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NeuroShop: An augmented reality serious game for people with Acquired Brain Injury

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Mestrado em Engenharia Informática

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Resumo

A Lesão Cerebral Adquirida (LCA) resulta frequentemente em défices de longa duração em múltiplos domínios, incluindo a comunicação social, o processamento cognitivo e a coordenação motora. A reabilitação nestas áreas é frequentemente conduzida através de exercícios isolados, que carecem de integração entre si e de relevância no contexto das atividades diárias dos pacientes. Esta dissertação aborda esta lacuna propondo e implementando uma plataforma de realidade aumentada (RA), concebida para o Meta Quest 3, que unifica a reabilitação social, cognitiva e motora num único sistema coerente.

A plataforma coloca os pacientes num cenário de supermercado em realidade mista, onde tarefas do quotidiano desempenham atividades terapêuticas. Foram desenvolvidos três minijogos para abranger domínios complementares: *Customer Care* (treino de interação social através de diálogo com personagens não jogáveis), *Memory Aisle* (desafio cognitivo baseado na recordação e atenção a listas de itens) e *Stock Shift* (treino motor através da manipulação controlada de objetos). O sistema utiliza passthrough AR, âncoras espaciais e rastreamento das mãos para garantir uma interação natural com o ambiente real, enquanto mecanismos de dificuldade adaptativa ajustam o nível de desafio ao desempenho do jogador. Foram ainda integradas funcionalidades de acessibilidade, como diálogo em síntese de fala, apoio visual baseado no olhar e mecanismos de prevenção de perda de objetos, de modo a acomodar as diversas necessidades dos pacientes com LCA.

As entrevistas com pacientes, familiares e profissionais de saúde, recolhidas no âmbito de um processo de co-design foram codificadas em temas de design, orientando a implementação de mecanismos de acessibilidade, envolvimento e feedback. A plataforma resultante oferece não apenas uma experiência de jogo envolvente, mas também uma base para exercícios de reabilitação com significado contextual e em ambiente seguro. Ao integrar treino de competências psicossociais, cognitivas e motoras num único enquadramento de RA, este trabalho demonstra o potencial dos jogos sérios para proporcionar experiências de reabilitação mais holísticas e eficazes para indivíduos em recuperação de LCA.

Palavras-chave: Lesão Cerebral Adquirida; Jogos Sérios; Realidade Aumentada; Realidade Mista; Interação Social; Treino Cognitivo; Capacidades Motoras; Co-Design

Abstract

Acquired Brain Injury (ABI) often results in long-term deficits across multiple domains, including social communication, cognitive processing, and motor coordination. Rehabilitation in these areas is often carried out through isolated exercises, which lack integration with each other and relevance to the context of patients' daily activities. This thesis addresses this gap by proposing and implementing an augmented reality (AR) platform designed for the Meta Quest 3, which unifies social, cognitive, and motor rehabilitation into a single, coherent system.

The platform situates patients in a mixed-reality supermarket scenario, where everyday tasks serve as therapeutic activities. Three minigames were developed to target complementary domains: *Customer Care* (social interaction training through dialogue with non-playable characters), *Memory Aisle* (cognitive challenge based on item recall and attention), and *Stock Shift* (motor training through controlled object manipulation). The system leverages passthrough AR, spatial anchors, and hand tracking to ensure natural interaction with the real environment, while adaptive difficulty mechanisms adjust the challenge level to the player's performance. Accessibility features, such as text-to-speech dialogue, gaze-assisted placement aids, and safeguards against object loss, were integrated to accommodate the diverse needs of ABI patients.

Interviews gathered through co-design, were coded into design themes, guiding the implementation of accessibility, engagement, and feedback mechanisms. The resulting platform provides not only engaging gameplay but also a foundation for rehabilitation exercises that are contextually meaningful and safe. By integrating training of psychosocial, cognitive, and motor skills within a single AR framework, this work demonstrates the potential of serious games to offer more holistic and effective rehabilitation experiences for individuals recovering from ABI.

Keywords: Acquired Brain Injury; Serious Games; Augmented Reality; Mixed Reality; Social Interaction; Cognitive Training; Motor Skills; Co-Design

UN Sustainable Development Goals

The United Nations Sustainable Development Goals (SDGs) serve as a global framework for promoting peace, prosperity, and sustainability for all. Among the 17 goals established by the United Nations in the 2030 Agenda for Sustainable Development, this dissertation contributes directly to **SDG 3: Ensure healthy lives and promote well-being for all at all ages**, with a particular emphasis on **Target 3.4**.

SDG 3.4 Promote mental health and well-being

Target 3.4 focuses on the reduction of mortality from non-communicable diseases through prevention and treatment, as well as the promotion of mental health and well-being. Within this scope, the development of accessible and engaging rehabilitation solutions plays a crucial role in improving quality of life and fostering psychosocial, cognitive, and motor recovery.

This dissertation directly contributes to SDG 3.4 by presenting the design and implementation of *NeuroShop*, an Augmented Reality based serious game designed to support individuals with Acquired Brain Injury. The platform promotes holistic rehabilitation by integrating **psychosocial**, **cognitive**, and **motor** dimensions into a single interactive experience. Through immersive AR interactions, adaptive difficulty, and contextually grounded activities, the system aims to enhance motivation, support emotional well-being, and encourage sustained engagement in rehabilitation exercises.

Moreover, by embedding rehabilitation tasks within meaningful real-world contexts, the project aligns with SDG 3.4's focus on mental health promotion, fostering autonomy, confidence, and social reintegration. The co-design process with health professionals further ensures that the system addresses real clinical needs, contributing to more inclusive and patient-centered care.

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To my close friends, I owe gratitude for keeping me motivated and reminding me of the importance of laughter.

Finally, my deepest appreciation goes to my family. Above all, I dedicate this work to my mother and father. From my father, I learned the courage to face the world, from my mother, the determination and heart to pursue my dreams. While I undertook this thesis for myself, I also did it to make them proud, and I hope I succeeded.

At the end of this journey, all I can say is: I did it!

Miguel Teixeira

“Not all those who wander are lost”

J.R.R. Tolkien

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Abbreviations

AI	Artificial Intelligence
ABI	Acquired Brain Injury
AR	Augmented Reality
LIACC	Laboratory of Artificial Intelligence and Computer Science
MR	Mixed Reality
MRUK	Mixed Reality Utility Kit
NPC	Non-Playable Character
SDK	Software Development Kit
SGs	Serious Games
TBI	Traumatic Brain Injury
URP	Universal Render Pipeline (Unity)
VR	Virtual Reality
XR	Extended Reality (umbrella term covering AR, VR, MR)
TTS	Text-to-Speech
UI	User Interface

Chapter 1

Introduction

1.1 Context

Acquired Brain Injury (ABI) is composed of a range of non-degenerative brain injuries, such as Traumatic Brain Injury (TBI) and Non-Traumatic Brain Injury (Non-TBI) [1], which can significantly impact an individual's cognitive, motor and emotional functioning. With TBI affecting approximately 69 million people globally every year, and the projected rise in stroke cases, effective rehabilitation programs are crucial. While many approaches focus on cognitive, motor, and psychosocial recovery, there is a growing recognition of the need to integrate all three rehabilitation approaches to provide holistic care[2][3].

Serious games (SGs), which are designed for purposes beyond mere entertainment [4], offer engaging and interactive experiences that can enhance motivation and participation among patients. By incorporating elements of gameplay, these games can simulate real-life scenarios, making therapy more enjoyable. In this regard, integrating innovative technologies such as serious games into rehabilitation programs represents a promising approach for advancing treatment.

Furthermore, the inclusion of another technologies, Augmented Reality (AR), in these serious games can significantly enhance the experience. AR overlays digital information onto the real world, allowing patients to interact with both virtual elements and their physical environment. This immersive experience can provide immediate feedback, enabling users to practice skills in a safe setting while also improving their spatial awareness and cognitive functions. Overall, the combination of serious games and AR not only facilitates cognitive and psychosocial rehabilitation but also contributes to a more holistic approach to patient recovery.

This dissertation, conducted under the support of the Laboratory of Artificial Intelligence and Computer Science (LIACC) at the University of Porto, aims to explore this potential. LIACC, a research centre in artificial intelligence (AI) and computer science founded in 1988, has been at the forefront of AI research with a focus on complex systems, machine learning, intelligent robotics, and natural language processing. The lab has developed various projects in health and well-being, among other thematic areas, with a strong focus on innovation.

Although LIACC has led numerous research initiatives in cognitive and psychosocial rehabilitation using serious games, this dissertation represents a pioneering effort as the lab's first project incorporating augmented reality into ABI rehabilitation. This use of AR in serious games aims to create a more immersive and engaging therapeutic experience, bridging the gap between cognitive and socio-emotional rehabilitation. This could potentially open new ways for future applications in mobile-based health solutions.

1.2 Motivation

While traditional methods have laid the groundwork for treatment, there remains an increasing awareness of the need for more engaging and personalized approaches [5]. The integration of innovative technologies into rehabilitation programs offers an opportunity to enhance patient experiences and outcomes. Recent developments [6] in serious games provide an opportunity to reimagine rehabilitation. These games, designed with therapeutic goals in mind, facilitate recovery and engagement. By providing a sense of power and motivation, serious games can transform the rehabilitation process.

Incorporating AR into serious games adds another layer of interaction that can stimulate physical interaction challenges within a safe environment, while also allowing an easier visualization of progress and feedback [7]. As a result, AR-infused serious games can help bridge the gap between therapeutic exercises and functional application.

1.3 Problem and Objectives

Despite advances in rehabilitation techniques, current serious games for health often focus on isolated aspects of recovery, such as physical or cognitive rehabilitation, without addressing the holistic needs of individuals recovering from ABI. This fragmented approach limits their effectiveness, as the complex nature of ABI often requires simultaneous interventions across social, physical, and cognitive domains [7].

AR presents a unique approach to enhancing rehabilitation, offering interactive environments that can improve patient engagement. While Virtual Reality (VR) is another viable option [8] for immersive rehabilitation, AR is a more accessible solution because it only requires a mobile device, such as a smartphone, making it more practical for widespread use. VR often demands more expensive and complex equipment, which can limit its accessibility for both patients and rehabilitation centres. However, the use of AR in rehabilitation, particularly in serious games, remains relatively underdeveloped, especially when addressing both cognitive and motor skill recovery[7].

The objective of this project is to develop a serious game that integrates social, physical, and cognitive rehabilitation in one unified platform, using an AR-based approach. By incorporating a co-design process, where patients and healthcare professionals contribute to the development, the game will provide individualized experiences tailored to each user's needs. This integration

will address the current gap in serious games, which tend to focus narrowly on specific aspects of rehabilitation, and offer a comprehensive, accessible solution that promotes engagement, social interaction, and motor skill recovery.

1.4 Research Questions

- How can an AR-based serious game be effectively developed through a co-design process involving healthcare professionals and patients?
- How can such a game address current limitations in engagement in rehabilitation programs?
- How can integrating social, cognitive, and physical rehabilitation into a single AR-based solution support holistic recovery for ABI patients?

Chapter 2

Conceptual Background

2.1 Acquired Brain Injury

Acquired Brain Injury (ABI) [9] refers to brain damage that occurs after birth and is not related to congenital, degenerative, or hereditary conditions. It can result in significant impairments across cognitive, motor, emotional, and psychosocial functions, affecting an individual's ability to perform daily activities and engage in social interactions. Unlike developmental disorders, ABI occurs due to external or internal factors that damage the brain after a period of normal development.

ABI is generally categorized into two main types: traumatic brain injury (TBI) and non-traumatic brain injury (Non-TBI)[9]. Traumatic brain injury results from an external force applied to the head, leading to damage to the brain. Common causes include falls, motor vehicle accidents, sports-related injuries, assaults, and combat-related incidents, such as explosions in military contexts. The severity of TBI can range from mild concussions with temporary effects to severe injuries that cause long-term impairments in memory, motor function, and cognition.

In contrast, non-traumatic brain injury occurs due to internal factors such as strokes, infections, or oxygen deprivation. Stroke is one of the leading causes of non-TBI, often resulting in long-term neurological deficits [10]. Other causes include brain tumours, infections such as encephalitis or meningitis, hypoxia caused by drowning or cardiac arrest, and neurotoxic exposure due to poisoning or drug overdose[9].

ABI represents a significant global health concern, affecting millions of individuals each year [11]. Studies estimate that approximately sixty-nine million people worldwide suffer from TBI annually, while the incidence of stroke continues to rise due to ageing populations and lifestyle factors [11]. The long-term impact of ABI varies depending on the severity, location, and nature of the brain damage. However, common consequences include cognitive impairments such as memory loss, attention deficits, and difficulties with executive functioning [9]. Motor impairments, including reduced coordination, muscle weakness, and difficulties with balance, are also frequent outcomes. Additionally, many individuals experience psychosocial challenges, such as mood disorders, personality changes, and difficulties in social interactions, which further complicate the rehabilitation process.

Given the complexity of ABI and its wide-ranging effects, rehabilitation efforts must address multiple dimensions of recovery, integrating cognitive, motor, and psychosocial rehabilitation. Traditional rehabilitation methods, including physical therapy, occupational therapy, and cognitive training, play an essential role in recovery but often lack engagement and accessibility. As a result, technology-driven approaches, such as serious games and augmented reality, have emerged as promising tools to enhance rehabilitation outcomes, providing more immersive, interactive, and motivating experiences for patients.

2.2 Serious Games

A 2023 survey of video game players in Europe (France, Germany, Italy, Poland, Spain, and the United Kingdom) revealed that 74% of players agree that games provide mental stimulation, 68% feel that playing games reduces stress, and 67% believe games serve as a healthy outlet for everyday challenges. Moreover, 75% of respondents stated that there is a video game suitable for everyone, reinforcing the notion that games can reach broad audiences with diverse needs [12].

The European video games market continues to show steady growth. In 2024, revenue increased by 4% compared to the previous year, reaching 26.8 billion euros in key markets. Approximately 54% of Europeans aged 6–64 play video games, representing 128.3 million people. Of these, 45% are women, showing increasing gender balance [12]. These statistics highlight the broad agreement on the value of video games in supporting learning and well-being among players.

Building on this perspective of games as tools for purposes beyond entertaining, arises the foundation for the concept of *serious games*. The term itself was popularized by Clark Abt in his 1970 book *Serious Games* [13], where he described games designed with an explicit educational, political, or social purpose, rather than solely for entertainment. Since then, the notion has expanded significantly, encompassing applications in healthcare, education, and rehabilitation [4]. In this context, serious games leverage the inherent motivational and interactive qualities of gaming to create safe, controlled environments where players can acquire knowledge, develop skills, or practice behaviours with real-world relevance. This historical perspective grounds the growing interest in their application to healthcare challenges, such as rehabilitation after ABI.

Today, the serious gaming market in Europe is valued at around 10 billion USD and continues to expand rapidly. This growth is fuelled by the increasing adoption of gamification in education, healthcare, and corporate training. Countries such as the United Kingdom, Germany, and France lead this sector thanks to their strong technological infrastructure and investment in research and development. At the policy level, the European Union has also contributed through initiatives such as the *Digital Education Action Plan* [14], which promotes the integration of digital technologies, including serious games, into educational systems to enhance digital literacy and foster innovative teaching. This demonstrates how the early conceptual foundations of serious games have evolved into a thriving industry with wide-reaching applications.

2.2.1 Serious Games In Rehabilitation

In the context of rehabilitation, serious games provide a structured environment where patients can practice cognitive, motor, and social skills through gameplay. Unlike traditional rehabilitation exercises, which can feel repetitive and monotonous, serious games leverage game mechanics such as challenges, rewards, and interactive feedback to enhance motivation and adherence to therapy [15].

One of the key advantages of serious games in rehabilitation is their ability to simulate real-life scenarios in a controlled and adaptive manner. For cognitive rehabilitation, games can target memory, attention, and problem-solving skills by presenting players with tasks that require strategic thinking, pattern recognition, or multitasking. Many of these games are designed to adjust difficulty levels based on the player's performance [16], ensuring a personalized experience that keeps the user challenged without causing frustration. This adaptability is particularly beneficial for individuals with ABI, whose cognitive impairments may vary in severity and progression.

In motor rehabilitation, serious games encourage movement and coordination through interactive exercises that require precise control of body movements. Many rehabilitation games use motion-tracking technology, such as cameras or sensors, to detect physical actions, allowing patients to practice exercises in a more engaging and immersive way. Games designed for motor rehabilitation often focus on improving strength, flexibility, and coordination, with real-time feedback to help patients refine their movements. Studies have shown that gamified rehabilitation can increase participation and consistency in therapy, leading to better recovery outcomes[17].

Beyond cognitive and motor recovery, serious games also play a role in psychosocial rehabilitation by facilitating social interaction and emotional engagement[18]. Multiplayer or cooperative games allow individuals with ABI to interact with others in structured environments, helping to rebuild social confidence and communication skills. Additionally, games with narrative elements or role-playing mechanics can provide emotional support by allowing players to engage in scenarios that promote self-expression, empathy, and resilience.

2.2.2 Examples of Serious Games in Rehabilitation

2.2.2.1 Balloon Buddies

An illustrative example of a serious game developed for rehabilitation is *Balloon Buddies* [19], created by researchers at Imperial College London and the University of Southampton. The game is designed to support upper-limb rehabilitation, particularly for patients recovering from stroke, and leverages a custom device called *GripAble* that tracks arm and hand movements. Gameplay centers on controlling balloons that lift a beam, which must be carefully balanced to guide a ball toward moving targets.



Figure 2.1: Serious game *Balloon Buddies* session, which combines motor and social rehabilitation.

What makes *Balloon Buddies* especially relevant to this thesis is its emphasis on combining motor training with social engagement. The game was conceived as a multiplayer experience, encouraging patients to cooperate in order to complete tasks. This not only promotes physical exercise through repeated and purposeful arm movements but also fosters communication and interaction between players. As such, it illustrates how rehabilitation games can be designed to target multiple domains simultaneously, though still focusing on a subset rather than the full spectrum, breaking away from the fragmented approaches often found in traditional therapy.

2.2.2.2 Painting Discovery

Painting Discovery is a serious game that applies projected augmented reality (AR) to support shoulder rehabilitation exercises [20]. Instead of requiring a headset, the system employs a compact desk-mounted frame with a mini projector and a Leap Motion Controller. Interactive visuals are projected directly onto a rubber desk pad, allowing patients to perform functional tasks, such as painting on the surface, while their arm and hand movements are tracked in real time.

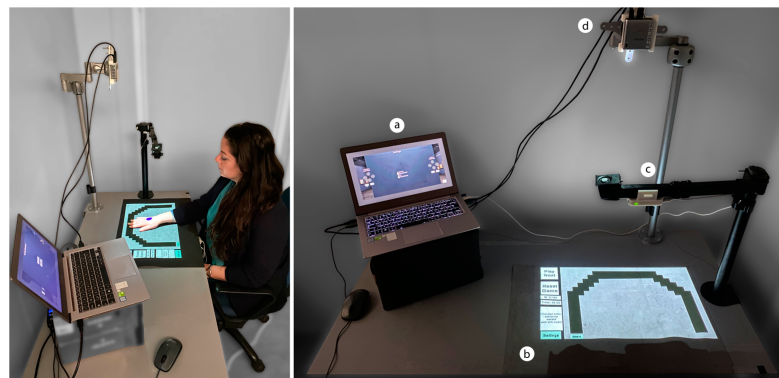


Figure 2.2: Serious game *Painting Discovery* session, using the mini projector.

The system focuses on motor rehabilitation by capturing precise kinematic data during gameplay. Performance indicators such as completion time, movement speed, acceleration, and normalized jerk are extracted to evaluate the quality of motion. This allows therapists to monitor both the progress and smoothness of patient movements, ensuring that exercises are not only completed but also performed with control and accuracy. Feedback from users and clinicians highlighted high levels of engagement and ergonomic suitability, underscoring the feasibility of projected AR for rehabilitation settings.

The relevance of *Painting Discovery* to this thesis lies in its demonstration of how augmented reality can be directly applied to rehabilitation contexts. By projecting interactive tasks onto physical surfaces and integrating them with motion-tracking technology, the game shows how AR can transform conventional exercises into engaging therapeutic activities. Although it focuses specifically on motor rehabilitation, it highlights the broader potential of AR.

