DM

The Impact of Cognitive Training on Social Cognition Abilities

An exploratory study with acquired brain injury

MASTER DISSERTATION

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MASTERS IN CLINICAL HEALTH PSYCHOLOGY AND WELL-BEING

UNIVERSIDADE da MADEIRA

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"Our deepest fear is not that we are inadequate. Our deepest fear is that we are powerful beyond measure. It is our light, not our darkness, that most frightens us."

—Marianne Williamson

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Abstract

Introduction: Acquired Brain Injuries (ABI)are responsible for progressive and irreversible cognitive and behavioral deterioration, which can impair patients' lives, increasing social isolation and mood changes, low control of impulses, reduced quality of life and, sometimes, loss of work. Post-ABI neuropsychological assessment is generally focused on memory, attention, language, and executive functions. Social cognition abilities are often overlooked, but these deficits can significantly impact a patient's personal and professional life. Assessment and intervention in social cognition within the context of ABI pose several challenges, namely the fact that existing instruments are mostly paper-and-pencil and, as such, might be impossible to perform by patients with motor deficits and, also importantly, lack ecological validity. Interactive technologies represent a promising alternative to tackle traditional paper-and-pencil instrument limitations. In the present study, we have used a virtual reality social cognition test - the CogMap-Social Cognition - to examine the impact of a tablet-based cognitive training program on ABI patients' social cognition, mood, and quality of life.

Method: A single-blind experimental study with 12 ABI patients was performed. Participants were randomly assigned to the experimental (N=6) or control group (N=6). The experimental group underwent a 12-session tabled-based intervention with the *Task Generator 2.0*, and the control group performed time-matched treatment-as-usual (TAU). Both groups went through a multidomain neuropsychological assessment, which included the CogMap-SC, pre- and post-intervention.

Results: The experimental group improved significantly in all the cognitive domains assessed: memory, attention, executive functions, and social cognition, with higher levels of quality of life and a decrease in depressive symptomatology. In the control group, slight improvements were observed in attention and memory domains, along with a slight reduction in perceived quality of life and an increase in depressive symptomatology. However, there were no statistically significant differences between groups in social cognition after intervention. We have used the reliable change index to confer some robustness to our results. According to it, there were significant individual improvements in all the cognitive domains, suggesting that there was a change after the cognitive training.

Conclusions: Despite the well-known cognitive training benefits in patients who suffered an ABI, there is no solid evidence to corroborate the efficacy of this intervention, mainly due to the study's small sample size and lack of statistical power. Although the results are modest and require further investigation, our study outcomes are promising and suggest that cognitive training benefits not only memory, attention, and executive functions but can generalize to social cognition abilities.

Keywords: Social Cognition; Theory of Mind; Virtual Reality; Acquired Brain Injury; Neuropsychological Assessment; Neuropsychological Rehabilitation.

Resumo

Introdução: As Lesões Cerebrais Adquiridas (LCA) são responsáveis por défices deterioração cognitivos e comportamentais que podem afetar a vida dos pacientes, contribuindo para alterações de humor, dificuldade no controlo dos impulsos e défices motores, o que pode levar ao isolamento social, reduzida qualidade de vida percebida e até perda de trabalho. A avaliação neuropsicológica pós-LCA habitual é geralmente focada na memória, atenção, linguagem e funções executivas, sendo as capacidades de cognição social frequentemente negligenciadas, no entanto estes défices podem impactar significativamente a vida pessoal e profissional do indivíduo. A avaliação e intervenção na cognição social no contexto de LCA apresenta vários desafios, nomeadamente o facto de os instrumentos existentes serem maioritariamente em papel e lápis e, como tal, poderem ser impossíveis de realizar por pacientes com défices motores, surgindo desse modo as tecnologias interativas como uma alternativa promissora para superar as limitações dos instrumentos tradicionais. No presente estudo, utilizámos um teste de cognição social em realidade virtual - o CogMap-Cognição Social (CogMap-CS) para examinar o impacto de um programa de treino cognitivo apresentado em tablet na cognição social, humor e qualidade de vida de pacientes com LCA.

Método: Foi realizado um estudo experimental cego para os participantes (*single blind*)com 12 pacientes com Lesão Cerebral Adquirida. Os participantes foram distribuídos aleatoriamente para o grupo experimental (N=6) ou para o grupo de controlo (N=6). O grupo experimental participou numa intervenção de 12 sessões utilizando tablet com o *Task Generator 2.0*, enquanto o grupo de controlo realizou um tratamento convencional com a mesma duração. Ambos os grupos foram sujeitos a uma avaliação neuropsicológica multidimensional, que incluiu o CogMap-CS, antes e após a intervenção.

Resultados: O grupo experimental melhorou significativamente em todos os domínios cognitivos avaliados: memória, atenção, funções executivas e cognição social, apresentando níveis mais elevados percebidos de qualidade de vida e uma diminuição na sintomatologia depressiva. No grupo de controlo, foram observadas ligeiras melhorias nos domínios de atenção e memória e uma ligeira diminuição na qualidade de vida percebida e um aumento na sintomatologia depressiva. No entanto, não houveram diferenças estatisticamente significativas entre os grupos no domínio da cognição social após a intervenção. Adicionalmente, utilizou-se o *Reliable Change Index* para conferir maior robustez aos nossos resultados. De acordo com este, houveram melhorias individuais significativas em todos os domínios cognitivos, sugerindo que existiu uma mudança devida ao treino cognitivo.

