acquired brain injury with the contribution and involvement of the stakeholders?

To answer the question, the process will include:

- Study and identification of the set of cognitive areas we want to address and which games on the market have the same goal

- Study how to ensure ecological validity to make the experience as intuitive and generalized to real-life settings as possible
- Study and identify the social aspect of each game, and how the player can interact with the other players
- Study of difficulty balance models, setting parameters to ensure a fair and steady progression in difficulty in the game
- Co-design the serious game to ensure the usability for individuals with ABI
- Test the usability and acceptance of the serious game

For the platform to provide value, the game must exercise different cognitive areas and the tool must create the opportunity for patients to socialize with peers. Hence, the application must meet the following requirements:

- The game has a user-friendly design
- Each mini-game must exercise a different cognitive area
- Some mini-games must be multiplayer if not all of them
- The game must follow the requirements and suggestions made by the participants of co-design

1.4 Structure

Besides the introduction, this dissertation has 6 more chapters. In Chapter 2, the current state of the art and related works are described, along with a deeper elucidation of the specific subjects of this thesis. An examination of features and design choices in games for cognitive rehabilitation is also included, as well as a discussion about the ones used in the final tool. Chapter 3 presents the problem and proposed solution, with further detail on the co-creation process that was initially intended to be conducted. Chapter 4 displays the actual solution and co-creation steps, with details of the previous versions of the design changes. Chapter 5 presents the game designed and developed, with images to illustrate it. Chapter 6 explains the usability tests performed with key stakeholders to ensure the platform's usability. Finally, Chapter 7 will state the conclusion, the answer of the initial research question, and propose future work.

Chapter 2

Literature Review

To better understand the need and importance of this project, this chapter covers the explanation of important subjects such as Acquired Brain Injury, Cognitive and Psychosocial Rehabilitation, Serious Games, Intelligent Agents, Handicapping Systems, and Co-Design. This will also be the place to discuss previous works on Serious Games in general, Serious Games for Rehabilitation, Co-design in Serious Games for Rehabilitation, and Co-design for the Analysis of Rehabilitation for patients with Acquired Brain Injury. Finally, other subjects specifically important to this project will be mentioned, such as the Ethical Challenges the study might face.

2.1 Acquired Brain Injury

An ABI is an umbrella term that could refer to a Traumatic Brain Injury (TBI) or a Non-Traumatic Brain Injury (Non-TBI) since both injuries are caused after birth. The difference between the terms lies in the origin of the injury. While a TBI is provoked by an external traumatic event in which the person suffers a disruption in brain function, Non-TBI is inferred by a disease that among other possible consequences, damages brain tissue. Causes of TBI include falls, accidents, sports-related injury, and violence, while Non-TBI could be caused by a stroke, neoplasm, infection, and anoxia (Goldman et al., 2022).

TBI is traditionally seen as a sudden and brutal event with both short-term and life-long consequences. Studies indicate that there is a limited number of cases available on long-term outcomes of TBI (Stocchetti and Zanier, 2016). According to Maas et al. (2022), few studies have estimated the fatal and non-fatal burden of TBI (seen as disability-adjusted life years (DALYs)), but a study on European data from 16 countries suggests that each TBI death is associated with about 24 years of lost life (YLLs). The same source reports the results from the Global Burden of Diseases, Injuries, and Risk Factors (GBD), which rated a worldwide age-standardized TBI incidence of 346 per 100,000 people in 2019. In Portugal, the incidence of TBI is 65 per 100,000 people, while the mortality rate is 10 per 100,000 inhabitants (Santos and Agrela, 2019). Another study, made to assess the provision of rehabilitation services for individuals with a disability after TBI, concluded that while 90% of them reported rehabilitation needs, only 30% received in-patient rehabilitation

and 15% received outpatient rehabilitation (Andelic et al., 2021b). This indicates that even though studies such as Khellaf et al. (2019) suggest that "TBI is a major global health challenge and priority", there's still a need to increase the efforts to reach the care it requires.

As for Non-TBI, the reviews and studies of the previously mentioned diseases are few but the most common cause is considered to be cerebral vascular accidents (CVA), commonly referred to as 'stroke'. The incidence of strokes is a source of preoccupation since GBD reported that in 2019, stroke was the second leading cause of DALYs worldwide in both the 50–74 years and 75 years and older age groups (GBD 2019 Diseases and Injuries Collaborators , 2020). In addition, the number of people living with stroke impacts is estimated to increase by 27% between 2017 and 2047 in the European Union, mainly because of population aging and improved survival rates (Wafa et al., 2020). Furthermore, Luengo-Fernandez et al. (2020) shows that stroke costs European countries €60 billion a year, and the costs of stroke are rising over time, also for aging reasons. As for Portugal, CVA is the main cause of death and prolonged incapacity in the country, according to a member of the Portuguese Society of Internal Medicine (Fonseca, 2021).

With the surface of the COVID pandemic in 2019, patients showed complications of the central nervous system (CNS), such as ischemic CVA. Studies on the variety of symptoms of the pandemic were conducted and it was revealed in Parsay et al. (2021) an incidence of 1.7% for ischemic CVA in the setting of COVID-19 infection, with a mortality rate of 29.2% amongst the COVID-19 patients who are suffering from ischemic CVA. In Portugal, according to Fonseca (2021), the COVID-19 pandemic had other impacts such as the decrease in demand for hospital healthcare, and in the cases where it happened, it was too late. In the case of stroke patients, the delay often led to more severe sequelae since the treatment began after the acute phase.

For cases of ABI, different interventions and combinations of interventions are required to meet the needs of patients with different problems. There are various approaches to this rehabilitation process, such as in-patient, out-patient, or group-based rehabilitation. Rehabilitation processes that promote interaction are ideal when patients feel disconnected from society since Watson et al. (2020) show that individuals with ABI often experience emotional, cognitive, and behavioral disturbances including anxiety, stress, depression, and impulsivity. Given that, Andelic et al. (2021b) affirms that "targeted rehabilitation programs aimed at improving outcomes should involve psychological services to meet the needs of individuals after TBI".

There's an understanding of the need to study and improve the rehabilitation process for ABI, as well as the need for more extensive multidimensional and standardized assessments of functional and psychological impairments. In addition, the provision of corresponding rehabilitation services is deficient (Andelic et al., 2021b), especially in low and middle-income countries (Kaloyan Kamenov and Cieza, 2019) where the incidence is many times higher than in high-income countries (Rubiano et al., 2021; Maas et al., 2022). Andelic et al. (2021b) indicate that there are various unmet rehabilitation needs for individuals with moderate-to-severe disabilities after TBI.

In Portugal, the usage of modern technological applications is already a topic of discussion in an attempt to ease the work of health professionals, including those working with CVA patients.

The program of the latest Congress of the Center for the Study of Cerebral Vascular Disease of the Portuguese Society of Internal Medicine addressed the topics of the role of artificial intelligence in pre-hospital care and the benefits it can have for CVA patients. The perspective of the coordinator of the Center is that pre-hospital use will allow for the optimization of the distribution of resources, to improve the quality and response time of the teams in the assistance to the users (Fonseca, 2023). This project is a proposition to explore that but about the patients themselves. It's an opportunity to explore the benefits of incorporating software in the treatment of ABI patients, with a platform that meets their needs and helps them reach their rehabilitation goals.

2.1.1 Cognitive Functions

Disorders of cognitive functions (language, perception, attention, memory, or executive functions) are frequent following ABIs and have a significant impact on independence, school attendance, social relationships, and employment opportunities, ultimately causing reduced quality of life (Mantovani et al., 2020; Fride et al., 2015). Cognitive deficits are present in over 70% of stroke survivors (Rost et al., 2022), and clinical studies indicate that impairments in attention, executive function, and processing speed are the most prevalent among stroke survivors (Teasell et al., 2018). However, these impairments may be differently impacted throughout neurological recovery. For example, attention, and executive functions may be most affected at stroke diagnosis, while impairments in memory, executive, and visuospatial functions are notable 3 months post-stroke (Lingo VanGilder et al., 2020).

While strokes are usually accompanied by more noticeable motor, sensory, or speech issues, they can sometimes be the sole symptom of a stroke. Deficits such as alexia, agraphia, acalculia, or a mix of these are often seen in such patients (Friedman et al., 1993; Johansson-Malmeling et al., 2021; Mycroft et al., 2002; Fung et al., 2011; Beeson et al., 2005). Therefore, a stroke should be suspected in any patient who suddenly has difficulty reading, writing, or doing simple math calculations (Grimaldi and Jeanmonod, 2018) and rehabilitation programs for individuals with such brain injuries should encompass not only language and writing skills but also numerical abilities to address the diverse cognitive deficits they may face.

Alexia is a rare condition characterized by a complete or severe loss of reading comprehension due to brain injury, damage, or trauma. It is associated with neurological issues and often occurs alongside agraphia, which is the inability to write. This condition most frequently appears after cerebrovascular accidents (strokes), but it can also result from brain trauma, tumors, infections, or abscesses affecting certain brain regions (Barbosa et al., 2024b).

Acalculia is characterized by the inability to mentally perform basic arithmetic calculations. It can be seen in conditions such as dementia, central nervous system (CNS) tumors, and stroke (Velasco and Moreno, 2006). The main cause is damage to the left parietal cortex. When acalculia happens due to a stroke, it is typically accompanied by other impairments in speech, sensation, or motor skills (Grimaldi and Jeanmonod, 2018). Symptoms may include difficulty with number recognition, sequencing, and basic arithmetic operations. Despite its significance, the prevalence of acalculia following stroke remains understudied.

2.1.2 Cognitive Rehabilitation

To improve cognitive functioning, three types of non-pharmacological cognitive interventions have been developed. Cognitive stimulation includes a wide variety of non-specific exercises, such as discussions, reminiscence therapy, and reality orientation, being focused on cognitive and social functioning reinforcement. Cognitive training aims to maintain or improve an aspect of cognitive functioning such as memory, attention, or problem-solving through structured and guided practice on a set of tasks that reflect cognitive functions (Clare et al., 2003; Bahar-Fuchs et al., 2020). Finally, cognitive rehabilitation is a process that involves identifying ways of meeting individual needs, with an emphasis on improving or maintaining cognitive abilities related to everyday task performance, compensating impairments, and supporting independent living. It includes a wide range of therapeutic cognitive interventions to achieve functional changes by reinforcing, strengthening, and reestablishing previously learned patterns of behavior or establishing new patterns of cognitive activity (Mantovani et al., 2020). It is generally delivered by neuropsychologists, clinical psychologists, occupational therapists, speech pathologists, nurses, and rehabilitation physicians.

The most common classifications for the different approaches taken in cognitive rehabilitation are "cognitive retraining" and "functional compensation". According to Clare Nowell and Ponsford (2020), cognitive retraining aims to restore impaired cognitive functioning and often involves specific and repetitive ordered training exercises with gradually increasing difficulty or cognitive demand. Functional compensation, on the other hand, involves developing alternate strategies and utilizing remaining abilities to complete everyday tasks, circumventing or lessening the burden of impairment.

Clare Nowell and Ponsford (2020) explored current clinician practice in cognitive rehabilitation following TBI across countries. Among its conclusions, clinicians identified the use of specific and appropriate goals for cognitive rehabilitation as an important factor in the success of cognitive rehabilitation. Furthermore, it demonstrated that, based on the survey, the domains of attention, executive functioning, and memory are most commonly addressed by international clinicians engaged in cognitive rehabilitation.

It is shown that rehabilitation is a very extensive and tiring process that requires the inclusion of, and access to, well-coordinated multidisciplinary tasks, which address the varying needs of patients with ABI. Those needs are, many times, unmet in the long run following ABI (Andelic et al., 2021a). Fuentes et al. (2018) conducted a longitudinal cohort study investigating the unmet needs of children following TBI during the first two years after injury. They reported that children with brain injuries generally have persistent, unmet functional needs across multiple areas and should be monitored closely for unresolved functional impairments. Increased time post-injury and a diagnosis of complicated mild TBI were associated with unmet therapy needs, particularly in the areas of cognition and communication.

Different studies have tried to understand the effectiveness of treatments for cognitive rehabilitation. Most of the reviews on the subject conclude that there's a limited quantity and quality of available research (Ali et al., 2020; Alashram et al., 2019; Cisneros et al., 2021). However, stud-

ies show that having multimodal cognitive training targeting executive functions (EFs) has shown positive results, especially in older groups of patients of ABI. Cisneros et al. (2021) addressed the efficacy of a multimodal cognitive rehabilitation program developed for older adults with TBI, and its effect on enhancing EFs. It concluded that older adults with TBI "can improve their cognitive and daily life functioning after multimodal cognitive training targeting EFs".

2.1.3 Psychosocial Rehabilitation

Humans have a fundamental need for social connection and belonging. People who suffer with ABI, like many that experience hardships, could struggle with fulfilling that need. It has been shown that individuals with an ABI report their primary long-term concern to be social isolation and loss of social contact (Lowe et al., 2021). According to Zavaleta et al. (2014), social isolation is seen as the deprivation of social connectedness; or the inadequate quality and quantity of social relations with other people at the different levels where human interaction takes place such as individual, group, or community. Motor, cognitive, and socio-emotional impairments often limit social participation, which causes individuals with acquired brain injury to be especially vulnerable to social isolation (Salas et al., 2022).

Social cognition (SC) consists of mental representations of interpersonal relationships, which are crucial to the mind of the individual to promote functional social behaviors. SC may be considered as the ability to process, interpret, and foresee thoughts, emotions, and actions by other people. This area of cognition includes a vast number of distinct but interdependent psychological domains, including both perceptual functions, such as the recognition of emotions and perception of social cues, and more elaborate functions, such as empathy, Theory of Mind (ToM), and pragmatic abilities of communication (Maggio et al., 2022; Milders, 2019). Although the knowledge of such social cognition impairments in TBI patients is over 40 years old, the research on the mechanisms and ways to assess it only gained attention at the beginning of the century.

After a TBI, studies have shown that many patients change in emotional and social behavior. According to Anneli Cassel and Togher (2019), relatives report 60–80% of people with severe TBI experience enduring changes to their behavior and personality after their injury. Besides, they can become indifferent, egocentric, aggressive, impulsive, disinhibited, or irritable, as well as show emotional liability and poor social judgment and communication (Milders, 2019). Those changes can result in a major obstacle to psychosocial recovery, as they impose difficulties in social integration by undermining a person's capacity for independent social activities, making and sustaining relationships, and employment opportunities. Alterations to behavior and personality are long-lasting and enduring (Williams et al., 2020), so reduced participation in society and social isolation are reportedly usual for those with TBI, with individuals' circumstances often only worsening with time (Anneli Cassel and Togher, 2019). According to Stocchetti and Zanier (2016) disorders such as TBI may disrupt previous relationships and preclude return to work, with severe economic and social impacts. The same source affirms that family and social support play an important role in attenuating the consequences of injury, as well as high-quality care over the whole rehabilitation process.

McLean et al. (2014), a study on the association between social participation and subjective quality of life for non-employed, community-dwelling adults with moderate to severe TBI at 1 year or greater post-injury, concluded that lower levels of loneliness were associated with higher levels of general social integration and higher levels of perceived social support. It also suggested that to increase the subjective quality of life, it is important to increase opportunities for individuals to participate with others and also to enhance their subjective experience of social and leisure activities.

Muldoon et al. (2019) identified how social identity changes may impact those affected by acquired brain injury. Participants reported social identity loss as well as changes in their social networks and social group memberships. Furthermore, they talked about how identification with their family, community support, and group activity was an important resource they needed in their most difficult times. That suggests that belonging to groups, and the support these groups offer, are important factors in life after brain injury. Adapting to life after injury has been proven to be linked to social identity processes, which points to the importance of a social healing approach to rehabilitation.

Although this aspect of rehabilitation is considered overlooked when compared to others, recent studies were conducted on innovative kinds of methods such as animal-assisted therapy (AAT) as a method to address psychosocial skills and socioemotional functioning in patients with various deficits, including ABI. Hediger et al. (2019) proved that AAT was an effective complement to conventional therapy types in neurorehabilitation since the patients showed more social behavior with an increase in verbal and non-verbal communication and satisfaction levels, the display of positive emotions, and motivation during AAT. This method, however, depends on the availability of professionals and the presence of animals and other patients, which makes it difficult to determine its possibility and frequency in a lot of cases. Other challenges for this approach could be financial disadvantages and motor impairments which could prevent patients from interacting with the animals.

Lowe et al. (2021) assessed the true feeling of loneliness among people with ABI and reported that, although the participants did mention reduced social circle as a contributor to their social isolation and loneliness, their core experience of loneliness was considered an internal process. According to the study, each contributing factor is a possibly inevitable process in the aftermath of a brain injury. It was these internal experiences rather than external factors that participants regarded as the most significant obstacles to their re-engagement in society.

For those reasons, it would be very beneficial to introduce a platform that could comfortably connect people with ABI through entertaining activities. Patients could feel less lonely and socially uncomfortable if they engage more frequently with people who have the same condition as them while sharing a fun and effortless multiplayer game experience. That approach could help them socialize even at a distance, which means that the impairments regarding being physically present to engage in the activities wouldn't be a problem. It would also be a way to feel connected to people the patients already know and who can't be present in their daily lives, like family members and friends. As for the feeling of loneliness being associated with internal experiences, it

could be very beneficial for people with such cognitive and psychological disabilities to be able to see their progress, which can be possible through frequent activity that allows them to compare their performance over time.

2.2 Serious Games

Serious Games (SGs) are games intended for a variety of serious purposes other than pure entertainment (Larson, 2020). In contrast to gamification, which refers to the inclusion of the process of game-thinking and game mechanics to engage and solve problems (Zichermann and Cunningham, 2011) in scenarios that don't necessarily relate to a game, serious games are fully-fledged games. The mechanics of gaming are increasingly transferred to generally game-free contexts, such as primary and secondary school education, adult and higher education, healthcare, or the workplace to promote desired motivational, behavioral, and learning outcomes (Krath et al., 2021). According to Bai et al. (2020), one of the reasons why gamification, serious games, and game-based learning have become so popular is that gaming is considered as motivating. Motivation can be seen as a change in perspective that manifests in behavior and can lead to positive cognitive outcomes such as improved learning and achievement (Krath et al., 2021).

SGs became popular in teaching because unlike traditional teaching environments, where the teacher controls the learning, they present a learner-centered approach to education. The trainee feels in control of an interactive learning process, as a result facilitating active and critical learning (Checa and Bustillo, 2020). They have proved to be effective and highly motivational educational tools capable of increasing awareness, teaching knowledge, changing behavior, and improving skills (Calvo-Morata et al., 2020). SGs could be a very valuable resort for cognitive rehabilitation since patients are encouraged to perform most of their daily rehabilitation exercises at home and around only 31% of stroke patients follow it 10 due to the repetitive nature of conventional rehabilitation exercises, and lack of supervision and feedback during exercises (Hung et al., 2016).

A literature review on the usage of serious games and gamification in corporate training environments, Larson (2020), showed significant empirical evidence of successful applications of game-based learning in the business realm. L'Oreal, Siemens, IBM, Cisco, Deloitte, and McDonald's implemented gamification and serious games as a component of their training strategy and had successful results.

Similarly, a review on the usage of immersive virtual reality serious games (VR-SGs) in learning and training showed that user satisfaction, learning rates and skills improvement are higher with the VR-SG experience than with other learning methodologies, which could be seen in the greater engagement, interest, and motivation in comparison with traditional learning and training methods (Checa and Bustillo, 2020).

Haoran et al. (2019), a review of trends and learning efficacy of serious games in health professions, supports the view that serious games can work for short-term learning in the domain of health professions education and can potentially be even more efficacious than conventional teaching methods. This may be attributed to the appealing and inviting aspect of games.

Finally, focusing on the possibility of teaching and changing habits, a review of gamification and serious games pointed at children's eating habits and identified game element patterns that are characterized in terms of effective interventions and their potential to facilitate dietary behavior changes (Chow et al., 2020).

2.2.1 Serious Games for Rehabilitation

As stated, lately serious games have been widely studied as an approach to dealing with health problems. For long processes such as rehabilitation, it can be especially good to have an entertaining game that keeps patients engaged in their tasks toward recovery. In this subsection, there will be presented examples of serious games used for rehabilitation purposes.

Most of the SGs developed for rehabilitation are intended to be played by children, most likely because that target audience needs tools that help them associate their recovery with positive and fun activities or the process could be very difficult or unsuccessful. Furthermore, most of the projects found on this scope are meant to support physical rehabilitation (Rego et al., 2017), as the games focus on exercising motor skills.

For cognitive rehabilitation, there are options already available in the market, such as CogniPlus (CogniPlus, 2023). This platform offers training programs that exercise different dimensions of cognition such as attention, memory, executive functions, spatial processing, visuomotor skills, and processing speed. This intelligent interactive system identifies the user's ability level and adapts to it, making it possible for different people with different levels of cognition impairments. However, their programs are not intended to be used in a collective setting, which means the patients complete the tasks alone and most likely don't feel socially connected to others.

Figure 2.1: Example of one of CogniPlus' pieces of training that simulates driving a car. Picture from the help manual

Another example of a widely known and utilized application of serious games for cognitive rehabilitation is RehaCom (RehaCom, 2023). This system assists the therapy of cognitive disorders and claims to remain relevant through all stages of recovery. The modules of RehaCom, just like CogniPlus, are intended to be used by the patients alone and not in a group setting or in pairs, which doesn't contribute to reducing their feeling of social isolation.

Figure 2.2: Man playing one of RehaCom's serious games

NeuronUP (NeuronUP, 2024) is an online platform offering a range of materials and resources designed for neurorehabilitation professionals to enhance their session planning. It also includes a patient management tool to keep results organized. NeuronUP is accessible anytime, anywhere, allowing professionals to review patient outcomes, plan sessions, and access exercises. Additionally, the platform is continuously updated with new material, available in real-time. One of the key benefits of NeuronUP is its ability to create personalized sessions that patients can complete from any location. Therapists can monitor patient progress remotely and adjust exercises to better meet their patients' needs. This platform includes difficult tasks and games that simulate real life, as well as practices of social skills. It allows for the group execution of tasks, which can be beneficial for patients who need a more socially connected approach on cognitive training.

Figure 2.3: Man playing one of NeuronUP's serious games

Cogmed (Cogmed, 2024) is a personalized digital training program, designed to improve the brain systems responsible for attention and working memory. Working memory is closely related to control of attention, and uses, in part, the same regions of the brain. It is a thoroughly researched platform, with several testimonies and studies of its efficacy. Though widely used in cognitive rehabilitation, it focuses solely on those areas of cognition and doesn't mention multiplayer tasks or activities.

Figure 2.4: Example of a Cogmed game interface

In a study about the usage of SGs to promote engagement in stroke rehabilitation, a research group used different serious games that included Virtual Reality (VR) and video-capture technologies (Burke et al., 2009). Their focus, however, was upper limb rehabilitation, as motor impairments are a common consequence of stroke. The games saved information about the players to let them assess their progress and gave constant feedback to keep the players involved in the tasks. A playability study with elders from a stroke group showed that all participants exhibited enthusiasm and excitement during gameplay. The feedback mechanisms adopted also showed to be successful, with the participants agreeing that they were able to identify when a mistake was made. The image below shows one of the participants of the tests playing.

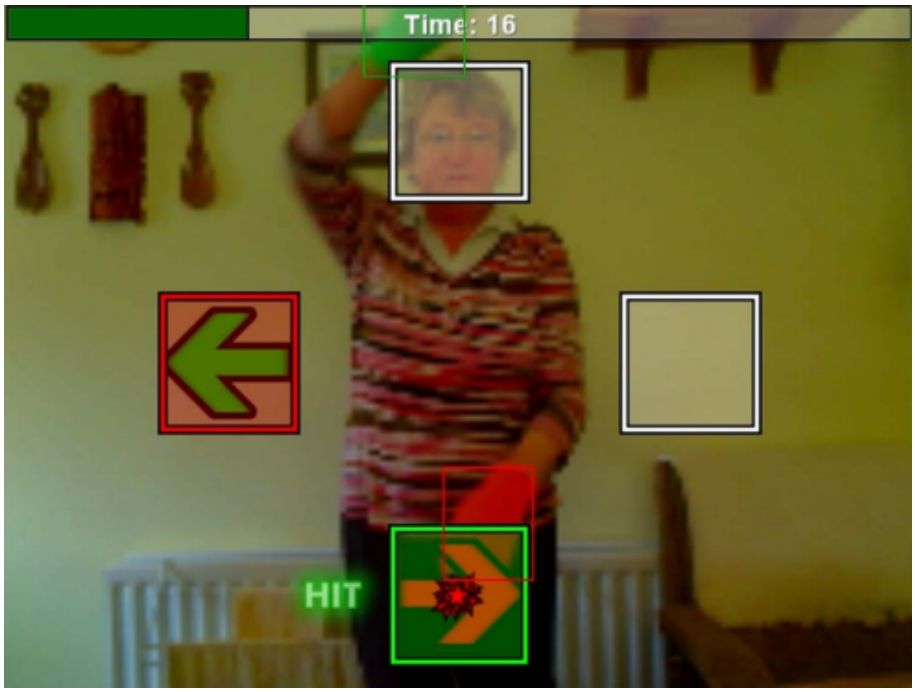

Figure 2.5: Woman playing "Arrow Attack" (Burke et al., 2009)

Rehab+ is a platform of serious games developed by Rego et al. (2017) that includes single-player, cooperative, and competitive games. It incorporated a memory game accessible in single-player mode, a sorting game, available in both single-player and multiplayer modes which covered competitive elements and a handicapping system. It also included an arithmetic game, accessible in both single-player and multiplayer versions, with the latter emphasizing cooperative features, and the single-player variant also allows for interaction through voice recognition. Finally, the "noughts and crosses" game has implemented a handicapping system.

The previously mentioned study stated that cooperative features represent a social-oriented approach to games, intending to foster increased interaction among patients and promote camaraderie with peers who use the same games. The expectation was that as patients engaged in team play, they exhibited heightened interaction, communication with fellow participants, and the establishment of social bonds, thereby mitigating any tendencies toward isolation. In the case of this project, the features described were integrated with a design that assigns specific roles to each

user in completing tasks, ensuring that both players contribute to the team's success (Rego et al., 2017). On the other hand, competitive gaming involves two users striving to achieve the best individual result, acting not as teammates but as opponents, which can be motivating. It's crucial to acknowledge the diverse difficulties among patients; since they may have distinct problems and limitations, competing in these conditions can be complex, unfair, and demotivating, contrary to the intended purpose of including these features (Rego et al., 2017).