2.3 Augmented Reality in Serious Games

AR has emerged as a transformative technology in serious games, enhancing interactivity by merging digital content with the real world[21]. Unlike traditional screen-based experiences, AR allows players to engage with virtual objects in physical spaces, creating immersive and context-aware gameplay. In the field of serious games, AR introduces new possibilities for training, education, and rehabilitation by providing an engaging and interactive way to practice skills and receive real-time feedback.

One of the defining features of AR in serious games is environmental integration, where digital elements are overlaid onto real-world surroundings[22]. Using mobile devices, AR headsets, or smart glasses, players can interact with virtual characters, objects, and challenges that appear to exist within their immediate environment. This real-world anchoring enhances the sense of presence and engagement, making tasks feel more meaningful and relevant. For instance, AR-based training games can place instructional overlays on physical objects, guiding users through hands-on learning experiences.

Interaction methods in AR serious games extend beyond traditional input devices like keyboards and controllers. Many AR games incorporate gesture recognition[23], allowing players to manipulate virtual objects using their hands. Some applications use voice commands to interact with the game, while advanced systems integrate eye tracking to detect player focus and engagement. Additionally, spatial awareness technology, powered by LiDAR and SLAM (Simultaneous Localization and Mapping), enables AR systems to understand the player's environment, allowing virtual elements to react dynamically to real-world surfaces and obstacles. This creates more interactive and adaptive gameplay, where challenges can be adjusted based on the player's surroundings.

Another major advantage of AR in serious games is contextual learning and skill reinforcement. Instead of requiring players to remember abstract concepts and later apply them in real life,

AR allows immediate practice within relevant environments[22]. For example, an AR-based rehabilitation game can instruct a patient to perform a movement while visualizing digital guidance directly on their arm or leg. This real-time augmentation enhances understanding and retention by linking learning experiences to real-world actions[24].

From a technological perspective, the development of AR serious games relies on game engines such as Unity and Unreal Engine, which provide AR integration tools for creating interactive 3D content[25]. These engines support cross-platform AR development, ensuring compatibility with mobile devices, AR headsets, and other hardware.

2.4 Multidimensional Rehabilitation

Rehabilitation following ABI is inherently complex due to the multifaceted nature of the impairments that patients may experience. Traditional rehabilitation approaches often isolate cognitive, motor, and psychosocial domains, treating them in parallel or sequentially rather than through a unified strategy. However, growing evidence suggests that these dimensions are interdependent[26], and an isolated approach may limit the effectiveness of long-term recovery. In response, the concept of multidimensional rehabilitation has gained prominence, advocating for integrative interventions that address multiple aspects of functioning simultaneously.

Multidimensional rehabilitation recognizes that successful recovery from ABI requires coordinated progress across various domains[27]. For instance, improvements in motor function can enhance autonomy and mobility, which in turn may facilitate social participation and emotional well-being. Similarly, gains in cognitive functioning—such as attention and memory—can support more effective communication and engagement in social contexts. Therefore, interventions that deliberately combine these dimensions are better aligned with the holistic needs of individuals recovering from ABI[26].

Despite its clinical relevance, the implementation of multidimensional rehabilitation faces several challenges. Standard therapy environments often lack the flexibility, personalization, and interdisciplinary coordination needed to deliver integrated treatment plans. Moreover, limited resources and therapist availability can restrict the frequency and scope of interventions, potentially hindering long-term outcomes[26].

Emerging technologies, particularly serious games and AR, offer promising solutions to bridge these gaps. Their capacity to simulate real-world tasks, provide immediate feedback, and personalize difficulty levels aligns well with the principles of multidimensional rehabilitation[28]. AR-based serious games, in particular, can seamlessly incorporate cognitive tasks into physical activities while embedding social or emotional engagement elements through interactive narratives or multiplayer features. These hybrid experiences not only foster simultaneous skill development but also promote patient motivation and sustained participation.

2.5 Game Engines in Serious Game Development

Game engines are software frameworks that provide the fundamental building blocks for developing interactive applications, particularly video games. At their core, engines offer modules for graphics rendering, physics simulation, audio processing, asset management, and user input. By abstracting these low-level functionalities, engines allow developers to focus on gameplay logic and design rather than implementing every technical component from scratch. Beyond games, engines have become powerful platforms for simulations, visualization, and training applications, including rehabilitation and education[29].

2.5.1 General Purpose Engines

Modern game engines such as *Unity* and *Unreal Engine* dominate the industry due to their versatility and cross-platform capabilities[30]. These engines provide high-level authoring tools, visual editors, and scripting environments that streamline development pipelines. Importantly, both engines support integration with extended reality (XR) technologies, including virtual reality (VR) and augmented reality (AR), enabling developers to create immersive applications that bridge physical and digital spaces[31][32].

Other engines, such as *Godot*[33] or proprietary simulation frameworks, have niche communities or domain-specific uses, but Unity and Unreal remain the most widely adopted in research and industry because of their extensive documentation, plugin ecosystems, and device compatibility.

2.5.2 Engines for AR Serious Games

AR serious games impose specific requirements on the underlying engine[34]. First, the engine must support real-time spatial mapping and environmental anchoring, allowing virtual content to align with physical surroundings. Second, natural interaction modalities such as hand tracking, gesture recognition, or voice input require middleware support and integration with hardware APIs. Third, the system must deliver stable performance under real-time constraints, as latency or misalignment can cause discomfort or hinder rehabilitation progress. Finally, AR games often demand flexible deployment across devices such as smartphones, AR headsets, or standalone systems like the Meta Quest 3.

Both Unity and Unreal provide AR-focused toolkits to meet these requirements. Unity includes *AR Foundation*, a cross-platform framework that supports ARKit (iOS), ARCore (Android), and device-specific SDKs. Unreal offers the *AR Framework*, with comparable features for anchoring, spatial meshes, and gesture recognition. These toolkits abstract platform differences, making it easier to build AR applications with consistent behavior across devices[31][32].

2.5.3 Unity and the Meta XR All-in-One SDK

Unity is one of the most widely adopted engines for XR development, offering support for both virtual and augmented reality applications. It provides a component-based architecture and cross-platform deployment pipeline, which makes it suitable for projects requiring flexibility across different devices. For AR development, Unity integrates toolkits such as *AR Foundation*, enabling anchoring, plane detection, and spatial awareness across multiple hardware platforms.

The *Meta XR All-in-One SDK* extends Unity with device-specific features tailored to the Meta Quest family of headsets. It consolidates key functionalities including passthrough AR, hand tracking, spatial anchors, and scene understanding into a single package. These features are exposed through high-level APIs, reducing the overhead of working directly with low-level device interfaces and facilitating the creation of stable AR experiences. In addition, the SDK supports rendering optimizations through Unity's Universal Render Pipeline (URP), which is designed to balance graphical fidelity and performance in standalone hardware[35].

Chapter 3

Systematic Literature Review

3.1 Introduction

This chapter presents a systematic review of literature to evaluate how augmented reality (AR)-based serious games can support multidimensional rehabilitation, focusing on social, cognitive, and motor skills for patients with ABI. The objective is to gather comprehensive insights into existing AR interventions and their impact across these rehabilitation dimensions, building a foundation for understanding how serious games can address ABI recovery needs.

3.2 Methodology

Following the PRISMA methodology [36], this review incorporates a structured approach to data gathering, inclusion/exclusion criteria, and quality assessment.

3.2.1 Research Question

The primary question guiding this literature review was:

How effective are AR-based serious games in promoting psychosocial, cognitive, and motor rehabilitation?

3.2.2 Search Strategy

The literature search involved a combination of keywords, iteratively refined for specificity. The search strings were developed to capture variations in terminology and relevant combinations.

3.2.3 Justification for Search Strings

The search strings in Table 3.1 were formulated to capture studies focusing on different dimensions of rehabilitation—social, cognitive, motor, and integrated approaches. Each search string is justified as follows:

QS1	("augmented reality" OR "AR") AND ("social rehabilitation" OR "social skills" OR "social interaction" OR "social communication" OR "community integration")
QS2	("augmented reality" OR "AR") AND ("serious games" OR "gamification") AND ("cognitive" OR "memory" OR "attention" OR "problem-solving") AND ("rehabilitation")
QS3	("augmented reality" OR "AR") AND ("serious games" OR "gamification") AND ("motor skills" OR "physical activity" OR "movement" OR "coordination") AND ("rehabilitation" OR "therapy" OR "recovery")
QS4	("augmented reality" OR "AR") AND ("social rehabilitation" OR "cognitive rehabilitation" OR "motor rehabilitation") AND ("integrated" OR "multidimensional" OR "holistic") AND ("serious games" OR "game-based" OR "therapy")

Table 3.1: Search Strings for Systematic Review on AR-based Rehabilitation

- **Social Rehabilitation:** The first search string is focused on identifying studies where AR interventions aim to improve *social interaction* and *communication*. Terms like “social skills” and “communication” were included to cover a range of outcomes relevant to social rehabilitation, particularly for patients who benefit from engagement and interactive exercises.
- **Cognitive Rehabilitation:** The second string targets studies that assess cognitive benefits, such as *memory improvement*, *attention* enhancement, and *problem-solving* abilities. Including multiple cognitive functions broadens the search to capture a variety of cognitive rehabilitation aspects within AR-based studies.
- **Motor Rehabilitation:** The third string seeks studies centred on *motor skills* improvement, *physical activity*, and *coordination*. These terms are essential for finding AR interventions focused on physical rehabilitation, such as movement and balance training.
- **Integrated Approach:** The final string is aimed at capturing studies that assess AR-based interventions with a *multidimensional focus*, covering all three rehabilitation aspects (social, cognitive, and motor). Terms like “integrated,” “multidimensional,” and “holistic” are included to find studies where AR interventions address these aspects within the same framework.

3.3 Data Extraction

3.3.1 Data Sources

The data for this review were sourced by first using Search Smart[37] to identify the most relevant academic databases for literature on AR-based serious games in rehabilitation. This tool helped guide the selection of databases that would provide comprehensive coverage across the rehabilitation, AR, and serious gaming fields. Based on the results from Search Smart, the following databases were used for the search:

- **PubMed:** A comprehensive resource for biomedical and clinical studies, particularly relevant for research on rehabilitation and patient outcomes.
- **IEEE Xplore:** A database specializing in engineering, computer science, and technology literature, which provided access to studies on AR applications and serious games.
- **Public Library of Science (PLOS):** A leading open-access publisher, offering a wealth of peer-reviewed research articles across various fields, including health sciences, rehabilitation, and AR technologies.
- **Scopus:** A multidisciplinary database that covers a wide range of subjects, including health, medicine, and engineering. Scopus is particularly valuable for its comprehensive indexing of peer-reviewed journals and conference proceedings.

3.3.2 Document Retrieval Results

In this section, we present the results of the database search for the selected query strings (QS1, QS2, QS3, QS4). The table (3.2) summarizes the number of documents retrieved from the selected databases using the search queries. The number of documents varies across databases, reflecting the scope and indexing practices of each database. This variation helps to identify which databases provide more relevant sources based on the focus of the research.

	QS1	QS2	QS3	QS4	Total
PubMed	126	12	12	2	152
IEEE Xplore	131	20	16	0	167
PLOS	66	17	7	1	91
Scopus	86	11	5	2	104

Table 3.2: Documents retrieved

3.4 Inclusion and Exclusion Criteria

The inclusion and exclusion criteria for this review were selected to ensure a focused and relevant body of research that would address the role of AR in multidimensional rehabilitation or health care. Each criterion was crafted with specific objectives in mind, as outlined below:

3.4.1 Inclusion Criteria

- **Publication Date (2020 and later):** We included studies published from 2020 onward to capture the latest advancements in AR technology. The rapid evolution of AR means recent studies are more likely to reflect current capabilities and applications relevant to rehabilitation.

- **Peer-Reviewed Journals, Conferences, and Book Chapters:** Only peer-reviewed publications were considered to ensure that each study met rigorous scientific standards. By focusing on journals, conference proceedings, and select book chapters, we prioritized sources that contribute validated findings and high-quality research to the field.
- **Language (English):** Studies were limited to English to maintain consistency in interpretation and avoid the risk of translation bias, ensuring accurate and thorough data extraction.
- **Focus on AR Interventions:** Only studies specifically investigating AR interventions were included. This focus was essential to directly assess AR's unique contribution to social, cognitive, and motor skill development.
- **Dimensions (Social, Cognitive, Motor):** Studies needed to address at least one of the three target dimensions—social, cognitive, or motor to align with our objective of a multidimensional approach. This criterion ensures relevance to the overall research question and the review's comprehensive scope.

3.4.2 Exclusion Criteria

- **Non-AR Interventions:** Studies that did not utilize AR technology were excluded to maintain a focused analysis on the specific impact of AR in rehabilitation settings. Non-AR approaches, while valuable, fall outside the intended scope of this review.
- **Publications Prior to 2020:** Older studies were excluded to ensure that the review reflects recent developments and innovations. Given the pace of technological advances in AR, research prior to 2020 may not provide the insights necessary to evaluate modern AR applications in rehabilitation.
- **Non-Peer-Reviewed Content (e.g., News Articles, Opinions, Abstracts Only):** Excluding non-peer-reviewed sources allows us to concentrate on research that has undergone critical evaluation, providing a stronger foundation for the systematic review. This approach reduces the risk of including unverified claims or preliminary findings.
- **Work-in-Progress or Preliminary Findings:** Studies still in development stages or without full experimental data were excluded to avoid uncertainties. The focus remains on fully completed research to ensure reliability and validity in the outcomes considered.

3.4.3 Prisma methodology

To ensure a rigorous and transparent methodology, the systematic review process followed the PRISMA guidelines, which outline the essential steps for identifying, screening, and including relevant studies. The following diagram, made using [38], illustrates the flow of studies through each stage of the review process, from initial database searches to the final selection of articles for analysis. This process involved removing duplicates, screening titles and abstracts for relevance, and conducting a full-text review to assess eligibility based on predefined inclusion and exclusion criteria.

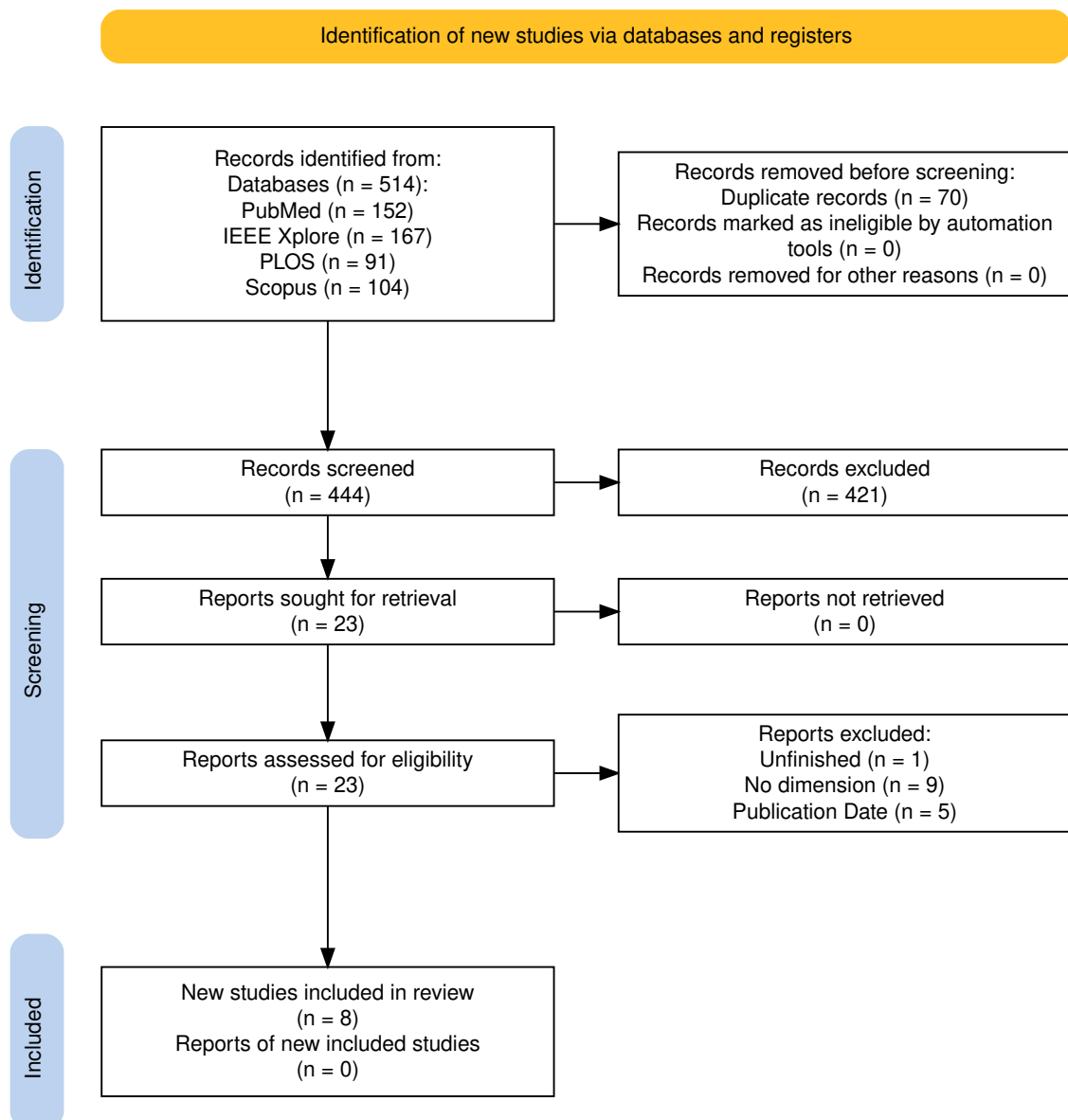


Figure 3.1: PRISMA Flow Diagram illustrating the systematic review process.¹

¹Legend: **Unfinished** – The study was not completed at the time of analysis. **No dimension** – The study was not inserted in any of the rehabilitation dimensions (physical, psychosocial, cognitive) after analysis.

3.4.4 Approach

Document data extraction was performed using a standardized form to ensure consistency and accuracy in gathering relevant information from each study. The following key data points were extracted from the included studies:

- **Study Characteristics:** Author(s), year of publication, study design, sample size and target population.
- **Intervention Details:** Specific AR technologies used, the nature of the serious game, and the outcomes targeted.
- **Context:** Study setting (e.g., clinical, home-based).
- **Outcomes and Effectiveness:** Measures used to assess the effectiveness of the intervention in terms of rehabilitation (e.g., improvements in motor skills, cognitive abilities, or social engagement).
- **Results and Findings:** Main findings regarding the impact of AR-based serious games on rehabilitation outcomes and measures used.

3.5 Results

The analysis of data collected from various studies on AR technologies in rehabilitation and educational contexts spanned the years 2020 to 2024 as shown in the figure 3.2.

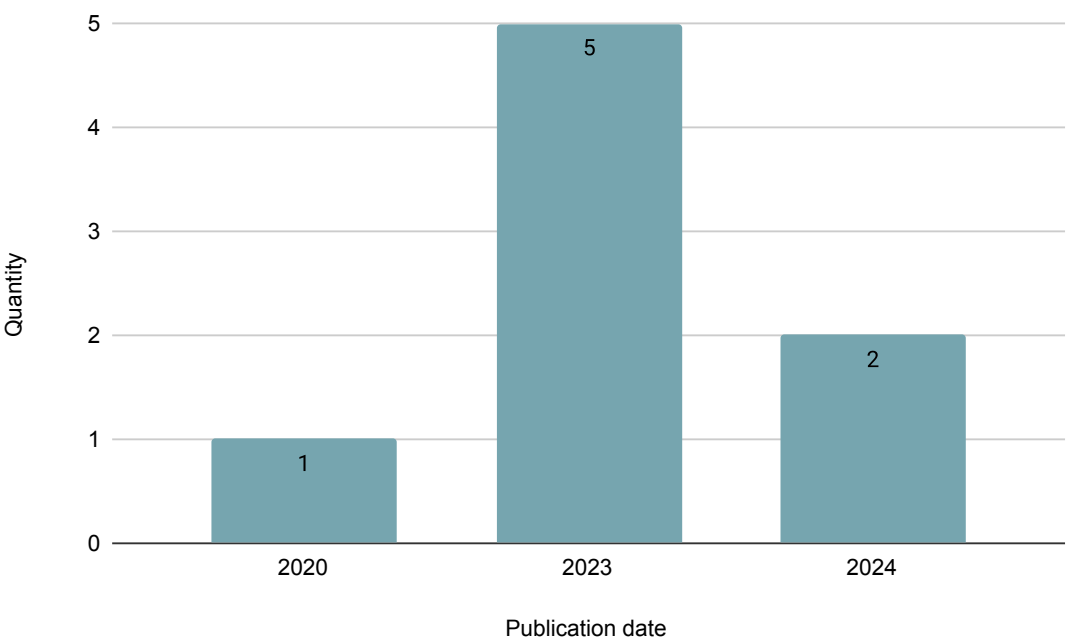


Figure 3.2: Publication dates of the 8 selected articles.