A systematic literature review on serious games to cognitively stimulate older adults (Palumbo and Paternò, 2020) showed that, while the majority of the serious games used in the research were played on tablets, PC games were also very common. Many Virtual Reality, Augmented Reality (AR) or Mixed Reality (MR) serious games were found and as reported, the usage of those technologies is strongly driven by the potential to offer realistic simulations of scenarios found in the actual world. Finally, some WII and Kinect games were also found, although in a smaller percentage because the choice to use such technologies, similar to using AR and VR, has the goal to improve motor skills.

Palumbo and Paternò (2020) also analyzed the cognitive functions addressed in the games and reported that the majority of them focused on memory (36%), but executive function and attention were also popular (25.2% and 16.2%, respectively). Lastly, a few games in the research involved orientation (10.8%), visuospatial abilities (3.6%), and working memory (8.1%). Finally, the review concluded that, although only a limited number of articles provided valuable insights into the advancements experienced by the elderly during and after training, those that did, highlighted specific enhancements in the targeted areas. The assessment of these improvements is based on the disparity between the parameters measured in a pre-test phase and the scores obtained in a post-test phase, with some cases including results from the middle-test phase. The parameters encompass scores from various cognitive tests, and the results or scores obtained from game interactions, including metrics like the number of errors, response time, etc.

2.3 Co-design

Co-design refers to the use of user-centric research and service/systems development approaches to solve a particular problem or challenge. It has also been described as "a creative approach to research that embodies partnership with the community and focuses on how systems can improve the human experience" (Moll et al., 2020). It is a methodology increasingly used in health studies and in various of those studies it was considered beneficial to have more than one phase in which the development team met with the participants to have continuous support and feedback (Faria et al., 2018; Hou et al., 2023).

Universal Design is a concept that strives to develop services and products that cater to individuals of all abilities and possible disabilities, ensuring accessibility for everyone (Demirkan and Olguntürk, 2014). According to Burgstahler (2020), among the principles of this design foundation, some important ones would be:

- *Simple and intuitive*: The use of the design must be easy to understand on the first try, regardless of the user's experience, knowledge, or level of concentration.
- *Low physical effort*: The design can be used efficiently and comfortably, with minimal fatigue.
- *Flexibility in use*: The design caters fits in with a wide range of preferences and abilities.
- *Tolerance for error*: The design minimizes hazards and the adverse consequences of accidental or unintended actions.
- *Perceptible information*: The design must transmit necessary information effectively to the user, no matter the conditions or the user's sensory abilities.

Another interesting approach is Design Thinking, a method that seeks to innovate thinking processes, analyze and comprehend user-product interactions, and explore the operational conditions they exist. It also asks significant questions and challenges assumptions (Dam and Teo, 2022). According to Brown and Katz (2011), "The mission of design thinking is to translate observations into insights, and insights into the products and services that will improve lives." that mission could be possible through observation and empathy towards the group we want to connect to. As stated by Dam and Teo (2022), this method's main characteristics are:

- The deep desire to understand the people for whom the product/service is being developed.
- Facilitating the understanding of a problem that is poorly defined or entirely unknown.
- The observation and development of empathy with future users.
- The ability to question: it is necessary to question not only the problem but its assumptions and implications as well.

Since both aspects of co-design and serious games are relatively new, few projects have combined the two. Some co-design serious games were created for rehabilitation, and most of them focused on a more juvenile audience. Another important aspect is that those projects aimed at rehabilitation approaches that are not the focus of this study, such as physical or psychosocial for patients with physical disabilities or mental health conditions, respectively.

The process of co-design, which will be explained in more detail in the next section, included the participation of ABI patients. For that purpose, an informed consent document was used to ensure the formalization of the process and the following of Portuguese ethical, legal, and regulatory standards. For many reasons, obtaining informed consent is especially challenging in patients with compromised decision-making capacity from ABI (Kompanje et al., 2020). Due to the extensive impact of strokes, healthcare professionals encounter numerous challenges when communicating with patients. They also navigate diverse situations involving variations in the patient's cognition and mood (Rannikko et al., 2019). Several ethical challenges have to be taken

under consideration when performing the different phases of co-design, especially with a sensitive community such as the one involved in this project.

A study assessed the methods of obtaining informed consent from acute ischemic stroke patients within this context (Demarquay et al., 2005). It underscored the unique ethical challenges associated with obtaining informed consent in the context of acute stroke research. A minority of patients could provide consent during such a stage, with increasing age and neurological deficit serving as independent predictors of incapacity to give consent. Therefore there's a need to take time and explain in detail the objectives and the process that patients go through to participate in the research, even if they are not in the acute stage. Such practice was adopted in all of the co-design phases of this work.

Finally, in order to fully respect the patients' availability and time given to the project, the meetings ideally happen on days that the patients have appointments in the clinic, so the amount of extra time spent volunteering for the work is minimal. The team was also aware of the patients' limitations and tendency to cognitive fatigue, which is something to always be mindful and respectful of during the interviews and tests.

2.3.1 Co-design in Serious Games for Rehabilitation

Recently, with the increase in the usage of co-design for studies in health and the knowledge of the impact of serious games in a lot of different areas, other projects explored the idea of co-designing a serious game for rehabilitation.

Roxo and Carmo (2023) was a study that followed a co-design process to develop SGs for the therapy of children with disabilities. It assessed the benefits of serious games in the context of physical therapy as it is, just like cognitive rehabilitation, a long and tedious path without immediately visible results. It also reported the helpfulness of incorporating gamification such as the use of challenges, points, levels, and ranking systems in therapy, since it improves people's motivation to learn and increases engagement levels. 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.

Figure 2.6: Workshop at "Cresce com Amor"

Shah et al. (2023) was a co-design project for the development of a social VR-based collaborative exergame for elderly players. Key principles of exergame design were identified based on the lessons learned through the codesign and development process. The game was co-designed to train the full body according to therapeutic goals and to support avatar-mediated social interaction through collaborative game tasks. The discoveries from the five-week intervention in which the participants played the exergame either collaboratively or alone presented self-reported motivation, enjoyment, usefulness, and objective measures of effort. It was reported that playing the exergame collaboratively was significantly more beneficial for motivation, enjoyment, and social connectedness in comparison to playing alone. In terms of user experience, no motion sickness and high scores in comfort, usability, and satisfaction were reported by the participants.

Figure 2.7: Diagrams showing trunk, arm, leg, wrist, hand, and body movements in correspondence with the gameplay activity

Guglietti et al. (2022) is a co-design project of a system to treat cognitive impairment in Parkinson's disease that counted with 13 voluntary participants between the ages of 48 and 81 years old. The platform, NeuroOrb, targeted working memory, attention, cognitive flexibility, problem-solving, visuospatial function, and learning. The study reported that the response to the games was positive, with all games except one receiving an above-average overall rating. It also stated that the number of issues identified and addressed in the study underscores the significance of embracing a co-design process involving key stakeholders before the process of an intervention trial. Overlooking the identified issues could have had consequences for intervention trials, as those problems could have adversely impacted system engagement or the successful completion of the trial.

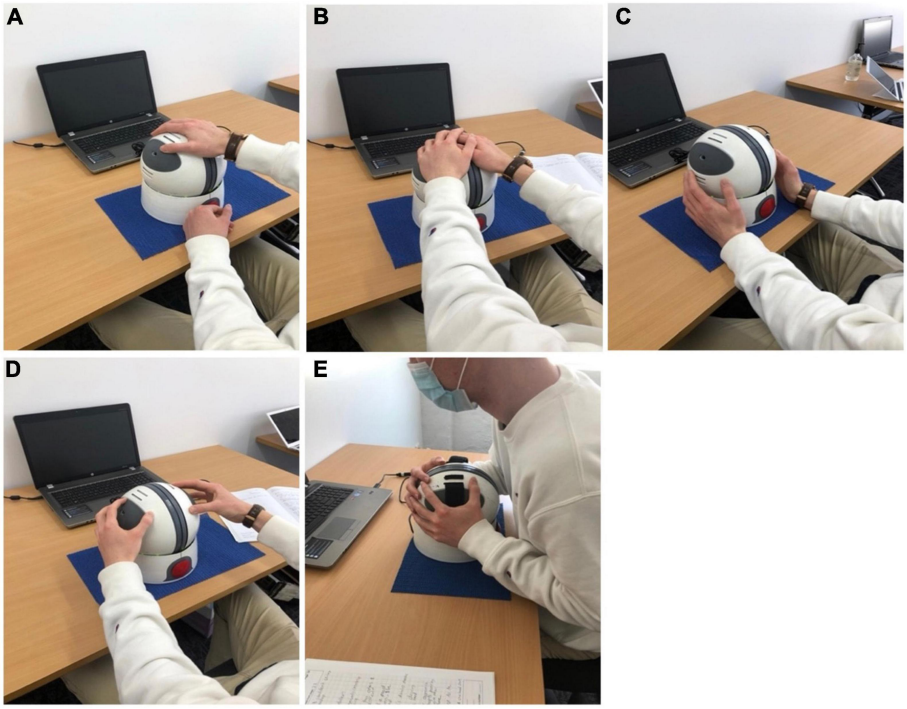

Figure 2.8: Participant of the NeuroOrb study using the controller

2.3.2 Co-design for the Analysis of Rehabilitation for Patients with Acquired Brain Injury

Since the co-design process had shown its value in assessing the needs of patients with complex problems such as brain injuries, recent studies were made to make a deep analysis of cognitive and psychosocial rehabilitation for patients with acquired brain injury.

A study identified barriers to accessing insurer funding for rehabilitation and healthcare services, for adults with cognitive-communication challenges after TBI claims that using a co-design approach allows the collaboration with persons with lived experience in designing a survey of adults who sustained a TBI in a motor vehicle collision. In the study, participants were asked about the challenges to "accessing auto insurance funding for private community services", and

their responses illustrated the broader challenges individuals with TBI face in communicating their deficits, transmitting service needs, educating service administrators, and self-advocating (Hou et al., 2023).

Nunnerley et al. (2023), a co-design of a therapeutic virtual reality tool to increase awareness and self-management of cognitive fatigue after traumatic brain injury using the method of focus groups with clinicians and individuals with lived experience of TBI to identify the design parameters and later develop a prototype using interdisciplinary design iterations. Finally, they tested the prototypes, which showed promise for addressing awareness of cognitive fatigue after traumatic brain injury in rehabilitation settings.

In the co-design approach to examine and develop pathways to open employment for people with acquired brain injury (Bould and Callaway, 2021), the method used was four different focus groups for people with ABI, health professionals, employers of people with ABI, and social injury insurers funding employment services. The participation of the stakeholders was considered a helpful tool to identify the barriers people with ABI suffer when it comes to employment and the strategies to facilitate inclusion on such matters.

These studies show that the best way to understand the limitations in the resocialization of this population truly is by consulting the ones using their methods. They showed different weak points that were found in the assessment of rehabilitation and reinsertion of ABI patients into society.

2.4 Systematic Review - An Overview on Serious Games for Cognitive Rehabilitation

To systematize the available solutions and the main design elements to be taken into consideration for the development of the project, a systematic review was conducted through the teamwork of two students. A systematic review is a research method designed to gather all empirical evidence within a specific field, critically evaluate it, and draw conclusions that encapsulate the research findings (Sriganesh et al., 2016). It involves systematically identifying, appraising, and synthesizing individual studies on a given topic to create a comprehensive summary of the available evidence. This review followed the PRISMA protocol, which stands for Preferred Reporting Items for Systematic reviews and Meta-Analyses. The main goal of this review was to comprehend the design specifics and the mechanics that are normally used in serious games for cognitive rehabilitation and which are important to include in the work here described. Parameters that were incorporated include the platform, the preoccupation with usability, the genre of the game, and the presence of immediate feedback, for example. The inclusion criteria for the papers used in this review were the following:

- Articles in which usability tests are carried out with individuals over the age of 18 and diagnosed with acquired brain damage.
- Articles on the subject of serious games used in cognitive and psychosocial rehabilitation.

- Articles that address the design, mechanics, and/or elements of serious games.

As for exclusion criteria determined by the team:

- Articles focusing on children and/or adolescents.
- Articles dealing with serious games for physical rehabilitation.
- Articles dealing with serious games with a focus on neurodegenerative diseases such as Parkinson's and Alzheimer's.
- Articles that address serious games with a focus on diseases such as Autism and Schizophrenia.
- Articles that do not describe the design, mechanics and/or elements of serious games.
- Articles in which usability tests are only carried out with healthcare professionals.

The systematic review followed the process of importing references, screening titles and abstracts, and finally reviewing the articles with the support of Covidence[1], an online software tool designed to streamline the process of conducting a systematic review. The members of the team chose two databases each (PubMed, Web Of Science, IEEExplore and ScienceDirect) to search for articles using the following keywords: ("brain injury" OR stroke OR "acquired brain injury") AND ("serious games" OR "vr" OR "computerized systems") AND ("cognitive" OR "cognition" OR "social cognition") AND "rehabilitation". In the phase of title and abstract screening, 110 studies were screened by both of the team members, where 50 of those studies were discarded due to irrelevance. The remaining 60 articles went through a full-text review, where the team searched for important aspects of this study such as design specifications and methods, and mechanics and themes involved in the games. After this evaluation, 42 articles were excluded and the remaining 18 went through the extraction phase, where the team members divided the articles to be thoroughly read and analyzed. The PRISMA flow diagram of this review can be seen in Figure 2.9.

[1]Covidence webpage: https://www.covidence.org/.

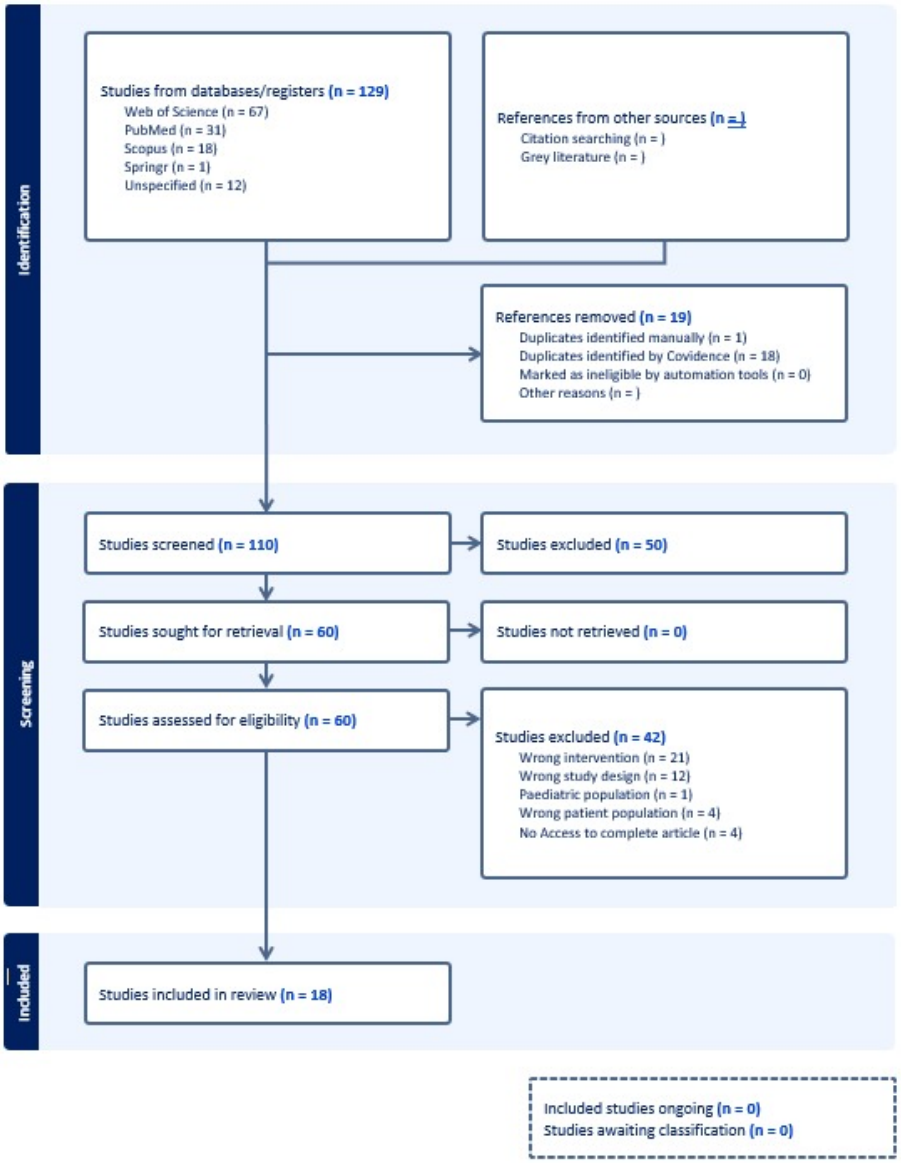

Figure 2.9: PRISMA flow diagram of An Overview on Serious Games for Cognitive Rehabilitation

The review is still being developed, but the team has already created a table summarizing the findings, of which is possible to draw some conclusions that will be taken into account for the work proposed in this document. Tables 2.1 and 2.2 present the findings of this research.

Table 2.1: Systematic Review of Serious Games for Cognitive Rehabilitation

Serious Games for Cognitive Rehabilitation						
Name	***2D/ 3D***	***Platform/ Devices***	***Feedback***	***Difficulty Adjustment***	***Genre***	***Ecological Validity***
Lanzoni et al. (2022), Vitali et al. (2021)	3D	VR[2]	-	NO	Simulation	YES
Faria et al. (2016)	3D, 2D	VR, Joystick	YES	YES	Simulation	YES
van der Kuil et al. (2018)	3D	Mouse, Keyboard	YES	NO	Maze, Puzzle	YES
Specht et al. (2023)	3D	VR, Mobile	YES	YES	Simulation	YES
Dores et al. (2012)	3D	VR	YES	YES	Simulation	YES
Mohammadian et al. (2023)	2D	Mobile Devices	NO	NO	Casual	NO
Kang et al. (2008)	3D	VR, Joystick	-	-	Simulation	YES
Elaklouk and Zin (2019), Elaklouk and Zin (2017)	2D	Mouse, Keyboard	-	-	Maze	NO
Jung et al. (2020)	2D	Mobile, Devices	-	YES	Puzzles	NO
John et al. (2019)	3D	HDM-VR[3]	YES	YES	Simulation	NO
Morán et al. (2024)	2D	Mobile, Devices	YES	NO	Simulation	YES
Park et al. (2015)	2D	Joystick, TouchScreen	YES	NO	Simulation	YES
Stammler et al. (2023)	3D	Mobile, AR[4]	YES	NO	Puzzle	-
Dores et al. (2011)	3D	VR	-	YES	Simulation	YES
Silva et al. (2023)	2D	Mouse, Keyboard	-	YES	Simulation	NO
Vallejo et al. (2017)	3D	VR	-	-	Simulation	YES

[2]Virtual Reality
[3]Head-mounted Display Virtual Reality
[4]Augmented Reality

Table 2.2: Systematic Review of Serious Games for Cognitive Rehabilitation

Serious Games for Cognitive Rehabilitation					
Name	***Usability/ Accessibility***	***Monitoring***	***Personalization***	***Guidance***	***1st/3rd Person***
Lanzoni et al. (2022), Vitali et al. (2021)	YES	YES	YES	YES	1st
Faria et al. (2016)	YES	NO	NO	YES	1st
van der Kuil et al. (2018)	YES	NO	NO	YES	1st
Specht et al. (2023)	YES	YES	NO	-	1st
Dores et al. (2012)	YES	YES	-	-	1st
Mohammadian et al. (2023)	YES	YES	NO	-	3rd
Kang et al. (2008)	YES	YES	NO	-	1st
Elaklouk and Zin (2019), Elaklouk and Zin (2017)	-	YES	YES	YES	3rd
Jung et al. (2020)	YES	YES	-	YES	3rd
John et al. (2019)	YES	-	-	YES	1st
Morán et al. (2024)	YES	-	-	-	3rd
Park et al. (2015)	YES	YES	YES	YES	3rd
Stammler et al. (2023)	YES	-	YES	-	1st
Dores et al. (2011)	YES	-	-	-	1st
Silva et al. (2023)	-	-	-	YES	3rd
Vallejo et al. (2017)	-	YES	-	-	1st

2.4.1 Preliminary Conclusions

Most of the games are VR in order to make the gaming experience closer to reality for patients. In addition, the controls are simpler and closer to how humans handle life in reality. Additionally, many games have constant feedback, as this is a fundamental feature in serious games with a focus on learning and training. Feedback is important for patients to feel progression, maintain motivation, and learn from mistakes. Many games also feature difficulty adapted to each patient, that is, automatic difficulty adjustment. This is important to keep patients motivated and avoid frustration. Furthermore, the ecological validity allows the learning during the session to be passed on to people's everyday lives, i.e. what patients have trained/learned can be easily applied to real life and everyday life. It is also an attractive point for elderly patients, who are not used to playing video games and therefore find it harder to understand the appeal of fantasy scenarios, for example. Usability tests have been carried out on most of the games in order to test them and see if the games are well suited to their target audience, but not all the studies mention specific techniques or special accessibility mechanics to cover as many patients as possible. Monitoring, personalization, and guidance are fundamental elements to maintain motivation, avoid frustration, and help the patient during the rehabilitation session with a serious game. Personalization is a feature that is not often present in games, but it is fundamental so that the game comes as close as

possible to the individual needs and preferences of each patient. Finally, the games found in this review can fall into two main categories. Most of the games fall into a category that includes the following characteristics: 3D and first-person games, mainly because they are mostly simulations, usually using VR. The other group of games includes characteristics such as being 2D, in the third person, including themes such as puzzles and mazes, and covering platforms such as computers and mobile.

Chapter 3

Problem and Proposed Solution

This chapter presents the distinct problem that this project addresses and the intended solution to it, including details on the co-design strategy, phases, and demographic specifics.

3.1 Problem

It has been shown the seriousness of the situation of incidence of ABIs in Europe and Portugal and the great part that brain injuries can take on the development of psychosocial problems such as anxiety and depression. It has also been stated that reinserting patients into society is a great challenge. Cognitive rehabilitation can be a long and exhausting process with monotonous tasks that show little change over time, which can affect the patients' motivation in the treatment. For those reasons, there is a need to reevaluate the methods used in cognitive rehabilitation and possibly innovate such a process.

Although the existing and highly adopted serious games for cognitive rehabilitation such as CogniPlus, NeuronUp, RehaCom, and Reh@City are great alternatives, all previous games are single-player. It has been proven that patients of ABI could benefit from a platform focused not only on the training of their cognitive abilities but also on their socialization.

This study proposes a simple analysis of what rehabilitation lacks as a whole, what the existing serious games could improve, and the development of a platform to help patients feel more engaged in their treatment and with each other.

3.2 Proposed Solution

The solution we intend to develop is a platform with various serious games that allow patients to exercise cognitive capacities and interact with each other, their family members, or caretakers. The platform has the goal to add value and motivation to their rehabilitation process, with cooperative and competitive games that make them see the progress of their treatment. Being a multiplayer platform, it creates the opportunity for the patients to socialize with others, even in the comfort of their homes.

Furthermore, as stated in Palumbo and Paternò (2020), the tablet is the most used device in projects similar to the one proposed, so the development of the application will have that under consideration. According to the paper, the primary rationale for utilizing the tablet is that it offers the same functionalities as a PC but with easier manageability. There is no requirement for eye-hand coordination, which is essential for mouse usage, making the interaction direct and likely more intuitive due to its touch-based nature.

We hope this project gives the patients a motivating and appealing tool adapted to their needs and preferences. The innovative aspect of this project, however, is the co-design. The co-design will make it possible, as it did in many studies before this, to understand and empathize with the patients' living conditions and experiences and adapt the product to fit their idea of the tool, in a way that will be useful and improve their rehabilitation.

As shown in the Gantt Chart below, the co-design plan includes three different phases that will enrich the process and help to better understand the needs and opinions of the stakeholders. Such a plan and its specifics will be better explained in the next subsection.

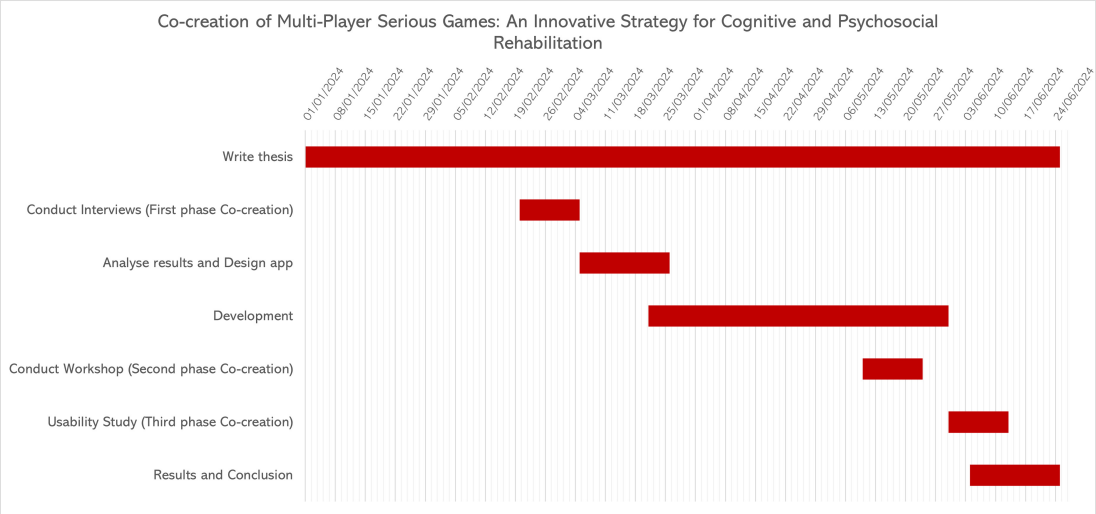

Figure 3.1: Intended Gantt Chart of the project

3.2.1 Co-Design

As this is a project centered on user experience and usability, we believe that the collaboration between those responsible for development and people with different perspectives is essential. It has also been proved critical to include diverse people in the co-design process, including those with lived experience, those who deliver or implement a service or program, and other key stakeholders (Mulvale et al., 2019). Therefore, the points of view of professionals in the field, patients, and their families will be comprehended in the research. The inclusion criteria for this study were patients over the age of 18 who have already started a cognitive rehabilitation process and who have preserved general intellectual abilities and comprehensive language skills to understand informed consent and perform the tasks required for participation (interview, serious game, and self-report

questionnaires), family members or caretakers of such patients, therapists or professionals in the field (e.g. neuropsychologists, psychologists, neurologists, occupational therapists).