In terms of geographical context, the studies span multiple locations, including Italy, Indonesia, Portugal, Germany, etc, being all centered around Europe and Asia.

There were a total of 215+ participants with a wide range of sample sizes, from 8 to 65 years old, targeting diverse populations, including stroke patients, office employees, and children.

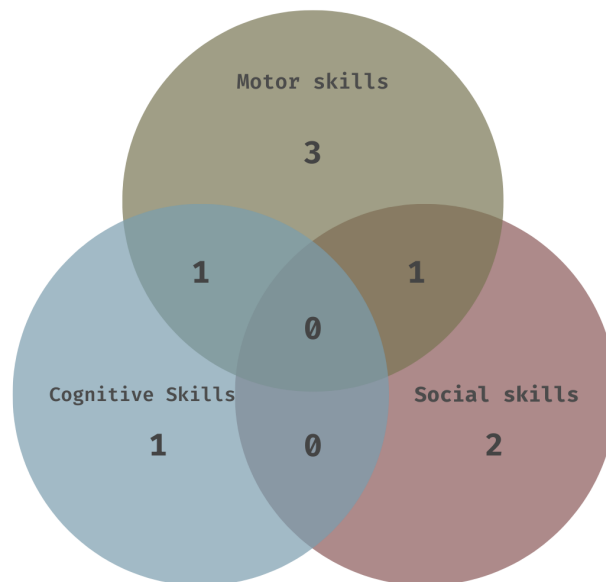


Figure 3.3: Circular graph indicating the targeted skills.

The targeted skills in these studies (Figure 3.3) include cognitive, motor, and social skills. Notably, motor skills are the most frequently addressed, appearing in **five out of the eight studies** reviewed, while social skills are targeted in **three studies**, and cognitive skills in **three studies**. This indicates a slight focus on motor rehabilitation, particularly in the context of stroke recovery through AR games or simulations. Furthermore, there is no study that focuses on the three areas, neither on both cognitive and social simultaneously.

No.	Year of Publication	Study Design	Sample Size	Target Population	Skills Targeted	AR Technologies Used	Nature of the Serious Game	Outcomes Targeted	Setting	Measures used
[39]	2023	Experimental study	N=4	Office employees or individuals in a workplace setting	Communication (verbal and non-verbal)	HoloLens 2	AR-based social game (AR.S.Space) designed for ice-breaking and social engagement	Establishing long-term connections in office environments	Simulated office environment	GEQ
[24]	2023	Experimental study	Not specified	Individuals recovering from stroke	Motor rehabilitation	Meta Quest	AR serious games for stroke rehabilitation	Cognitive and motor rehabilitation	Home-based rehabilitation with remote physiotherapy support	Metrics from wearable sensors
[40]	2023	Experimental study	N=14	Individuals using or training with lower limb prosthetics (future application for amputees)	Cognitive and motor	SAR	Competitive training task involving a virtual prosthetic leg	Cognitive and motor rehabilitation	Controlled laboratory environment	Proprioceptive drift, EMG signal analysis, subjective questionnaires
[41]	2023	Experimental study	N=50+	Children aged 8-12 years	Cognitive and motor	AR board game	Interactive board game designed to enhance children's communication skills	Improve non-verbal communication	Home or educational environments	Online questionnaires
[42]	2024	Experimental study	N=6	Stroke patients, with a focus on adults aged 25 to 60 years	Communication (verbal and non-verbal)	Xamarin APP, AR, VR, Kinect, Meta quest 2	3D serious games for stroke rehabilitation	Improve physical rehabilitation	Physiotherapy sessions, potentially in clinical or home environments	Time to complete tasks, error rates during the use of the app
[43]	2024	Experimental study	N=27	Individuals with trans-femoral amputations (though the study was conducted on unimpaired participants)	Social and motor	SAR, EMG	Simulating kicking a virtual wall using a virtual leg controlled by EMG signals	Enhancement of prosthetic embodiment and engagement in individuals with transfemoral amputations	Controlled laboratory environment	EMG signals, proprioceptive drift, heart rate variability, skin conductance
[44]	2020	Quasi-experimental study	N=115	Students majoring in Non-Formal Education at Universitas Negeri Malang, Indonesia	Cognitive	AR board game	Ar game to help students understand the concept of family functions	Improvement in students' mastery of family functions concept	Educational environment	Pre-test and post-test scores
[45]	2023	Experimental study	Not specified	Post-stroke patients	Motor	AR with marker tracking	Game-based rehabilitation focusing on hand coordination and motor skills	Improvement in hand coordination	Rehabilitation environment, potentially in clinical or home settings	FMA

Table 3.3: Data Extraction Results: Study characteristics

No.	Main Findings
[39]	Personalized profiles in the game helped players quickly learn about each other, reducing initial social discomfort. Virtual social agents (plants) alleviated face-to-face awkwardness. Suggestions for improvement included adding dynamic social information and richer interactive content.
[24]	The developed games (Boxes Game, Puzzle Game, Garden Care Game) effectively target both cognitive and motor rehabilitation. The system allows physiotherapists to analyze patient performance and adapt training plans based on collected data. Future work includes developing new metrics and AI models for rehabilitation.
[40]	The competitive task led to a higher number of kicks and increased engagement. The social context may distract users, reducing the embodiment effect. Future work will involve testing with actual prosthetic users and larger sample sizes to validate findings.
[41]	The AR game was well-received, with a significant majority of respondents acknowledging its potential to enhance children's communication skills. The game design promotes interaction and engagement, leading to improvements in non-verbal communication and social skills. The study highlights the dual perception of technology's impact on communication skills, recognizing both its potential drawbacks and benefits.
[42]	The app was rated highly for usability and accessibility by the volunteers. The study identified areas for improvement in user experience and interface design. The app aims to enhance the rehabilitation process for physiotherapists and their patients through interactive serious games.
[43]	Social tasks (cooperative and competitive) increased engagement and embodiment compared to non-social tasks. The study suggests that alternating between social and non-social tasks can enhance the integration of prosthetic devices. Further research is needed to validate these findings with a larger sample of transfemoral amputees.
[44]	The augmented reality-based board game was effective in enhancing students' understanding of family functions. The study demonstrated that integrating AR with traditional board games can significantly improve learning outcomes and student engagement.
[45]	The game effectively engages post-stroke patients in rehabilitation tasks. Accurate marker recognition and data recording capabilities enhance the rehabilitation process. Future studies are suggested to focus on clinical trials to validate the game's effectiveness in real-world settings.

Table 3.4: Data Extraction Results: Main findings

(AR) - Augmented Reality (VR) - Virtual Reality (SAR) - Spatial Augmented Reality (EMG) - Electromyography

3.5.1 Overview

The majority of the studies were published in 2023, with five out of eight entries originating from this year. The study designs predominantly followed an experimental approach, with seven out of eight studies using this methodology, while one study was quasi-experimental, suggesting a strong preference for controlled empirical evaluations.

Sample sizes varied significantly, ranging from as few as 4 participants to as many as 115, with some studies not specifying their sample size. The most frequently targeted populations included stroke patients, individuals using prosthetics, children, students, and office employees. In terms of skills targeted, motor skills were the most commonly addressed, followed by cognitive and communication skills, with a smaller emphasis on social skills. Some studies focused on multiple skill areas, particularly in rehabilitation settings.

The AR technologies utilized across the studies were diverse, with SAR (Spatial Augmented Reality), Meta Quest, and AR board games appearing most frequently. Other technologies included HoloLens 2, Microsoft Kinect, Xamarin APP, and marker-based AR, demonstrating the wide range of hardware and software applications in this field. Several studies explored the impact of AR-based serious games on social interaction. Personalized profiles in an AR game helped players quickly learn about each other, reducing initial social discomfort, while virtual social agents (such as digital plants) alleviated face-to-face awkwardness. However, some studies suggested the need for richer interactive content and dynamic social information to enhance engagement further.

Motor and cognitive rehabilitation were central to many studies. Games such as the Boxes Game, Puzzle Game, and Garden Care Game effectively targeted both cognitive and motor functions, allowing physiotherapists to analyze patient performance and adapt training plans. Similarly, a competitive AR-based training task increased user engagement by encouraging frequent physical movement, though the social aspect sometimes led to distraction, reducing the intended embodiment effect.

The integration of AR with board games also proved effective in various contexts. One study demonstrated that an AR-based board game significantly enhanced children's communication skills, fostering greater interaction and engagement. Another study highlighted the potential of AR in education, showing that an AR-integrated board game improved students' comprehension of family functions. In rehabilitation, an AR-based game designed for post-stroke patients facilitated hand coordination and motor skill development, with accurate marker recognition and data tracking enhancing the therapeutic process.

Outcomes primarily targeted motor rehabilitation and cognitive improvements, while some studies also focused on social engagement and educational mastery. The settings in which these studies were conducted varied, with controlled laboratory environments being the most common, followed by home-based rehabilitation, educational settings, and simulated office environments. Various measures were employed to assess outcomes, including EMG signals, proprioceptive drift analysis, subjective questionnaires, error rates, and pre/post-test scores being the most frequent. Some studies incorporated physiological measures such as heart rate variability and skin conduc-

tance, reflecting a comprehensive approach to evaluating AR-based serious games. Further research is needed to validate these findings through clinical trials and larger sample sizes, ensuring their applicability in real-world settings.

3.5.2 Augmented Reality in Motor Rehabilitation

One of the most studied application areas for AR was physical rehabilitation. The study [24] illustrates the benefits that AR can bring compared to traditional methods, elucidating how AR can improve the engagement and motivation of patients. Such engagement is more likely to yield better rehabilitation results, since the patients are more compliant with their therapies. Still, the limited sample population in this investigation makes these findings hard to generalize to broader populations, and further work is needed with bigger and more varied sample groups.

An additional contribution is in [40], which harnesses the use of AR for Prosthetic limb embodiment using competitive training task scenarios. The insights gained make a case for AR training, making the way for enhanced user motivation and engagement in rehabilitation tasks, along with a feeling of attachment towards the prostheses. Nonetheless, the short period of the intervention did raise queries about the longevity of such alterations in the future. It is necessary to assess the long term consistency of efficacy of AR based treatments on motor rehabilitation.

3.5.3 Augmented Reality in Cognitive Rehabilitation

There is significant potential in how AR can be applied in cognitive rehabilitation. For example, AR has been investigated with the goal of enhancing communication skills within children, as discussed in [41]. The major finding in that work is that communication abilities improved due to cognitive engagement while playing AR board games. That said, the study overlooks the significant possibilities of other external factors being involved, such as the home situation and parents' engagement with the child.

In a similar vein, AR technology has been used for the improvement of memory, attention, and problem-solving skills. Although many studies have reported success, there are weaknesses in research designs, such as not having control groups or follow-up evaluations, which make it difficult to come to conclusive evidence.

3.5.4 Augmented Reality and Psychosocial Rehabilitation

No studies specifically exploring psychosocial rehabilitation were found to meet the criteria. The studies primarily focused on improving social interaction, communication, and engagement. For example, [39] presented an AR game that aims to promote social interaction among individuals working in an office setting. The study points out AR's unique ability to address social problems within the workplace by providing constructive and participative situations. The results clearly show an improvement in social interaction and contact after the intervention; nevertheless, the danger of relying on self-reported evidence handicaps the accuracy of the results.

The educational potential of AR is exemplified in [44]. In this, AR is shown to be beneficial in the classroom for both learning and social activities, and even improves the students' grasp of intricate ideas. Nonetheless, limited follow-up assessments are a cause of concern regarding the knowledge and skills acquired through the AR driven means.

3.5.5 Current Gaps in Research

Despite the promising findings, several gaps remain in the current research on AR applications in rehabilitation:

1. **Integration of Multimodal Approaches:** There is a lack of exploration into how AR can be effectively combined with other therapeutic modalities, such as virtual reality (VR).
2. **Multi targeted approaches:** There is a lack of studies that group the rehabilitation areas mentioned, the currently available studies focus mainly on one dimension.
3. **Exploration of User Experience:** There is a need for in-depth qualitative research to understand user experiences with AR applications in rehabilitation. Insights into user preferences, challenges, and motivations can inform the design of more effective AR tools.
4. **Long-Term Effects:** Many studies focus on short-term outcomes, leaving the long-term efficacy of AR interventions largely unexplored. Longitudinal studies are needed to assess the durability of benefits and identify potential drawbacks over time.

3.6 Challenges and Future Directions

While there is a vast potential for the use of Augmented Reality, the application of this technology in rehabilitation therapy has its own unique challenges. For instance, the high cost of AR devices and software combined with the limited access to the latest AR technologies slows down its adoption rates. There are also important considerations like user's data privacy as well as how different AR interventions will be standardized.

Going forward, the focus of the research should shift towards:

- Creating affordable AR technologies to make it easier for all sections of society to access them.
- Assessing the effects of AR usage over an extended period on the rehabilitation process.
- Investigating the synergy of AR with other new technologies such as AI, which can improve customization and make it easier to use.

3.7 Conclusion

The existing status of augmented reality in terms of its application for rehabilitation shows the capacity to modify practice in physical as well as cognitive and social therapies. Research indicates that there are very satisfactory engagements and rehabilitation results, although issues of scalability and generalization and long-term effects still exist. Overcoming these issues will be the first step toward achieving the full potential of augmented reality in rehabilitation and this will only be accomplished through focused investigation and development. The future of rehabilitation by means of augmented reality is multidimensional and can be personalized to meet the needs of each patient.

Chapter 4

Approach & Methodology

This project, proposes the development of a serious game that addresses motor, social and cognitive rehabilitation on one single platform and using augmented reality technology. The intent is to come up with a platform that enables constant rehabilitation by merging these three aspects into one, thus offering an improved solution than what currently exists. The game will be developed through a co-design [46] process involving patients with ABI and relevant stakeholders, such as physiotherapists, clinical psychologists, neuropsychologists and so on, so that the product actually addresses the needs of the users. This project was submitted to the Ethics Committee, ensuring compliance with all ethical guidelines and principles necessary for research involving human participants. The submission included detailed documentation outlining the study's objectives, methodology, data collection procedures, and measures to ensure participant confidentiality and data protection. These documents, along with the informed consent form template, are attached as annexes to this dissertation. This project was developed following the Scrum methodology[47], which is an Agile development technique that focuses on moving step by step forward. Scrum encourages constant feedback gathering and interaction with users, and other stakeholders, in this case, health care professionals and patients, to increase the effectiveness of the gaming solution. The development roadmap will break the project into sprints, where certain tasks such as implementation of features, testing, and refinement are performed. Sprints will make sure that there are set deadlines for tasks and allow for changes that lead to improvement. Regular sprint reviews and retrospectives will allow adaptation to the feedback gained and prioritize changes that will maximize the game's utility in multidimensional rehabilitation.

4.1 Methodology

The target users for this study will be patients with ABI who require multidimensional rehabilitation, integrating cognitive, motor, and social areas.

Therefore, the inclusion criteria for this study are defined as follows: participants must be over 18 years old, have already begun a cognitive rehabilitation process, and possess preserved

general intellectual abilities and comprehension language skills to understand the informed consent and perform the necessary tasks for participation (interview, serious game, and self-report questionnaires).

To better address the users' needs, it will be necessary to conduct interviews focused on AR, as this topic has not yet been extensively explored in the existing literature.

Data collection will preferably take place in consistent locations to ensure uniform study conditions and facilitate continuous interaction with participants. Additionally, collaboration will be sought with rehabilitation clinics, institutions, and patient associations.

4.1.1 Implementation Plan

The project will be implemented in three main phases, based on an iterative approach that allows for the continuous adjustment of the game according to user needs.

1. Phase 1: Requirements Gathering and Feature Definition

This phase will include interviews and co-design sessions (with a minimum of 4 participants) involving healthcare professionals and ABI patients, conducted at FEUP or in partner clinics (depending on the availability of participants and healthcare professionals). The interviews will follow a semi-structured script, allowing for the inclusion of additional questions as needed during the data collection process. The study will be promoted in clinics to maximize participation. The focus will be on understanding user needs, considering the complexity of the ABI rehabilitation process, to define essential game features with an emphasis on AR integration. This includes identifying the most effective types of interactions (e.g., taps, gestures, body movements, interactions with virtual objects through AR), the types of feedback (visual, auditory) that are most motivating, especially in the context of AR, and how to balance the game's difficulty level to ensure patients feel challenged but not frustrated.

2. Phase 2: Prototype Development and Usability Testing

Based on the data from Phase 1, a functional prototype of the game will be developed. This prototype will be tested with a pilot group of patients and healthcare professionals. Usability tests will be conducted to assess ease of use, navigability, feedback, and motivation provided by AR. During this phase, online questionnaires will be used, including the Game Experience Questionnaire (GEQ) [48], the System Usability Scale (SUS) [49], and the User Satisfaction Evaluation Questionnaire (USEQ) [50], to collect data on the user experience. Additionally, some open-ended questions will be applied to obtain more specific feedback.

3. Phase 3: Evaluation and Refinement

In the final phase, participants will play the game prototype once, after which they will be asked to respond to the same questionnaires and questions, allowing for a direct comparison with the previous phase. This process aims to evaluate the evolution of the prototype and

identify areas for improvement. Based on the responses obtained, the game will be refined to ensure that all dimensions of social, cognitive, and motor rehabilitation are adequately integrated, providing an engaging and motivating experience for patients.

4.1.2 Planned Activities

The development of the project will involve the following activities:

1. **Literature Review:** Research documentation, studies, or articles to gather existing information about AR and related technologies.
2. **Requirement Identification:** Define the specific needs and goals for the target population.
3. **Platform Exploration:** Identify and test key features of the Meta quest 3 to evaluate its functionality.
4. **Prototyping and co-design:** Designing and implementing an AR-based serious game prototype, integrating social, cognitive, and motor rehabilitation features using a co-design process.
5. **Usability Analysis:** Evaluate the user interface, ease of use, and learning curve for interacting with the technology.
6. **Feedback Analysis:** Gather open response inputs from stakeholders or users who interact with the technology.
7. **Dissertation writing**

4.2 Technology

Based on the research conducted and considering availability, the Meta Quest 3 will be used for this project. This device offers several advantages, including its portability, affordability compared to other AR/VR headsets, and high performance. Additionally, the Meta Quest 3 features advanced pass-through capabilities, which allow users to seamlessly interact with their physical surroundings, making it particularly suitable for rehabilitation scenarios that use AR and real-world interactions. However, it is important to note that this decision will be also based on the results of the interviews, as the feedback from participants and health professionals will be crucial in determining the most appropriate hardware for achieving the project's objectives.

4.3 Expected Results

This project aims to create a serious AR game that combines all three modalities of rehabilitation into one solution. The design of this game is hypothesized to increase the focus and motivation of the patient, which will consequently improve adherence to rehabilitation activities, and ultimately

achieve better results. First, the game should exploit the engaging and participatory nature of AR to enable users to have meaningful interactions, give and receive feedback, and immerse themselves into the environment for maximal engagement. Moreover, the game will be refined over and over again so that the voices of real users, acquired from interviews and usability testing, enable the game to be specific to populations, hence making rehabilitation solutions custom-fit and easy to scale. Ultimately, this project seeks to contribute to the growing body of evidence on the potential of AR-based interventions in promoting more accessible and comprehensive recovery pathways for individuals with ABI.

4.4 Co-design - Phase 1

4.4.1 Data Protection and Ethics

All data collected during the development of the project, including personal information and questionnaire results, was treated confidentially in accordance with the General Data Protection Regulation (GDPR) [51], the Declaration of Helsinki, and the Oviedo Convention.

Some of the interviews were audio-recorded and transcribed verbatim but anonymized. During the research, any data collected was stored on a password-protected computer and was only accessible by the research team, in an anonymized format. Identification data (e.g., sociodemographic information) was stored in separate files from the other collected data and was password-protected. Online self-report measures were collected through an online questionnaire system that ensures access control and anonymization of the collected data. No data was shared with third parties. The physical and electronic security of the data was ensured during and after the study. Personal data collected in the study was destroyed at the end of its implementation. The remaining data will be retained, in anonymized form, for scientific research purposes (e.g., conducting comparative studies between different versions of the game or the questionnaires) until the conclusion of the project associated with this dissertation, with a projected end date of 2029.

It is guaranteed that the data collected was used exclusively for this study, under anonymous conditions (no identification data was recorded), ensuring that the participants' identification was never made public. All contact was conducted in a private and secure environment.

4.4.2 Interviews

In order to align the design of the platform with real needs, a set of interviews was analyzed. These included transcripts from previous studies conducted at LIACC as well as new interviews performed for this work. Each theme was then translated into a design implication for the platform.

Table 4.1: Coded quotes from interviews, their themes, and design implications.

Quote (Portuguese)	Theme	Design Implication
(Health professional) <i>"Não conseguir monitorizar o desempenho."</i>	Accessibility	Include adaptive difficulty and performance tracking
(Family member) <i>"Melhor tipo de interação: voz"</i>	Design	Support voice interaction
(Health professional) <i>"Cenários do dia a dia: pouca capacidade de abstração"</i>	Environment	Use real-world scenarios; avoid fictional ones
(Health professional) <i>"Não treinar muitas competências ao mesmo tempo"</i>	Design	Focus on one or two cognitive skills per session
(Health professional) <i>"Feedback constante — auditivo e visual"</i>	Feedback & Clarity	Provide both visual and auditory feedback
(Family member) <i>"10 min cada jogo e depois mudar"</i>	Accessibility	Keep sessions short and rotate cognitive tasks
(Health professional) <i>"Forma correta e emoção associada"</i>	Accessibility	Add emotional cues and correctness indicators
(Patient) <i>"Letras maiores"</i>	Accessibility	Use large, readable fonts
(Patient) <i>"Som talvez maior também"</i>	Accessibility	Increase default volume; allow adjustments
(Patient) <i>"Jogo nunca ser monótono"</i>	Engagement	Vary tasks and pacing to reduce monotony
(Patient) <i>"Desafio para continuar a jogar"</i>	Engagement	Ensure meaningful challenge progression
(Health professional) <i>"Divisão por áreas cognitivas e níveis"</i>	Design	Separate content by cognitive skill and use levels
(Health professional) <i>"Adaptar os jogos a cada paciente"</i>	Accessibility	Allow personalization per patient profile
(Health professional) <i>"Ir aumentando a dificuldade"</i>	Design	Scale difficulty with player performance
(Health professional) <i>"Estimulação da memória a curto prazo"</i>	Design	Include short recall tasks
(Patient) <i>"Maior perceção visual"</i>	Accessibility	Use visual contrast and object recognition tasks
(Health professional) <i>"Não querem sentir-se infantilizados"</i>	Environment	Avoid childish graphics, language, or tone
(Health professional) <i>"Nem todos respondem dentro do tempo"</i>	Accessibility	Allow flexible response times
(Health professional) <i>"Demora no setup"</i>	Design	Streamline game startup to reduce wait time

As shown in Table 4.1, the interviews revealed a set of consistent needs. Accessibility concerns were the most common, mentioned by both health professionals and patients, and included requests for adaptive difficulty, clear multimodal feedback, and flexible response times. Design-related remarks emphasized focusing on specific skills, avoiding childish aesthetics, and keeping the game monotonic-free through variation and progression. Environment-related remarks suggested grounding the experience in familiar, everyday contexts such as markets or kitchens.

From these findings, several implications were implemented directly into the prototype. For example, text-to-speech output and subtitles were introduced to guarantee auditory and visual access to dialogue, adaptive difficulty mechanisms were designed in all minigames, and everyday objects were used to maintain familiarity. Feedback mechanisms (visual highlights, audio cues) were integrated. Play sessions were limited to 5 levels so each session would be short, and three mini games were created to separate rehabilitation fields as well. Accessibility measures such as invisible barriers, reduced rotation forces for objects, and gaze-assisted slot highlighting were also inspired by the concerns raised in the interviews.

Overall, the interviews provided validation that the chosen direction, an AR-based supermarket role-play, aligns with both therapeutic expectations and patient needs, as the supermarket context reflects daily tasks and familiar motions, making it easier to transfer progress from therapy into real-life situations. The coded implications were mapped across the three minigames, ensuring that each domain (social, cognitive, and motor) incorporated relevant accessibility and design considerations.

Chapter 5

Proposed Solution

5.1 Conceptual Overview

The solution is implemented as a serious augmented reality game called *Neuroshop*, designed for the Meta Quest 3. Players assume the role of a supermarket employee who interacts with customers and performs work-related tasks. This consistent narrative framework provides continuity across all exercises.

5.2 Narrative and Game World

The supermarket setting establishes a familiar and meaningful environment in which all minigames occur. A virtual tabletop and shelving system is instantiated around the player's real-world space, aligning with detected surfaces through scene anchors. Customers appear virtually and interact with the player using animations and sound, maintaining immersion and coherence across different activities.

5.3 Minigames

Three minigames form the core of the experience. Each is associated with a rehabilitation goal and designed to fit naturally within the supermarket role.

5.3.1 *Customer Care: Social Interaction Training*

In this activity, customers approach the player with complaints such as incorrect items or confusion about pricing. The player is presented with several possible responses, and must choose the most professional and empathetic option. As difficulty increases, conversations become more complex and are presented extra options and clients.

5.3.2 Memory Aisle: Cognitive Challenge

Here, customers provide shopping lists ranging from one to 10 items. After briefly reviewing the list, the player must recall and collect the correct products from surrounding shelves in order. Interaction is performed with natural hand gestures, and difficulty scales by increasing the number of items the player needs to memorize. The time to memorize is constant.

5.3.3 Stock Shift: Motor Coordination

This game focuses on fine and gross motor skills. The player receives a delivery of products that must be placed on shelves using color coding. Objects differ in size and shape, requiring varied hand poses and movements. Some tasks encourage bilateral coordination by alternating shelf sides, thereby engaging both hands. Performance is measured by accuracy, smoothness, and correct placement.

5.3.4 Interaction Model

Interaction relies on a combination of gaze and gesture-based input. Gaze direction is used to highlight important places or objects, while hand gestures allow natural manipulation of items. Passthrough mode ensures that players remain aware of their real surroundings, with virtual objects consistently anchored to physical space through MR scene data.

5.3.5 Progression and Feedback

Task difficulty is adaptive. The system monitors performance indicators such as accuracy, error types, and response times, then adjusts the challenge accordingly. For example, consistently correct answers in social interactions unlock more nuanced conversations, while success in memory tasks increases the list length. Feedback is provided through immediate audio and visual cues.

5.3.6 Art and Audio Style

Visual and audio design aim to provide clarity without overstimulation. The graphics adopt a semi-realistic style with rounded forms and muted colors, ensuring objects are recognizable but not distracting. Important items are highlighted through subtle visual emphasis. Customers are fully voiced and short auditory signals mark correct actions.

5.3.7 Accessibility and Safety

The solution incorporates accessibility measures such as text-to-speech support and visual cues for players with sensory difficulties. All activities are designed for seated play, reducing physical strain. Scene data from the Quest 3 ensures that spatial boundaries are respected, preventing virtual interactions from extending into unsafe areas of the real environment.

5.3.8 Evaluation and Metrics

Every gameplay session generates detailed metrics that record success rates, response times, error patterns, and motor trajectories. These logs can be exported for therapist review, allowing professionals to track rehabilitation progress, identify difficulties, and adjust treatment plans as needed.

5.4 Co-design - Phase 2

5.4.1 Procedure

Following the initial interviews and thematic coding of requirements, a *Game Design Document* (GDD) was produced to consolidate the conceptual framework of the rehabilitation platform. This document outlined the narrative setting, the minigames, accessibility measures, and technical underpinnings. To validate its adequacy, the GDD was shared with a group of healthcare professionals for review. Their feedback provided external validation of the design choices and offered constructive suggestions to further enrich the therapeutic scope of the platform. The GDD resulting from this phase is provided in the annexes (Appendix A).

5.4.2 Results

The responses highlighted strong approval of the project's direction, emphasizing its ecological validity, accessibility, and integration of multiple rehabilitation domains. The main remarks can be summarized as follows:

- **General Impressions.** Reviewers noted that the game was carefully thought out and presented significant potential for rehabilitation. The choice of situating the player as a supermarket employee was praised for being functional, realistic, and relevant to everyday life. The modular structure of the minigames was recognized as a strength, covering social, cognitive, and motor domains simultaneously.
- **Social Interaction Training.** Suggestions included expanding the NPC dialogue beyond complaints to encompass other scenarios such as providing directions to products or taking orders. Emotional and empathic aspects of NPC interactions were also recommended, to stimulate engagement and train socio-emotional responses.
- **Cognitive Training.** Feedback proposed adding task variations that stimulate different forms of memory. For example, requiring the player to memorize and follow a specific sequence of items, or locating products within shelves to engage visual memory. Another suggestion included balancing shopping bags by weight, promoting both mental calculation and planning skills.
- **Accessibility and Adaptability.** Experts valued the use of passthrough AR, hand and gaze-based controls, and seated play mode for safety. They also encouraged the inclusion of

options for therapists to customize tasks, difficulty, and instructions according to the profile of each patient. Additionally, a patient feedback space at the end of each session was suggested to capture subjective experiences and difficulties.

- **Motivation and Progression.** To maintain engagement, suggestions included adding light narrative progression (e.g., promotions, symbolic rewards), multiplayer or cooperative modes for long-term development, and comparative clinical reports for therapists.

5.4.3 Integration into Development

The feedback was crucial in validating the soundness of the project's core design. Several suggestions were incorporated into the implementation:

- Dialogue scenarios were diversified to include non-complaint interactions.
- The cognitive game was extended to now featuring memorization of ordered sequences, reinforcing working memory.
- Accessibility features such as gesture-based controls, gaze assistance, and safety mechanisms (e.g., preventing objects from falling irretrievably) were confirmed.

Other proposals, while valuable, were not implemented in the current version due to time and scope constraints:

- Complex tasks such as weight-balancing or therapist-controlled customization require more development effort and will be considered in future iterations.
- Narrative progression, multiplayer modes, and advanced reporting functionalities were recognized as promising directions but were deferred to a future time.

5.4.4 Conclusion

Overall, the feedback reassured that the GDD was aligned with clinical expectations and patient needs. At the same time, it provided a roadmap for future enhancements, highlighting the potential for personalization, emotional engagement, and advanced monitoring features. By selectively integrating feasible suggestions, the project was able to maintain focus on delivering a functional prototype, while keeping open pathways for future extensions that further strengthen its therapeutic impact.

Chapter 6

NeuroShop

6.1 Resources

The development of the *AR Supermarket* platform relied on a combination of assets sourced from online repositories and custom integration to ensure both performance and clinical relevance. Given the constraints of the Meta Quest 3 hardware and the target audience of patients with ABI, careful attention was paid to selecting resources that balanced visual clarity and accessibility.

6.1.1 Assets

Most of the 3D models used for props throughout the minigames, were obtained from the Unity Asset Store. These assets were deliberately chosen for their simple, low-poly style, which reduces rendering overhead and ensures consistent frame rates. At the same time, the design avoided cartoonish or overly stylized elements. The assets depict real-world supermarket objects such as tables, shelves, groceries, and objects.

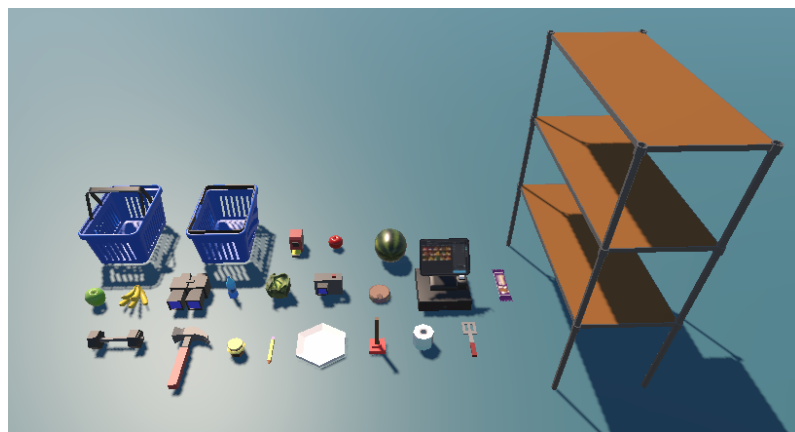


Figure 6.1: Props models used in NeuroShop

6.1.2 Sound Effects

Sound effects were sourced from Pixabay, a platform offering free and royalty-free audio libraries. These sounds include, ambient music, and confirmation cues. All sound effects were kept subtle and natural to avoid overstimulation while still providing feedback.

6.1.3 NPC Models and Animations

The non-playable characters (NPCs) are central to the social interaction mechanics of the platform. Their 3D models and base animations were sourced from Mixamo, a widely used repository for rigged humanoid models and motion-capture animations. Animations such as walking, waiting, and talking were integrated into the NPC, providing naturalistic movement and interactions with the player.

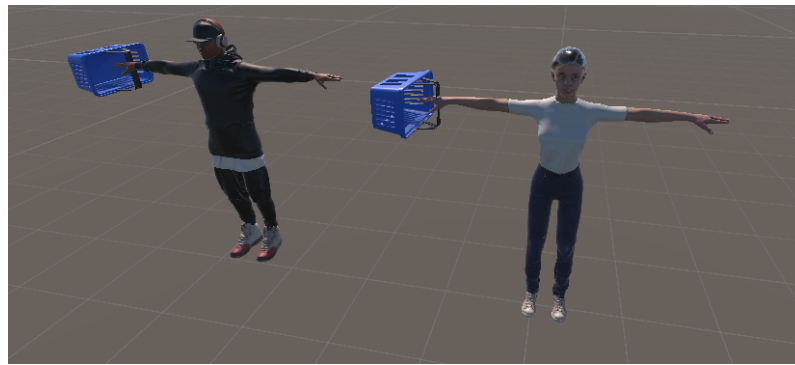


Figure 6.2: NPC models used in NeuroShop

6.2 Implementation

6.2.1 Overview

This section describes the implementation of the platform, addresses device and SDK (software development kit)[52] setup, MR spatial understanding and anchoring, and runtime scene orchestration that adapts to diverse room layouts.

6.2.2 Toolchain and Project Setup

6.2.2.1 Game engine and SDK

The implementation was carried out in Unity, using the Universal Render Pipeline (URP) together with the *Meta XR All-in-One SDK*. Unity was chosen as the development engine due to its robust support for XR workflows and its wide integration with the Meta ecosystem. The URP ensured efficient rendering performance on the Quest 3, which is essential for maintaining smooth frame rates in AR applications, particularly when multiple objects and dynamic physics must be processed at runtime. The Meta XR All-in-One SDK provided the foundation for hand tracking,

passthrough rendering, scene understanding, and other device-specific features required to build the project without relying on external plugins.

6.2.2.2 Passthrough

In order to combine virtual content with the user's physical environment, passthrough mode was enabled through the Meta XR SDK. When activated, the headset's outward-facing cameras continuously capture the real world and stream it to the display as a live video background. Unity then renders virtual objects on top of this video feed using the same rendering pipeline as for standard 3D content. We then can configure transparency levels, edge blending, and rendering order so that digital prefabs appear integrated with the camera feed rather than floating independently. In practice, this means that the player sees their actual surroundings, provided directly by the headset cameras, with menus, props, and Non-player-characters (NPCs) rendered in real time as overlays within the same visual space.

6.2.2.3 Hand Tracking Support

The application relies on controller-free interaction by using the Quest 3's built-in optical hand tracking system. This system operates by capturing the user's hands with the headset's front-facing cameras and running real-time computer vision algorithms to estimate a full skeletal model. The SDK exposes this data as a hierarchy of tracked joints, including wrist, palm, and finger bones, each represented by a 3D transform. Unity then uses these transforms to drive either a rendered hand mesh model or abstract colliders that can be used for interaction.

Gestures such as pinch, poke, or grab are not explicitly recognized as discrete button presses, but instead calculated from joint distances and orientations. For example, a pinch is detected when the distance between the index fingertip and the thumb tip joints falls below a configurable threshold, and the SDK reports a pinch strength value in the range $[0, 1]$. In practice, the application listens for pinch events with confidence above a defined threshold (e.g., 0.8) to trigger reliable interactions such as pressing a button or selecting an item.

Interaction with virtual objects is handled through Unity's physics and interaction layers. Each hand includes colliders placed at the fingertips and palm, which interact with UI components configured for it.



Figure 6.3: Hand tracking example with manipulation of objects.

6.2.2.4 Debugging

For debugging and profiling, development was performed using the *Meta Quest Link* cable, a USB-C connection between the headset and the development machine. This setup allowed the Unity editor to stream directly into the headset in Play Mode, making it possible to observe changes instantly without requiring repeated build-and-deploy cycles. This iterative workflow significantly accelerated testing, especially during the frequent adjustments to scene anchors, hand interaction components, and spatial alignment logic.

6.3 Room Scanning and MRUK Integration

Before the game can begin, the environment must be scanned using the Quest 3 system interface (Figure 6.4). This scanning step (Figure 6.5) generates a semantic map of the room, classifying surfaces such as tables, walls, windows, shelves, floors, etc. The application then accesses this structured spatial data through the Mixed Reality Utility Kit (MRUK). By relying on the scan, the game avoids hard-coded coordinates and instead adapts to each new space where it is played. MRUK provides both the semantics and the geometric information of the scanned surfaces, including their position, rotation, and physical bounds. With this information, our platform is able to place anchors, which are virtual representations of the position, and dimensions of the real objects in the room.

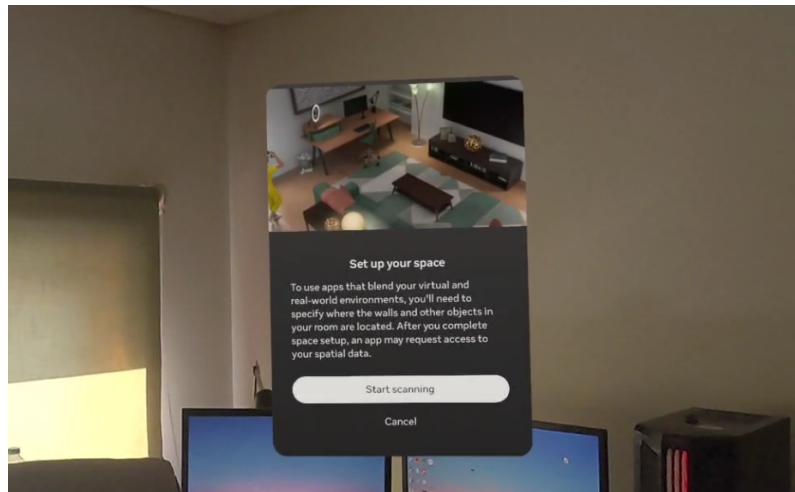


Figure 6.4: Initial room scanning prompt, when no room data is available

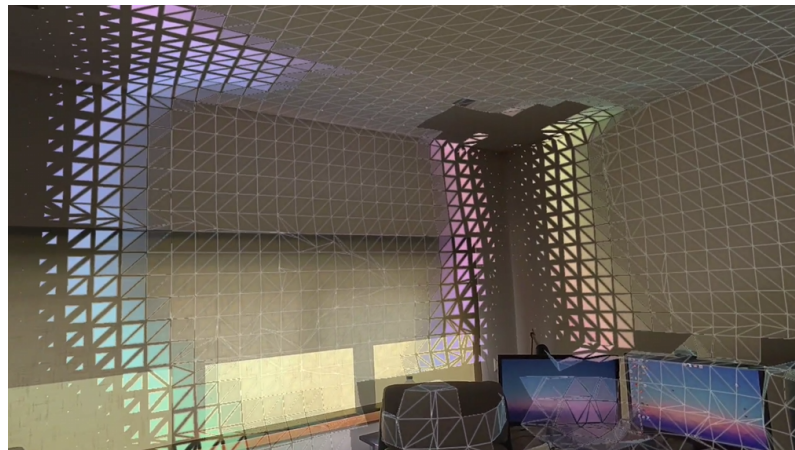


Figure 6.5: Room scanning procedure

6.3.1 Anchor-Driven Prefab Spawning

Because the gameplay is centered around the tabletop, the table anchor becomes the most important element of the spatial setup. When a table is detected in the scanned environment, the system spawns a virtual object directly on that anchor. This object is not fixed to a predefined size, instead, it is scaled to match the real-world dimensions of the detected table. By doing so, the virtual table surface becomes a faithful representation of the physical one, and all subsequent elements of the game—such as menus, props, and interaction points, can be positioned relative to this scaled surface.