Due to the short duration of this study, the co-design process will have only three phases in total. The first will be structured interviews, with open and distinct questions for each group, to understand their needs and preferences at the start of development; the second phase will be a workshop, to understand the participants' opinions on general aspects of the game; finally, the third phase will be the usability study, which will aim to validate the final prototype of the project.

The co-design is one of the most important and innovative aspects of this project. It is crucial to keep in mind the fact that the people using the platform are often affected by motor disabilities as well as the cognitive ones mentioned earlier and that the users could be of old age which could implicate a difficulty or estrangement with the usage of the technology. That's why it is indispensable to truly understand their needs and priorities in terms of appropriate subjects for the games, as well as their preferences in usability and format.

For a study of this nature involving a vulnerable population, it is essential to be mindful of how to make time and space for sharing and conversing despite timelines and resource constraints, as well as what tools, processes, and techniques will be used to fully understand lived experiences, build rapport and foster trust (Moll et al., 2020). While this section presents the idea and goal for the co-design objectively, a more detailed explanation of the methodology and the process itself will be provided in the next chapter. Furthermore, to go through with such a process of co-design in the scope of this dissertation, it was necessary to submit the project to the Ethics Committee of the University of Porto and receive their approval, and for that, a series of documents were created, which can be found in the Appendix section, under Supporting Documents.

Chapter 4

Solution and Co-Design

This chapter presents details about the solution adopted, which had to be an adapted version of the one proposed due to different postponements and delays in the data collection phases. Afterward, it demonstrates details regarding the co-design and its phases.

4.1 Solution

Because the process of acceptance from the Ethics Committee of the Engineering Faculty of the University of Porto mentioned in 3.2 took longer than expected, the plan had to be adapted to a longer period. The updated schedule is shown in the Gantt Chart below, including the work done before the Committee's verdict.

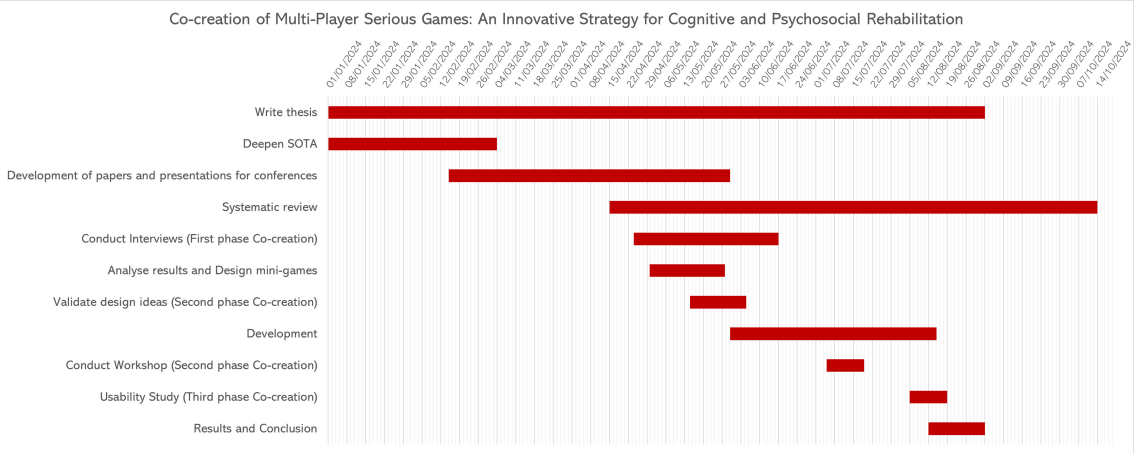

Figure 4.1: Updated Gantt Chart of the project

4.1.1 Conceptual Framework

A conceptual framework outlines the anticipated relationships between variables in a project. It identifies the key objectives of the research and illustrates how they interconnect to form coherent

conclusions. A conceptual framework includes the key process parameters, defining variables, and cause-and-effect relationships.

For the work on this project the Conceptual Framework is presented in Figure 4.2.

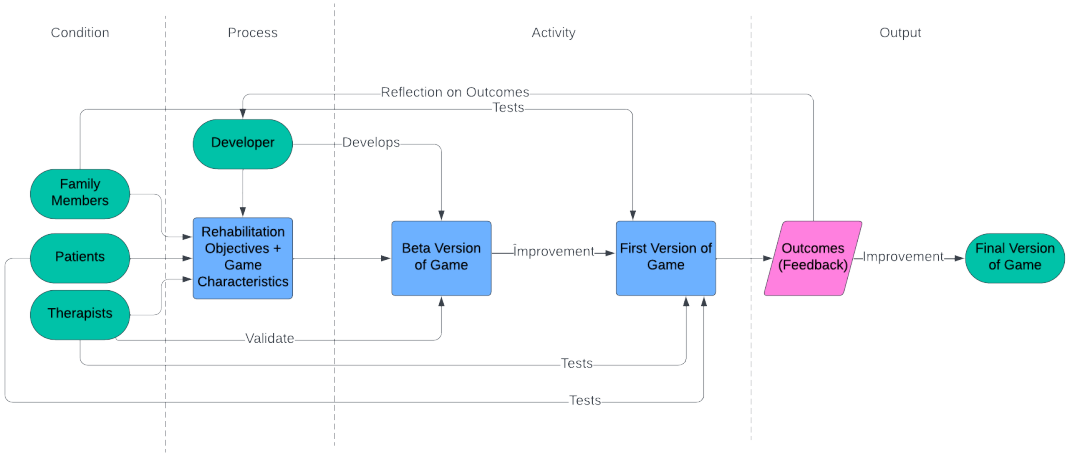

Figure 4.2: Conceptual Framework of the project

In the Condition stage, the patient's selection should be conducted by a therapist, then their family members are contacted and invited to participate in the project. The first phase consists in identifying patients' deficits, abilities, needs, and preferences, allowing for the definition of realistic therapy goals with the input of the three previously mentioned groups. The evaluation provides valuable information that aids in customizing the game-based intervention.

In the Process stage, the developer designs the game in terms of game's characteristics and defines rehabilitation goals, creating a therapeutic game that is well-suited to the patients' needs.

In the Activity stage, the game starts to be developed and a beta version is presented to the professionals, to retain validation and feedback from them. The first version of the game is then completed and enables testing with the participants. If the application successfully aligns the game's characteristics with the intended rehabilitation goals, the game may help maintain the patients' engagement in the rehabilitation process, potentially leading to specific cognitive and emotional progress.

In the Output stage, gameplay activities produce specific outcomes that provide insights into the acceptance of the application. This achievement may be reflected in simple indicators like questionnaire answers or more comprehensive measures such as the perceived level of comfort and fun while playing and level of connection with other players.

4.1.2 Serious Game Design

To develop a serious game, it is essential to consider design features related to the game genre (GG), game nature (GN), and game development strategy (GDS). The GG encompasses categories like sports, simulation, and strategy, among others. GN features include factors such as player

perspective (first-person vs. third-person), gameplay mode (multiplayer vs. single-player), the type of in-game environment (realistic, fantasy-themed, or simple), the presence or absence of playable characters, and the level of immersion, whether through immersive or non-immersive virtual reality. GDS refers to whether the game is custom-developed specifically for the study at hand or designed as a direct-to-consumer product.

In the case of the presented game, the chosen genre was puzzles and quizzes revolving around activities of daily life (ADL), such as house chores, and scenarios that would be familiar to the players and increase ecological validity. In the case of GN that approach included a first-person perspective, single-player and multiplayer experience, realistic scenarios, the absence of playable characters, and no virtual reality immersion. Lastly, concerning the third game design feature, GDS, our serious game was specifically developed for this study. However, it will be made freely available for download and use by adults with ABI and healthcare institutions interested in using it, after careful clinical validation of its effectiveness.

4.2 Co-Design

As intended, the co-design had three phases that made it possible to understand requirements and create and validate the application.

4.2.0.1 First Phase - Interviews

The first co-design phase included exploratory interviews with the three groups. For this phase it was necessary to develop documents such as the description of the project for the Faculty's Ethics Committee, the scripts for the interviews, the questionnaires, an informative flyer, and the informed consent.

Methods

Design We interviewed individuals with dementia doing cognitive training, their family members, and health professionals involved in cognitive training. The initial plan was to interview patients with ABI but that wasn't possible given the circumstances and the availability of the patients. Since the cognitive capacities affected by the conditions and the training techniques used in treatments are similar, the research wasn't influenced by that compromise.

The interviews with each group had different goals, being the ones with the patients intended to better understand their level of comfort with the technologies and devices, as well as their design preferences and daily life struggles. From the family members, we sought to understand the role that the platform could have in their engagement in treatment, as well as their preferences in terms of design and themes. Finally, to the professionals, we asked questions related to the games they used in treatment and what they lacked, and the specific mechanics and details that could make the app more enjoyable and relevant for the public.

Participants The participants were recruited from a private Neurorehabilitation Clinic. Data collection occurred between May and June of 2024. Potentially eligible participants were identified by a psychologist who worked at the clinic and to support the process of recruitment they were given an informative flyer about the project. The professional was asked to choose other clinicians working at the clinic, as well as patients undergoing cognitive rehabilitation at the clinic and their family members. They were informed that the family members and patients didn't have to be paired since the interview was very generic and the participation of any family member of a patient in such conditions was valid, even if the patients themselves weren't participating. The inclusion criteria for the participation of patients were that they were older than 18 years of age, had already begun the process of cognitive rehabilitation, and presented preserved general intellectual abilities and the ability to understand language in order to understand the informed consent and to carry out the tasks necessary for participation (interview, serious game, and self-report questionnaires)

Our sample of professionals included 5 individuals (1 male, 20%), aged 26 to 40 years old (M= 32.8; DP= 5.76), the sample of patients was of 3 individuals (1 female, 33.3%), aged 65 to 72 years old (M= 69; DP= 3.06), and finally for family members, 3 individuals (1 male, 33.3%), aged 42 to 55 years old (M= 47.66; DP= 6.66). All of the professionals specialized in either Clinical Psychology (n= 3; 60%) or Neuropsychology (n= 2; 40%), and all of the participants were Portuguese.

Table 4.1: Participants' sociodemographic data

	n	%	$\overline{X}$
Professionals			
Gender			
Female	4	80%	
Male	1	20%	
Age (range)			32.8 (26-40)
Years of Experience (range)			8.6 (3-14)
Patients			
Gender			
Female	1	33.3%	
Male	2	66.6%	
Age (range)			69 (65-72)
Working	0	0%	
Daily Caretaker/Family help	2	66.6%	
Family Members			
Gender			
Female	2	66.6%	
Male	1	33.3%	
Age (range)			47.66 (42-55)
Working	3	100%	

Procedure Data was collected at the clinic with all of the patients and one of the family members, through an online meeting and a phone call with the other two, and online direct contact with the professionals (by sending them the interview and receiving the written answers). All of which through structured interviews tailored to each group. The voice interviews lasted, on average, approximately 15 minutes (range 10-22 min). The interview structures explored the participants' personal experience with cognitive impairments and their views of the existing games used for cognitive rehabilitation, both digital and non-digital. Participants in the interviews were not compensated. All of the participants signed the informed consent document. The study was approved by the Faculty of Engineering of the University of Porto's Ethics Committee and the study procedures were performed in accordance with the declaration of Helsinki.

Data Analysis Interviews were audiotaped and transcribed verbatim in an anonymized manner. We chose to organize the data analysis by the thematic analysis method (Clarke and Braun, 2018) since the themes varied but different groups had similar perspectives. We identified 3 main themes during the analysis of the interviews, listed below. It is important to be mindful of the relation that the participant has with the condition in order to analyze the answers.

THEME 1: MULTIPLAYER APPROACH

"*For me, my concern is to be with people. I hate solitude.*"[2, Patient]

One of the important aspects of this first phase was to validate the importance of the multiplayer approach for the game that was going to be developed. According to the professionals, it was very innovative and could bring great value to the rehabilitation of this population. They added that more people could use it if it were possible to choose between single or multi-player at the beginning of the game since the patients are more used to interacting with single-player games, especially common puzzle games such as sudoku and crosswords.

"*I do the Cruzadex (crosswords), with the little book I have, and that is the most playful part. I practice at home every day, I always do a little bit before going to bed, when I go to the bathroom, to do my business, and while I'm there, I play a little bit. But I do it every day.*"[3, Patient]

Secondly, we asked about the type of multiplayer approach to be adopted by the platform. According to the feedback given by all of the groups, it was better to focus on cooperative dynamics rather than competitive. That can be explained by the importance of mutual help in the resocialization process and the fact that competition could frustrate them into giving up on the challenge.

"*I think collaborative, because if you're not at ease, you don't play well, I think it's better. I think so.*" [3, Patient]

As for whether the games should be played locally on the same computing system or online, all of the groups responded positively to a system where interaction is in person instead of remote. Professionals responded that it is interesting for clinics and community centers that both players play the games on the same system, which would imply the need for physical proximity, which could be very beneficial for their resocialization but difficult to obtain in real life.

"*I always prefer human contact. I think it's always better, but when sometimes there are disabilities or that, it's better than nothing [online games], but if everything could be human contact, I think it's much better.*" [1, Family Member]

"*Of course, the proximity would help a lot, because then I could also be a player and he could be a player. And that, that proximity, would certainly, would captivate more, would motivate more. That's for sure. So I see it more as being on the same device.*" [2, Family Member]

THEME 2: SERIOUS GAME DESIGN AND MAIN THEME

As for the main theme of the game, all of the groups suggested that it was important to make it as ecological as possible. That means that the surroundings and conditions of the mini-games should be similar to daily life, so they can easily relate to the tasks and objectives.

"*Yes, games that allow skills to be transferred to everyday life are very useful, and this is what is often lacking in rehabilitation protocols (shopping, making payments, dressing, household chores, interpersonal activities/dialogues, dilemmas, task sequences, etc.).*" [3, Professional]

When interviews with patients and family members happened, the game's main theme was culinary and food-related scenarios such as restaurants, supermarkets, and kitchens. The patients and family members very widely accepted that since those activities normally involve not only cooking but planning and managing time and money. However, the two male patients said they had less interest in cooking, meaning that the kitchen scenario wouldn't be that interesting.

As seen in Subsection 2.1.2, the main cognitive areas affected by ABI are attention, memory, and executive functioning. While in some cases it was perceptible for us, during the interview, that the patients had problems with focusing on the questions and remembering what they were talking about or what stories they had already told, other patients confirmed that those are widely affected areas for them:

"*What I often have, as I'm a very frantic person, and a bit nervous, is that sometimes, in my head, I'm doing things and suddenly everything slips my mind. I get a bit flustered, and then I have to stop and see if I can remember what I had to do.*" [3, Patient]

"*My memory isn't what it used to be, it's no use to me, is it? And it doesn't appeal to anyone's compassion for my state of mind, does it? But. Okay, now I've lost my way with this whole thing. But. Anyway, I'm getting on and trying to manage.*" [2, Patient]

As is shown in Subsection 2.1.1, the literature also refers to the impact of ABI on areas such as linguistics and mathematical reasoning, which are areas not that well explored in serious games for cognitive rehabilitation. Therefore, we asked the health professionals about the importance of those rehabilitation exercises and whether they should be part of the game.

"*I believe that the most beneficial exercises would be expressive language exercises: naming; verbal fluency; finding the right words; completing sentences; saying synonyms and antonyms. With regard to receptive language, exercises such as: spelling words you've heard or pictures you've seen, understanding sentences you've read or heard [...]. As for mathematical reasoning, it would be important to work on mental calculation, counting money, basic arithmetic, number*

processing (saying a number between x and y, ordering numbers), and applying problem-solving strategies. " [4, Professional]

One important aspect we noticed in our first interview with a family member was that for those with cognitive impairments, it is very important to exercise orientation as much as possible. Multiple interviews with patients and their families clearly highlighted the challenges they faced in situating time and place. One family member mentioned the difficulty in reading the clock hands:

"*The time, yes. The time, it's the [clock] hands. It's very confusing for him, the hands. Orienteering games might be interesting, yes. [...] That's right, the days, months, and orientation of places too. Yes, that would be interesting. He has difficulty with orientation.*" [1, Family Member]

THEME 3: SERIOUS GAME DEVICES AND MECHANISMS

Most of the professionals agreed that the best device would naturally be tablets because the interaction is by a simple touch. However, since the patients were older and showed some trouble with more recent technologies, the agreement between patients and family members was that the easiest and most intuitive device for them to interact with would be a laptop with an attached mouse or a personal computer. However, some patients showed a complete lack of comfort with any technological device, which showed the barrier that this type of solution still had to go through to be suitable for this public.

"*Yes, maybe a computer, because they don't use their cell phones, they don't really know what to do besides calling. I think the computer would be used for that, for games. It would be better too, we don't have a tablet, so maybe the computer would be better.*" [1, Family Member]

"*I have a cell phone, but it's more for receiving phone calls or something. Okay. I was traumatized by the computer, because when I was working, I did my work on the computer, passing it around, and suddenly everything went out. (...) I was lucky that I had the paper support, the work, because if I didn't, I'd have to do it all over again. (...) And I was traumatized by that. So, for me, a computer is a bug, it's a bug, I can't get to grips with it, I can't get to grips with it and I don't want to.*" [3, Patient]

We also asked professionals about feedback and game progression, and their opinion was that giving the patients both visual and audible constant positive feedback about their actions was crucial to keep them motivated. They advised us not to give negative feedback but to help them instead of highlighting errors. That can encourage them to complete the task instead of punishing them for making mistakes.

Another important detail was that we should focus on one cognitive function at a time and keep a limit for each training to not cause cognitive fatigue. That is why the solution includes several different mini-games, each with a duration of 10 minutes, instead of one big complex game.

"*It's impossible to focus on just one [cognitive function]: it's a myth. But it works better to compartmentalize in order to train mostly one area at a time. And watch out for cognitive fatigue, so focus 10 minutes on each area.*" [1, Professional]

Conclusions The games had to be first conceptualized in an early stage of the project, that is, even before the first phase of interviews with patients and family members. The reason for such a decision was the delay in receiving approval from the Ethics Committee. The first ideas for the mini-games were based mainly on the games studied in Chapter 2 and some feedback from professionals, which meant they could change and be adapted in different phases of the co-design, such as the one described in this section and the next. After the patients' and family members' feedback, some alterations were made.

After the interview with a professional who informed us that it is a myth that the training procedures only exercise one cognitive area at a time, it became clearer for the team that attention was one of the main areas that was constantly exercised even during the interviews themselves, let alone while playing a game. Thus, we chose to focus the mini-games on other areas of cognition. The solution focused on memory and executive function for the multiplayer mini-games since those were the areas that the patients seemed to have more trouble with. Since the professionals' answers were positive for the idea of including games focused on linguistic issues and mathematical reasoning, we added two other single-player mini-games to the catalog, to comprise the exercise of those two areas.

GAME ADAPTATIONS

After the feedback described above, some changes were made to the games initially conceptualized. A brief description of the adaptations can be found in table 4.2.

Table 4.2: Adaptations in the mini-game catalog after the first phase of co-design

Adaptations of mini-games		
Type	***Before***	***After***
Change of game general theme	Initially, to have a prevalent theme and aesthetic for the game, all the mini-games were designed to be focused on culinary and food in general. We reasoned that some distinct scenarios could be included in the different mini-games, and people would feel engaged.	The game was redesigned after receiving feedback on the actual problems faced by patients in their daily lives and the difficulty with simple tasks around the house. The interviews also showed that male participants had little to no interest in cooking, which would make the platform less organic for them.
Change of mini-game general theme (Perfect Pair)	The mini-game was intended to be about ordering cooking books in alphabetical order and more difficult levels categorizing by type of book and later ordering them.	After feedback on the actual problems faced by patients with Alexia from the professionals, the game was adapted to be more useful in treatment.
Change of mini-game general theme (Counting Change)	This mini-game was first thought as a cooperative multiplayer game where both players are in a restaurant and need to order while having a shared account, with a set budget. The goal was to make them solve mathematical problems of mainly subtraction.	After consulting with professionals and understanding the difficulties that players could have with mathematical reasoning, we considered that a game only about sharing an account could be too focused on a single set of math problems, so the game was changed to a completely different approach.
Change of mini-game general theme (Everything Ready?)	Initially, this game was conceptualized to be similar to other games for planning and executive functioning but adapted to multiplayer. It focused on a route that the player needed to plan by looking at a map and organizing the places they had to visit by order of proximity to create the optimal trajectory.	In order to adapt it to the suggestions given by patients and family members, the game was changed to be about organizing and planning tasks around the house, which was a common problem that most of the interviewed mentioned.

4.2.0.2 Second Phase

The second phase intended to validate the ideas for the platform conceptualized for and developed after the first phase. It was very important to have a phase where stakeholders could analyze and suggest changes during development, before the last phase of testing the prototype of the app with

the end users. Since by the time the second phase started the game wasn't finished, it wasn't possible to test the first version of it with patients and family members, so the phase described in this subsection consisted of a consultation with health professionals and a designer, presenting doubts and questions, as well as validating the game themes, features, and small details.

Professionals In the second phase, we contacted the same psychologists and neuropsychologists involved in the first phase and focused on getting validation for the mini-games initially conceptualized. Only two of the professionals were able to give us input on time for the final version of the game before the tests.

The professionals were given a video demonstrating a simplified version of the game to verify the relevance of the mini-games, their themes, and other smaller details about implementation and design. All the mini-games were approved, but some had to go through small changes. Some examples of adaptations made after their feedback can be seen in tables 4.3 and 4.4.

We also included a question about the progression of levels in the game. We saw the options of progressing dynamically through response time to incorporate dynamic difficulty strategies in the game or progressing through the percentage of wins following the example of the literature. The professionals argued that it was best to progress through a percentage of games won while having a minimum of phases for each level because focusing on response time would harm patients who have a slower response to stimuli due to their impairments.

To have a second opinion on the user experience and user interface (UI/UX) of the platform, we also consulted with an interface designer. The designer was given screenshots of the game, a description of the platform, and questions about the usability aspects regarding the text-to-speech robotic voice and what other usability options should be included in the options menu. On the questions made, the professional advised that the options menu had the ideal and most important features necessary for the end users and that the text-to-speech voice being robotic wasn't a downside on the platform. The second was explained by the importance of reminding the player that they're dealing with a machine that has limitations, making the clarity of the message the most important part. Some changes suggested by the designer are described in table 4.4.

Table 4.3: Adaptations in the mini-game catalog after the second phase

Adaptations of mini-games after second phase		
Type	***Before***	***After***
Memorization time (Memory Tornado)	The video demo of the game showed one scene from Memory Tornado where four objects had to be memorized, two by each player, and the time for the memorization of the objects' positions before the tornado passed was five seconds	Both of the professionals said that the time was too short, and suggested at least ten seconds for the first phases with fewer objects.
Shadows of the objects (Memory Tornado)	We presented the idea of showing the shadows of the objects on the screen after they were moved by the tornado. The professionals were asked if the shadows of the objects should appear in the scene right after the tornado moved them out of place or if that feature could work as the hint for this mini-game.	Both of the professionals said that, since the levels of difficulty of the patients were different, to some, having the shadows would make the game 'too easy'. They advised to keep the feature as it was useful to the game, but that the shadows should only be visible to the players in need of a hint.
Font size	Along with the demo video we asked if the font size was adequate for the patients since most of them are of old age and could find it hard to read the instructions of the mini-games.	The professionals advised that it would be best to make the font size bigger as well as the objects shown in the scenes of the game, for that same reason.
Game focus (Perfect Pair)	In the demo video, the questions of the mini-game "Perfect Pair" focused on the position of the objects shown in the scenario in relation to other objects (e.g. "The burger is..." next to/under/on "the table"). We asked if it was important to focus solely on that matter or if the mini-game should have a broader approach to the linguistics exercise.	In the professionals' feedback, they claimed that although understanding and elucidating the positioning of objects is a common difficulty for patients of ABI, it would be interesting to include phases that focused on other aspects of the scene, especially in a perspective of describing the scene and only one description in the options is correct and true.
Background noise	After first contact with patients in the first phase of co-design, we noticed that they could very easily lose a train of thought if their surroundings were too stimulating. For that reason, we made the conscious choice to keep the game very simple, focusing mainly on the objectives of each mini-game.	One professional suggested that we add low background noise to the higher levels of the game, to better emulate real life and make the experience more ecological.

Table 4.4: Adaptations in the mini-game catalog after the second phase

Adaptations of mini-games after second phase		
Type	***Before***	***After***
Instructions and feedback	The version presented to the professionals had a feature that made the text for the instructions of the mini-games and the feedback at the middle and end of the mini-games have a typewriter-like animation, where the text would appear letter by letter and a typewriter sound would play in the background.	One professional argued that "the simpler the better", and that as long as the player could choose when to advance, the text could be static for them to read at their pace.
Space between buttons	When the games were sent to the designer, Par Perfeito and Contando Trocos had their option buttons for the possible answers very close together in the middle-bottom part of the screen.	The designer advised creating some space between the buttons to augment the safety margin, since a lot of the patients show motor impairments as well as cognitive and because of that, could have less precision when pressing the buttons.
Chunking the information of the instructions	When the games were sent to the designer, the instructions scenes of all the mini-games showed the instructions as one block of text.	The designer suggested that we use the method of chunking, used in cognitive psychology which involves grouping information into smaller, meaningful clusters that are easier to remember (Psychology, 2023).
Previews of the games	When the games were sent to the designer, the mini-game menu only had the names of the four mini-game, in the center of the screen.	The designer suggested that we include images working as 'previews' of the games to illustrate what they are like and make a better usage of the space.
Standardize the 'back' button	When the games were sent to the designer, the mini-game menu had the button to go back to the main menu in a different position compared to the other 'back' buttons.	The designer suggested that we keep the button always in the same place on the screen to facilitate navigability and keep the design coherent.

After the second phase of co-design, the game described in Chapter 5 was finally conceptualized.

Chapter 5

The Game

In this chapter you can find in more detail information regarding the design and implementation of the game "CogniSpace".

5.1 Serious Game Design

The platform, named "CogniSpace", features written and audio content in Portuguese to cater to the target audience of Portuguese adults with Acquired Brain Injuries. To keep players motivated, all games provide constant visual feedback through positive symbols, accompanied by cheerful sound effects. Players will have four mini-games with tasks ranging from text and image interpretation, and mathematical problems to planning tasks step by step, and memorizing where the objects were in a scene. Each session of a mini-game lasts a maximum of 10 minutes to not cause cognitive fatigue. That means that at the 10-minute mark, the mini-game is always interrupted by the system by showing the final feedback scene with the player's score because the player could be feeling 'stuck' on a task.

Before starting each game, players will receive text explanations and rules, with an option for text-to-speech narration, which they can turn on or off in the options menu. Thinking of players who are in a more advanced stage of impairment, we also included the possibility of turning the feedback sound effects off in the same menu.

The player starts the game by pressing the 'Iniciar' button and is presented with an introduction to the platform along with a welcome message. The first challenge is a question about what time it is. The player is presented with a clock showing the current time and can input the hour and minute to receive a congratulation pop-up. That task is not obligatory to continue and is not a part of any mini-game, but it was incorporated in the game thinking about the patients' difficulty in orienting themselves in the day. After this small question, the player sees the mini-game menu, where they can choose what mini-game to play. All mini-games have an instruction scene where the rules and roles of each player are explained.

Once ready, the game begins, and a 10-minute countdown timer starts. Although there's a timer, progress will be indicated solely by a progress bar that shows the points won, with no

display of the exact points or the time elapsed or remaining, so to not stress the player. The players receive a rating based on points won in each level when they progress to the next level. After finishing the game, players will receive a rating based on their performance during the 10-minute session, ranging from 'Good' to 'Excellent'. The games were designed to have the least amount of content on the screen not to distract players from their objectives.

5.1.1 Mini-Game Catalog

The mini-games developed to be part of the platform intend to train cognitive areas such as short-term visuospatial memory, linguistics, mathematical reasoning and planning and management of simple daily tasks. Table 5.1 displays of the four mini-games and below it, the catalog furthers the information regarding the theoretical fundamentals, tasks, feedback and difficulty balancing strategies behind each mini-game.

Table 5.1: Mini-games in "CogniSpace"

CogniSpace's mini-games		
Name	***Cognitive Area***	***Type***
Tornado da Memória (Memory Tornado)	Visuospatial Memory	Cooperative Multiplayer
Par Perfeito (Perfect Pair)	Linguistics	Single-player
Contando Trocos (Counting Change)	Mathematical Reasoning	Single-player
Tudo Pronto? (Everything Ready?)	Action Planning and Implementation	Cooperative Multiplayer

5.1.1.1 Memory Tornado

Theoretical Fundamentals Working memory in managing daily demands is evident, especially when information needs to be retained and processed cognitively, or when tasks and goals need to be accomplished (Jung et al., 2020). The training of such cognitive function requires patients to respond to visual stimuli within a set timeframe. These tasks engage the patient's capacity to retain and continuously update information leading to more efficient mnemonic recall.

Task This is a cooperative multiplayer game. To play this minigame both players must memorize an image of a different setting. It could be a kitchen, a bedroom, a living room, or a garden. They must see where the items, furniture, and decorations were before a hurricane moved everything out of their original place. The players work together to reorganize the scene by putting the items back in place to win the game. One player becomes responsible for one half of the scenario while the other positions the objects on the other half. That goes on until all the objects are placed in the picture. For each object, the game checks if they got the placement right. If so, it becomes the other player's turn and if not, they can try again.

Feedback The players receive positive visual and sound feedback when they get an item in the correct place and are asked to try again when they fail.

Difficulty Balancing A more difficult level can be reached if both players react well to the stimuli. That would mean them getting all the places correctly in two out of three games in the level. The scenes then have more items and the hurricanes are more violent, putting more items out of place.

More impaired patients could have a harder time memorizing the objects. In those cases, the players could ask for hints on where to put items by clicking the help button. The hint shows a shadow of the items where they were initially. Getting the places wrong and asking for hints show that the players are having difficulties, so they get fewer points and the game does not increase difficulty right away.

Figure 5.1: Example scene of Tornado da Memória

5.1.1.2 Perfect Pair

Theoretical Fundamentals Alexia, or the inability to understand written text, typically occurs following a brain injury (Barbosa et al., 2024a). This impairment typically arises from damage to regions responsible for the visual processing of written language, such as the left occipital and temporal lobes or their connections. While patients retain their ability to write and spell, they struggle to comprehend written material, including their own writing moments after producing it. This condition presents a unique challenge where individuals can accurately write and spell words and sentences but struggle to grasp the meaning of the written text.

Task This is a single-player game. It focuses on receptive language exercises, in a quiz format with three answer options. In the first phase of the game, to understand the level of difficulty that the player has with alexia, the questions focus on the preposition of location such as “on” “in” or “under” to describe the hamburger’s position shown in the image. Depending on how they interact with the game, it could become harder with exercises like finding the correct description of the scene. The scenes will be related to the outside area of the house during a barbecue.

Feedback The player receives positive visual and sound feedback when they get an answer correctly and are asked to try again when they fail.

Difficulty Balancing A more difficult level can be reached if the player gets three out of five questions correctly in the level. In more complex levels the scenes have more details and the descriptions don't focus solely on the positioning of the hamburger.

More impaired patients could find it harder to find the correct description of the scenes. In those cases, the players could ask for hints by clicking the help button. The hint disables one of the three answer options. Giving wrong answers and asking for hints show that the players are having difficulties, so they get fewer points and the game does not increase difficulty right away.

Figure 5.2: Example scene of Par Perfeito

5.1.1.3 Counting Change

Theoretical Fundamentals Acalculia and dyscalculia can develop due to localized conditions like ischemic stroke, neoplasm, or trauma to specific parts of the brain, affecting complex neural pathways associated with calculations (Grimaldi and Jeanmonod, 2018). Symptoms may include difficulty with number recognition, sequencing, and basic arithmetic operations, often occurring alongside deficits like alexia and agraphia. Despite its significance, the prevalence of such difficulties following stroke remains understudied. Therefore, rehabilitation programs for individuals with acquired brain injuries should encompass not only language and writing skills but also numerical abilities to address the diverse cognitive deficits they may face.

Task This is a single-player game in a quiz format with three answer options. The player is presented with different challenges when it comes to money. In simpler scenarios, the main goal is for the player to see a set of bill and count the money so they can buy something for the home. More complex scenarios have coins, making the addition more complicated. Finally, the mix between both coins and bills, making them focus while counting the change on the table. The game's goal is to make the players use addition, and possibly multiplication, to prepare to go outside and deal with money.

Feedback The players receive positive visual and sound feedback when they successfully solve a mathematical problem and are asked to try again when they fail.

Difficulty Balancing A more difficult level can be reached if the player gets three out of five questions correctly in the level. In more complex levels the scenes have bigger amounts and combinations of bills and coins.

More impaired patients could find it harder to find the correct description of the scenes. In those cases, the players could ask for hints by clicking the help button. The hint disables one of the three answer options. Giving wrong answers and asking for hints show that the player is having difficulties, so they get fewer points and the game does not increase difficulty right away.

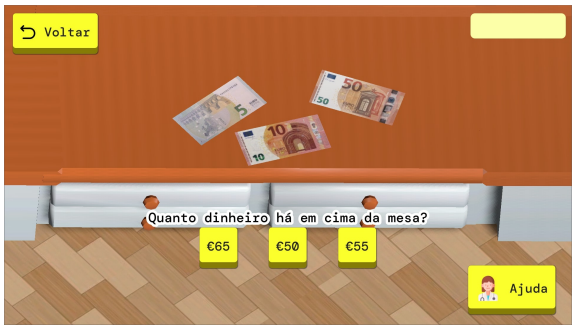

Figure 5.3: Example scene of Contando Trocos

5.1.1.4 Everything Ready?

Theoretical Fundamentals In everyday life, the execution of actions with meaning and independence only becomes possible when behavior is planned and organized over a relatively long period, with priorities established at the task level. Executive functions encompass a range of cognitive abilities involved in planning, organizing, problem-solving, decision-making, and self-monitoring. The ability to successfully use those abilities may be compromised when there are brain injuries, especially when these injuries occur in the frontal structures (High et al., 2006).

Task This is a cooperative multiplayer game. The players plan to perform different tasks in the house or outside. Tasks may involve cleaning, cooking, or going outside to buy supplies. In the scene, the players will find two sets of images regarding the steps involved in the tasks. Each turn, the players will be given a task to plan and while one must select an item on the left side, the other selects an item on the right side, by order. The goal is for both players to work together on pairing specific objects from each side of the scene by order of usage in the task.

Feedback The players receive positive visual and sound feedback after choosing all of the items correctly. If they forget any items or choose the wrong ones, they are asked to try again.

Difficulty Balancing A more difficult level can be reached if both players react well to the stimuli. That would mean them getting all the associations correctly in two out of three games in the level. In more complex scenarios the tasks will involve more steps, therefore more objects will be shown in the scene.

More impaired patients could have a harder time memorizing the objects. In those cases, the players could ask for hints by clicking the help button. The hint gives the players the next association between the buttons. This game also already gives the players a hint when they select a correct pair but the order is incorrect. Getting the associations wrong and asking for hints show that the players are having difficulties, so they get fewer points and the game does not increase difficulty right away.

Figure 5.4: Example scene of Tudo Pronto?

5.1.2 Decision Making

This Subsection focuses on explaining the decision-making aspect of the design process, meaning the balance between the known facts and studies from the literature and the interviews in the first phase of the co-design. In some cases, the two crashed in ideals and a decision was made having in mind the best way to deliver a platform that would be useful. In Table 5.2 is displayed a series of important decisions made about the design of the application and the justifications behind each of them are below.

Table 5.2: Decision Making for the design of "CogniSpace"

Decision-making	
Description	***Co-Design/Literature***
The chosen platform for this game was the computer instead of mobile (smartphones and tablets)	Co-Design
The type of interaction chosen for this game was both singleplayer and cooperative (co-op)	Co-Design
The approach chosen for this game was local/in-person (local co-op) interaction instead of online	Co-Design
The chosen areas of cognition for the mini-games are memory, linguistics, math and executive functions	Co-Design and Literature
The chosen formats for the mini-games are quizzes and puzzles with elements of daily life activities such as dealing with money, the environment of the home, and planning house tasks	Co-Design and Literature
The game has constant positive feedback to motivate the players and make them feel good and proud of their achievements	Co-Design and Literature
The game has an automatic difficulty adjustment system that prevents frustration	Co-Design and Literature
The game tries its best to have high ecological validity to feel natural and useful for the patients	Co-Design and Literature
A big importance was given to accessibility aspects of the game, to make it adaptable and accessible for the largest amount of people possible	Co-Design and Literature
Though the literature shows the importance of focusing on attention training, in this platform there is no mini-game focused on it	Co-Design

5.1.2.1 Justifications

The literature suggested that the majority of serious games for rehabilitation focused on devices such as tablets since there is no requirement for eye-hand coordination making the interaction direct and likely more intuitive due to its touch-based nature. However, after consulting with the patients and family members the majority showed more comfort with the personal computer. Furthermore, the patients showed more interest in puzzle games and told the team that the cognitive training they had at the clinic followed the question-and-answer format of play. Thus the approach adopted to make it as comfortable for them to interact was to have simple puzzles with a dynamic and easy-to-learn mechanic, focusing on giving them constant rewards and progressing steadily. The goal was to create a platform that resembled the training they did at the clinic, but that they could incorporate into their life at home and with family members.

The possible types of interaction included single-player, player-versus-player (PvP), player-versus-environment (PvE), local co-ops, or online co-ops. During the interviews with patients and family members, all possibilities were presented: playing alone or with someone, and online or using the same device. The general response was that they were most comfortable with playing alone, as they already do with some popular games such as Sudoku or Crosswords. For that reason, two of the four games were kept single-player so the patients wouldn't need a second party to engage with the game. The ones who did show appreciation for multiplayer games said that they would prefer both players involved to be participating in the game through the same device, so it was possible to interact more easily with each other. They also showed more interest in cooperative games instead of competitive games. Since the goal of this project is to introduce multiplayer games for cognitive rehabilitation, the other two games were designed to be cooperative and played on the same device, allowing a feeling of deeper connection while playing.

In the literature, most of the games either focused on motor rehabilitation or, when cognitive rehabilitation was the main goal, in areas such as attention, memory, and executive functions. While interviewing patients and family members, the main cognitive area that the patients seemed to struggle with was memory, so CogniSpace had to focus on that. However, the literature also showed that an important training area that was not well-explored by the existing platforms was mathematical reasoning and linguistic issues. The professionals confirmed the importance of such areas and showed us what kind of exercises could be a part of the mini-games focused on that training, while the patients and family members helped the most with finding the themes for such games.

Most of the mini-games were built on the existing CogniPlus platform for cognitive training CogniPlus (2023), incorporating similar rehabilitative features. Since these games include an automatic difficulty adjustment mechanism, there is no need for third-party supervision or control during analysis. The professionals were asked if it would be interesting to implement dynamic difficulty adjustment with the usage of data on the time elapsed since the player was supposed to interact with the platform, for example. They answered that it could make it unfair to the players with a slower cognitive response, so it was fairer to have the progression of difficulty following

a system of minimum points earned to progress to the next phase. Another thought was that the system could have a log system that kept track of the difficulty achieved by that player in order not to make it 'too easy' for some players. However, even if the platform had a system that kept a log of the players' achieved levels in the game, the games could never start or progress too quickly to higher levels because the severity of symptoms increases as the impairment progresses, and the players in question could suddenly find the more progressed levels too difficult.

Finally, the decision to not include games focusing on attention was mostly due to the remaining time for development, but also based on an interview with a professional who informed the team that it is almost impossible to train one cognitive ability without accidentally training others. In that sense, the most intuitive area of cognition that is exercised while exercising other abilities is selective attention. Small tasks included in the multiplayer mini-games require the patients to pay selective attention to the scene presented. In the case of 'Tornado da Memória' they have to pay attention to memorize the objects of half of the scene and in 'Tudo Pronto?', they have to pay attention to the order in which the associations should be made.

5.2 Implementation

This section details relevant information on the implementation of the application.

5.2.1 Architecture

The software was developed using GODOT[1], a free and open-source game engine with an intuitive scene-driven design that allows developers to build games from simple blocks called 'nodes' and compose a node hierarchy system making game logic clear.

The development follow the Model-View-Controller (MVC) pattern. The MVC pattern divides the program logic into three interconnected elements, as shown in figure 5.5.

- The model is responsible for managing the data of the application. It receives user input from the controller.
- The view renders a presentation of the model in a particular format.
- The controller responds to the user input and performs interactions on the data model objects. The controller receives the input, optionally validates it, and then passes the input to the model.

However, because GODOT's nodes operate individually and the scripts that work as controller and models are directly attached to their respective view with no way of decoupling them, it's very difficult to perform data binding. In order to keep track of the flow of the game and handle the game's important data at any given scene, the most important variables and information needed to be stored in a global script.

[1] GODOT's website: https://godotengine.org.

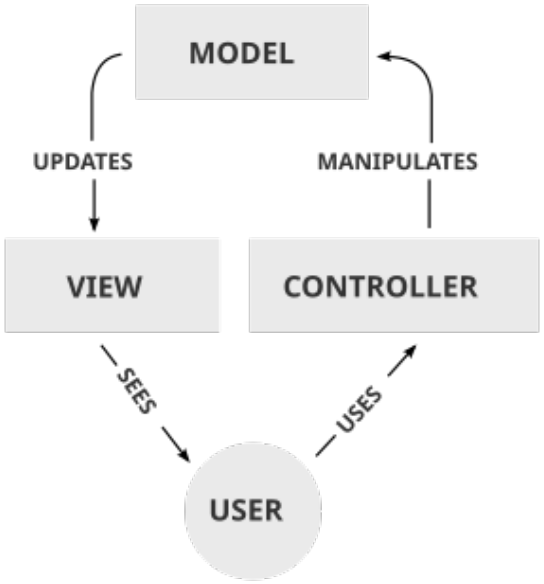

Figure 5.5: Diagram of interaction of the MVC pattern

5.2.2 Game Flow

As the player enters the game, they are presented with buttons that allow them to start, exit, or go to the options menu, where activating or deactivating the sound and the text-to-speech feature is possible. When they click on the button to start, a welcome message and a presentation of the game's objectives are shown. The first challenge is then delivered: the player has to look at a clock and tell what time it is. That question was added after a suggestion made by a family member during the interview phase and had the goal of creating a first challenge that would help situate the player at the moment, which is something they often lose when living with cognitive impairment. After that, the player can click on 'Continuar' to proceed to the next scene, which shows the mini-game menu.

The games were based on the existing CogniPlus (CogniPlus, 2023) platform for cognitive training, incorporating similar rehabilitative features. Since these games already include an automatic difficulty adjustment mechanism, there is no need for third-party supervision or control for analysis. The four mini-games follow a similar format of difficulty adjustment. The two single-player mini-games ('Par Perfeito' and 'Contando Trocos') are more fast-paced and follow a quiz format so to proceed to the next level the player must conclude 5 games and earn at least 3 points. In the case of the other two mini-games ('Tornado da Memória' and 'Tudo Pronto?'), the player must play 3 games and win 2 points to move to the next level, since the phases take longer and require the participation of two people. To earn points the player must answer correctly, meaning they earn 1 point on each phase if they answer right away, and 0.5 if they get it wrong first or if they ask for help with the 'Ajuda' button. The players also never lose points. When they make a mistake they are notified by a pop-up and asked to try again. Whenever the player moves to a higher level, they receive visual and auditory feedback.

To better understand the game's flow, Figure 5.6 presents a visual representation of CogniSpace's flowchart.

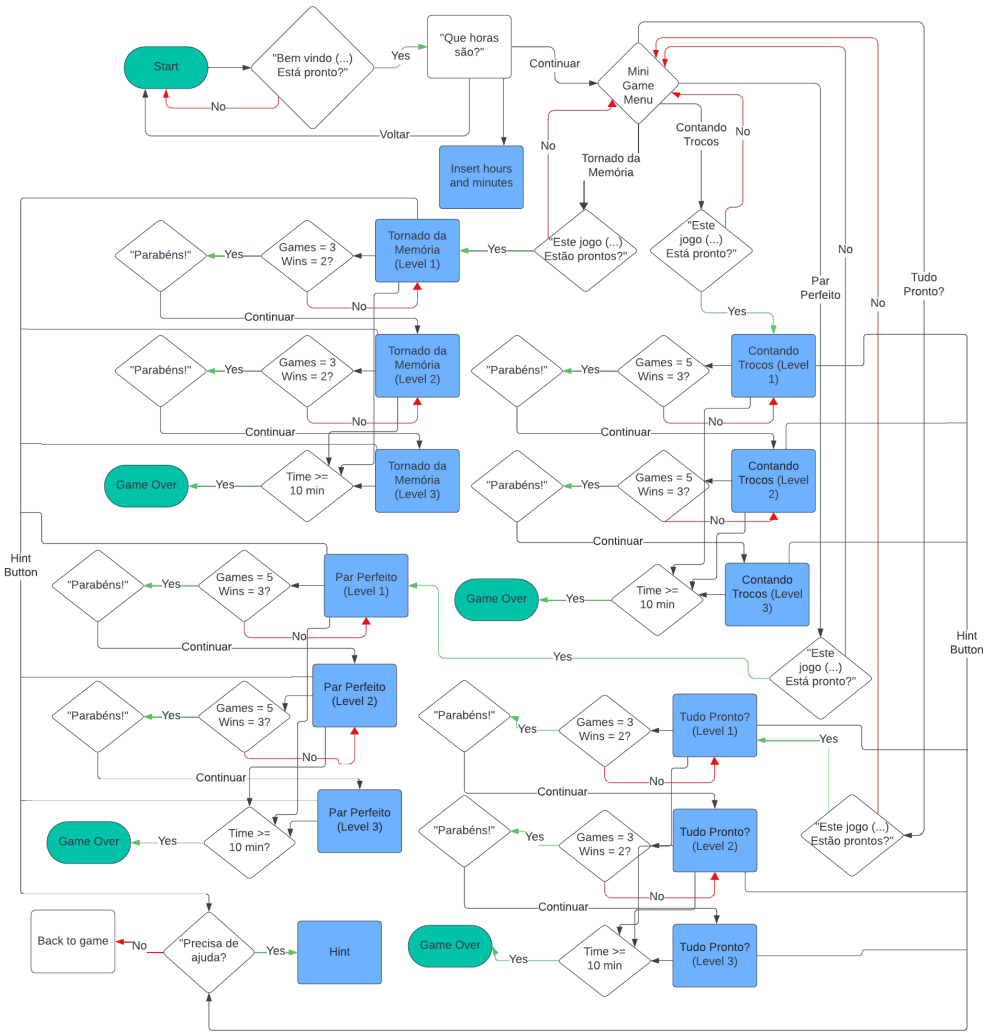

Figure 5.6: Representation of the game's flowchart

5.2.3 Graphics

One big concern in this project was to make the scenes as ecological as possible, so the quality of the assets was of the most importance. For that reason, we chose to develop a 3D game, since 3D models can more easily achieve a 'better looking' game. However, the mini-games didn't intend to include the usual 3D gameplay patterns and dynamics of interaction. The player wasn't supposed to have a 3D character of its own and walk or interact with its surroundings, for example. The design of the games didn't include that type of dynamic since the players would be of old age and weren't used to games of such a nature, as seen in the interview phase of the co-design. The objective was to have a 'static' game with pre-rendered scenes with a fixed camera, with different phases of which the players could observe. The interaction with the system

and conclusion of objectives was chosen to be made using a simple and intuitive UI, with the least amount of exploration needed. For that reason, we chose to develop a 3D game where the interaction with the interface was always the most intuitive as possible, while three of the mini-games only included interaction with buttons and the other one used a point-and-click model of interaction.

The serious game developed had a simple interactive UI using mainly buttons for most of the mini-games, but the scenes created for the phases to be observed used 3D assets of public domain (CC0 Licensed). All of the 3D assets used in this project are copyright-free and some were slightly modified but all were downloaded from Kay Lousberg's itch.io page[2]. All the sounds and images used as icons are copyright-free.

5.2.4 Characteristics

Some mini-games were based on the Cogniplus game catalog CogniPlus (2023) to serve as a guideline since its games already have an automatic difficulty adjustment mechanic.

The platform intended to achieve the training of social competencies by having two multi-player games, but it also had the goal of training competencies not usually included in cognitive rehabilitation serious games, like dealing with money and solving basic math problems.

The developed games use both the mouse and the keyboard as the peripherals of choice to interface with the player.

Because the development phase had less time than intended due to external delays in the project plan, it wasn't possible to develop some initially intended features, such as the ability to choose between multiplayer and single-player. We chose to keep the multiplayer games always multiplayer instead of giving the player the option to choose in the beginning, but the interaction with the system was easy enough to learn that those games can be adapted to single-player if the user is comfortable with the device. That means the best option is for it to be played by two people, but if the player is comfortable with using the mouse and the arrows on the keyboard, for example, it can be played by one. So the player can use the platform in the comfort of their home and even interact with it alone, as seen in the interviews with the patients.

Another important aspect to mention is the multiplayer gameplay is on the same device, not allowing online multiplayer gameplay. The main motivation for this decision was the interview phase of the co-design, in which most of the participants showed their preference for a platform that allowed the patients to play with people they know, in physical proximity.

5.2.5 Accessibility Elements

ABI often affects patients in ways other than cognition, causing difficulties such as motor, visual, or hearing problems. To make sure the platform's use was as inclusive as it could be, the font was kept large through all of the scenes with instructions and congratulations, and the platform and scenes involved in the games had very bright and appealing colors, that contrasted well so it wasn't

[2]Kay Lousberg's itch.io page: https://kaylousberg.itch.io/.

challenging to read while interacting with the platform. Furthermore, the platform has the option of turning off the sound incorporated in different areas of the game such as the congratulating scenes and the constant feedback. It also included the option of text-to-speech, which is a built-in function of GODOT and can easily be turned off and on according to the patient's needs and preferences while playing.

The buttons have a safe distance between them so to not cause mistakes while pressing with the mouse, and the navigation and help buttons are always located in the same areas of the screen, so to not cause confusion. Such areas follow a focus order of the top left corner of the screen, meaning the 'Go Back' button is placed on the top left corner and the 'Continue' button on the top right corner. All of the buttons needed to interact with the games are located in the bottom center of the actual center of the screen.

5.2.6 Features

This section showcases the components of the game along with screenshots. The game uses the colors blue and yellow since they contrast well and because of the feelings they induce in people. While yellow is associated with cheerfulness and warmth, blue is associated with calm, serenity, and tranquility. Both sentiments are very important in a game for health. The main menu focuses on having as little information as possible, being simply a blue background with the buttons on the left side and the logo on the right. The buttons can take the player to either the start of the game by pressing "Iniciar", the options menu by pressing "Opções" or to exit the game by pressing "Sair". A screenshot of such scene can be seen in Figure 5.7.

Figure 5.7: CogniSpace's main menu

In the options menu, the player is presented with the options to select text-to-speech and unselect audio, which is selected by default. Those options help with usability for slower readers or people with reading issues, as well as patients who get easily distracted by sudden sounds. The scene of the options menu can be seen in Figure 5.8.

By clicking on "Iniciar", the player enters the game and an introduction is shown to present the goal of the game and the cognitive areas that it tackles. The introduction scene can be seen in Figure 5.9.