This scaling process ensures consistency across different environments. If the player is seated at a small coffee table, the menus and props are automatically arranged so that they still fit comfortably within reach. Conversely, if a larger dining table is detected, the content is spread accordingly,

without appearing stretched or misplaced. The anchor-driven scaling therefore guarantees that, regardless of the actual size of the physical table, the player perceives the virtual content in a stable and proportionate way, always aligned with the surface in front of them.

Once the table object has been placed, it is also used as the primary reference for all other spatial elements in the game. Shelves, NPC spawn points, and approach paths are positioned relative to the detected table rather than being scattered arbitrarily across the room. This design choice ensures that the entire game world is organized around a single, consistent focal point, making the table both the core of interaction and the anchor that structures the rest of the experience.

To manage multiple tables in the same environment, a dedicated `TableManager` was introduced. Each detected table registers itself with this manager, which then selects the most appropriate one, typically the table nearest to the player as the active surface for gameplay. This ensures our platform works even if more than one table exist in the room.

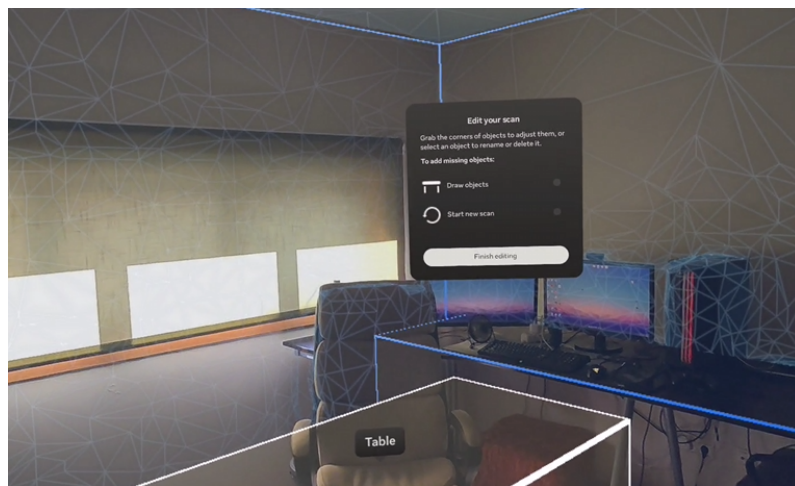


Figure 6.6: Room scanned with virtual table and objects identified

6.3.2 Content orientation

Initially there was an issue of content orientation. Menus and props appeared at awkward angles, sometimes facing away from the player or positioned in ways that forced uncomfortable neck movement. This was addressed by computing the player's initial facing direction at the start of the session and rotating all spawned content accordingly.

6.4 Platform Initialization Pipeline

The initialization process follows a clear sequence of steps as seen in 6.7, beginning from the moment the application starts and ending with a fully prepared environment where the player can select which minigame to play. The pipeline can be described as follows:

1. **Application Startup.** The Unity project launches with default values configured for lighting, interaction layers, and XR settings. Hand tracking and passthrough are enabled immediately, ensuring that the player sees their real environment overlaid with tracked hands.
2. **Environment Scan.** If no recent scan exists, the player is prompted to perform a short room scan using the Quest 3 system interface.
3. **Anchor Retrieval.** The Mixed Reality Utility Kit (MRUK) retrieves the scanned surfaces as scene anchors.
4. **Table Registration.** Anchors labeled as tables are identified. Every detected table registers itself with the global `TableManager`, which maintains a list of available tables. The manager later decides which table is most suitable to host the game based on proximity to the player.
5. **Scene Reference Setup.** Once the table is placed, it becomes the primary reference point for positioning other elements of the scene. Shelves, NPC spawn points, and approach paths are instantiated relative to the table.
6. **Player Orientation.** The system calculates the player's initial facing direction. Menus, props, and UI elements are rotated so that they appear naturally aligned with the player's viewpoint.
7. **Collider Assignment.** Virtual colliders are added to the floor, walls, and other detected objects to ensure proper interaction, navigation constraints, and occlusion.

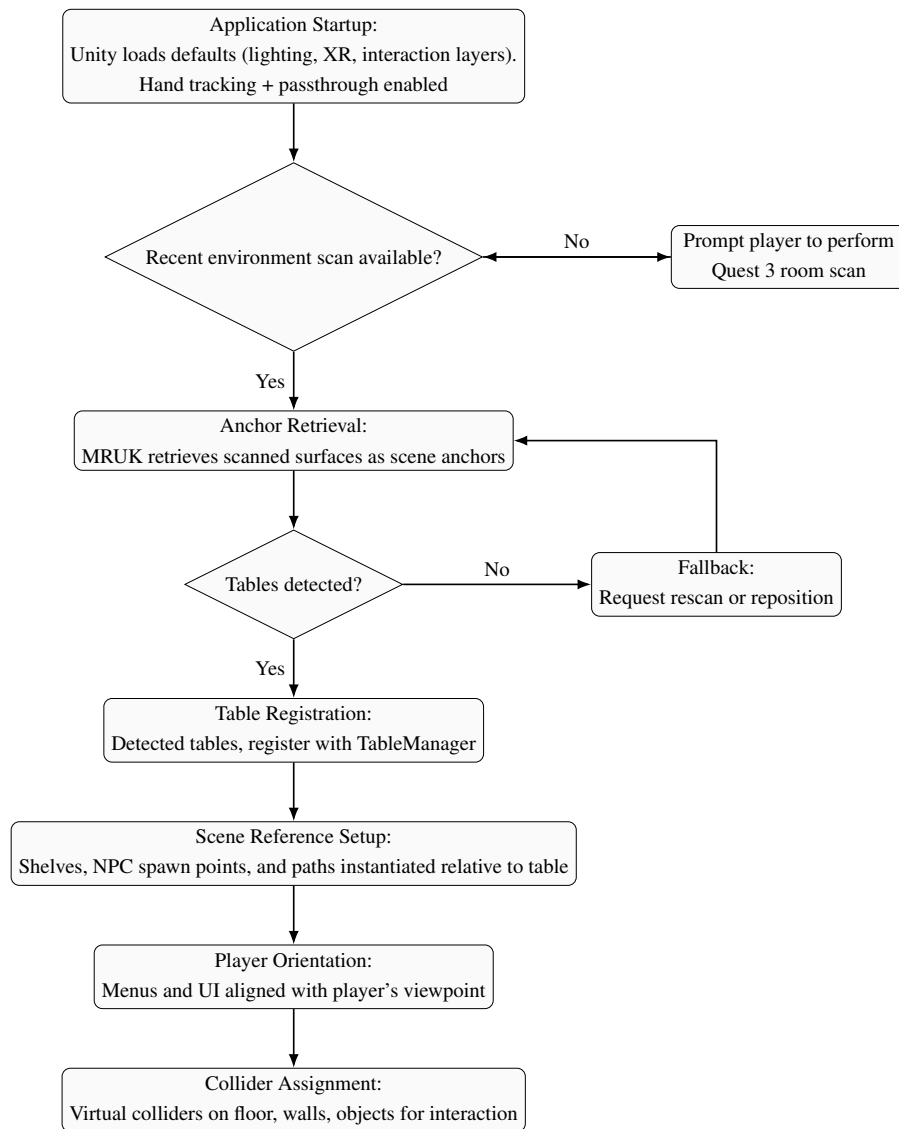


Figure 6.7: Platform Initialization Pipeline: from application startup to environment setup and interaction readiness.

6.5 Core systems

6.5.1 NPC Management and Queue System

NPCs are a central element of the first two minigames, as they simulate customers approaching the player with complaints or requests. Their presence makes it necessary to structure not only how NPCs are spawned and animated, but also how their positions are coordinated relative to the player's table.

When the player selects a minigame that involves customers, the system first ensures that the floor is mapped with colliders. These colliders are derived from the MRUK-provided floor anchors and allow NPCs to walk across the environment in a physically consistent way. Navigation meshes

are then generated, enabling pathfinding from NPC spawn points to the interaction area near the player's table, while also being able to avoid physically scanned objects.

6.5.1.1 Queue logic

To coordinate NPC arrivals, the game uses a dedicated `QueueManager`. This script keeps track of all active NPCs and guarantees that each one is assigned to a valid position in front of the selected table. For the active table, there are always two queue positions defined: a primary position directly in front of the player, and a secondary position slightly behind. When a new NPC is spawned, the Queue Manager evaluates the current occupancy of these positions. If the first position is free, the NPC is directed there; if not, the NPC is assigned to the second position.

As interactions conclude and the NPC in the primary position leaves, the Queue Manager automatically updates the other NPCs. The customer waiting in the secondary position moves forward to the primary slot, and the newly freed secondary slot becomes available for the next NPC. This system ensures a continuous, natural flow of customers approaching the player without overlap or confusion, and it abstracts the complexity of position reassignment from the individual NPC logic.

Although this queue system is essential to the first two minigames, it is not used in the third one, since the restocking activity focuses exclusively on object manipulation without customer interaction. For this reason, NPC management is presented here as a general subsystem of the overall platform rather than as part of a single minigame.



Figure 6.8: NPCs aligned waiting in queue during gameplay

6.5.2 NPC System and State Machine

The behavior of NPCs is implemented through a finite state machine that provides a consistent framework across the first two minigames. This design abstracts away the common control logic such as movement, queuing, and leaving while allowing each minigame to customize the interaction content presented during the conversation phase.

6.5.2.1 State Machine Overview

Every NPC transitions through a fixed sequence of states that define its role in the interaction flow. The five states are:

1. **Walking.** When an NPC is spawned, it is placed directly into the walking state. At this moment, the `QueueManager` assigns it a valid position in the queue. The NPC navigates toward the assigned spot using the floor colliders and navigation mesh. If the NPC is not first in line, it will stop at the secondary position until the queue advances.
2. **Waiting.** Upon reaching the designated queue slot, the NPC enters the waiting state. It remains idle in this position until the NPC in front of it leaves. Once it becomes the first in line, it is transitioned back to the walking state and moves forward to the primary interaction spot.
3. **Talking.** When the NPC reaches the main table position, it switches to the talking state. The specific content of this state depends on the active minigame. In the *Customer Care* game, the NPC delivers a complaint through voice and subtitles. In the *Memory Aisle* game, the NPC presents a shopping list that the player must memorize. Although the dialogue and presentation vary, the underlying logic of entering the talking state remains the same across both games.
4. **Waiting for Response.** After delivering its line, the NPC transitions into the response state, where it waits for the player to complete the corresponding task. In *Customer Care*, this means selecting one of the dialogue options; in *Memory Aisle*, it means recalling and collecting the correct items. The NPC remains idle but attentive in this state until the task is resolved.
5. **Leaving.** Once the interaction is complete, the NPC enters the leaving state and is directed toward an exit point. If the environment scan included a door anchor, this is used as the exit; otherwise, a fallback point away from the player's table is selected. After reaching the exit, the NPC is despawned and the Queue Manager assigns the freed position to the next waiting character.

6.5.2.2 NPC Movement and Valid Positions

NPCs rely on navigation meshes generated from the scanned floor to move naturally between their spawn points, queue positions, and exit locations. However, real environments can present constraints that prevent smooth navigation. For example, if the table selected for interaction is positioned close to a wall or in a confined corner, the designated queue slots may fall outside the physically accessible area. In these cases, the system disables the standard movement logic and instead teleports the NPC directly to its assigned position. This guarantees that the interaction can still proceed without requiring unobstructed walking space.

A similar fallback mechanism is applied when NPCs become stuck. If an NPC fails to make progress toward its target and remains immobile against an obstacle for more than two seconds, the navigation is interrupted and the NPC is teleported to the intended location. This prevents the queue from breaking due to navigation errors and keeps the flow of interactions uninterrupted.

The same principle also applies when NPCs leave the scene. Normally, they are guided to an exit anchor such as a detected door. If no valid exit can be identified, or if the fallback exit point is unreachable, the system again resolves the issue by teleporting the NPC out of view. In this way, teleportation is used as a controlled safeguard to ensure robustness of the NPC system in imperfect or constrained physical environments.

6.5.2.3 Integration with the Queue Manager

The NPC state machine is tightly integrated with the `QueueManager`, which tracks available queue positions and ensures smooth transitions between NPCs. When an NPC leaves, the Queue Manager reassigns positions so that the second customer in line moves forward automatically, maintaining a natural flow of interactions. This guarantees that the logic of the queue remains consistent regardless of which minigame is active.

6.5.2.4 Consistency Across Minigames

Although the details of the talking state differ between the first two minigames, the state machine itself remains unchanged. This separation of control logic from interaction content ensures that the same underlying NPC system can be reused across multiple rehabilitation scenarios. Only the content presented during the talking state is replaced, depending on whether the task involves responding to a complaint or memorizing a shopping list.

6.5.3 Game Manager

At the center of the application logic is the `GameManager`, a persistent class that remains active across all minigames and acts as the central controller of the platform. It maintains the overall game state, supervises the operation of other systems, and coordinates their interactions.

One of its primary responsibilities is to track player actions during gameplay. Whenever a user performs an interaction, such as selecting a dialogue option in the social interaction game or handling items in the memory task, the `GameManager` records the result and updates the relevant subsystems. For example, after a response is given, the manager signals the NPC state machine to advance, triggers the `QueueManager` to free a slot, and updates the session's statistics.

The `GameManager` also calculates scores at the end of each level. These scores are derived from the success or failure of player actions, and the number of errors made. Based on these results, the system determines the difficulty parameters for the following level. Since each minigame defines its own criteria for difficulty adjustment, the `GameManager` only provides the framework for difficulty scaling, while the individual games supply the specific rules for their domain.

Finally, because it operates as a singleton instance across the entire platform, the `GameManager` keeps track of global statistics. This ensures continuity across sessions and provides a unified source of data.

6.6 Minigames

6.6.1 First Minigame: *Customer Care*



Figure 6.9: *Customer Care* gameplay

The *Customer Care* minigame focuses on training social interaction and emotional reasoning. In this scenario, customers approach the player through the NPC queue system and present a complaint that the player must respond to by choosing from multiple dialogue options. The underlying logic of NPC spawning and positioning is handled by the `QueueManager` (6.5.1) and the NPC state machine (6.5.2), while the dialogue logic and scoring are controlled by the `GameManager` (6.5.3).

6.6.1.1 Dialogue System

Dialogue interactions are organized into *dialogue scenarios*, implemented as Unity `ScriptableObjects`. Each scenario groups 10 possible dialogues and is associated with a specific difficulty level. The difficulty of a scenario is primarily determined by the number of available dialogue options: scenarios with two options are considered easier, while those with up to four options are more demanding.

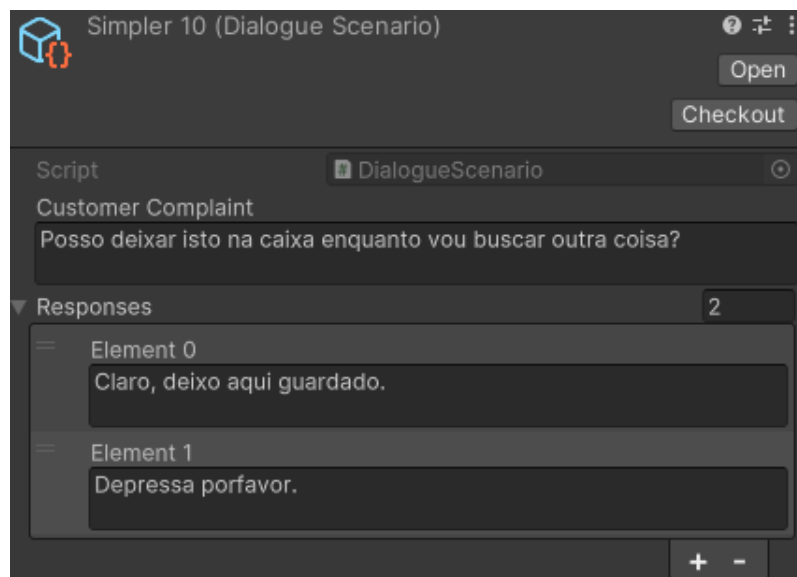


Figure 6.10: Dialogue scriptable object example.

At the beginning of the game, the difficulty is set to level 0. This means that the first scenario selected by the *GameManager* will always be from the easiest pool. When an NPC reaches the front of the queue and enters the *Talking* state, a dialogue is randomly chosen from the active scenario and presented to the player. The player's task is to select the most appropriate response from the given options. Each option carries a score value: 1 point if it is a poor choice, 2 points if it is a neutral choice, and 3 points if it is the best possible response. This scoring allows nuanced evaluation of player decisions, rather than a simple binary classification.

6.6.1.2 Level Flow

Each level is defined by the number of customers the player must serve. At the start, this is set to 2 clients per level. Once the assigned number of NPCs has been processed, the level ends and results are compiled. The game is structured to always run for five levels, but the difficulty of these levels may evolve differently depending on player performance. As a result, two players may both complete all five levels but obtain different overall scores due to variations in difficulty scaling.

6.6.1.3 Difficulty Adaptation

Difficulty scaling is calculated dynamically at the end of each level. For every interaction, the system tracks two main metrics: the score obtained from dialogue choices and the response time taken to select an answer. These values are normalized and averaged across all customers in the level. Unlike the score, response time is **not used as a penalty**, since players with ABI may require longer thinking times. Instead, it serves as an engagement indicator, distinguishing between fast, balanced, and slow response patterns.

Based on the combination of normalized score and time, the system decides how to adjust difficulty for the next level. Two parameters can be modified: the number of dialogue options

and the number of clients to serve. High performance with fast responses increases both the number of options and the number of clients, while low scores with slow responses decrease them. Intermediate cases result in smaller or no adjustments. The logic for this difficulty shift is summarized in the following rules:

- **High score + fast time:** increase both options and customers.
- **High score + slow time:** keep current difficulty.
- **High score + average time:** increase options only.
- **Low score + slow time:** decrease both options and customers.
- **Low score + fast time:** keep options, decrease customers.
- **Low score + average time:** decrease options only.
- **Medium score + fast time:** keep options, increase customers.
- **Medium score + slow time:** keep options, decrease customers.
- **Medium score + average time:** keep difficulty unchanged.

This adaptive process ensures that the minigame remains challenging without becoming overwhelming. It also individualizes the experience: a patient who consistently chooses appropriate responses but requires more time will not be penalized, whereas faster and accurate players are gradually given more complex scenarios to sustain engagement.

6.6.1.4 Scoring Model

Although all players complete the same number of levels, their final scores depend on the difficulty paths they encountered. A player who progresses through higher-difficulty dialogue scenarios and faces more customers will achieve a higher score ceiling than one who remains at easier levels. In this way, the system not only records success but also reflects the context in which it was achieved.

6.6.1.5 Accessibility Features

Accessibility is a key concern in the *Customer Care* minigame, since players with ABI may present difficulties with reading, visual attention, or language processing. To reduce these barriers, every dialogue presented by the NPCs is delivered through both text and speech.

When an NPC reaches the interaction position and enters the talking state, the complaint or question is displayed on the tabletop user interface as a subtitle panel. At the same time, the same content is spoken using a text-to-speech framework integrated into the Unity project. This multimodal presentation ensures that the player is not limited to a single sensory channel.

By providing simultaneous audio and visual delivery, the system accommodates players who may have difficulties reading or focusing on text alone, while still offering subtitles for those who prefer or require visual reinforcement.