Before entering the game, the player is asked to answer a question: what time it is, by looking at a mantel clock. That was a suggestion made by a family member during the interview phase,

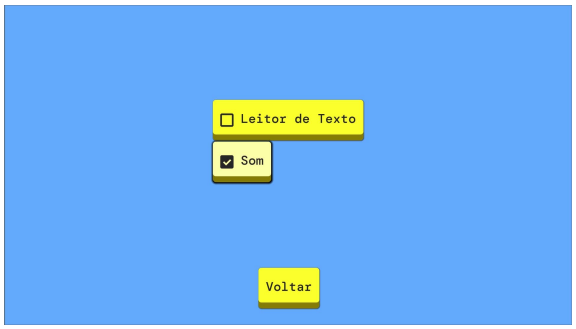

Figure 5.8: CogniSpace's options menu

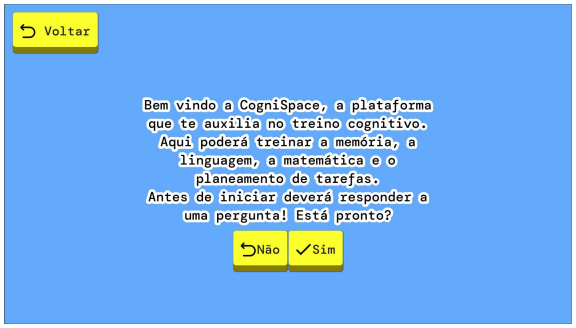

Figure 5.9: CogniSpace's introduction scene

because she felt like it was challenging for the patient to identify the time by looking at a clock, and that most of the time they were completely disoriented on what time of the day it was, or what day of the week, even. Therefore, that little challenge was added but it isn't required to enter the platform, as one can simply press "Continuar" and go to the mini-game menu. It is, however, encouraged, since the platform gives cheering positive feedback when the player answers correctly. Both the mantel clock question and the feedback can be seen in Figure 5.10 and Figure 5.11, respectively.

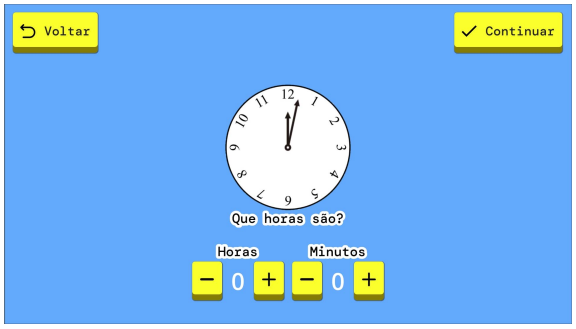

Figure 5.10: Mantel clock scene

The mini-games menu presents the four mini-games: "Tornado da Memória", "Par Perfeito", "Contando Trocos" and "Tudo Pronto?". For each mini-game, there's a picture to illustrate the game to showcase the games and make them more recognizable to players who aren't used to the platform yet. That can be seen in Figure 5.12.

Figure 5.11: Feedback after getting the time correctly

Figure 5.12: CogniSpace's mini-game menu

For each one of the mini-games, there's an instruction scene where the player can get familiarized with the commands and objectives of the game. Those can be seen in Figure 5.13, Figure 5.14, Figure 5.15 and Figure 5.16.

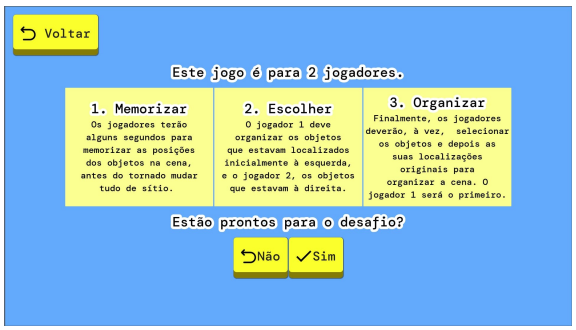

Figure 5.13: Tornado da Memória instruction scene

In terms of visuals of the game, as stated before, the idea was that the scenes constructed for them to analyze were made with 3D assets but the interaction should be as easy and intuitive as possible, since many of them had motor impairments as well as cognitive and the interaction itself wasn't part of the challenge, the solving of the problems was. Examples of phases of each game can be seen in Figure 5.17, Figure 5.18, Figure 5.19, and Figure 5.20.

In every mini-game, there's a possibility to ask for a hint once in every phase by clicking on a button with the image of a therapist and the word "Ajuda" located at the bottom right of the screen. After clicking on it, the icon of the therapist becomes bigger, to simulate a character in the game,

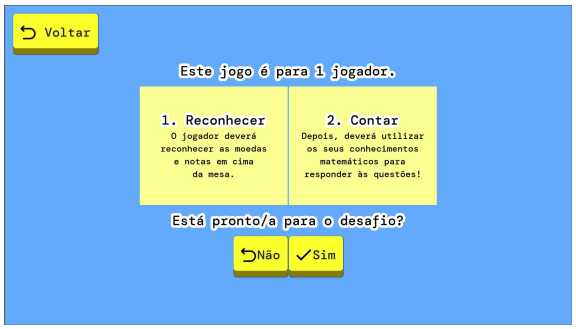

Figure 5.14: Contando Trocos instruction scene

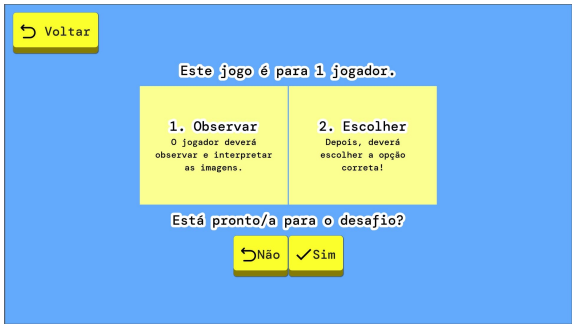

Figure 5.15: Par Perfeito instruction scene

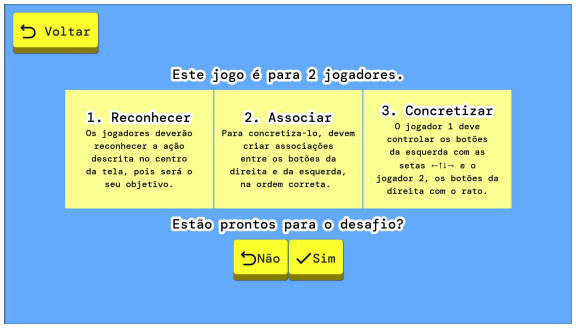

Figure 5.16: Tudo Pronto? instruction scene

Figure 5.17: Example scene of Tornado da Memória

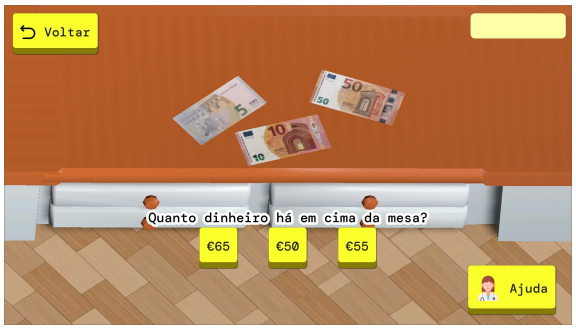

Figure 5.18: Example scene of Contando Trocos

Figure 5.19: Example scene of Par Perfeito

Figure 5.20: Example scene of Tudo Pronto?

and a pop-up appears to request confirmation about wanting the hint. That can be seen in Figure 5.21. In each phase, the players only have one hint and if they choose to take the hint, they get fewer points for that phase.

Figure 5.21: Pop-up for hint

In the case of Contando Trocos and Par Perfeito, because they are more dynamic quiz games, the hint simply discards one of the three options for an answer. The hint in "Tudo Pronto?" gives the players the next combination, because when the players ask for the hint it is assumed that they are stuck. In the case of "Tornado da Memória", however, the hint shows shadows of the objects in their initial positions, as seen in Figure 5.22.

Figure 5.22: Scene with shadows in Tornado da Memória

In the same mini-game, a semi-hint is shown when a player gets the placement of an object correctly, but it's not their turn. That message also serves as an error message for the players to respect their turn but isn't negative feedback. That can be seen in Figure 5.23.

In the same mini-game, an animation was created for the tornado that passes after a certain memorization time (which depends on the level of the game) and moves some objects from the scene out of their initial place. A screenshot of an example of one of those animations can be seen in Figure 5.24.

In the case of "Tudo Pronto?" there are some specifics to be presented. The players receive something close to a hint if they find a combination that is correct, but select it at the wrong time, meaning the steps to complete the task are in the wrong order. That feedback message can be seen in Figure 5.25.

Figure 5.23: Pop-up informing that it's not the player's turn in Tornado da Memória

Figure 5.24: Animation of tornado passing and objects moving in level one of Tornado da Memória

Figure 5.25: Semi-hint given in Tudo Pronto?

In the same mini-game, player one is supposed to interact with the buttons on the left part of the screen using the arrows while player two interacts with the ones on the right using the mouse. When the player tries to use the mouse to interact with the buttons on the left, an error message appears to inform the error, which can be seen in Figure 5.26.

Figure 5.26: Error message in Tudo Pronto?

When it comes to feedback, the game does not give any negative feedback or negative points, except for when a player gets an answer wrong and a pop-up asks them to try again, which can be seen in Figure 5.27. For positive feedback, there are a couple of scenes and pop-ups. Firstly, when a player concludes a phase there's visual and audio feedback of fireworks, as seen in Figure 5.11. After passing to the next level on a mini-game, the player receives again visual and audio feedback of one to three stars showing their ranking in that game and sounds of cheering and clapping, on a congratulating scene as seen in Figure 5.28. Finally, when the player finishes the game after a 10-minute session or by quitting on their own, a congratulating scene showing them the final rank and the amount of time spent in the game, which can be seen in Figure 5.29.

Figure 5.27: Feedback to try again

Also for feedback, in both Tudo Pronto? and Tornado da Memória there are smaller feedback pop-ups congratulating the players on getting an association or placement correctly, though it's an in-game feedback and it has no visual and auditory appeal. That can be seen in Figure 5.30 and Figure 5.31 for the two mini-games respectively.

When a player wants the leave the mini-game, a motivating feedback also appears saying that it was going well and they shouldn't leave yet. That serves as to confirm that pressing that

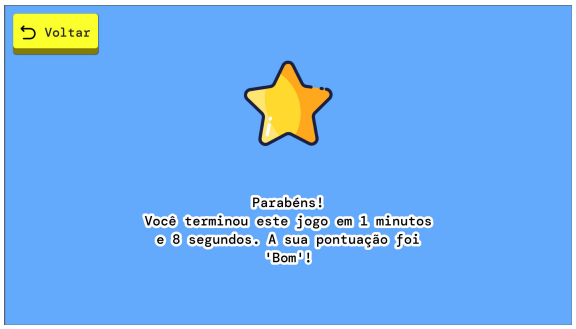

Figure 5.28: Feedback after passing to the next level

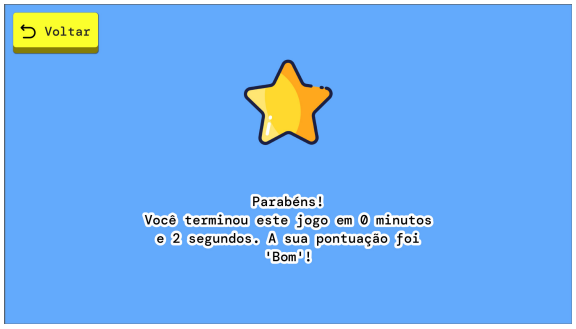

Figure 5.29: Feedback after finishing a game

Figure 5.30: Small feedback in Tudo Pronto?

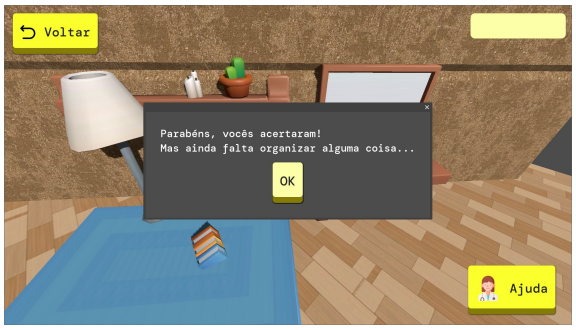

Figure 5.31: Small feedback in Tudo Pronto?

button was not by mistake and try to get the players to train for 10 minutes, as suggested by the professionals. The pop-up can be seen in Figure 5.32.

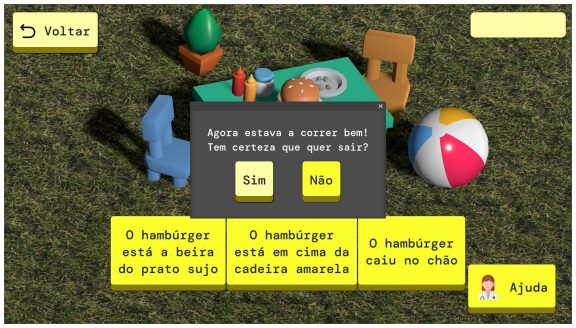

Figure 5.32: Pop-up to confirm player leaving the mini-game

Chapter 6

Usability Tests

This chapter describes the tests conducted on the platform to evaluate its usability and consistency, identify potential improvements in the system, and assert it meets all of the requirements.

6.1 Procedure

Three types of tests were conducted for this phase. One type utilized a Think Aloud protocol, encouraging users to vocalize their thoughts, feelings, and actions while using the application. Those tests happened in the same clinic as the first phase, in person and with the patients of ABI, some of which also participated in the first phase. The second type was a remote usability test, for professionals and family members of patients with ABI, where they were encouraged to reach out and message their suggestions about the platform to the team. Lastly, it was asked of all of them to fill out a survey about the game experience and system usability, to evaluate the perception of the application.

Before participation, all new participants were required to sign the same consent document used for the other co-design phases.

6.1.1 Think-Aloud Protocol

The initial phase of testing utilized the Think Aloud protocol, offering valuable insights into users' cognitive processes and highlighting usability issues and areas for improvement. Moreover, these tests provided the opportunity to observe how the application performed when approached differently by various users. As each person interacted with the application in unique ways and sequences, this testing phase helped reveal bugs that had previously gone unnoticed during internal testing. The primary objective during this stage was to observe and determine if patients were comfortable with the system and its interface, as well as listen and note their suggestions and ideas.

Each test began with explaining its purpose, ensuring participants understood that it was the application being tested, not their abilities. They were then instructed to verbalize everything

they were thinking, feeling, and doing as they navigated the application, including their expectations, confusion, frustrations, and any positive reactions. The tests consisted of exploring the platform and playing the mini-games, only with assistance from the supervisor when the patients got distracted or confused mainly due to their impairments. Some participants didn't test all of the mini-games due to cognitive fatigue.

6.1.2 Remote Usability Testing

The tests with family members and professionals followed the Remote Usability Testing protocol, mainly because most people take vacations around the time of the year when the tests took place, which made it impossible to meet some of the participants in person. In addition, most participants have a very busy schedule, making it more difficult to conduct the tests in person or with supervision. For those reasons, we tried to make the testing experience as flexible as possible to appeal to the largest number of participants. They were more than happy to test the platform on their personal computers and report their experiences with it through the post-game questionnaire described in the next subsection, and they were also instructed to leave any feedback and commentary deemed pertinent.

6.1.3 Post-Game Questionnaire

Upon completing the test, participants were asked first to fill out a form using the UPorto's survey platform to provide sociodemographic information including age, sex, education level, and nationality as well as to offer feedback on the game experience and system usability. The questionnaire included both the Post-Study System Usability Questionnaire (Vlachogianni and Tselios, 2023) and the Game Experience Questionnaire (IJsselsteijn et al., 2013), as documented in the thesis description for the Ethics Committee.

6.1.3.1 Post-Study System Usability Questionnaire

The Post-Study System Usability Questionnaire (PSSUQ) is a 19-item tool designed to evaluate user satisfaction with system usability with scales ranging from 1 to 5, with 1 being 'Completely Disagree' and 5, 'Completely Agree'. It is widely recognized and has strong psychometric properties. The version of this questionnaire used for this test was translated, adapted, and validated to Portuguese (Rosa et al., 2015).

6.1.3.2 Game Experience Questionnaire

The Game Experience Questionnaire (GEQ) has a modular structure, consisting of three parts: The Core Questionnaire, The Social Presence Module, and The Post-Game Module.

These modules are intended to be administered consecutively, immediately after a game session. Parts 1 and 2 explore the players' emotions and thoughts during gameplay, while Part 3, the Post-Game Module, evaluates how players felt after finishing the game (IJsselsteijn et al., 2013).

For all of the 3 parts, the participants have to answer in a sub-scale ranging from 1 to 5, with being 1 'Not at all' and 5 'Extremely'. The used version of this questionnaire was also translated into Portuguese which has been widely used in Portuguese studies.

6.2 Results

This section outlines the results from the user testing sessions, which took place between August 12th and August 24th. As stated before, the sessions were conducted using a mixed approach: some users had access to the platform and got to explore it without supervision, while others took part in person and spoke freely with the supervisor during the experience.

6.2.1 Participants

A total of 8 individuals volunteered to test the applications, and all of them were project stakeholders.

A recruitment process similar to the one used in the first phase of co-design was performed, where a psychologist employed at the clinic identified potentially eligible participants. This individual was requested to select other clinicians from the clinic, along with patients currently undergoing cognitive rehabilitation and their family members. From the participants of the previous phases of co-design, two of the same professionals participated in this phase, as well as two of the family members and two of the patients. One new professional and one new patient joined as participants in the tests, were given an introduction to the study, and were asked to fill out the consent document previously mentioned.

Our sample of professionals included 3 individuals (3 female, 100%), aged 26 to 28 years old (M= 27; SD= 1), the sample of patients was of 3 individuals (1 female, 33.3%), aged 65 to 78 years old (M= 71.66; SD= 6.5), and finally for family members, 2 individuals (1 male, 50%), aged 42 and 55 years old (M= 48.5; SD= 9.19). All of the participants were Portuguese and all of the participants who weren't patients with cognitive impairments answered that they worked at the moment, while the patients answered that they were retired.

Table 6.1: Participants' sociodemographic data

	n	$\overline{X}$	%
Professionals			
Gender			
Female	3		100%
Male	0		0%
Age (range)	(26-28)	27	
Working	3		100%
Patients			
Gender			
Female	1		33.3%
Male	2		66.6%
Age (range)	(65-78)	71.66	
Working	0		0%
Family Members			
Gender			
Female	1		50%
Male	1		50%
Age (range)	(42-55)	48.5	
Working	3		100%

6.2.2 Post-Game Questionnaire

The chosen questionnaires had various questions aimed at asserting aspects of the game experience and system usability, with answers ranging from 1 to 5, 1 representing complete disagreement with the statement, and 5 complete agreement. The results of the different subscales of each questionnaire are featured in Figure 6.1, Figure 6.2, Figure 6.3, and Figure 6.4. The GEQ's subscales range from the core experience of the game, for example, the level of competence, tension, or challenge felt by the players, to the overall post-game experience and the level of involvement during gameplay. The calculations of each component followed the guidelines of each questionnaire, in order to be true to their objectives and best assess the intended results and discussion.

The Core Module consists of seven components: Competence, Sensory and Imaginative Immersion, Flow, Tension/Annoyance, Challenge, Negative affect, and Positive affect. Component scores are computed as the average value of its items.

The Social Presence Module consists of three components: Psychological Involvement – Empathy, Psychological Involvement, and Behavioural Involvement. Component scores are computed as the average value of its items.

The post-game Module consists of four components: Positive Experience, Negative experience, Tiredness, and Returning to Reality. Component scores are computed as the average value of its items.

The results of the PSSUQ there are 3 sub-scales, namely System Usefulness, Information Quality, and Interface Quality. The sub-scales provide a more detailed breakdown of different

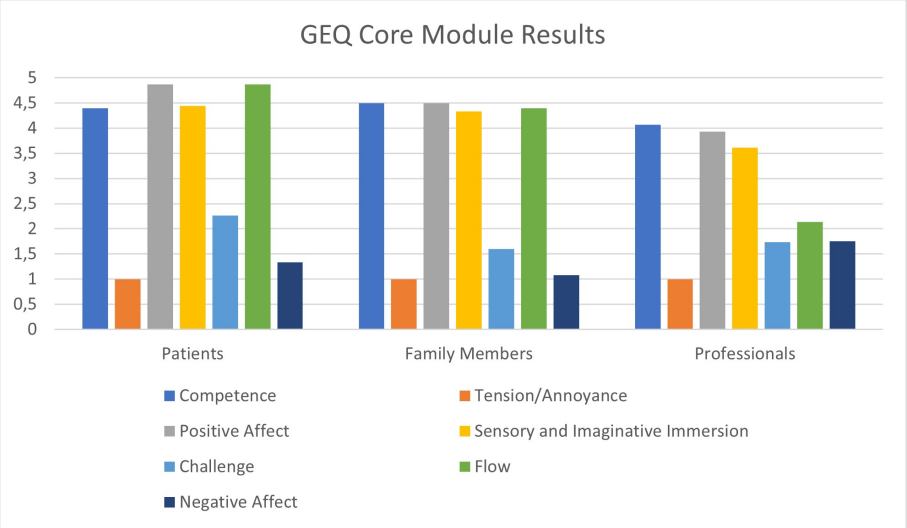

Figure 6.1: Usability Tests: GEQ Core Module Results

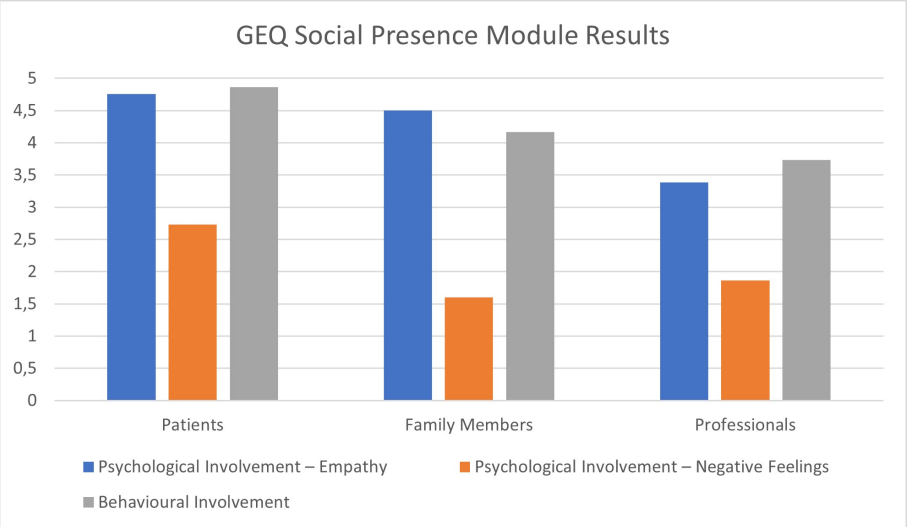

Figure 6.2: Usability Tests: GEQ Social Presence Module Results

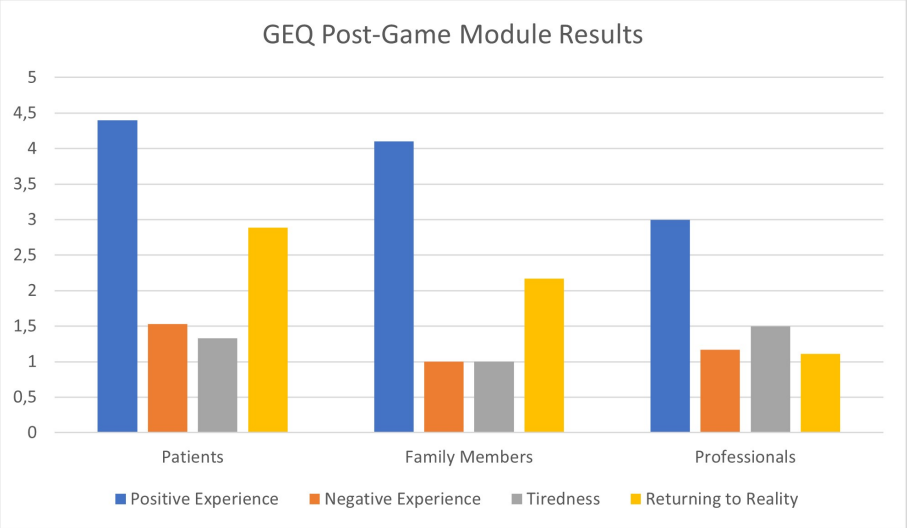

Figure 6.3: Usability Tests: GEQ Post Game Module Results

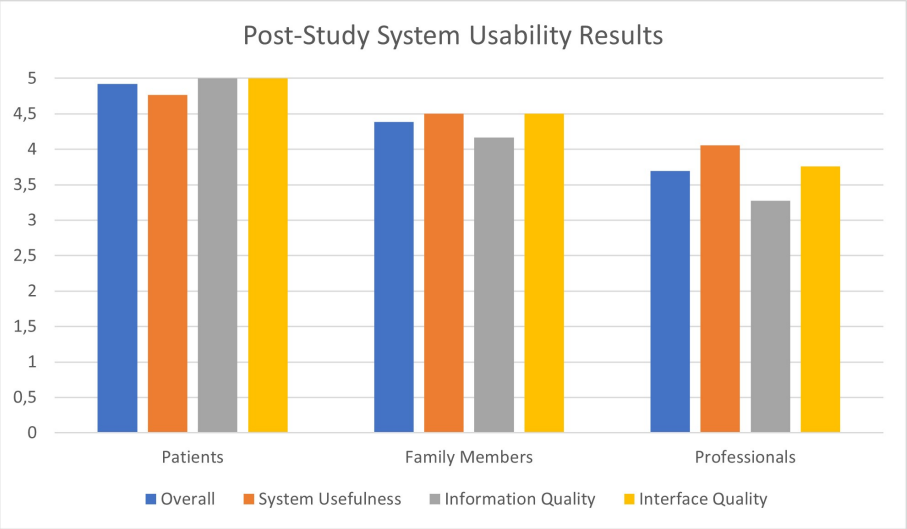

Figure 6.4: Usability Tests: PSSUQ Results

factors affecting the software.

6.2.3 Think-Aloud Protocol

The Think-Aloud protocol proved to be very fruitful to the testing since it made it possible to notice various minor issues with the system and correct them in time to test with other participants. It was a continuous work of improvement until the final version of the system was reached, and used in the last tests with mainly the professionals and family members. Further detail on the issues found and the improvements that resulted from the suggestions made during this process are described in 6.4.