6.6.2 Second Minigame: *Memory Aisle*

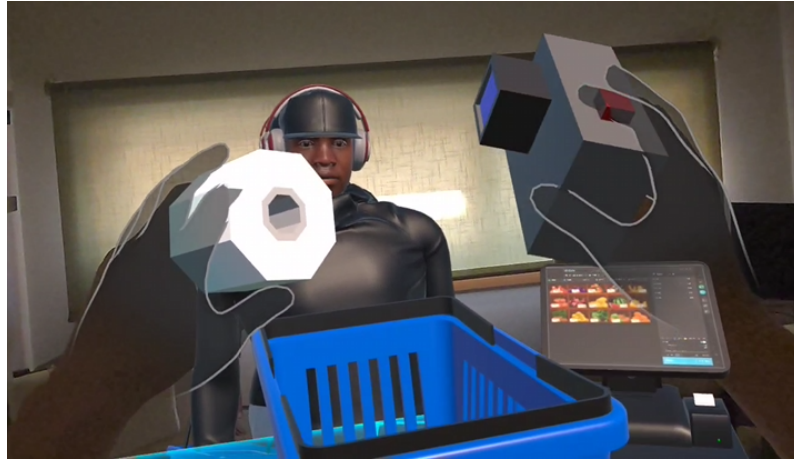


Figure 6.11: *Memory Aisle* gameplay.

The *Memory Aisle* minigame targets cognitive functions such as attention, short-term memory, and sequencing. In this scenario, customers approach the player through the NPC queue system and present a shopping list of items that must be recalled and collected from surrounding shelves. The organization of shelves, items, and scoring is controlled by the `GameManager`, while NPC flow follows the same state machine described in Section 6.5.2.

6.6.2.1 Environment Setup

At the beginning of the minigame, the system prepares the play area by spawning shelves around the player. Each shelf contains nine slots where virtual objects can be placed. Items are randomly assigned to these slots so that every level appears different and prevents predictable patterns.

6.6.2.2 Gameplay loop

When an NPC reaches the primary queue position and enters the *Talking* state, it presents a shopping list to the player. The list contains between two and ten items, depending on the current difficulty. The NPC places an empty basket on the player's table, and the player must retrieve the requested items from the shelves and drop them into this basket.

Each object placed in the basket is despawned, and we immediately repopulate the shelves with a new random distribution of unique items. This ensures that the shelves never contain duplicates and that each level remains varied. Once the required number of items for the current NPC has been collected, the interaction ends and the system prepares for the next customer.

6.6.2.3 Hint System

To assist players who struggle to recall the correct sequence, a hint button is available on the tabletop. When pressed, the system highlights the next item in the order presented by the NPC.

This provides guidance without directly completing the task for the player. Hints influence scoring (see below), but they are not heavily penalized; the effect of each additional hint is progressively smaller, so players are not discouraged from using them if needed.

6.6.2.4 Scoring Model

Scoring is based on two factors: the number of items correctly retrieved in the exact order requested and the number of hints used. The calculation first determines a base score as the ratio of correctly retrieved items to the maximum possible. A normalization step then applies a diminishing penalty for hints, using the following formula:

$$\text{normalized score} = \frac{\text{scoreActual}}{\text{scoreMax} \times (1 + \delta \times \text{hints})}, \quad \delta = 0.3$$

This formula ensures that hints reduce the score, but the penalty decreases with each additional hint, striking a balance between accuracy and accessibility.

6.6.2.5 Difficulty Adaptation

At the end of each level, the normalized score is used to update the difficulty for the next level. In this minigame, difficulty is represented by the number of items that the player must memorize in sequence. The minimum number of items is fixed at

$$n_{\min} = 2$$

and the maximum at

$$n_{\max} = 10,$$

ensuring that the task remains within achievable bounds for all players.

The system computes a target number of items proportionally to the normalized score, following the equation:

$$n_{\text{target}} = n_{\min} + (n_{\max} - n_{\min}) \times \text{score}_{\text{norm}}.$$

To avoid sudden jumps in difficulty, the next value is smoothed by interpolating between the current difficulty and the target:

$$n_{\text{next}} = n_{\text{current}} + \gamma \times (n_{\text{target}} - n_{\text{current}}), \quad \gamma = 0.3.$$

Finally, the result is rounded to the nearest integer and clamped between $n_{\min}$ and $n_{\max}$. This guarantees that difficulty evolves gradually over the course of the five levels, with no fewer than two items and no more than ten items to memorize by the end of the level.

6.6.2.6 Level Flow

As in the first minigame, the structure consists of five levels. Each level requires the player to serve two NPCs, regardless of difficulty. What changes is the number of items that must be memorized per NPC. This adaptive scaling means that while all players complete the same number of levels and interactions, their final scores will vary depending on the difficulty path they experienced.

The memorization phase is always limited to a fixed duration of 10 seconds, independent of the number of items on the list. This constraint ensures consistency across levels and prevents longer lists from creating excessive waiting times that could disrupt the flow of gameplay. It also avoids penalizing players with ABI who may need more time to focus, since the challenge is shifted to remembering more items within the same timeframe rather than being pressured by a reduced time limit. In this way, the scaling mechanism adjusts only the quantity of information to retain, while the available preparation time remains constant and predictable.

6.6.2.7 Accessibility Features

As in the *Customer Care* minigame, accessibility in the *Memory Aisle* scenario is addressed through multiple channels of interaction. All shopping list requests presented by the NPCs are both displayed as text and spoken using a text-to-speech framework. This ensures that players with visual or reading difficulties are still able to perceive the task requirements, while subtitles remain available for those who prefer visual reinforcement.

In addition to multimodal presentation, the game introduces further accessibility measures focused on the manipulation of objects. A virtual representation of the player's hands is rendered in passthrough mode, providing clear feedback of hand position relative to the shelves and objects. This visual aid helps players orient their movements and improves accuracy when selecting items. At the same time, the physical properties of objects were adjusted to reduce rotational forces. Rounded objects, which would otherwise roll or spin, now behave more stably, lowering the precision required for successful interaction.

A specific accessibility safeguard was also implemented to prevent objects from being lost on the floor. An invisible barrier is placed just below the lowest shelf level. If an item falls through this barrier—for example, after being dropped, it is automatically teleported back to its original spawn slot. Since every object stores its spawn position, the teleportation restores it precisely to where it belongs. This prevents items from accumulating on the floor, which could be difficult or unsafe for ABI patients to retrieve, while also maintaining the continuity of the task.

6.6.3 Third Minigame: *Stock Shift*

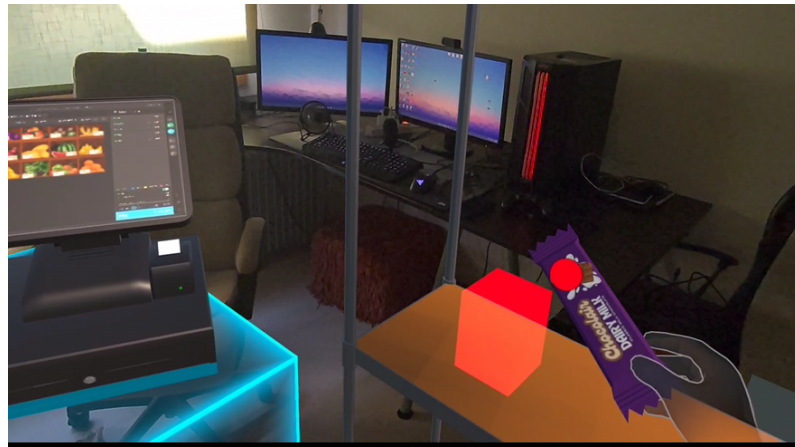


Figure 6.12: *Stock Shift* gameplay.

The *Stock Shift* minigame emphasizes motor coordination and precision. In this scenario, the player must take items from the table and place them into their designated shelf slots. Each item is assigned a target slot based on a color-coded system, requiring the player to perform accurate placements using natural hand movements.

6.6.3.1 Gameplay Loop

At the beginning of each level, a set of items is spawned on the player's table. Each item carries a small colored sphere that indicates its target slot. The shelves surrounding the player also display colored holographic cubes marking the valid slots. The task is to pick up each item and place it in the slot of the matching color.

Once an item is placed correctly, the corresponding shelf slot reverts to a default grey state, indicating that it is no longer active. This provides immediate visual feedback and prevents the player from reusing the same slot multiple times. The loop continues until all items for the level have been placed.

6.6.3.2 Scoring via Hand Tracking

In *Stock Shift* the focus is on movement quality and accuracy. To evaluate motor performance, a dedicated `HandMovementTracker` component continuously records the player's hand trajectories while objects are manipulated. The tracker samples hand positions at a default rate of 90 Hz, which corresponds to approximately one measurement every 11 milliseconds. This frequency is sufficient to capture fine details of hand motion, including small tremors or sudden changes in velocity, while keeping the memory footprint manageable by capping the buffer at 4096 samples.

Each sample consists of the 3D position of the hand at a given time, stored together with a timestamp. Sampling begins when the player grabs an object and continues until the object is

released. At release, the accumulated trajectory is analyzed to extract the metrics that determine motor performance.

The calculations proceed as follows:

- Distances between consecutive samples are divided by their time differences to estimate instantaneous velocities. From these values the system derives both average and maximum speeds.
- A special case is used to detect tremor: only samples from the last second where the hand was moving slower than 0.1 m/s are considered. The root-mean-square (RMS) deviation of these positions from their mean gives the tremor amplitude in meters.
- For approach speed, only the last 0.25 seconds of samples are selected. The total distance traveled during this interval divided by elapsed time gives the average velocity with which the hand approached the target slot.

These metrics are then combined with task accuracy, whether the item was placed in the correct slot or not, to produce the final score for each object. Correctness has the highest weight, but smoother, steadier approaches yield additional credit. Thus, the scoring emphasizes both precision and control, qualities critical to motor rehabilitation.

Table 6.1: Summary of hand-tracking metrics used in *Stock Shift*.

Metric	Definition	Unit	Window / Threshold
Average speed	Total distance / total time	m/s	Entire grab duration
Maximum speed	Peak instantaneous velocity	m/s	Entire grab duration
Tremor	RMS deviation of hand positions at low speed	m	Last 1 s, $v < 0.1$ m/s
Approach speed	Avg. velocity before release	m/s	Last 0.25 s before release

6.6.3.3 Difficulty Adaptation

As with the previous minigames, the difficulty scales across five levels. In *Stock Shift*, difficulty is adjusted along three dimensions:

1. **Number of items:** starts at 2 items and can increase up to 6 items per level.
2. **Color variety:** the number of distinct colors ranges from 2 (easy) to 4 (hard).
3. **Shelf height:** slots can appear at three difficulty tiers: low (easiest), medium, or high shelves (most demanding).

Difficulty adaptation is calculated from the player's normalized performance in the previous level. Based on the score, the algorithm determines the appropriate number of items, the range of colors, and the shelf tier. High performance increases variety and shelf height, while lower performance reduces them. This ensures that the challenge grows gradually but remains aligned with the player's abilities.

6.6.3.4 Level Flow

The structure mirrors the other minigames: the player completes five levels, with two NPC requests per level replaced here by two sets of stock items to place. Although all players complete the same number of levels, their individual scores differ depending on the complexity of items, color variety, and shelf positioning encountered during their run.

6.6.3.5 Accessibility Features

Several accessibility measures are integrated into this minigame to support ABI players.

Firstly object physics were adjusted, also here, to reduce rotational forces, preventing rounded items from rolling or spinning excessively. This stabilizes manipulation and reduces fine-motor strain.

Secondly, the invisible barrier introduced in the second minigame is also active here. If an item falls below the bottom shelf level, it is automatically teleported back to its spawn position, avoiding situations where objects accumulate on the floor and become difficult to retrieve.

Finally, to further facilitate precise placement, a gaze-assisted slot aid is enabled. A head-gaze ray is continuously cast from the player's view direction toward the shelves, when a slot is looked at, it subtly "opens" (a short scaling/offset animation with a soft highlight) to increase visual salience and slightly enlarge the placement affordance. The activation requires a minimal dwell (e.g., 200–300 ms) and a valid angle/distance window to prevent accidental triggers during normal scanning. When gaze shifts away or the item is released, the slot smoothly returns to its default size and color state. This mechanism complements hand tracking by providing a low-effort visual guide that makes the intended target easier to identify and reach, improving accuracy without increasing cognitive or motor load.

6.6.4 End Game Scene

At the conclusion of each minigame, the system transitions to an end-of-game scene designed to provide feedback to the player. This scene presents a summary panel displaying the player's chosen name, the score achieved in the current session, and their highest score to date.



Figure 6.13: End of game scene example.

6.7 Persistent Data and Save Mechanism

To support long-term rehabilitation and provide continuity across sessions, the platform implements a structured load/save system. At the beginning of the game, the player is prompted to enter a name or nickname, which initializes a persistent player profile. This profile is stored locally in the Meta Quest 3's `persistentDataPath` directory as a JSON file, ensuring data remains intact between sessions.

6.7.1 Persistent Data Structure

The central data container is the `GameData` object, which maintains global information across the application. It contains:

- **List of players:** All players who have used the system are stored in a list, allowing multiple individuals to share the same application while keeping separate progress records.
- **App usage metadata:** For example, the number of times the application has been launched.
- **Active player:** A reference to the currently logged-in player, simplifying access to relevant statistics during gameplay.

Each player is represented by a `PlayerRecord`, which contains identifying information (player name) and cumulative performance indicators such as high scores and games played. Player records also store detailed lists of game-specific sessions, enabling fine-grained analysis of rehabilitation progress.

6.7.2 Stored Statistics

The data structure captures information at multiple levels, ranging from global performance summaries to per-session details. For each rehabilitation domain, the following statistics are recorded:

- **Customer Care:** Capture interaction metrics, including correct and incorrect responses, total questions asked, average response accuracy, time per question, and extremes of response time (best/worst).
- **Memory Aisle:** Store metrics such as overall score, average score per level, number of faults, hints used, and total items successfully recalled or delivered. This enables the monitoring of memory performance and cognitive accuracy over time.
- **Stock Shift:** Extend beyond success/failure by measuring motor quality indicators such as average hand speed, maximum speed, tremor levels, and approach speed during object placement. These parameters provide a relevant picture of motor control and stability.

6.7.3 Clinical Relevance

This persistent save mechanism ensures that every session contributes to a longitudinal dataset. Over time, therapists and patients can observe improvements or identify difficulties in specific domains, reinforcing motivation and guiding individualized treatment. Furthermore, storing results in a structured JSON format makes the data portable and analyzable outside the platform, should it be required for clinical reporting.

6.7.4 Data Privacy and Simplicity

While persistence is essential, the system was designed with minimalism in mind. No sensitive personal data is collected or transmitted; the JSON file is stored locally and contains only the information necessary for gameplay and rehabilitation progress. This ensures compliance with privacy considerations while keeping the mechanism lightweight and transparent.

Chapter 7

Usability Assessment

7.1 Overview

To assess the usability, a structured evaluation was conducted with health professionals after game-play sessions. The goal of this evaluation was to collect both quantitative and qualitative feedback regarding accessibility, engagement, and the overall rehabilitation potential of the system.

7.1.1 Procedure

The evaluation process relied on a post-game questionnaire (Appendix C) delivered through the *Inquéritos UP* platform. This institutional tool ensures that all collected data is securely stored on University of Porto servers.

The study received ethical approval from the Ethics Committee of the Faculty of Engineering of the University of Porto (PARECER N° 24 /CE FEUP/2025). All procedures were carried out in accordance with the ethical principles of the Helsinki Declaration and its later revision. The data collection process ensured privacy, confidentiality and security.

Due to time constraints and limited opportunities for patient recruitment, the evaluation of the platform could not be conducted directly with individuals diagnosed with ABI. As an alternative, the study was conducted with health professionals and a UX designer, who offered feedback on the system and its possible use in rehabilitation.

Prior to participation, each participant was presented with an informed consent (Appendix B) form that outlined the objectives of the study, the nature of their involvement, and the guarantees of confidentiality and voluntary participation.

7.2 Measures

To evaluate usability and user experience, several self-report questionnaires were used. It was structured to capture both subjective impressions and standardized usability scores, combining open-ended qualitative feedback with validated quantitative instruments.

7.2.1 Open-Ended Questions

The questionnaire began with 33 open-ended questions aimed at gathering qualitative insights about the participants' experience. These questions addressed a wide range of aspects, including:

- General impressions, likes, and dislikes about the game.
- Comfort when using the Meta Quest 3 headset.
- Perceived ease of use and intuitiveness of the interactions.
- Opinions on personalization and accessibility features.
- Perceptions of social interaction and attention demands.
- Suggestions for improvements, including what participants would change.

7.2.2 System Usability Scale (SUS)

The System Usability Scale (SUS) [49] is one of the most widely adopted tools for assessing the usability of interactive systems. It consists of ten statements rated on a five-point scale, alternating between positive and negative phrasing to minimize bias. Scores range from 1 (Strongly disagree) to 5 (Strongly agree). After scoring, the responses are converted into a single composite score ranging from 0 to 100, where higher values reflect better perceived usability.

7.2.3 Game Experience Questionnaire (GEQ)

The Game Experience Questionnaire (GEQ) [48] is a validated instrument specifically designed to capture players' subjective experiences during gameplay. Uses a five-point scale ranging from 0 (*not at all*) to 4 (*extremely*). It focuses on several psychological dimensions, including immersion, competence, flow, affect, and challenge.

7.2.4 User Experience Questionnaire (USEQ)

The User Experience Questionnaire (USEQ) [50] is a short six-item tool developed to evaluate interactive applications and games. Despite its brevity, it captures both pragmatic and hedonic qualities of the user experience. Pragmatic aspects include clarity, ease of use, and efficiency, while hedonic aspects capture enjoyment and overall satisfaction. Each item is rated on a five-point scale, ranging from 1 (*strongly disagree*) to 5 (*strongly agree*), and the resulting score provides a concise indicator of the perceived quality of the interaction.

7.2.5 Socio-Demographic Data

Finally, the questionnaire collected basic socio-demographic information, including, age and gender.

7.3 Participants

Two health professionals (2 females) participated in the study (one neuropsychologist and one physiotherapist), with ages ranging between 28 and 40 years old, who reported prior experience with video games, and one UX professional designer.

7.4 Results

7.4.1 SUS

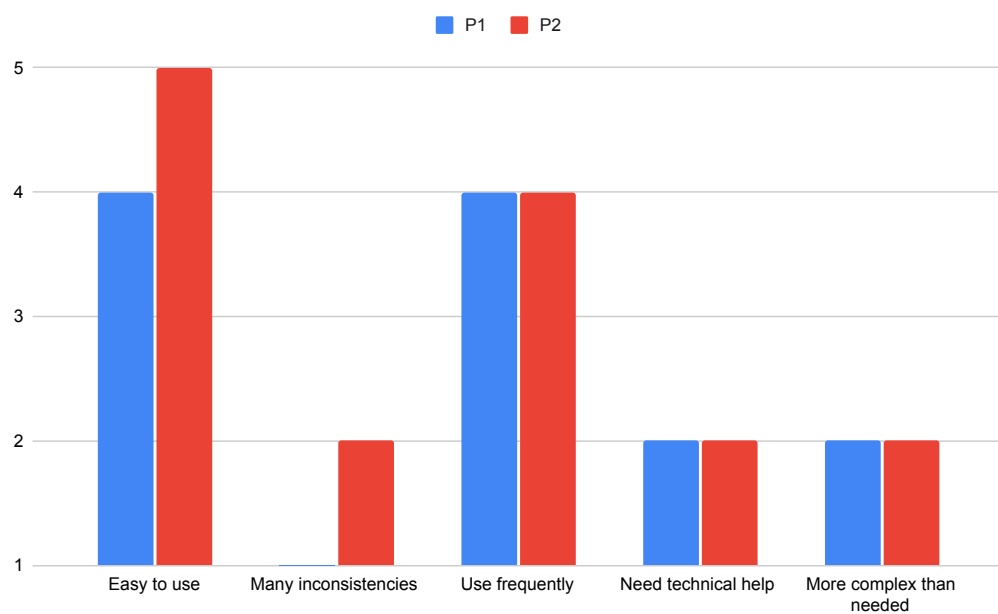


Figure 7.1: SUS responses from the two participants.

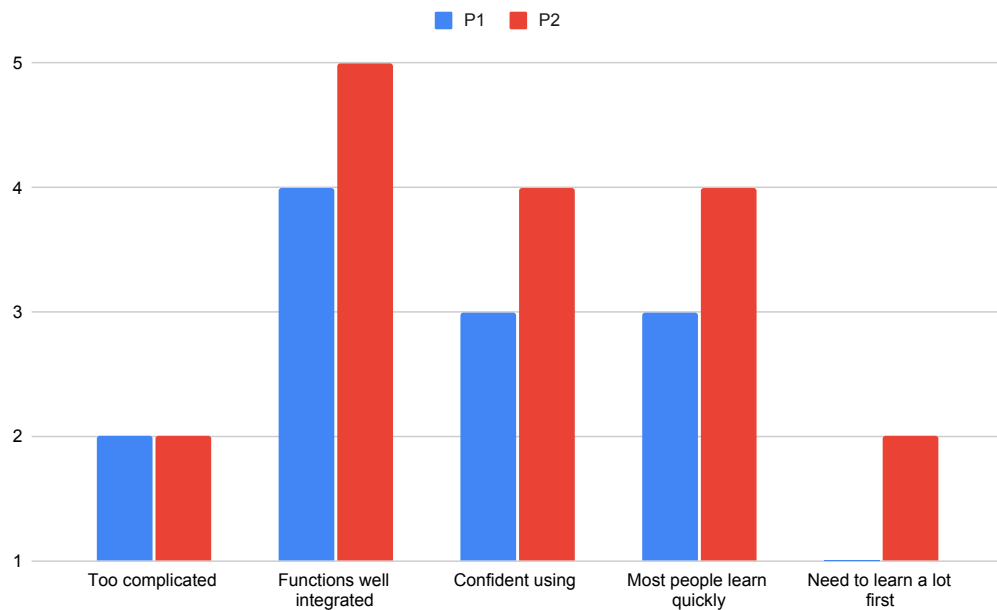


Figure 7.2: SUS responses from the two participants.

Overall, the results indicate that both participants perceived the system as generally usable. On positive items such as “Easy to use,” “Use frequently,” and “Functions well integrated,” the scores were consistently high, ranging from 4 to 5. This suggests that participants found the platform straightforward. Confidence in using the system was also rated positively, with scores of 3 and 4, reflecting that the controls and interactions were accessible even to non-technical users.

Alternatively, negative items such as “Need technical help,” “Too complicated,” and “More complex than needed” received low scores (2 from both participants), further reinforcing the perception that the system is not unnecessarily difficult to operate. Similarly, “Many inconsistencies” was rated low (1 and 2), indicating that participants found the interface consistent and reliable. The lowest ratings were observed for “Need to learn a lot first” (1 and 2), suggesting that minimal prior training is required to start interacting with the application.

7.4.2 GEQ

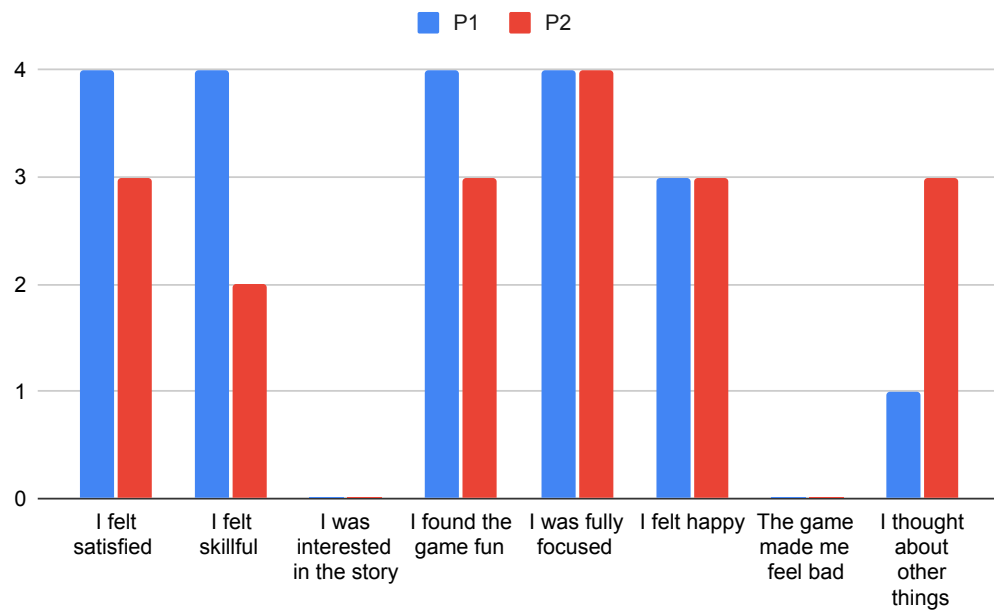


Figure 7.3: GEQ responses from the two participants.

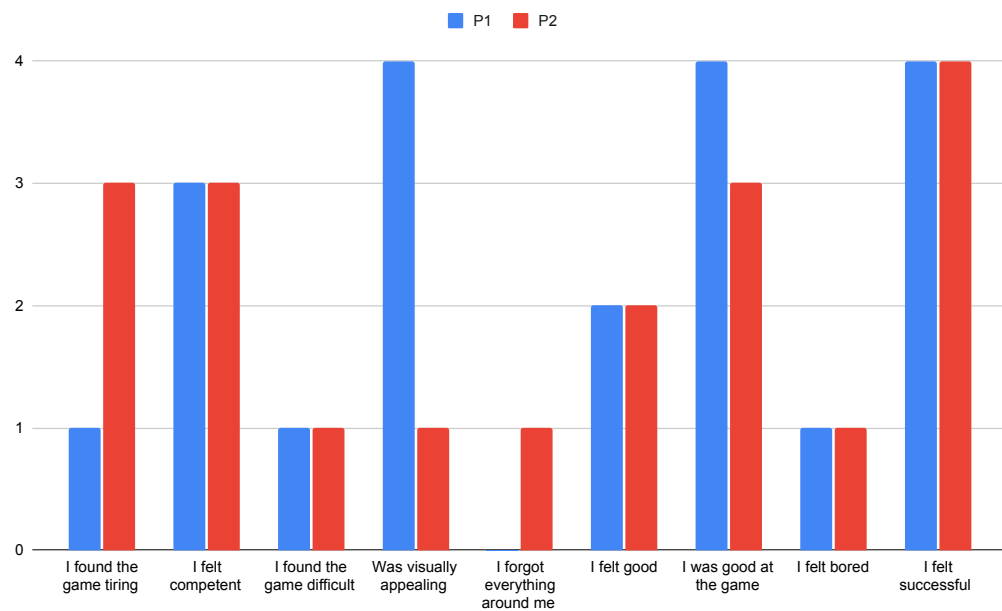


Figure 7.4: GEQ responses from the two participants.

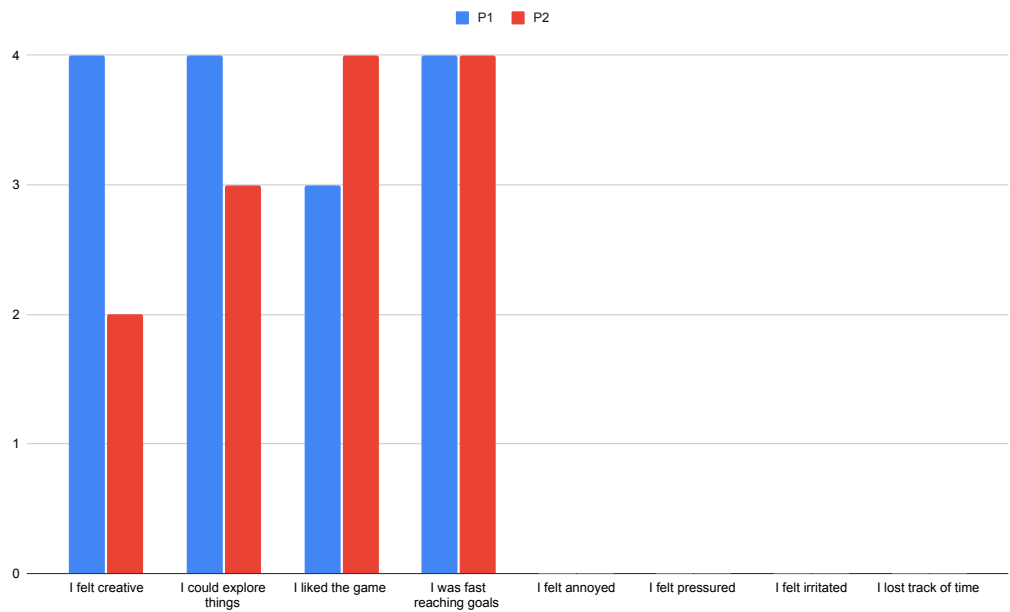


Figure 7.5: GEQ responses from the two participants.

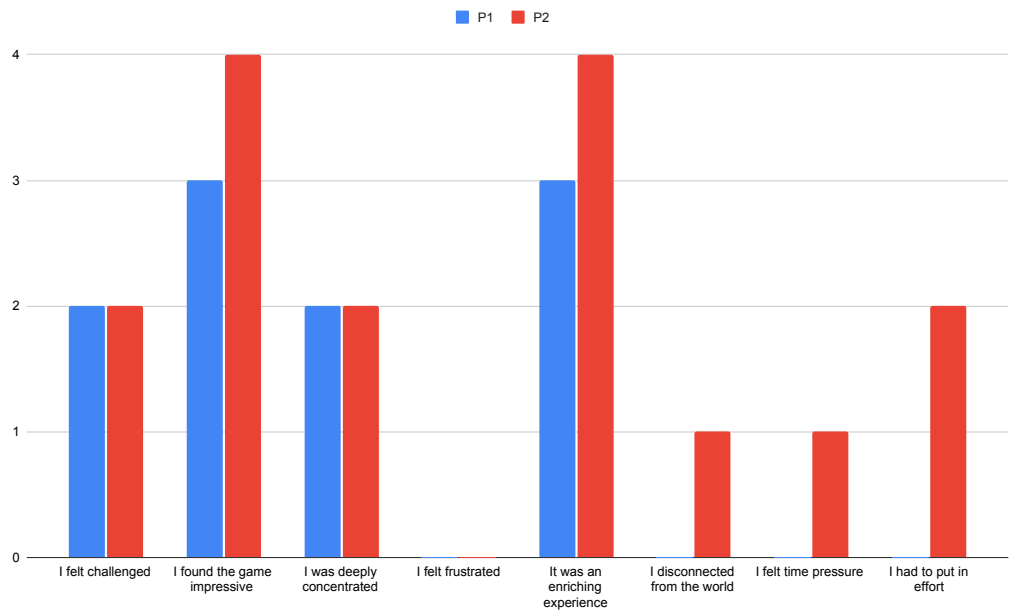


Figure 7.6: GEQ responses from the two participants.

Results indicate that both participants reported predominantly positive experiences. High scores were observed for dimensions such as *satisfaction*, *fun*, and *happiness*, suggesting that the game was enjoyable and engaging. Similarly, both participants reported being *fully focused* and *deeply*

concentrated, which aligns with the immersive qualities of the AR-based minigames. These findings suggest that the platform successfully maintained players' attention and involvement during the session.

Low scores were reported for negative affect dimensions such as *frustration* and *feeling bad*, indicating that the experience was not perceived as discouraging or overly stressful. Time pressure was also rated as minimal, which is consistent with the rehabilitation-oriented design that emphasizes accessibility over speed.

Interestingly, some divergence was observed between the two participants. For example, one participant reported higher feelings of challenge and effort, while the other indicated a smoother experience with less perceived difficulty. This discrepancy may reflect differences in familiarity with interactive technologies or personal expectations. Nonetheless, both participants consistently highlighted the *impressiveness* and *enriching nature* of the experience.

7.4.3 USEQ

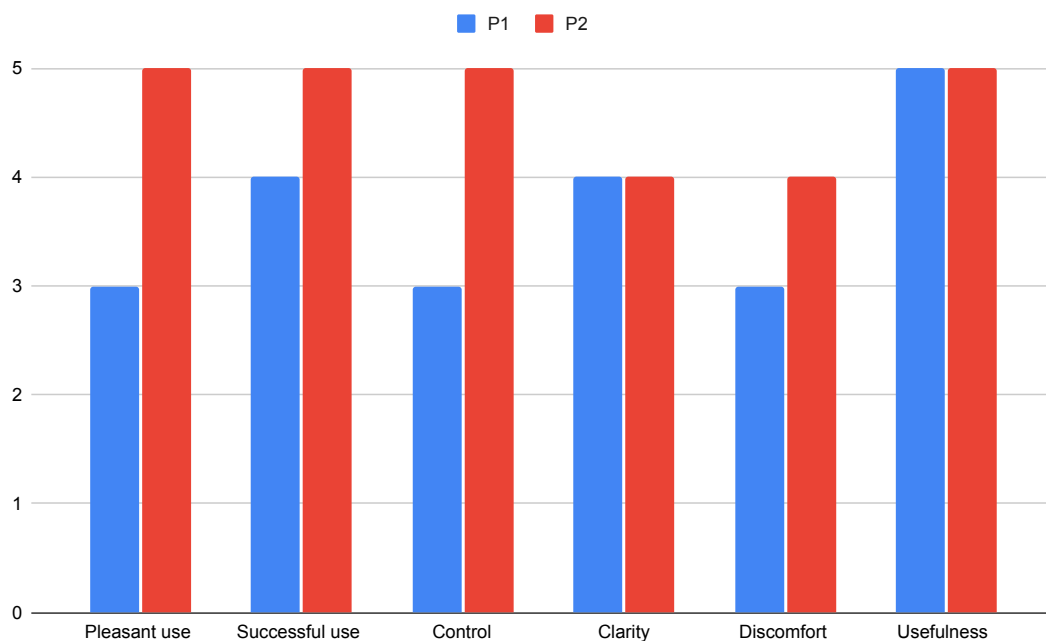


Figure 7.7: USEQ responses from the two participants.

Both participants reported positive experiences across all items. Scores ranged from 3 to 5, with particularly strong ratings in *pleasant use* and *usefulness*, where both participants agreed that the system provided value and was enjoyable to interact with. *Clarity* and *successful use* were also rated highly, suggesting that the interface and instructions were perceived as straightforward and easy to follow.

One participant reported slightly lower control, indicating that while the system was generally manageable, improvements to interaction precision could further enhance usability. For *discomfort*, both participants rated values above the neutral midpoint, but not at the maximum, highlighting that while the headset and interaction modalities were acceptable, there may still be room for refinements to ensure long-term comfort during rehabilitation sessions.

Overall, the USEQ results indicate that the platform achieved a **high level of usability and acceptability**, with only minor areas for potential improvement in control responsiveness and ergonomic comfort. This positive evaluation aligns with the objectives of developing a rehabilitation tool that is not only functionally effective but also engaging and user-friendly.

7.4.4 Open-Ended Questionnaire Analysis

On the positive side, participants consistently emphasized the *ease of use*, *intuitive controls*, and *accuracy of interaction*. These qualities are critical for rehabilitation contexts, where accessibility and minimal learning effort are essential. Participant 1 also praised the dynamic and varied contexts of the game, reinforcing the importance of ecological validity and realism in serious games.

However, several areas for improvement were also noted. Participant 2 reported experiencing mental fatigue after gameplay, suggesting that while tasks are accessible, they may impose a significant cognitive load during extended sessions. Audio design was also highlighted as a weakness, with one participant disliking the background music, pointing to the need for greater personalization of audio settings. In terms of future iterations, Participant 1 suggested expanding the range of features, while Participant 2 did not identify specific improvements.

Importantly, neither participant reported technical difficulties, indicating that the platform is stable and reliable under test conditions. Both expressed willingness to play again, underscoring the perceived value and engagement of the system despite some shortcomings.

Overall, the open-ended analysis suggests that the platform successfully addresses usability and ecological relevance but must also consider potential cognitive overload, audio customization, and opportunities for feature expansion in future iterations. These insights align with the structured questionnaire results, reinforcing the value of combining quantitative and qualitative measures in usability studies.

7.4.5 UX Designer Feedback

In addition to the questionnaires, the prototype was also evaluated by a visual designer to gather professional insights regarding interface clarity, visual consistency, and overall user experience. This complementary evaluation aimed to identify aspects that might not be fully captured by questionnaires, particularly those related to visual communication and aesthetic coherence.

The feedback highlighted (Figure 7.8) two major areas for improvement. First, the need for consistent use of language across the application was identified, as the coexistence of English (Minigame Names) and Portuguese elements could create confusion and reduce the perceived credibility of the platform.

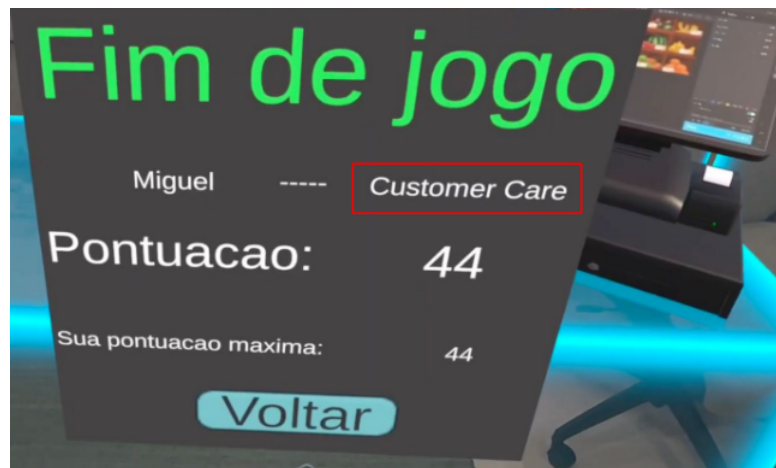


Figure 7.8: Designer feedback about consistency in language

Second, the designer pointed out the limited accessibility of pause and exit functions (Figure 7.9), which were only available at the end of each level. It was suggested that these options should be permanently accessible during gameplay, allowing players to pause or exit at any time. This change would enhance user autonomy and align the interface with standard practices in interactive applications, without compromising the immersive experience.



Figure 7.9: Designer feedback about accessibility of pause and exit functions.

Chapter 8

Conclusions

8.1 Contributions

The design and implementation of *NeuroShop* demonstrated the feasibility of embedding rehabilitation tasks within a familiar narrative setting that merges psychosocial interaction, memory challenges, and motor coordination. The co-design process ensured that principles of accessibility and adaptability were incorporated into the platform, resulting in a structured environment where tasks can be monitored, adjusted, and scaled according to patient needs. Feedback from healthcare professionals validated the conceptual soundness of the approach, while also providing concrete suggestions for future refinements.

8.1.1 Addressing the Research Questions

The central research question guiding this dissertation was: *How effective are AR-based serious games in promoting social, cognitive, and motor rehabilitation?* This work contributes to answering this question by delivering and evaluating an AR-based rehabilitation game that simultaneously targets all three domains in an integrated manner. Although clinical testing with patients was not feasible within the available timeframe, preliminary evaluation with healthcare professionals indicated that the proposed system is conceptually robust, safe, and holds potential for transfer to real rehabilitation contexts.

The sub-questions explored whether AR could support psychosocial interaction training, foster cognitive skills such as memory and attention, and promote motor coordination in ecological settings. *NeuroShop* responded to these questions through three complementary minigames: *Customer Care*, which emphasizes communication and social interaction, *Memory Aisle*, designed to challenge memory and attention processes, and *Stock Shift*, which engages motor coordination and fine motor control. Together, these modules illustrate how AR-based serious games can create ecologically valid rehabilitation scenarios that move beyond the fragmented approaches of traditional therapy and provide a more holistic experience.

8.1.2 Final Remarks

This dissertation advances the understanding of augmented reality in rehabilitation by demonstrating that cognitive, motor, and psychosocial domains can be addressed within a single integrated platform. The implementation on standalone hardware, specifically the Meta Quest 3, illustrates that multidimensional rehabilitation experiences are technically feasible without compromising accessibility or performance. Features such as gaze-based interaction, gesture recognition, and adaptive difficulty highlight how AR can be tailored to the diverse needs of patients while ensuring engagement and clinical relevance.

In sum, this work bridges a critical gap in the literature by presenting the first AR-based rehabilitation game explicitly designed to target psychosocial, cognitive, and motor domains simultaneously. It shows that multidimensional rehabilitation can be delivered in an engaging and ecologically valid manner, informed by systematic evidence and supported through a co-design process. Although further studies with patients are required to validate its therapeutic effectiveness, the prototype lays a solid foundation for future clinical trials and underlines the potential of AR-based serious games to reshape rehabilitation practices.

8.2 Future Work

Although this dissertation demonstrates the feasibility of an AR-based serious game for multidimensional rehabilitation, several aspects remain open for further development and refinement. First, the usability assessment highlighted that the current evaluation relied on a small sample size, which restricts the generalizability of the findings. Future studies should involve larger and more diverse participant groups, including patients with different types of ABI, to enable a more reliable assessment of therapeutic outcomes and long-term engagement.