6.3 Discussion

As seen in Figure 6.1, the overall satisfaction with the game was high in terms of positive affect (average values ranging from 3.9 to 5), competence (average values ranging from 4 to 4.5), and sensory and imaginative immersion (average values ranging from 3.5 to 4.5), in all of the three groups. The negative affect (average values ranging from 1 to 2) and level of tension/annoyance (around 1) are low, which is promising. In terms of flow, the groups had different opinions, being that the patients and family members showed higher averages, meaning that the flow of the game followed a good pace and the tasks were easy to navigate, while the professionals showed lower averages, which is something to be mindful about. The game was also not considered a big challenge either, not even for the patients, which perhaps indicates a comfort with the system, but also a need to reevaluate the difficulty adjustment mechanisms or the mini-games' goals altogether.

As for social involvement, seen in Figure 6.2, it is clear that the three groups showed little negative feelings such as envy and vengefulness, but much more positive ones while playing the game, as seen in the levels of empathy and behavioural involvement.

The post-game module in Figure 6.3 aimed to assess the overall experience after playing the game, and patients, family members, and professionals answered the positive experience questions with high values (average values ranging from 3 to 4.5) and negative experience and tiredness with lower ones (average values ranging from 1 to 1.5 for both), which is very positive for the analysis of the acceptance of this serious game. As for the feeling of returning to reality, as expected, the professionals and family members answered with lower values when compared to the patients, since the game was not aimed at those populations and the immersion was not as high. The answers regarding the feelings identified by the participants show that, naturally, the professionals and family members felt less powerful or capable while playing, as well as challenged by the game or disconnected from the outside world. Those feelings, as predicted, would affect patients more than the other two groups because the game is aimed at them, and the exercises involved in the mini-games could be deemed trivial for the other two groups.

Finally, by looking at the answers of the PSSUQ in Figure 6.4 it is possible to see the high acceptance of the platform in terms of usefulness, information quality, and interface quality, with average values ranging from 5 to 3.2. These results are promising since they assess the ability to

complete the tasks and learn how to use the system, which are very important aspects of a new system and of a first interaction with a game. It is crucial that the participants understand the dynamics and interaction models of the game in order to complete the tasks the game requires without external help or guidance. The lowest level in terms of system usability is, however, the information quality, considering the answers of the professionals. That is definitely an important part of a concise system, especially a system targeting people who are not always comfortable with technology and have cognitive issues. Therefore, it would be a pivotal aspect to work on in order to improve the project at hand.

6.4 Improvements After User Testing

Improvements were mainly possible due to the few Think-Aloud tests. That is because even though the professionals were asked to leave feedback on the game after testing it, none of them provided one for the team. However, One family member messaged the team with a suggestion presented in Table 6.3. Thankfully, the Think-Aloud tests were conducted with patients, who were the stakeholders this project intended to focus on and who could help us the most with sensitizing to their impairments and adapting the system to meet their needs. The improvements made are listed in tables 6.2 and 6.3 and include important accessibility and usability aspects such as the wording and the colors used in the instructions and the scenes, respectively, as well as the mouse pointer size and the aspects of the buttons. A suggestion about the Memorization Tornado's inner functionality and difficulty was also very valuable to the improvement of the game.

Table 6.2: Adaptations made after the usability test phase

Improvements after testing		
Type	***Before***	***After***
Wording and clarity	During the testing phase the instructions of the mini-games have been worded by the developer and had not been proofread by anyone else, having some issues in wording that confused the participants. Because the developer was the supervisor of the tests, it was possible to clarify the instructions in person.	Because the idea of the game is to not only be played with supervision and help from others but to be accessible and intelligible for all players, we changed some words and divided long sentences so it became clearer.
Mouse pointer size	As requested by the professionals, we made all the scenes and the text in the platform very large, to make it more accessible for older patients. However, before the tests, we didn't think that the pointer of the mouse could be an issue. Naturally, after the first test with an elderly patient that was the first comment they had.	We adjusted it so the game has a particular pointer for the mouse, with set a width and height that makes it very visible during the interaction with the platform.
Colors (Par Perfeito)	Another usability issue found during the tests was the colors used in the game 'Par Perfeito'. The patients found it difficult to distinguish the colors since they weren't as bright as they could be, deeming many times that the correct options were incorrect and vice-versa	Since the objective of the game was for the player to choose the correct description of the scene, the matter of the color of the objects was of importance, and there was no room for confusion between orange and yellow, for example. To correct this issue we simply made the colors brighter and more vivid, so there was no longer any confusion regarding these details.
Memorization time (Tornado da Memória)	The game 'Tornado da Memória' requires that the players memorize the objects of a scene for a couple of seconds before a tornado changes the positions of some of the objects. For most of the patients, even the first level of that game was too difficult, and that was explained by the memorization time.	To make it possible for even the patients with more difficulties with short-term memory to play and train their abilities, we increased the memorization time by 5 seconds for each level.

Table 6.3: Adaptations made after the usability test phase

Improvements after testing		
Type	***Before***	***After***
Button Aspects (Tudo Pronto?)	The game 'Tudo Pronto' has a specific theme for its set of buttons, due to the fact that the images in each button need to be visible for the elders playing the game, which means less space between and overall a different aspect when compared to the buttons in the menus. While playing that game, a patient's family member noticed that the player controlling the keyboard had a hard time understanding what button was pressed and what was not. That confusion happened because immediately after pressing the button kept the aspects of a button in focus instead of a pressed button.	GODOT doesn't have any functionality to cover this issue. The most intuitive one would be to set the priority of the 'pressed' aspect of the button higher than the 'focused' since combining both aspects (a highlight on the border and a different color, for example) is not possible. Therefore, to better identify the pressed button on the left side of the game (the side controlled by the keyboard's arrows), the solution was to change the focus automatically to a different button on the list after pressing. That way the player has immediate feedback on what was done and still knows what button the arrow is focusing on at that moment.

Chapter 7

Conclusion and Future Work

This final chapter serves as a summary of this documentation and all the work accomplished during this project. It presents a conclusion and future work, as well as details the scientific divulgation and the contributions and limitations of this project.

7.1 Conclusion

This project aimed to present an alternative component that complements the cognitive rehabilitation of patients with ABI. This was the first multiplayer platform for cognitive rehabilitation developed in codesign with several parties involved. Because it followed a co-design process, it was possible to better understand and empathize with the key stakeholders. Through a study of three phases including the participation of professionals, patients, and their family members, this thesis strived to widen the capabilities of cognitive training programs for patients of ABI. Although the main goal was to create an app that would be useful to exercise their cognitive functions, this project also focuses on the necessity of promoting the socialization of this community. Given the isolation that patients feel after diagnosis and during rehabilitation, it is crucial to create the opportunity for them to naturally socialize with one another and with people around them, such as family and friends.

This study and research have shown existent projects similar to this one. The alternatives available proved to be helpful for the process of rehabilitation of people with ABI. The serious games developed in recent projects showed positive results and the alternatives present in the market are already very useful for cognitive rehabilitation. However, these options many times don't contemplate multiplayer and therefore there's a lack of ways to facilitate the resocialization of patients with cognitive impairments. In addition, most alternatives don't contemplate exercises of daily living activities, which can be the most beneficial to this population due to their usage in daily life. For those reasons, this project created a platform that allows patients to feel socially connected while exercising cognitive abilities through scenarios of their daily lives. Furthermore, there are few platforms of serious games for cognitive rehabilitation in which the development followed a co-design approach. Finally, we aimed to focus on an area of cognition that is rarely

considered in cognitive training programs but represents a great part of daily living which is to deal with money and be able to solve simple math problems.

7.1.1 Summary

To achieve the goals of this study, a systematic review of the serious games for cognitive rehabilitation is being developed, focusing on design and usability aspects. A literature review was also completed, targeting important concepts surrounding serious games, cognitive and psychosocial rehabilitation, as well as the existing established serious games or gamified platforms for cognitive rehabilitation.

The first phase of the project involved meeting with stakeholders, who played a crucial role in refining the project goals. This phase made sure the goals aligned with their practical needs and after this contact, it was possible to understand the issue at hand and the specifics that mattered the most.

After developing a presentable product, the second phase ensured that the the application was going in the direction it was supposed to and that in terms of usability, the patients wouldn't have problems interacting with it, by validating the platform with a designer and health professionals working with cognitive rehabilitation.

Finally, CogniSpace was developed and evaluated through testing with professionals, patients going through cognitive training, and their family members. This iterative process enabled ongoing refinement, ensuring the final product effectively met user needs and expectations.

7.1.2 Scientific Divulgation

While working on this project the team participated in multiple conferences and symposiums by submitting papers related to the work of this dissertation. The conferences had different purposes and targets, such as Serious Games in general, Serious Games for Health, etc. More detail on the conventions is presented below.

OPP - Congresso da Ordem dos Psicólogos Portugueses This Congress was an open-to-the-community event focusing on promoting mental health literacy. Featuring debates and roundtable discussions with notable figures and representatives from public, private, and social entities, both local and national. This congress will happen between the 25th and 27th of September 2024.

IJUP - Investigação Jovem da Universidade do Porto The U.Porto Young Researchers Meeting – IJUP is an annual event held at the beginning of the second semester, providing U.Porto students with the opportunity to present and discuss the results of research projects they have been involved in. This event happened between the 8th and 10th of May 2024 and a poster was presented in person.

IEEE Conference on Games 2024 The IEEE Conference on Games (IEEE CoG) is an annual event that serves as a premier platform for researchers and professionals to share ideas and innovative methods for advancing games and their broader applications. Games provide a rich environment for exploring and developing new concepts in areas such as design, artificial intelligence, human-computer interaction, psychology, education, sociology, and creativity, as well as their practical applications in solving real-world challenges.

ADITGameS - III Simpósio Internacional de Inovação, Tecnologias e Jogos em Saúde This symposium was created and managed by the Association for the Development of Technological Innovation and Games in Health. Their goal is to promote and support the development and research of technological innovations and health-related games, share specialized knowledge, and participate in both national and international scientific activities. Establish an open scientific society, build connections with similar organizations globally, and collaborate on scientific initiatives aligned with the association's goals. The theme for this event was "Technology and Gamification Applied in Health", it happened on the 5th of June 2024, and a poster was presented online.

GALA Conf 2024 - Games and Learning Alliance Conference The GALA Conference 2024 (13th edition) is organized by the Serious Games Society in partnership with the Berlin School of Economics and Law (HWR Berlin). The Serious Games Society is focused on creating an international scientific community dedicated to advancing research in the field of serious games. This community brings together both industry and academic professionals who are committed to the study, development, and application of serious games as effective tools for enhancing teaching, learning, training, and assessment. This Conference will happen between the 20th and 22nd of November 2024, and the paper acceptance was notified on the 2nd of September 2024 after their review. That means the paper has to go through some final changes before its submission to be published and the work will be presented at this event as a poster.

In the mentioned events, all of the work was presented by Carolina Figueira except for the case of the OPP, where there was a limited number of papers that could be submitted by a participant. For that reason, Eliana Silva, the supervisor of this dissertation, will present the work described in this thesis along with other projects she supervised at the time of subscription.

In the case of the IEEE Conference on Games, the work submitted was not accepted. That happened mostly due to the heavy amount of submitted works relating to similar health issues and solutions and the early stage in which the project was at the time of the abstract submission. Since this was a bigger conference, with many papers proposed, the administration team had to hand-pick between them and select the more fitting ones.

7.1.3 Contributions

This section seeks to address the core question: "Is it possible to develop a useful and accessible multiplayer serious game for cognitive and psychosocial rehabilitation of patients with acquired

brain injury with the contribution and involvement of the stakeholders?". The following subsections highlight important topics to answer the question.

7.1.3.1 Co-Design

For a product to be useful and tackle the specifications and requirements the public needs, the best approach is to consult with them. Instead of relying solely on the literature to understand the objectives of rehabilitation and how a platform could be integrated into it, co-design can open the developer's mind to new possibilities. In the case of this project, the main issue was to understand the level of difficulty the players could have with the games. The goal was to create a game that was easy enough that they wouldn't give up on it, but difficult enough that they wouldn't feel offended or bored. Through the first phase of co-design, interviewing the patients, it was possible to better understand and empathize with patients with cognitive impairments and create a simple but effective set of games, with tasks similar in format to the ones they were used to performing in the clinic. Such a game would not have been accomplished as it was, and the development process would have gone in different directions if had been any other way. Because of this contact with the stakeholders and according to the feedback given and the usability study, it is evident that the game meets their requirements and therefore could improve their cognitive rehabilitation.

7.1.3.2 Connection

Patients of ABI often have a very lonely life, with little to no interaction in their daily lives, and depending mostly on their families. Diseases as difficult to treat as ABI often create unbalanced relationships where one party feels like the other is a burden, and patients can see themselves as burdens. That often sets people apart and makes patients unmotivated to continue treatment, as they can feel hopeless and alone. A good multiplayer game that brings people together can bring a lighter, fun perspective to cognitive training.

7.1.4 Answer

Finally, it is possible to answer that the involvement of stakeholders such as the patients going through cognitive rehabilitation, their family members and caretakers, and the health professionals working in the field was crucial for the development of a well-rounded and concise platform. Their contributions in terms of usability and accessibility, as well as themes and genres of games, were entirely essential for the creation of a product that patients of ABI could truly benefit from and use to connect with peers.

7.1.5 Limitations

This project had some limitations in its development. The first one was the delay in the response from the Ethics Committee of the Engineering Faculty of the University of Porto, which delayed the rest of the planned process. We had the alternative to not proceed with all of the co-design

phases and cut the development phase short, but the team agreed to delay the rest of the schedule and continue working during the summer. That led to the second shortcoming, which is the small sample size on the usability tests. This happened mainly due to the time of the year, when most co-design participants of the different groups were unavailable or out of town, making it impossible to contribute to the project in the last phase.

Another limitation of this project is the fact that the mini-games rely on scenes (phases) that must be developed individually. That means that except for their logic, the phases of the mini-games were done separately and some of them required some time. The last version of the game doesn't have an appropriate amount of phases per level to be released to the public. However, the number of phases was enough to enable the usability tests, as every participant only played each mini-game once.

Another limitation is the reduced number of mini-games, that focus on some specific tasks not applicable to every patient. The initial design of the game catalog had two more games for attention, which could benefit patients who find the training of that ability challenging. A more complex and comprehensive game would ideally have a diverse set of mini-games that could attract a wider audience.

Other limitations include possible features that the application could have had such as accounts that patients could create and log in to store their progress in the mini-games, and the possibility for the professionals to create an administrator account that allowed them to monitor the patients' progress. Another possibility was for the multiplayer games to have intelligent agents playing with the patients in order to allow them to play without a second player. However, in the case of the developed game, the focus was for the patients to feel connected with the people around them, making an agent counter-intuitive for this purpose.

7.2 Future Work

This platform would have way more practical use and would benefit a lot from having a monitoring system where the therapists could follow the patients' participation and progress on the game. The patients could have accounts linked to the therapists' accounts, and by consistently playing the game, both users could see the patient's history in the game, the amounts of wins, and the time of each game they entered.

Furthermore, the catalog of mini-games was tailored to the ideas of the participants of co-design, making the game not completely useful to all patients of ABI. Thus the platform could have more mini-games that encompass different areas of cognition, such as attention, to appeal to a broader audience and help more people in their journey on rehabilitation.

Moreover, as seen in Section 6.3, the developed game is not in the correct standards in terms of error messages and displaying important information for the user, which is a primary concern in good software design and accessibility studies. Therefore, the platform could use some further work on that functionality in order to be as accessible as possible. The messages should be clearer

and the user should receive error messages more often so to not get confused on the usage of the platform.

As stated before, the games should have more phases, so the player's usage isn't restricted to one game before memorizing all of the answers to the quizzes and puzzles. Since the phases of all of the mini-games are individually built, time is a very important factor to create a round and complete game, where a player is capable of playing multiple times without encountering the same phases.

Finally, apart from the entertainment aspects of the mini-games and the constant positive feedback, we did not incorporate elements that address other motivational factors, such as self-monitoring of functional improvements or providing personalized feedback tailored to a patient's specific condition. Future research should focus on developing a patient-centered, interactive system that enhances motivational factors, aiming to improve patient adherence and engagement when using CogniSpace in uncontrolled environments.

References

Anas R. Alashram, Giuseppe Annino, Elvira Padua, Cristian Romagnoli, and Nicola Biagio Mercuri. Cognitive rehabilitation post traumatic brain injury: A systematic review for emerging use of virtual reality technology. *Journal of Clinical Neuroscience*, 66:209–219, 2019. doi: https://doi.org/10.1016/j.jocn.2019.04.026. URL https://www.sciencedirect.com/science/article/pii/S0967586819305600.

Jordan I. Ali, Jeremy Viczko, and Colette M. Smart. Efficacy of neurofeedback interventions for cognitive rehabilitation following brain injury: Systematic review and recommendations for future research. *Journal of the International Neuropsychological Society*, 26(1):31–46, 2020. doi: 10.1017/S1355617719001061.

Nada Andelic, Cecilie Røe, Olli Tenovuo, Philippe Azouvi, Helen Dawes, Marek Majdan, Jukka Ranta, Emilie I Howe, Eveline JA Wiegers, Cathrine Tverdal, et al. Unmet rehabilitation needs after traumatic brain injury across europe: results from the center-tbi study. *Journal of clinical medicine*, 10(5):1035, 2021a.

Nada Andelic, Cecilie Røe, Olli Tenovuo, Philippe Azouvi, Helen Dawes, Marek Majdan, Jukka Ranta, Emilie I. Howe, Eveline J.A. Wiegers, Cathrine Tverdal, Ida Borgen, Marit V. Forslund, Ingerid Kleffelgaard, Hilde M. Dahl, Louis Jacob, Mélanie Cogné, Juan Lu, Nicole von Steinbuechel, and Marina Zeldovich. Unmet rehabilitation needs after traumatic brain injury across europe: Results from the center-tbi study. *Journal of Clinical Medicine*, 10(5), 2021b. doi: 10.3390/jcm10051035. URL https://www.mdpi.com/2077-0383/10/5/1035.

Michelle Kelly Anneli Cassel, Skye McDonald and Leanne Togher. Learning from the minds of others: A review of social cognition treatments and their relevance to traumatic brain injury. *Neuropsychological Rehabilitation*, 29(1):22–55, 2019. doi: 10.1080/09602011.2016.1257435. URL https://doi.org/10.1080/09602011.2016.1257435. PMID: 27899036.

Alex Bahar-Fuchs, Anthony Martyr, Anita M.Y. Goh, Julieta Sabates, and Linda Clare. Cognitive training for people with mild to moderate dementia: a cochrane review. *BJPsych Advances*, 26 (2):66–66, 2020. doi: 10.1192/bja.2019.74.

Shurui Bai, Khe Foon Hew, and Biyun Huang. Does gamification improve student learning outcome? evidence from a meta-analysis and synthesis of qualitative data in educational contexts. *Educational Research Review*, 30:100322, 2020.

Ana C. D Barbosa, Ria Monica D. Asuncion, and Prabhu D. Emmady. Alexia, 1 2024a. URL https://www.ncbi.nlm.nih.gov/books/NBK557669/.

Ana C. D Barbosa, Ria Monica D. Asuncion, and Prabhu D. Emmady. *Alexia*. 2024b.

Pelagie Beeson, Joël Magloire, and Randall Robey. Letter-by-letter reading: Natural recovery and response to treatment. *Behavioural neurology*, 16:191–202, 02 2005. doi: 10.1155/2005/413962.

Em Bould and Libby Callaway. A co-design approach to examine and develop pathways to open employment for people with acquired brain injury. *Brain Impairment*, 22(1):50–66, 2021. doi: 10.1017/BrImp.2020.9.

Tim Brown and Barry Katz. Change by design. *Journal of Product Innovation Management*, 28(3):381–383, 2011. doi: https://doi.org/10.1111/j.1540-5885.2011.00806.x. URL https://onlinelibrary.wiley.com/doi/abs/10.1111/j.1540-5885.2011.00806.x.

S. Burgstahler. *Creating Inclusive Learning Opportunities in Higher Education: A Universal Design Toolkit*. Harvard Education Press, 2020. ISBN 9781682535400. URL https://books.google.es/books?id=rQqQzQEACAAJ.

James William Burke, MDJ McNeill, Darryl K Charles, Philip J Morrow, Jacqui H Crosbie, and Suzanne M McDonough. Optimising engagement for stroke rehabilitation using serious games. *The Visual Computer*, 25:1085–1099, 2009.

Antonio Calvo-Morata, Cristina Alonso-Fernández, Manuel Freire, Iván Martínez-Ortiz, and Baltasar Fernández-Manjón. Serious games to prevent and detect bullying and cyberbullying: A systematic serious games and literature review. *Computers and Education*, 157: 103958, 2020. doi: https://doi.org/10.1016/j.compedu.2020.103958. URL https://www.sciencedirect.com/science/article/pii/S0360131520301561.

David Checa and Andres Bustillo. A review of immersive virtual reality serious games to enhance learning and training. *Multimedia Tools and Applications*, 79:5501–5527, 3 2020. doi: 10.1007/s11042-019-08348-9.

Ching Yue Chow, Reisya Rizki Riantiningtyas, Mie Bojer Kanstrup, Maria Papavasileiou, Gie Djin Liem, and Annemarie Olsen. Can games change children's eating behaviour? a review of gamification and serious games. *Food Quality and Preference*, 80:103823, 2020.

Eduardo Cisneros, Véronique Beauséjour, Elaine de Guise, Sylvie Belleville, and Michelle McKerral. The impact of multimodal cognitive rehabilitation on executive functions in older adults with traumatic brain injury. *Annals of Physical and Rehabilitation Medicine*, 64 (5):101559, 2021. doi: https://doi.org/10.1016/j.rehab.2021.101559. URL https://www.sciencedirect.com/science/article/pii/S1877065721000774. Special issue Cognitive rehabilitation.

Linda Clare, Bob Woods, Esme Moniz-Cook, M Orrell, and Aimee Spector. Cognitive rehabilitation and cognitive training for early-stage alzheimer's disease and vascular dementia (cochrane review). *Cochrane database of systematic reviews (Online)*, 4:CD003260, 02 2003. doi: 10.1002/14651858.CD003260.

Peter Bragge Clare Nowell, Marina Downing and Jennie Ponsford. Current practice of cognitive rehabilitation following traumatic brain injury: An international survey. *Neuropsychological Rehabilitation*, 30(10):1976–1995, 2020. doi: 10.1080/09602011.2019.1623823. URL https://doi.org/10.1080/09602011.2019.1623823. PMID: 31164047.

Victoria Clarke and Virginia Braun. Using thematic analysis in counselling and psychotherapy research: A critical reflection. *Counselling and Psychotherapy Research*, 18:107–110, 6 2018. ISSN 1473-3145. doi: 10.1002/capr.12165.

Cogmed. Cogmed, 2024. URL https://cogmed.com/.

CogniPlus. Schuhfried cogniplus, 2023. URL https://www.schuhfried.com/en/other/cogniplus/.

Rikke Friis Dam and Yu Siang Teo. What is design thinking and why is it so popular? *Interaction Design Foundation*, 6 2022.

Geneviève Demarquay, Laurent Derex, Norbert Nighoghossian, Patrice Adeleine, Frédéric Philippeau, Jérôme Honnorat, and Paul Trouillas. Ethical Issues of Informed Consent in Acute Stroke. *Cerebrovascular Diseases*, 19(2):65–68, 02 2005. doi: 10.1159/000083250. URL https://doi.org/10.1159/000083250.

Halime Demirkan and Nilgün Olguntürk. A priority-based 'design for all' approach to guide home designers for independent living. *Architectural Science Review*, 57(2):90–104, 2014. doi: 10.1080/00038628.2013.832141. URL https://doi.org/10.1080/00038628.2013.832141.

Artemisa Rocha Dores, Irene Palmares Carvalho, Fernando Barbosa, Isabel Almeida, Sandra Guerreiro, Miguel Leitão, Liliana de Sousa, and Alexandre Castro-Caldas. *Serious Games: Are They Part of the Solution in the Domain of Cognitive Rehabilitation?*, pages 95–105. 2011. doi: 10.1007/978-3-642-23834-5_9.

Artemisa Rocha Dores, Maria João Miranda, Irene Palmares Carvalho, Liliana Mendes, Fernando Barbosa, António Coelho, Liliana de Sousa, and Alexandre Castro Caldas. Virtual city: Neurocognitive rehabilitation of acquired brain injury. In *7th Iberian Conference on Information Systems and Technologies (CISTI 2012)*, pages 1–4, 2012.

Ahmed Mohammed Elaklouk and Nor Azan Mat Zin. Design and usability evaluation of rehabilitation gaming system for cognitive deficiencies. In *2017 6th International Conference on Electrical Engineering and Informatics (ICEEI)*, pages 1–6. IEEE, 11 2017. ISBN 978-1-5386-0475-5. doi: 10.1109/ICEEI.2017.8312454.

Ahmed Mohammed Elaklouk and Nor Azan Mat Zin. A rehabilitation gaming system for cognitive deficiencies: Design and usability evaluation. *International Journal on Advanced Science, Engineering and Information Technology*, 9:181–187, 1 2019. ISSN 2460-6952. doi: 10.18517/ijaseit.9.1.6693.

Ana Lúcia Faria, Andreia Andrade, Luísa Soares, and Sergi Bermúdez i Badia. Benefits of virtual reality based cognitive rehabilitation through simulated activities of daily living: a randomized controlled trial with stroke patients. *Journal of NeuroEngineering and Rehabilitation*, 13:96, 12 2016. ISSN 1743-0003. doi: 10.1186/s12984-016-0204-z.

Ana Lúcia Faria, Maria Salomé Pinho, and Sergi Bermúdez i Badia. Capturing expert knowledge for the personalization of cognitive rehabilitation: Study combining computational modeling and a participatory design strategy. *JMIR Rehabil Assist Technol*, 5(2):e10714, Dec 2018. doi: 10.2196/10714. URL http://www.ncbi.nlm.nih.gov/pubmed/30522994.

Luisa Fonseca. "nedvc congress has established itself as a reference at the national level", 10 2023. URL https://www.spmi.pt/o-congresso-do-nedvc-estabeleceu-se-como-referencia-a-nivel-nacional/.