From a technical perspective, one of the most relevant limitations concerns the management of stored statistics. At present, gameplay data and rehabilitation metrics are saved directly to files and must be accessed outside of the platform. This restricts both usability and clinical applicability, as healthcare professionals cannot easily visualize or analyze patient performance through the system itself. Future iterations should integrate a dedicated interface for accessing and managing these statistics.

Another area for improvement relates to feedback mechanisms. The current design deliberately restricted visual feedback in order to avoid overstimulating patients during rehabilitation sessions. While this decision prioritized safety and accessibility, future work could explore more flexible approaches to feedback, offering therapists the ability to configure the intensity and modalities of feedback according to individual patient needs.

Overall, these future directions aim to transform the current prototype into a more robust and clinically useful tool, capable of complementing traditional rehabilitation while providing accessible, engaging, and multidimensional support for individuals recovering from ABI.

8.3 Scientific Divulcation

The work developed in this dissertation was also prepared for scientific dissemination through submissions to academic events. Although the projects were not presented in person or admitted for publication, these initiatives reflect the effort to communicate the research to the scientific community and to subject it to peer review processes. Preparing these submissions contributed to structuring the results in a format suitable for international dissemination and provided valuable experience in positioning the work within the broader research field.

8.3.1 Encontro de Investigação Jovem da U. Porto (IJUP)

An abstract derived from this dissertation was submitted to the *Encontro de Investigação Jovem da Universidade do Porto* (IJUP). The paper summarized the systematic review and early stages of development. Although the submission was accepted, it was not possible to be present at the event, and therefore the work was not showcased during the conference. Nevertheless, preparing the manuscript ensured that the research findings were articulated in a concise and accessible format for a broad academic audience, and that they addressed relevant themes with sufficient quality to merit acceptance.

8.3.2 IEEE Conference on Games (CoG)

A more extensive version of the work, focusing on the systematic review of augmented reality in rehabilitation, was submitted to the *IEEE Conference on Games (CoG)*. The paper presented a structured review of serious games for motor, cognitive, and psychosocial rehabilitation in patients with ABI. Despite not being accepted for presentation, the submission process provided important feedback, integrated in the work, and helped to refine the articulation of the research contribution. It also demonstrated the relevance of the topic within the international community working at the intersection of games and health.

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Appendix A

Game Design Document

AR Supermarket GDD

An Augmented Reality Game for ABI Patients

Miguel Teixeira

1 Overview

This document presents the Game Design Document (GDD) for *AR Supermarket*, a serious augmented reality (AR) game designed for the Oculus Quest 3. The game focuses on cognitive, social, and physical rehabilitation for individuals with Acquired Brain Injury (ABI).

The experience places the player in the consistent role of a supermarket employee, where they interact with customers and complete work-related tasks. It is intentionally scoped for a niche market, specifically ABI patients in rehabilitation, with the goal of increasing accessibility and immersion through physical interaction and contextual relevance.

2 Target Audience

The primary audience includes individuals recovering from ABI who may face challenges with social interaction, attention, memory, and motor coordination. The game is designed to be engaging yet safe, with intuitive controls, real-world anchoring, and therapist-driven progression monitoring.

3 Platform and Technology

The game is built using Unity and developed for the Oculus Quest 3, utilizing AR passthrough and scene understanding to create a believable mixed-reality workspace. The Meta Presence Platform and ARFoundation toolkit are used to detect hand gestures, recognize space, and enhance physical interaction with virtual elements.

4 Narrative and Setting

The player assumes the role of a supermarket employee working at a virtual tabletop setup that includes shelves, a checkout area, and a stockroom. Customers appear virtually and interact using voice and animations, creating continuity between all mini-games. The role-playing approach grounds the rehabilitation exercises in a familiar, goal-oriented environment.

5 Customer Care: Social Interaction Training

This mini-game emphasizes social reasoning and emotional regulation. Customers arrive with complaints (e.g., wrong item, delay in service, confusion about pricing). The player is given a set of three possible verbal responses, with one being the most professional and empathetic.

- Fully voiced and animated interactions simulate realistic conversations.
- Feedback is given immediately via customer satisfaction meters and score indicators.
- As the player progresses, the number and complexity of interactions increase.

6 Memory aisle: Cognitive Challenge — Item Retrieval

This mini-game targets attention, memory, and executive functioning. A customer presents a shopping list of 1–6 items, which the player must recall and collect from shelves around them.

- Item selection is performed using hand gestures and spatial awareness.
- Tasks may involve categories (e.g., “a dairy product”) or inferred descriptions (e.g., “something cold”).
- Difficulty increases with more items, reduced memorization time, or shelf reorganization.

7 Stock Shift: Motor Coordination — Shelf Restocking (Optional)

This game may be included in the final version and focuses on physical precision and bilateral coordination. The player receives a simulated delivery and must grab and restock shelves based on type, color coding, or voice instructions.

- Items vary in shape, requiring diverse hand poses and motions.
- Performance is measured by precision, motion smoothness, and correct positioning of the items.
- Encourages bilateral hand use by alternating shelf sides and tasks.

8 Game Mechanics and Interaction

All gameplay relies on gaze and hand tracking:

- Gaze targets are used for highlighting objects or activating dialogue.
- Gesture-based controls allow picking up, selecting, or moving items.
- Passthrough mode keeps players oriented in the real world.

9 Progression and Feedback

The difficulty of tasks scales based on player performance:

- An adaptive algorithm monitors success and adjusts challenges.
- Progress is saved locally; each session updates the player's profile.
- Visual and audio feedback are immediate and easy to interpret.

10 Art and Audio Style

The game's visual and audio styles are designed to avoid overstimulation:

- Semi-realistic visuals with soft lighting and round shapes.
- Muted color palettes with occasional highlights for important objects.
- Clean voiceovers, ambient supermarket sounds, and soft cues for errors.

11 Why Augmented Reality?

AR is chosen over full VR for therapeutic and safety reasons:

- Players remain anchored in their real environments.
- Tasks simulate daily activities, reinforcing real-world skills.
- AR passthrough enhances comfort and reduces cognitive overload.

12 Accessibility and Safety

- Text-to-speech and visual cues are included for sensory assistance.
- Spatial boundaries are respected using scene data and passthrough detection.
- Tasks are designed for seated play to focus on comfort.

13 Evaluation and Metrics

Detailed gameplay metrics are logged:

- Success rate, error patterns, response time, and motor movement are tracked.
- Data can be exported for therapist analysis.

Appendix B

Consentimento informato

CONSENTIMENTO INFORMADO, LIVRE E ESCLARECIDO PARA PARTICIPAÇÃO EM INVESTIGAÇÃO

de acordo com a Declaração de Helsínquia¹ e a Convenção de Oviedo²

Por favor, leia atentamente as informações a seguir. Caso tenha dúvidas ou precise de mais esclarecimentos, não hesite em contactar a equipa de investigação. Se concordar em participar, por favor assine este documento.

Título do Estudo: Desenvolvimento de um jogo sério baseado em Realidade Aumentada para a reabilitação psicossocial, cognitiva e motora em indivíduos com Lesão Cerebral Adquirida (LCA).

Enquadramento do Estudo: A LCA afeta milhões de pessoas em todo o mundo, resultando em dificuldades cognitivas, motoras e sociais que exigem intervenções de reabilitação personalizadas. Os métodos tradicionais de reabilitação, apesar de serem eficazes e benéficos, muitas vezes não abrangem todos esses domínios em simultâneo. Este projeto propõe desenvolver um jogo sério baseado em Realidade Aumentada (RA), que proporcionará uma abordagem integrada e acessível para a reabilitação.

Explicação do Estudo: O estudo, realizado por Miguel Teixeira, no âmbito da dissertação de mestrado em Engenharia Informática na Faculdade de Engenharia da Universidade do Porto (FEUP), sob a orientação de Eliana Silva e Luís Paulo Reis, conduzido pelo **Laboratório de Inteligência Artificial e Ciência de Computadores (LIACC)**, visa criar uma solução inovadora que combine reabilitação cognitiva, social e motora num único ambiente, facilitado por Realidade Aumentada (RA). A acessibilidade deste jogo por meio de dispositivos móveis (como “smartphones” e “tablets”) é um aspeto central, garantindo que a reabilitação possa ser feita de forma prática e adaptada ao quotidiano do paciente.

O estudo terá como utilizadores-alvo pacientes adultos com LCA que necessitam de reabilitação multidimensional, integrando as áreas cognitiva, motora e social.

A participação envolve várias fases de desenvolvimento e avaliação, baseadas num processo de co-design. O objetivo é desenvolver e melhorar o protótipo de um jogo sério de reabilitação para indivíduos com LCA.

¹https://www.arsnorte.min-saude.pt/wp-content/uploads/sites/3/2018/01/Declaracao_Helsinki_2008.pdf

²<https://files.dre.pt/1s/2001/01/002a00/00140036.pdf>

O jogo será desenvolvido com a colaboração de profissionais de saúde e pacientes, assegurando que as funcionalidades sejam adequadas às necessidades específicas dos utilizadores.

A sua participação consistirá numa:

- **Avaliação da Experiência do Utilizador:** Os participantes serão convidados a utilizar o jogo desenvolvido e, posteriormente, a preencher um conjunto de questionários sobre a sua usabilidade, nível de envolvimento e perceção da utilidade enquanto ferramenta de reabilitação. Esta avaliação será fundamental para compreender a adequação da solução às necessidades dos utilizadores e para identificar possíveis melhorias futuras.

Condições e Financiamento: Será obtido Consentimento Informado, Livre e Esclarecido de todos os adultos incluídos na investigação.

Este projeto é financiado pelo Financiamento Base - UIDB/00027/2020 da Unidade de Investigação LIACC.

Não haverá custos nem remuneração pela participação neste estudo. A participação é totalmente voluntária e o participante poderá desistir em qualquer momento, sem prejuízos.

Não são antecipados riscos decorrentes da participação no presente projeto de investigação. Potenciais benefícios imediatos incluem o treino de competências motoras, cognitivas e sociais de uma forma motivadora e envolvente.

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 (adultos com LCA). 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. (*caso se verifique*)

Confidencialidade e Anonimato: Todos os dados recolhidos durante o desenvolvimento do projeto, incluindo informações pessoais e resultados dos questionários, serão tratados de forma confidencial e consoante o Regulamento Geral de Proteção de Dados (RGPD) e de acordo com a Declaração de Helsínquia e a Convenção de Oviedo.

A recolha de dados online cumprirá os requisitos de anonimato, segurança e confidencialidade de acordo com as suas especificidades. Durante a investigação, quaisquer dados recolhidos serão armazenados num computador protegido por palavra-passe e serão acessíveis somente pela equipa de investigação, de forma anónima. Os dados de identificação (e.g., dados sociodemográficos) serão armazenados em ficheiros separados dos restantes dados recolhidos e serão protegidos por palavra-passe. A recolha de medidas

de autorrelato online será realizada através da plataforma Inquéritos@UP que garante controlo do acesso e anonimização dos dados recolhidos. Nenhum dado será transmitido a terceiros. Será garantida a segurança física e eletrónica dos dados durante e após a realização do estudo.

Os dados pessoais recolhidos no estudo serão destruídos no final da sua realização. Os restantes dados serão conservados, de forma anonimizada, para fins de investigação científica, até à conclusão do projeto com data prevista para 2029.

Os participantes poderão retirar o seu consentimento em qualquer fase do projeto, sem qualquer prejuízo, e terão o direito de solicitar a eliminação dos seus dados pessoais a qualquer momento.

Garante-se 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.

Equipa de investigação:

Laboratório de Inteligência Artificial e Ciência de Computadores Faculdade de Engenharia da Universidade do Porto

Orientadora: Eliana Silva

Contacto eletrónico: elianasilva@fe.up.pt

Estudante: Miguel Teixeira

Contacto eletrónico: up202005208@fe.up.pt

Assinatura: _____

Consentimento Informado Livre e Esclarecido para participação em investigação

de acordo com a Declaração de Helsínquia e a Convenção de Oviedo

-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 (se o menor tiver discernimento deve <u>também</u> assinar em cima, se consentir) NOME: BI/CD Nº: DATA ou VALIDADE /..... /..... GRAU DE PARENTESCO OU TIPO DE REPRESENTAÇÃO: ASSINATURA

Este documento é composto de 4 páginas e feito em duplicado: uma via para a equipa de investigação outra para a pessoa que consente.

Appendix C

Post-Game Questionnaire

Questionário de Usabilidade - Jogo Sério para Reabilitação Cognitiva, Psicossocial e Motora

There are 38 questions in this survey.

Perguntas Abertas

O que gostou mais no jogo?

Please write your answer here:

O que achou mais desafiador ou difícil no jogo?

Please write your answer here:

O que devia ser diferente na próxima versão do jogo?

Please write your answer here:

Teve algum problema técnico durante a utilização do jogo?

Please write your answer here:

Não gostou de algo que preferia que não estivesse presente no jogo?

Please write your answer here:

Voltaria a jogar?, Porquê?

Please write your answer here:

Cognição e Atenção

Houve momentos no jogo em que se sentiu mentalmente cansado(a) ou sobrecarregado(a)? O que acontecia nesses momentos?

Please write your answer here:

Quais foram as tarefas em que foi mais fácil manter o foco? O que o(a) ajudou a concentrar-se?

Please write your answer here:

Interação Social

Como se sentiu ao lidar com os “clientes” durante o jogo?

Please write your answer here:

As opções de resposta pareciam algo que diria numa situação real? Porquê?

Please write your answer here:

Foi fácil ou difícil perceber o que cada cliente queria ou sentia? O que ajudou ou dificultou essa compreensão?

Please write your answer here:

Interação Física e Motora

Como foi a experiência de agarrar e posicionar objetos com as mãos no jogo?

Please write your answer here:

Houve momentos em que os seus gestos não funcionaram como esperava? O que estava a tentar fazer?

Please write your answer here:

O que facilitou ou dificultou os seus movimentos durante a experiência?

Please write your answer here:

Imersão e Realidade Aumentada

Sentiu que estava mesmo a trabalhar num supermercado? O que contribuiu para essa sensação (ou falta dela)?

Please write your answer here:

Ver o ambiente real ao mesmo tempo que os elementos virtuais causou-lhe confusão ou desconforto?

Please write your answer here:

Como acha que seria a experiência se fosse num ecrã de tablet ou telemóvel?
Seria melhor?

Please write your answer here:

Conforto Físico e Sensações

Sentiu tonturas, náuseas ou outro tipo de desconforto durante o jogo? Quando e em que situação?

Please write your answer here:

Ficou com os olhos cansados ou com dor de cabeça durante ou depois de jogar?

Please write your answer here:

A utilização da câmara passthrough (ver o mundo real através dos óculos) foi confortável ou causou dificuldades?

Please write your answer here:

Teve alguma dificuldade em perceber o espaço real à sua volta enquanto jogava?

Please write your answer here:

O que mudaria para tornar a experiência mais confortável a nível físico?

Please write your answer here:

Usabilidade e Facilidade de Utilização

Houve algo que quis fazer no jogo mas não conseguiu ou não percebeu como?

Please write your answer here:

Alguma vez se sentiu perdido(a), apressado(a) ou sem saber o que fazer? O que teria ajudado?

Please write your answer here:

Adaptação e Personalização

A dificuldade do jogo ajustava-se às suas capacidades? O que mudaria?

Please write your answer here:

Se pudesse alterar algo para o jogo se adequar melhor a si, o que seria?

Please write your answer here:

Reflexão Final

Se tivesse de descrever esta experiência a um amigo ou colega, o que diria?

Please write your answer here:

Houve algo na experiência que o(a) surpreendeu — de forma positiva ou negativa?

Please write your answer here:

Dados Pessoais

Idade

Please write your answer here:

Sexo

Please write your answer here:

Tem experiencia com jogos digitais?

Please write your answer here:

Se sim com que frequência joga?

Please write your answer here:

Tem experiência com jogos em realidade aumentada?

Please write your answer here:

Gosta de videojogos?

Please write your answer here:

Gosta de ser desafiado/a em videojogos?

Please write your answer here:

Avaliação de Usabilidade (SUS)

Para cada afirmação, assinale o grau em que concorda ou discorda. Use a seguinte escala:

1 - Discordo completamente, 2 - Discordo parcialmente, 3 - Neutro, 4 - Concordo parcialmente, 5 - Concordo completamente

Please choose the appropriate response for each item:

	1	2	3	4	5
Acho que gostaria de utilizar este produto com frequência.	☐	☐	☐	☐	☐
Considereei o produto mais complexo do que necessário.	☐	☐	☐	☐	☐
Achei o produto fácil de utilizar.	☐	☐	☐	☐	☐
Acho que necessitaria de ajuda de um técnico para conseguir utilizar este produto.	☐	☐	☐	☐	☐
Considereei que as várias funcionalidades deste produto estavam bem integradas.	☐	☐	☐	☐	☐
Achei que este produto tinha muitas inconsistências.	☐	☐	☐	☐	☐
Suponho que a maioria das pessoas aprenderia a utilizar rapidamente este produto.	☐	☐	☐	☐	☐
Considereei o produto muito complicado de utilizar.	☐	☐	☐	☐	☐
Senti-me muito confiante a utilizar este produto.	☐	☐	☐	☐	☐

	1	2	3	4	5
Tive que aprender muito antes de conseguir lidar com este produto.	☐	☐	☐	☐	☐

Avaliação da Experiência do Jogo (GEQ)

Indique como se sentiu enquanto jogava. Use a escala de 0 a 4: Nada 0 <> Um pouco 1 <> Moderadamente 2 <> Bastante 3 <> Extremamente 4

Please choose the appropriate response for each item:

	0	1	2	3	4
Senti-me satisfeito/a	☐	☐	☐	☐	☐
Senti-me habilidoso/a	☐	☐	☐	☐	☐
Estava interessado/a na história do jogo	☐	☐	☐	☐	☐
Achei o jogo divertido	☐	☐	☐	☐	☐
Estava completamente focado/a no jogo	☐	☐	☐	☐	☐
Senti-me feliz	☐	☐	☐	☐	☐
O jogo deixou-me maldisposto/a	☐	☐	☐	☐	☐
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/boa no jogo	☐	☐	☐	☐	☐

	0	1	2	3	4
Senti-me entediado/a	☐	☐	☐	☐	☐
Senti-me bem-sucedido/a	☐	☐	☐	☐	☐
Senti-me criativo/a	☐	☐	☐	☐	☐
Senti que podia explorar coisas	☐	☐	☐	☐	☐
Gostei do jogo	☐	☐	☐	☐	☐
Fui rápido/a a alcançar os objetivos do jogo	☐	☐	☐	☐	☐
Senti-me chateado/a	☐	☐	☐	☐	☐
Senti-me pressionado/a	☐	☐	☐	☐	☐
Senti-me irritado/a	☐	☐	☐	☐	☐
Perdi a noção do tempo	☐	☐	☐	☐	☐
Senti-me desafiado/a	☐	☐	☐	☐	☐
Achei o jogo impressionante	☐	☐	☐	☐	☐
Fiquei profundamente concentrado/a no jogo	☐	☐	☐	☐	☐
Senti-me frustrado/a	☐	☐	☐	☐	☐
Senti que foi uma experiência enriquecedora	☐	☐	☐	☐	☐
Desliguei-me do mundo exterior	☐	☐	☐	☐	☐

	0	1	2	3	4
Senti a pressão do tempo	☐	☐	☐	☐	☐
Tive de me esforçar bastante no jogo	☐	☐	☐	☐	☐

Avaliação da Satisfação do Utilizador (USEQ)

Por favor, para cada afirmação abaixo, selecione o número que melhor reflete a sua experiência com o sistema do jogo. Muito pouco -> Bastante

Please choose the appropriate response for each item:

	1	2	3	4	5
Foi agradável usar esta tecnologia?	☐	☐	☐	☐	☐
Conseguiu usar com sucesso esta tecnologia?	☐	☐	☐	☐	☐
Foi capaz de controlar esta tecnologia?	☐	☐	☐	☐	☐
A informação fornecida por esta tecnologia foi clara?	☐	☐	☐	☐	☐
Sentiu-se desconfortável durante o uso desta tecnologia?	☐	☐	☐	☐	☐
Considera que esta tecnologia será útil na reabilitação?	☐	☐	☐	☐	☐

Submit your survey.

Thank you for completing this survey.