Luísa Fonseca. O avc é a principal causa de morte e incapacidade em portugal, 10 2021. URL https://www.spmi.pt/o-avc-e-a-principal-causa-de-morte-e-incapacidade-em-portugal/.

Y. Fride, T. Adamit, E. Ben Assayag A. Maeir, N. M. Bornstein, A. D. Korczyn, and N. Katz. What are the correlates of cognition and participation to return to work after first ever mild stroke? *Topics in Stroke Rehabilitation*, 22(5):317–325, 2015. doi: 10.1179/1074935714Z.0000000013. URL https://doi.org/10.1179/1074935714Z.0000000013. PMID: 26461878.

Rhonda B. Friedman, Mark Beeman, Susan N. Lott, Kathryn Link, Jordan Grafman, and Susan Robinson. Modality-specific phonological alexia. *Cognitive Neuropsychology*, 10:549–568, 11 1993. doi: 10.1080/02643299308253473.

Molly M Fuentes, Jin Wang, Juliet Haarbauer-Krupa, Keith Owen Yeates, Dennis Durbin, Mark R Zonfrillo, Kenneth M Jaffe, Nancy Temkin, David Tulsky, Hilary Bertisch, et al. Unmet rehabilitation needs after hospitalization for traumatic brain injury. *Pediatrics*, 141(5), 2018.

L.Y. Fung, E. Halpern, and K. Sivjee. Case report: An approach to the patient with reading difficulties in the primary care setting. *Journal of Neurolinguistics*, 24(1):89–95, 2011. doi: https://doi.org/10.1016/j.jneuroling.2010.08.001. URL https://www.sciencedirect.com/science/article/pii/S0911604410000813.

GBD 2019 Diseases and Injuries Collaborators . Global burden of 369 diseases and injuries in 204 countries and territories, 1990-2019: a systematic analysis for the global burden of disease study 2019. *The Lancet*, 396(10258):1204–1222, Oct 2020. doi: 10.1016/S0140-6736(20)30925-9. URL https://doi.org/10.1016/S0140-6736(20)30925-9.

Liam Goldman, Ehraz Mehmood Siddiqui, Andleeb Khan, Sadaf Jahan, Muneeb U. Rehman, Sidharth Mehan, Rajat Sharma, Stepan Budkin, Shashi Nandar Kumar, Ankita Sahu, Manish Kumar, and Kumar Vaibhav. Understanding acquired brain injury: A review. *Biomedicines*, 10, 9 2022. doi: 10.3390/biomedicines10092167.

Michael Grimaldi and Rebecca Jeanmonod. Acute stroke presenting with isolated acalculia. *The American Journal of Emergency Medicine*, 36(10):1923.e1–1923.e3, 2018. doi: https://doi.org/10.1016/j.ajem.2018.06.038. URL https://www.sciencedirect.com/science/article/pii/S0735675718305035.

Bianca Guglietti, David A. Hobbs, Bradley Wesson, Benjamin Ellul, Angus McNamara, Simon Drum, and Lyndsey E. Collins-Praino. Development and co-design of neuroorb: A novel “serious gaming” system targeting cognitive impairment in parkinson’s disease. *Frontiers in Aging Neuroscience*, 14, 2022. doi: 10.3389/fnagi.2022.728212. URL https://www.frontiersin.org/articles/10.3389/fnagi.2022.728212.

Gong Haoran, Eleni Bazakidi, and Nabil Zary. Serious games in health professions education: review of trends and learning efficacy. *Yearbook of medical informatics*, 28(01):240–248, 2019.

Karin Hediger, Stefan Thommen, Cora Wagner, Jens Gaab, and Margret Hund-Georgiadis. Effects of animal-assisted therapy on social behaviour in patients with acquired brain injury: a randomised controlled trial. *Scientific Reports*, 9:5831, 4 2019. doi: 10.1038/s41598-019-42280-0.

Walter M. High, Tresa Roebuck-Spencer, Angelle M. Sander, Margaret A. Struchen, and Mark Sherer. Early versus later admission to postacute rehabilitation: Impact on functional outcome after traumatic brain injury. *Archives of Physical Medicine and Rehabilitation*, 87:334–342, 3 2006. ISSN 00039993. doi: 10.1016/j.apmr.2005.11.028.

Yvette Hou, Aileen Zhou, Laura Brooks, Daniella Reid, Lyn Turkstra, and Sheila MacDonald. Rehabilitation access for individuals with cognitive-communication challenges after traumatic brain injury: A co-design study with persons with lived experience. *International Journal of Language & Communication Disorders*, n/a(n/a), 2023. doi: https://doi.org/10.1111/1460-6984.12895. URL https://onlinelibrary.wiley.com/doi/abs/10.1111/1460-6984.12895.

Ya-Xuan Hung, Pei-Chen Huang, Kuan-Ta Chen, and Woei-Chyn Chu. What do stroke patients look for in game-based rehabilitation. *Medicine*, 95:e3032, 3 2016. doi: 10.1097/MD.0000000000003032.

W.A. IJsselsteijn, Y.A.W. de Kort, and K. Poels. *The Game Experience Questionnaire*. Technische Universiteit Eindhoven, 2013.

Charlotte Johansson-Malmeling, Åsa Wengelin, and Ingrid Henriksson. Aphasia and spelling to dictation: Analysis of spelling errors and editing, 1 2021.

Nigel W. John, Thomas W. Day, Serban R. Pop, Kausik Chatterjee, Katy Cottrell, Alistair Buchanan, and Jonathan Roberts. Virtual reality environment for the cognitive rehabilitation of stroke patients. In *2019 11th International Conference on Virtual Worlds and Games for Serious Applications (VS-Games)*, pages 1–4. IEEE, 9 2019. ISBN 978-1-7281-4540-2. doi: 10.1109/VS-Games.2019.8864513.

Hee-Tae Jung, Jean-Francois Daneault, Tenzin Nanglo, Hyunsuk Lee, Byeongil Kim, Yangsoo Kim, and Sunghoon Ivan Lee. Effectiveness of a serious game for cognitive training in chronic stroke survivors with mild-to-moderate cognitive impairment: A pilot randomized controlled trial. *Applied Sciences*, 10:6703, 9 2020. ISSN 2076-3417. doi: 10.3390/app10196703.

Somnath Chatterji Kaloyan Kamenov, Jody-Anne Mills and Alarcos Cieza. Needs and unmet needs for rehabilitation services: a scoping review. *Disability and Rehabilitation*, 41(10):1227–1237, 2019. doi: 10.1080/09638288.2017.1422036. URL https://doi.org/10.1080/09638288.2017.1422036. PMID: 29303004.

Youn Joo Kang, Jeonghun Ku, Kiwan Han, Sun I. Kim, Tae Won Yu, Jang Han Lee, and Chang Il Park. Development and clinical trial of virtual reality-based cognitive assessment in people with stroke: Preliminary study. *CyberPsychology and Behavior*, 11:329–339, 6 2008. ISSN 1094-9313. doi: 10.1089/cpb.2007.0116.

Abdelhakim Khellaf, Danyal Zaman Khan, and Adel Helmy. Recent advances in traumatic brain injury. *Journal of Neurology*, 266(11):2878–2889, Nov 2019. doi: 10.1007/s00415-019-09541-4. URL https://doi.org/10.1007/s00415-019-09541-4.

Erwin JO Kompanje, Jeroen TJM van Dijck, Vicky Chalos, Sophie A van den Berg, Paula M Janssen, Paul J Nederkoorn, Mathieu van der Jagt, Giuseppe Citerio, Nino Stocchetti, Diederik WJ Dippel, et al. Informed consent procedures for emergency interventional research in patients with traumatic brain injury and ischaemic stroke. *The Lancet Neurology*, 19(12):1033–1042, 2020.

Jeanine Krath, Linda Schürmann, and Harald F.O. von Korflesch. Revealing the theoretical basis of gamification: A systematic review and analysis of theory in research on gamification, serious games and game-based learning. *Computers in Human Behavior*, 125:106963, 2021. doi: https://doi.org/10.1016/j.chb.2021.106963. URL https://www.sciencedirect.com/science/article/pii/S0747563221002867.

Daniel Lanzoni, Andrea Vitali, Daniele Regazzoni, and Caterina Rizzi. Design of customized virtual reality serious games for the cognitive rehabilitation of retrograde amnesia after brain stroke. *Journal of Computing and Information Science in Engineering*, 22, 6 2022. ISSN 1530-9827. doi: 10.1115/1.4053149.

Kristi Larson. Serious games and gamification in the corporate training environment: a literature review. *TechTrends*, 64:319–328, 3 2020. doi: 10.1007/s11528-019-00446-7.

Jennapher Lingo VanGilder, Andrew Hooyman, Daniel S. Peterson, and Sydney Y. Schaefer. Post-stroke cognitive impairments and responsiveness to motor rehabilitation: A review. *Current Physical Medicine and Rehabilitation Reports*, 8(4):461–468, Dec 2020. doi: 10.1007/s40141-020-00283-3. URL https://doi.org/10.1007/s40141-020-00283-3.

Niamh Lowe, Lorraine Crawley, Charlotte Wilson, and Brian Waldron. 'lonely in my head': The experiences of loneliness in individuals with brain injury. *British Journal of Health Psychology*, 26(2):444–463, 2021. doi: https://doi.org/10.1111/bjhp.12481. URL https://bpspsychub.onlinelibrary.wiley.com/doi/abs/10.1111/bjhp.12481.

Ramon Luengo-Fernandez, Mara Violato, Paolo Candio, and Jose Leal. Economic burden of stroke across europe: A population-based cost analysis. *European Stroke Journal*, 5(1):17–25, 2020. doi: 10.1177/2396987319883160. URL https://doi.org/10.1177/2396987319883160.

Andrew I. R. Maas, David K. Menon, Geoffrey T. Manley, Mathew Abrams, Cecilia Åkerlund, Nada Andelic, Marcel Aries, Tom Bashford, Michael J. Bell, Yelena G. Bodien, et al. Traumatic brain injury: progress and challenges in prevention, clinical care, and research. *The Lancet Neurology*, 21(11):1004–1060, Nov 2022. doi: 10.1016/S1474-4422(22)00309-X. URL https://doi.org/10.1016/S1474-4422(22)00309-X.

Maria Grazia Maggio, Giuseppa Maresca, Maria Chiara Stagnitti, Smeralda Anchesi, Carmela Casella, Valentina Pajno, Alfredo Manuli Rosaria De Luca, and Rocco Salvatore Calabrò. Social cognition in patients with acquired brain lesions: An overview on an under-reported problem. *Applied Neuropsychology: Adult*, 29(3):419–431, 2022. doi: 10.1080/23279095.2020.1753058. URL https://doi.org/10.1080/23279095.2020.1753058. PMID: 32301351.

Elisa Mantovani, Chiara Zucchella, Sara Bottiroli, Angela Federico, Rosalba Giugno, Giorgio Sandrini, Cristiano Chiamulera, and Stefano Tamburin. Telemedicine and virtual reality for cognitive rehabilitation: A roadmap for the covid-19 pandemic. *Frontiers in Neurology*, 11, 2020. doi: 10.3389/fneur.2020.00926. URL https://www.frontiersin.org/articles/10.3389/fneur.2020.00926.

Alison M McLean, Tal Jarus, Anita M Hubley, and Lyn Jongbloed. Associations between social participation and subjective quality of life for adults with moderate to severe traumatic brain injury. *Disability and rehabilitation*, 36(17):1409–1418, 2014.

Maarten Milders. Relationship between social cognition and social behaviour following traumatic brain injury. *Brain Injury*, 33(1):62–68, 2019. doi: 10.1080/02699052.2018.1531301. URL https://doi.org/10.1080/02699052.2018.1531301. PMID: 30325217.

Fatemeh Mohammadian, Meysam Rahmani-Katigari, and Leila Shahmoradi. Development of a serious game-based cognitive rehabilitation system for patients with brain injury. *BMC Psychiatry*, 23:893, 11 2023. ISSN 1471-244X. doi: 10.1186/s12888-023-05396-2.

Sandra Moll, Michelle Wyndham-West, Gillian Mulvale, Sean Park, Alexis Buettgen, Michelle Phoenix, Robert Fleisig, and Emma Bruce. Are you really doing 'codesign'? critical reflections when working with vulnerable populations. *BMJ Open*, 10(11), 2020. doi: 10.1136/bmjopen-2020-038339. URL https://bmjopen.bmj.com/content/10/11/e038339.

Juan Francisco Ortega Morán, J Blas Pagador, Vicente Gilete Preciado, José Luis Moyano-Cuevas, Trinidad Rodríguez Domínguez, Marta Santurino Muñoz, and Francisco M Sánchez Margallo. A serious game for cognitive stimulation of older people with mild cognitive impairment: Design and pilot usability study. *JMIR Aging*, 7:e41437–e41437, 4 2024. ISSN 2561-7605. doi: 10.2196/41437.

Orla T. Muldoon, R. Stephen Walsh, Mariah Curtain, Lorraine Crawley, and Elaine L. Kinsella. Social cure and social curse: Social identity resources and adjustment to acquired brain injury. *European Journal of Social Psychology*, 49(6):1272–1282, 2019. doi: https://doi.org/10.1002/ejsp.2564. URL https://onlinelibrary.wiley.com/doi/abs/10.1002/ejsp.2564.

Gillian Mulvale, Sandra Moll, Ashleigh Miatello, Louise Murray-Leung, Karlie Rogerson, and Roberto B. Sassi. Co-designing services for youth with mental health issues: Novel elicitation approaches. *International Journal of Qualitative Methods*, 18:1609406918816244, 2019. doi: 10.1177/1609406918816244. URL https://doi.org/10.1177/1609406918816244.

R. Mycroft, J.R. Hanley, and J. Kay. Preserved access to abstract letter identities despite abolished letter naming in a case of pure alexia. *Journal of Neurolinguistics*, 15(2):99–108, 2002. doi: https://doi.org/10.1016/S0911-6044(01)00003-3. URL https://www.sciencedirect.com/science/article/pii/S0911604401000033.

NeuronUP. Neuronup, 2024. URL https://neuronup.com/.

Joanne Nunnerley, Marcus King, Katie Hodge, Pat Hopkins, Riley Stockwell, Nadia Thorne, Deborah Snell, and Kristin Gozdzikowska. Co-design of a therapeutic virtual reality tool to increase awareness and self-management of cognitive fatigue after traumatic brain injury. *Disability and Rehabilitation: Assistive Technology*, 18(8):1404–1410, 2023. doi: 10.1080/17483107.2021.2014993. URL https://doi.org/10.1080/17483107.2021.2014993. PMID: 35286813.

Vanessa Palumbo and Fabio Paternò. Serious games to cognitively stimulate older adults: a systematic literature review. In *Proceedings of the 13th ACM International Conference on PErvasive Technologies Related to Assistive Environments*, PETRA '20, New York, NY, USA, 2020. Association for Computing Machinery. ISBN 9781450377737. doi: 10.1145/3389189.3393739. URL https://doi.org/10.1145/3389189.3393739.

Sung-Jun Park, Hee-Dong Chang, and KyungSik Kim. Effectiveness of the serious game 'rejuvenesce village' in cognitive rehabilitation for the elderly. *International Journal of E-Health*

and Medical Communications, 6:48–57, 1 2015. ISSN 1947-315X. doi: 10.4018/IJEHMC.2015010104.

Sina Parsay, Armin Vosoughi, Aytak Khabbaz, and Saeed Sadigh-Eteghad. The incidence and mortality ratio of ischemic cerebrovascular accidents in covid-19 cases: A systematic review and meta-analysis. *Journal of Stroke and Cerebrovascular Diseases*, 30(3):105552, 2021. doi: https://doi.org/10.1016/j.jstrokecerebrovasdis.2020.105552. URL https://www.sciencedirect.com/science/article/pii/S1052305720309708.

AuthorExplore Psychology. Chunking psychology: Definition and examples, 3 2023. URL https://www.explorepsychology.com/chunking-psychology-definition-and-examples/.

Sunna Rannikko, Minna Stolt, Riitta Suhonen, and Helena Leino-Kilpi. Ethical issues in the care of patients with stroke: A scoping review. *Journal of Clinical Nursing*, 28(1-2):20–31, 2019. doi: https://doi.org/10.1111/jocn.14661. URL https://onlinelibrary.wiley.com/doi/abs/10.1111/jocn.14661.

Paula Alexandra Rego, Rui Rocha, Brígida Mónica Faria, Luís Paulo Reis, and Pedro Miguel Moreira. A serious games platform for cognitive rehabilitation with preliminary evaluation. *Journal of Medical Systems*, 41:10, 1 2017. doi: 10.1007/s10916-016-0656-5.

RehaCom. Rehacom - cognitive therapy, 2023. URL https://hasomed.de/en/products/rehacom/.

Ana Filipa Rosa, Ana Isabel Martins, Victor Costa, Alexandra Queirós, Anabela Silva, and Nelson Pacheco Rocha. European portuguese validation of the post-study system usability questionnaire (pssuq). In *2015 10th Iberian Conference on Information Systems and Technologies (CISTI)*, pages 1–5, 2015. doi: 10.1109/CISTI.2015.7170431.

Natalia S. Rost, Amy Brodtmann, Matthew P. Pase, Susanne J. van Veluw, Alessandro Biffi, Marco Duering, Jason D. Hinman, and Martin Dichgans. Post-stroke cognitive impairment and dementia. *Circulation Research*, 130(8):1252–1271, 2022. doi: 10.1161/CIRCRESAHA.122.319951. URL https://www.ahajournals.org/doi/abs/10.1161/CIRCRESAHA.122.319951.

Gonçalo Simão Roxo and Maria Beatriz Carmo. Studying serious games for the therapy of children with disabilities following a co-design process, 2023.

Andres M. Rubiano, Dylan P. Griswold, Manuel Jibaja, Alejandro A. Rabinstein, and Daniel Agustin Godoy. Management of severe traumatic brain injury in regions with limited resources. *Brain Injury*, 35(11):1317–1325, 2021. doi: 10.1080/02699052.2021.1972149. URL https://doi.org/10.1080/02699052.2021.1972149. PMID: 34493135.

Christian E. Salas, Daniel Rojas-Líbano, Ramiro Cruces Osvaldo Castro, Jonathan Evans, Darinka Radovic, Camilo Arévalo-Romero, Julio Torres, and Álvaro Aliaga. Social isolation after acquired brain injury: Exploring the relationship between network size, functional support, loneliness and mental health. *Neuropsychological Rehabilitation*, 32(9):2294–2318, 2022. doi: 10.1080/09602011.2021.1939062. URL https://doi.org/10.1080/09602011.2021.1939062. PMID: 34139944.

Maria Emilia Santos and Nicole Agrela. Traumatic brain injury in portugal: progress in incidence and mortality. *Brain Injury*, 33:1552–1555, 10 2019. doi: 10.1080/02699052.2019.1658227.

Syed Hammad Hussain Shah, Anniken Susanne T. Karlsen, Mads Solberg, and Ibrahim A. Hameed. A social vr-based collaborative exergame for rehabilitation: codesign, development and user study. *Virtual Reality*, 27:3403–3420, 12 2023. doi: 10.1007/s10055-022-00721-8.

Eliana Silva, Ricardo Lopes, and Luís Paulo Reis. Cognichallenge: Multiplayer serious games' platform for cognitive and psychosocial rehabilitation. *International Journal of Serious Games*, 10:3–16, 11 2023. ISSN 2384-8766. doi: 10.17083/ijsg.v10i4.646.

Julian Specht, Barbara Stegmann, Hanna Gross, and Karsten Krakow. Cognitive training with head-mounted display virtual reality in neurorehabilitation: Pilot randomized controlled trial. *JMIR Serious Games*, 11:e45816, 7 2023. ISSN 2291-9279. doi: 10.2196/45816.

Kamath Sriganesh, Harsha Shanthanna, and JasonW Busse. A brief overview of systematic reviews and meta-analyses. *Indian Journal of Anaesthesia*, 60:689, 2016. ISSN 0019-5049. doi: 10.4103/0019-5049.190628.

Britta Stammler, Kathrin Flammer, Thomas Schuster, Marian Lambert, and Hans-Otto Karnath. Negami: An augmented reality app for the treatment of spatial neglect after stroke. *JMIR Serious Games*, 11:e40651, 2 2023. ISSN 2291-9279. doi: 10.2196/40651.

Nino Stocchetti and Elisa R. Zanier. Chronic impact of traumatic brain injury on outcome and quality of life: a narrative review. *Critical Care*, 20:148, 12 2016. doi: 10.1186/s13054-016-1318-1.

Robert Teasell, Katherine Salter, Pavlina Faltynek, Andreea Cotoi, and Gail Eskes. Post-stroke cognitive disorders. *Evidence-based review of stroke rehabilitation*, 86, 2018.

Vanessa Vallejo, Patric Wyss, Alvin Chesham, Andrei V. Mitache, René M. Müri, Urs P. Mosimann, and Tobias Nef. Evaluation of a new serious game based multitasking assessment tool for cognition and activities of daily living: Comparison with a real cooking task. *Computers in Human Behavior*, 70:500–506, 5 2017. ISSN 07475632. doi: 10.1016/j.chb.2017.01.021.

Milan N. A. van der Kuil, Johanna M. A. Visser-Meily, Andrea W. M. Evers, and Ineke J. M. van der Ham. A usability study of a serious game in cognitive rehabilitation: A compensatory navigation training in acquired brain injury patients. *Frontiers in Psychology*, 9, 6 2018. ISSN 1664-1078. doi: 10.3389/fpsyg.2018.00846.

Pedro Emilio Bermejo Velasco and Laura Castillo Moreno. Acalculia: clasificación, etiología y tratamiento clínico. *Revista de Neurología*, 43:223, 2006. doi: 10.33588/rn.4304.2005684.

Andrea Vitali, Daniele Regazzoni, Caterina Rizzi, and Andrea Spajani. Vr serious games for neuro-cognitive rehabilitation of patients with severe memory loss. *Computer-Aided Design and Applications*, 18:1233–1246, 2 2021. ISSN 16864360. doi: 10.14733/cadaps.2021.1233-1246.

Prokopia Vlachogianni and Nikolaos Tselios. Perceived usability evaluation of educational technology using the post-study system usability questionnaire (pssuq): A systematic review. *Sustainability*, 15:12954, 8 2023. ISSN 2071-1050. doi: 10.3390/su151712954.

Hatem A. Wafa, Charles D.A. Wolfe, Eva Emmett, Gregory A. Roth, Catherine O. Johnson, and Yanzhong Wang. Burden of stroke in europe. *Stroke*, 51(8):2418–2427, 2020. doi: 10.1161/STROKEAHA.120.029606. URL https://www.ahajournals.org/doi/abs/10.1161/STROKEAHA.120.029606.

Prue A. Watson, Gilles E. Gignac, Michael Weinborn, Sarah Green, and Carmela Pestell. A meta-analysis of neuropsychological predictors of outcome following stroke and other non-traumatic acquired brain injuries in adults. *Neuropsychology Review*, 30(2):194–223, Jun 2020. doi: 10.1007/s11065-020-09433-9. URL https://doi.org/10.1007/s11065-020-09433-9.

Claire Williams, Rodger Llewellyn Wood, Nick Alderman, and Andrew Worthington. The psychosocial impact of neurobehavioral disability. *Frontiers in Neurology*, 11, 2 2020. doi: 10.3389/fneur.2020.00119.

D Zavaleta, K Samuel, and C Mills. Social isolation: a conceptual and measurement proposal. 2014.

Gabe Zichermann and Christopher Cunningham. *Gamification by design: Implementing game mechanics in web and mobile apps*. " O'Reilly Media, Inc.", 2011.

Appendix A

Supporting Documents

A.1 Guiões das entrevistas

A.1.1 Pacientes

Introdução Este projeto pretende criar uma plataforma de jogos sérios multijogador que possa ser integrada ao processo de reabilitação cognitiva de pacientes com lesão cerebral adquirida. Estes jogos serão multijogadores para melhorar as competências sociais, acompanhados de mecanismos que adaptam a dificuldade e a jogabilidade para manter a equidade e o desafio entre os diferentes participantes. O jogo será composto por um conjunto de minijogos que focarão em diferentes áreas da cognição.

Perguntas

- Há quanto tempo está em reabilitação cognitiva?
- Faz uso de algum jogo para auxiliar a reabilitção cognitiva?
  - Se sim, que tipos de tarefas fazem parte do jogo?
  - Se sim, consegue apontar os pontos positivos e negativos sobre o jogo?
- E no seu dia a dia, costuma jogar algum tipo de jogo?
- Quanto a sua preferência pessoal, gostaria que o jogo que estamos a desenvolver incluísse aspetos do dia a dia? Que aspetos do a dia-a-dia considera mais motivadores? Tarefas da casa, situações de trabalho, cuidado da família ou de animais de estimação?
- Gostava de um jogo cujo tema fosse culinária? Que cenários considera mais interessantes? Ex: restaurante, cozinha de casa, mercado, etc
- Que tipo de dispositivo estaria mais confortável em utilizar enquanto joga (telemóvel, tablet, computador)?
- Preferia jogar sozinho ou com outras pessoas?

  - Se preferia jogar com pessoas, gostava de jogos em que jogasse contra elas ou com a ajuda delas?
  - Se preferia jogar sozinho, e se fosse uma plataforma que permite ambos os cenários, que jogue sozinho ou com outras pessoas, dependendo da vontade no momento?
  - Se preferia jogar sozinho, e se a plataforma for capaz de adaptar a dificuldade para que o jogo entre duas pessoas seja justo? Neste cenário, haveria uma maneira de equilibrar um jogo entre uma pessoa que não conhece o jogo e outra que já está habituada com as regras, por exemplo.

A.1.2 Familiares

Introdução Este projeto pretende criar uma plataforma de jogos sérios multijogador que possa ser integrada ao processo de reabilitação cognitiva de pacientes com lesão cerebral adquirida. Estes jogos serão multijogadores para melhorar as competências sociais, acompanhados de mecanismos que adaptam a dificuldade e a jogabilidade para manter a equidade e o desafio entre os diferentes participantes. A componente multijogador também tem a intenção de incluir familiares no processo de reabilitação e auxiliá-los no acompanhamento do mesmo. Possivelmente pode possibilitar a criação de um ambiente de socialização espontânea e natural, resultando numa melhor integração dos pacientes na vida familiar. O jogo será composto por um conjunto de minijogos que focarão em diferentes áreas da cognição e, quando colocados em modo multijogador, serão cooperativos para incentivar o espírito de colaboração e de entreajuda.

Perguntas

- Há quanto tempo acompanha o paciente em reabilitação cognitiva?
- O seu familiar faz uso de algum jogo para auxiliar a reabilitação cognitiva? ? (podem ser jogos sérios criados para a reabilitação ou jogos que considera que ajudam de alguma forma)
  - Se sim, que tipos de tarefas fazem parte do jogo?
  - Se sim, conhece pessoalmente o jogo, já experimentou jogá-lo ou é possível que joguem juntos?
  - Se sim, consegue apontar os pontos positivos e negativos sobre jogo?
- No que toca a componente multijogador, isto é, vários jogadores a jogar o mesmo jogo ao mesmo tempo, de que maneiras acha que esta componente poderá contribuir para o seu envolvimento e acompanhamento no tratamento?
- Ainda sobre tal componente, de que maneiras acha que a plataforma poderia facilitar o convívio entre si e o paciente?
- Que funcionalidades seriam mais apropriadas para esse tipo de plataforma (chat, chamada de voz, reações live com o uso de emojis etc.)?

- Considera que o seu familiar beneficiaria mais de jogos multiplayer competitivos – em que jogam uns contra os outros para um vencer, cooperativos – em que ambos colaboram para atingir o objetivo do jogo ou ambos?

A.1.3 Profissionais

Introdução Este projeto pretende criar uma plataforma de jogos sérios multijogador que possa ser integrada ao processo de reabilitação cognitiva de pacientes com lesão cerebral adquirida. Estes jogos serão multijogadores para melhorar as competências sociais, acompanhados de mecanismos de handicap que adaptam a jogabilidade para manter a equidade e o desafio entre os diferentes pacientes. O jogo será composto por um conjunto de minijogos que focarão em diferentes áreas da cognição e, quando colocados em modo multijogador, serão cooperativos para incentivar o espírito de colaboração e de entreajuda entre os pacientes.

Perguntas Técnicas

- Na prática profissional costuma recorrer a jogos para a reabilitação cognitiva?
  - Se sim, quais são mais usadas?
  - Se sim, quais são os seus pontos fortes e fracos?
- Conhece algum jogo auxiliar à reabilitação cognitiva que foi criado com esse objetivo?
  - Se sim, consegue apontar os pontos positivos e negativos sobre jogo?
  - Se sim, os sistemas são atuais? Que limitações existem nas tecnologias existentes?
- Que tipo de dispositivo considera que os pacientes estariam mais confortáveis em utilizar enquanto jogam (telemóvel, tablet, computador)?
  - É importante que os dispositivos tenham ecrãs táteis, ou os pacientes conseguiriam facilmente jogar um jogo com um rato normal conectado ao computador?

Perguntas Design

- Segundo o estudo da literatura, considera-se mais apropriado que o tema central do jogo seja aspetos do dia a dia ao invés de puzzles mais diretos ou temas fantasiosos. Que aspetos do dia a dia considera mais motivadores para um jogo? Planeamos focar no tema da culinária e em cenários como restaurante, food truck, mercado, ou a cozinha de casa. É pertinente? É algo que pode interessar os pacientes?
- Quanto a áreas da cognição, pretendemos incluir mini-jogos focados em atenção seletiva, atenção distribuída, memória visual e espacial, funções executivas (planeamento de tarefas e gerenciamento de tempo) e, finalmente, linguagem e raciocínio matemático. Quanto aos últimos dois, há menos estudos publicados quanto a dificuldade específica dos pacientes nessas áreas, o que torna mais difícil perceber como abordá-las. Sendo assim,

  - Quanto a linguagem e comunicação, de que tipos de exercício considera que os pacientes beneficiariam mais? Ex: afasia expressiva, expressar ideias verbalmente, encontrando as palavras corretas e produzindo frases coerentes; afasia receptiva, entender instruções e acompanhar conversas; discriminação visual, a capacidade de reconhecer letras, palavras e símbolos, assim como soletrar palavras corretamente.
  - Quanto a raciocínio matemático, de que tipos de exercício considera que os pacientes beneficiariam mais? Ex: cálculos matemáticos básicos como adição, subtração, multiplicação e divisão; raciocínio lógico como entender padrões, resolver problemas de lógica ou aplicar estratégias de resolução de problemas.

- Quanto aos restantes jogos, segue uma pequena descrição de cada um, para a validação da sua pertinência:

  - Foco no Truck (Atenção Selectiva): Ambos os jogadores são cozinheiros de um food truck com diferentes receitas do menu à sua frente. Um jogaor deve responder aos pedidos de comida enquanto o outro recebe o dinheiro dos clientes, para obter o máximo de pontos possível. Os papéis são distribuídos no início do jogo e mudam a meio - na marca dos 5 minutos. Os jogadores não devem reagir aos estímulos do trabalho do outro jogador.
  - Caos na Cozinha (Atenção Distribuída): Ambos os jogadores estão na cozinha, a cozinhar. Os diferentes electrodomésticos da cozinha, como o forno, o micro-ondas e as panelas no fogão, mostram notificações relativas a partes da receita que precisam de interação. Cada jogador será responsável por um par de electrodomésticos diferentes, e essa distribuição muda a meio do jogo - aos 5 minutos. Os jogadores devem trabalhar em conjunto para responder a essas notificações, controlando várias partes da receita.
  - Tornado da Memória (Memória Visual/Espacial): Para jogar este minijogo, os dois jogadores devem memorizar uma imagem de um cenário diferente. Pode ser uma cozinha, a área de refeições de um restaurante, a área de stock de um supermercado ou uma toalha colorida num piquenique. Têm de ver onde estavam os utensílios, os pratos, os ingredientes e as decorações antes de um furacão ter retirado tudo do seu lugar original. Cada jogador recebe um lado da sala, aleatoriamente, e deve reorganizá-lo, colocando os itens de volta no lugar para ganhar o jogo. Quando terminarem os jogadores têm de votar para a enviar e verificar se acertaram. Em caso afirmativo, recebem pontos e, em caso negativo, podem tentar novamente.
  - Rota da Comida (Funções Executivas): Os jogadores planeiam um jantar elaborado e têm de ir a diferentes locais para comprar as coisas de que necessitam. O objetivo é planear o melhor itinerário possível tendo em conta essas necessidades. Os jogadores têm de sair de casa e ir a diferentes locais, como o supermercado, a padaria ou o talho, entre outros. Os jogadores têm de ordenar os locais de forma a criar o melhor caminho e concluir todas as tarefas o mais rapidamente possível. Para o fazer, os jogadores recebem um plano em branco e preenchem à vez cada espaço com um local.

A.2 Flyer informativo

Figure A.1: Front of the flyer used to recruit participants for the interview phase

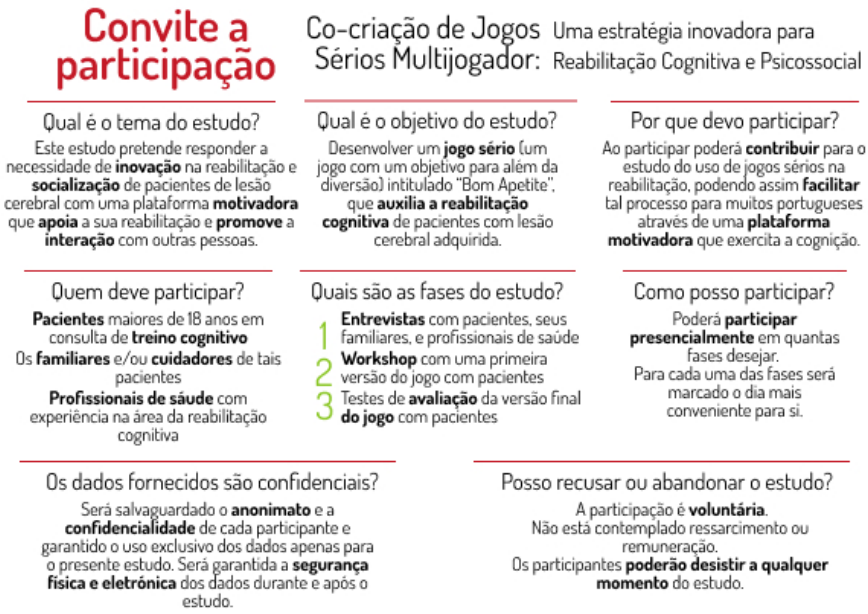

Figure A.2: Back of the flyer used to recruit participants for the interview phase

A.3 Consentimento Informado

CONSENTIMENTO INFORMADO, LIVRE E ESCLARECIDO PARA PARTICIPAÇÃO EM INVESTIGAÇÃO de acordo com a Declaração de Helsínquia[1] e a Convenção de Oviedo[2]

Por favor, leia com atenção a seguinte informação. Se achar que algo está incorreto ou que não está claro, não hesite em solicitar mais informações. Se concorda com a proposta que lhe foi feita, queira assinar este documento.

Título do Estudo:

Co-criação de Jogos Sérios Multijogador: Uma Estratégia Inovadora para Reabilitação Cognitiva e Psicossocial

Investigação no âmbito do Mestrado em Engenharia Informática e de Computação

Enquadramento do Estudo: De acordo estudos feitos em 2016 e 2019, na Europa, a incidência de traumatismos cranioencefálicos (TCE) situa-se entre 47.3-694/100.000 habitantes por ano e em Portugal, a incidência de TCE é de 65/100.000 habitantes por ano, com taxa de mortalidade de 10/100.000 habitantes. O AVC, por sua vez, é a principal causa de morte e incapacidade prolongada tanto na Europa quanto em Portugal, segundo a Sociedade Portuguesa de Medicina Interna. A reabilitação cognitiva é um tratamento especializado para recuperar funções parcialmente ou completamente perdidas, através de diferentes métodos e abordagens. O maior foco é corrigir déficits na memória, concentração, atenção, percepção, aprendizagem, planeamento, entre outros. O dano cerebral em cada área da cognição pode ter efeitos devastadores no funcionamento diário do paciente, de modo que a sua reinserção na comunidade pode ser desafiadora. Pessoas que sofreram uma lesão cerebral lidam com problemas psicossociais como ansiedade e/ou depressão, tanto durante quanto depois do processo de reabilitação. Dados esses impactos, é crucial avaliar sempre que possível a eficácia dos tratamentos disponíveis. As técnicas tradicionais dependem de terapeutas e da deslocação dos pacientes até clínicas, o que pode ser visto como uma inconveniência por motivos financeiros ou de mobilidade. Outra possível dificuldade encontrada pelos pacientes é relacionada com a natureza repetitiva das tarefas envolvidas no processo de recuperação, que podem ser vistas como tediosas ou monótonas. Este desencorajamento pode muitas vezes levar ao abandono do tratamento.

Explicação do Estudo: A estudante Carolina Cintra Fernandes Figueira, a frequentar o Mestrado em Engenharia Informática e Computação da Faculdade de Engenharia da Universidade do Porto, visa proceder a uma pesquisa sob orientação da investigadora Eliana Silva e Prof. Luís Paulo Reis com vista a compreender a melhor maneira que pacientes com lesão cerebral adquirida podem beneficiar de uma plataforma multijogador com jogos sérios para a reabilitação cognitiva e psicossocial. O estudo contará com a participação de três grupos distintos, sendo esses pacientes com mais de 18 anos, que já tenham iniciado um processo de reabilitação cognitiva, familiares e/ou cuidadores de tais pacientes, terapeutas/profissionais da área (e.g., neuropsicólogos, neurologistas, terapeutas ocupacionais). Será feito nas seguintes três partes:

- Na primeira fase serão contactadas clínicas de reabilitação cognitiva e associações de apoio a pessoas que tiveram um AVC, de maneira a entrevistar um mínimo de três participantes

dentre os três grupos mencionados. Idealmente as entrevistas serão presenciais, de modo a estabelecer uma conexão com os entrevistados e mais facilmente entender e empatizar com as suas contribuições. No entanto, há a possibilidade de realizá-las online, de acordo com a preferência dos participantes.

- A segunda fase será presencial, terá lugar numa altura intermédia do desenvolvimento e será conduzida na FEUP ou no local de estudo, de acordo com a preferência dos participantes. Estes serão os mesmos do grupo de pacientes adultos que participaram da fase anterior e outros que tenham interesse em participar, contemplando cerca de 10 pessoas.
- A terceira será um estudo de usabilidade, onde serão usados questionários impressos do tipo The Game Experience Questionnaire e Post-Study System Usability Questionnaire. Esta fase será conduzida presencialmente novamente com os pacientes de lesão cerebral que já conhecem o projeto e outros que desejem participar do estudo e terá um mínimo de 10 participantes.

Condições e financiamento: Será obtido Consentimento Informado, Livre e Esclarecido de todos os adultos incluídos na investigação. Não está contemplado qualquer ressarcimento ou remuneração para participação no estudo nem haverá qualquer custo para o participante. Não são antecipados riscos decorrentes da participação no presente projeto de investigação. As conclusões do estudo serão divulgadas através de artigos científicos para apresentação do jogo sério e do feedback obtido por parte do seu público-alvo (pacientes com lesão cerebral adquirida). Os participantes interessados poderão requerer as conclusões do estudo à equipa de investigação. O estudo mereceu um Parecer favorável da Comissão de Ética da Universidade do Porto, e das Comissões de Ética das Instituições onde está a ser realizado. [caso se verifique] O projeto é financiado por: Financiamento Base - UIDB/00027/2020 da Unidade de Investigação - Laboratório de Inteligência Artificial e Ciência de Computadores - LIACC - financiado por fundos nacionais através da FCT/MCTES (PIDDAC). A participação será voluntária, podendo negar ou descontinuar a qualquer momento. Ao aceitar participar desta pesquisa, estará a colaborar na produção de conhecimento sobre alternativas à metodologia tradicional da reabilitação cognitiva, que é essencial para a produção científica da Universidade do Porto e um importante contributo para essa comunidade sensibilizada.

Confidencialidade e anonimato: É garantido o uso exclusivo dos dados recolhidos para o presente estudo, em condições de anonimato (não registo de dados de identificação), garantindo, em qualquer caso, que a identificação dos participantes nunca será tornada pública. Todos os contactos serão feitos em ambiente de privacidade. As entrevistas serão gravadas para posterior transcrição. A participação no estudo será totalmente voluntária e não terá qualquer tipo de remuneração ou ressarcimento. Os dados recolhidos estarão armazenados num computador protegido por palavra-passe e serão acessíveis pela investigadora principal, de forma anónima, apenas durante a investigação. Os dados de identificação (e.g., dados sociodemográficos relevantes e endereços de email para envio de consentimento informado) serão armazenados em ficheiros separados dos restantes dados recolhidos e serão protegidos por palavra-passe. Na possibilidade da recolha de dados ser

online, esta cumprirá os requisitos de anonimato, segurança e confidencialidade. Durante e após a realização do estudo será garantida a segurança física e eletrónica dos dados e os dados pessoais recolhidos serão destruídos no final da realização do estudo. Os restantes dados serão conservados, de forma anônima, para fins de investigação científica (e.g., realização de estudos comparativos entre diferentes versões do jogo ou entre diferentes jogos). Este estudo se enquadra no projeto "Development of Game-based tools for Mental Health Intervention and Promotion", financiado pela FCT, de maneira que os dados serão conservados para esse estudo não ultrapassando o limite máximo de 6 anos.

Em nome da equipa agradecemos a sua participação. A estudante: Carolina Cintra Fernandes Figueira - up201906845@up.pt

Assinatura: … … … … … … … … … ... … … … … … ... … … … … … … … … … … … … …

-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o- Declaro ter lido e compreendido este documento, bem como as informações que me foram fornecidas pela pessoa que acima assina. Foi-me garantida a possibilidade de, em qualquer altura, recusar participar neste estudo sem qualquer tipo de consequências. Desta forma, aceito participar neste estudo e permito a utilização dos dados que de forma voluntária forneço, confiando em que apenas serão utilizados para esta investigação e nas garantias de confidencialidade e anonimato que me são dadas pela investigadora. Nome: … … … … … … … … … ... … … … … … ... … … … … … … … … … … … … … Assinatura: … … … … … … … … … ... … … … … ... … … … … … … … … … … … … … Data: …… /…… /……….

SE NÃO FOR O PRÓPRIO A ASSINAR POR IDADE OU INCAPACIDADE NOME: … BI/CD Nº: .... DATA OU VALIDADE ….. /..… /…..... GRAU DE PARENTESCO OU TIPO DE REPRESENTAÇÃO: .... ASSINATURA …

ESTE DOCUMENTO É COMPOSTO DE 3 PÁGINAS E FEITO EM DUPLICADO: UMA VIA PARA A INVESTIGADORA, OUTRA PARA A PESSOA QUE CONSENTE

[1] http://portal.arsnorte.min-saude.pt/portal/page/portal/ARSNorte/Comiss%C3%A3o%20de%20%C3%89tica/Ficheiros/Declaracao_Helsinquia_2008.pdf

[2] http://dre.pt/pdf1sdip/2001/01/002A00/00140036.pdf

A.4 Questionários

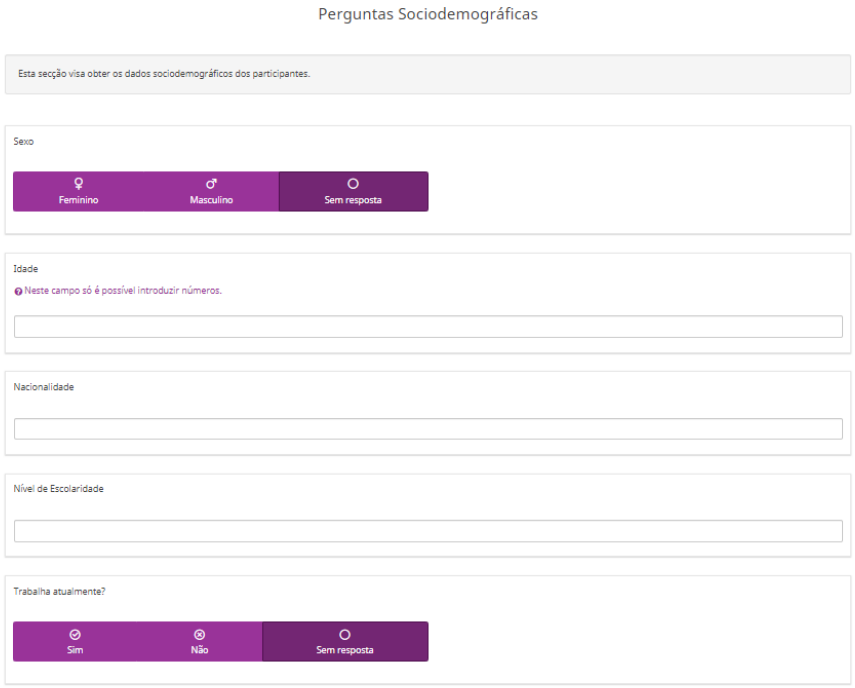

Figure A.3: Sociodemographic questions asked on the first and last phase of co-design

Por favor indique como se sentiu enquanto jogava o jogo, para cada um dos seguintes itens:

Nada - 1/ Um pouco - 2/ Moderadamente - 3/ Bastante - 4/ Extremamente - 5

	1	2	3	4	5	Sem resposta
Senti-me satisfeito	○	○	○	○	○	●
Senti-me habilidoso	○	○	○	○	○	●
Estava interessado na história do jogo	○	○	○	○	○	●
Achei o jogo divertido	○	○	○	○	○	●
Estava completamente focado no jogo	○	○	○	○	○	●
Senti-me feliz	○	○	○	○	○	●
O jogo deixou-me mal disposto	○	○	○	○	○	●
Pensei em outras coisas durante o jogo	○	○	○	○	○	●
Achei o jogo cansativo	○	○	○	○	○	●
Senti-me competente	○	○	○	○	○	●
Achei o jogo difícil	○	○	○	○	○	●
O jogo é esteticamente agradável	○	○	○	○	○	●
Esqueci tudo à minha volta	○	○	○	○	○	●
Senti-me bem	○	○	○	○	○	●
Fui bom no jogo	○	○	○	○	○	●
Senti-me entediado	○	○	○	○	○	●
Senti-me bem sucedido	○	○	○	○	○	●
Senti-me criativo	○	○	○	○	○	●
Senti que podia explorar coisas	○	○	○	○	○	●
Gostei do jogo	○	○	○	○	○	●
Fui rápido a alcançar os objetivos do jogo	○	○	○	○	○	●
Senti-me chateado	○	○	○	○	○	●
Senti-me pressionado	○	○	○	○	○	●
Senti-me irritado	○	○	○	○	○	●
Perdi a noção do tempo	○	○	○	○	○	●
Senti-me desafiado	○	○	○	○	○	●
Achei o jogo impressionante	○	○	○	○	○	●
Fiquei profundamente concentrado no jogo	○	○	○	○	○	●
Senti-me frustrado	○	○	○	○	○	●
Senti que foi uma experiência enriquecedora	○	○	○	○	○	●
Desliguei-me do mundo exterior	○	○	○	○	○	●
Senti a pressão do tempo	○	○	○	○	○	●
Tive de me esforçar bastante no jogo	○	○	○	○	○	●

Figure A.4: Game Experience Questionnaire - part 1

Módulo de Presença Social

Por favor indique como se sentiu enquanto jogava o jogo, para cada um dos seguintes itens:

Nada - 1/ Um pouco - 2/ Moderadamente - 3/ Bastante - 4/ Extremamente - 5

	1	2	3	4	5	Sem resposta
Sinto empatia pelos outros	○	○	○	○	○	●
As minhas ações dependem das ações dos outros.	○	○	○	○	○	●
As ações dos outros dependem das minhas ações.	○	○	○	○	○	●
Senti-me conectado com os outros	○	○	○	○	○	●
Os outros prestam-me atenção.	○	○	○	○	○	●
Presto atenção aos outros.	○	○	○	○	○	●
Senti-me invejoso/a em relação aos outros.	○	○	○	○	○	●
Sinto-me bem junto dos outros.	○	○	○	○	○	●
Quando eu estava feliz os outros estavam felizes.	○	○	○	○	○	●
Quando os outros estavam felizes eu estava feliz.	○	○	○	○	○	●
Influencio o humor dos outros.	○	○	○	○	○	●
Senti-me influenciado/a pelo humor dos outros.	○	○	○	○	○	●
Admiro os outros.	○	○	○	○	○	●
As ações dos outros afetam as minhas ações.	○	○	○	○	○	●
As minhas ações afetam as ações dos outros.	○	○	○	○	○	●
Senti-me vingativo.	○	○	○	○	○	●
Senti-me contente quando os meus colegas falharam.	○	○	○	○	○	●

Figure A.5: Game Experience Questionnaire - part 2

Módulo Pós Jogo

Por favor indique como se sentiu enquanto jogava o jogo, para cada um dos seguintes itens:

Nada - 1/ Um pouco - 2/ Moderadamente - 3/ Bastante - 4/ Extremamente - 5

	1	2	3	4	5	Sem resposta
Senti que correu mal.	○	○	○	○	○	●
Senti dificuldade em voltar à realidade.	○	○	○	○	○	●
Senti culpa.	○	○	○	○	○	●
Senti que a jogar consigo vitórias.	○	○	○	○	○	●
Senti que foi um desperdício de tempo.	○	○	○	○	○	●
Senti que tenho energia para participar em novos desafios.	○	○	○	○	○	●
Senti satisfação.	○	○	○	○	○	●
Senti alguma confusão (para quê jogar).	○	○	○	○	○	●
Senti que poderia ter feito coisas mais úteis em vez deste jogo.	○	○	○	○	○	●
Senti que sou poderoso.	○	○	○	○	○	●
Senti que foi maçador.	○	○	○	○	○	●
Senti arrependimento de ter aceite participar.	○	○	○	○	○	●
Senti vergonha.	○	○	○	○	○	●
Senti orgulho.	○	○	○	○	○	●
Senti como se estivesse a regressar de uma viagem.	○	○	○	○	○	●
Senti que me conheci melhor.	○	○	○	○	○	●
Senti que sou mais capaz do que pensava.	○	○	○	○	○	●

Figure A.6: Game Experience Questionnaire - part 3

Por favor responda a cada um dos seguintes itens:

1 - Discordo Totalmente / 2 / 3 / 4 / 5 - Concordo Totalmente

	1	2	3	4	5	Sem resposta
Em geral, estou satisfeito com a facilidade de utilização deste sistema	○	○	○	○	○	●
Este sistema foi simples de utilizar	○	○	○	○	○	●
Consegui completar as tarefas e os cenários utilizando este sistema	○	○	○	○	○	●
Consegui completar rapidamente as tarefas e os cenários utilizando este sistema	○	○	○	○	○	●
Consegui completar as tarefas e os cenários com eficiência utilizando este sistema	○	○	○	○	○	●
Senti-me confortável a utilizar este sistema	○	○	○	○	○	●
Foi fácil aprender a utilizar este sistema	○	○	○	○	○	●
Acredito que me tornaria rapidamente produtivo se utilizasse este sistema	○	○	○	○	○	●
O sistema deu mensagens de erros que me indicaram claramente como resolver os problemas	○	○	○	○	○	●
Sempre que cometi um erro durante a utilização do sistema, consegui recuperar de forma fácil e rápida	○	○	○	○	○	●
A informação fornecida pelo sistema (como ajuda online, mensagens no ecrã ou outra documentação) foi clara	○	○	○	○	○	●
Foi fácil encontrar a informação que precisava	○	○	○	○	○	●
A informação fornecida pelo sistema foi fácil de entender	○	○	○	○	○	●
A interface do sistema foi agradável (Nota: a "interface" inclui aqueles itens que se utilizam para interagir com o sistema. Por exemplo, algumas componentes da interface são o teclado, o rato, o microfone e o ecrã, incluindo a utilização de gráficos e de linguagem)	○	○	○	○	○	●
Gostei de utilizar a interface deste sistema	○	○	○	○	○	●
Este sistema tem todas as funcionalidades e capacidades que eu esperava	○	○	○	○	○	●
Em geral, estou satisfeito/a com este sistema	○	○	○	○	○	●

Figure A.7: Post-Study System Usability Questionnaire