Conclusões: Apesar dos já conhecidos benefícios do treino cognitivo em pacientes que sofreram uma lesão cerebral adquirida, não foram conseguidas evidências sólidas para corroborar a eficácia desta intervenção, principalmente devido ao reduzido tamanho da amostra e à falta de poder estatístico. Embora os resultados sejam modestos e possam requerer investigação adicional, as conclusões do nosso estudo são promissoras e sugerem que os benefícios do treino cognitivo não se limitam apenas à memória, atenção e funções executivas, mas também podem generalizar-se para as habilidades de cognição social.

Palavras-chave: Cognição Social; Teoria da Mente; Realidade Virtual; Lesão Cerebral Adquirida; Avaliação Neuropsicológica; Reabilitação Neuropsicológica

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Acronyms List

ABI – Acquired Brain Injury

BDI-II– Beck-II Depression Inventory

BT – Brain Tumor

CogMap-CS – CogMap-Social Cognition

DST - Digit Symbol Test

ESCoT - Edinburgh Social Cognition Test

FAB - Frontal Assessment Battery

CRT – Cognitive rehabilitation training

MoCA - Montreal Cognitive Assessment

MW - Mann-Whitney test

QoL – Quality of Life

RCI – Reliable Change Index

SC – Social Cognition

SS - Symbol Search subtest

SUS - System Usability Scale

TAU – Treatment as Usual

TBI – Traumatic Brain Injury

TG – *Task Generator*

TMT - Trail Making Test

ToM – Theory of Mind

TP - Toulouse-Piéron Cancellation Test

VPA - Verbal Paired Associates

VR – Virtual Reality

VRH – Virtual Reality Headset

W - Wilcoxon test

WHOQOL-BREF - World Health Organization Quality of Life Assessment-BREF

1. Introduction

1.1. Acquired Brain Injury

Every year, thousands of persons suffer from Acquired Brain Injury (ABI), the leading cause of death under 45 years and a major disability contributor (Dewan et al., 2018; Grafman & Salazar, 2015). Traumatic brain injury (TBI) incidence is approximately 500 per 100,000 in the US and Europe, with hospitalization rates varying from 100 to 330 per 100,000 (CTBI, 2023). Road traffic accidents are a significant cause, while falls are prevalent in older adults. Moderate and severe TBIs increase Alzheimer's disease risk by 2.3 and 4.5 times, respectively (CTBI, 2023). Severe TBI incurs a lifetime cost, imposing a global economic burden annually. Although 90% of TBIs are mild, over half of these patients don't fully recover within six months (Maas et al., 2022). In Europe, TBI costs are estimated at €33 billion, excluding non-hospitalized cases (León-Carrión & Machuca-Murga, 2001).

Additionally, up to one-third of milder TBI patients, not permanently hospitalized, may experience lifelong disabling issues, emphasizing the long-term consequences. Globally, TBI contributes significantly to health loss and disability, imposing a considerable socioeconomic burden. Addressing TBI's multifaceted challenges is crucial for mitigating its impact on individual lives and societal well-being (CTBI, 2023).

ABI can be defined as any damage to the brain after birth not caused by congenital or degenerative diseases (National Brain Injury Information Center, 2020). This definition includes open or closed traumatic head injuries (e.g., resulting from motor vehicle accidents, falls, sporting accidents) and non-traumatic causes, such as vascular accidents (e.g., stroke), infection (e.g., encephalitis), hypoxic injuries (e.g., near drowning), or toxic or metabolic insult (e.g., carbon monoxide) (Wallis et al., 2022). TBI is also recognized as a global silent epidemic and constitutes a public health concern (Dawodu, 2021). Both TBIs and brain tumors are the most frequent ABI causes found in neurosurgery services.

TBI results from direct or indirect mechanical force exerted upon the cranium, constituting a significant global public health concern and standing as one of the most prevalent trauma types encountered in emergency healthcare services (Raposo & Magalhães, 2023). They primarily originate from road accidents and falls. While historically faced high mortality rates, advancements in acute trauma care have reduced mortality significantly. However, better survival rates have led to increased morbidity, leaving patients with multiple impairments. TBI cases are typically accidental and adversely affect mental, cognitive, behavioral, and bodily functions.

TBI patients often experience short-term or persistent motor and cognitive deficits, necessitating round-the-clock care, primarily provided by a family member serving as the primary caregiver (Qadeer et al., 2017). While historically faced high mortality rates, advancements in acute trauma care have reduced mortality significantly. However, better survival rates have led to increased morbidity, leaving patients with multiple impairments. TBI cases are typically accidental and adversely affect mental, cognitive, behavioral, and body functions. TBI patients often experience short-term or persistent motor and cognitive deficits, necessitating round-the-clock care, primarily provided by a family member serving as the primary caregiver (Qadeer et al., 2017).

Brain tumors (BT) can be classified as primary tumors of the central nervous system or originate from metastases of malignant tumors originating in other organs. Over 25% of brain tumors are secondary, representing metastases of malignant tumors originating, for example, in the lung, breast, and skin (melanomas). In Europe, primary Central nervous system (CNS) cancer incidence ranges from 4.5 to 11.2 cases per 100,000 men and 1.6 to 8.5 per 100,000 women. High-grade glioma and brain metastasis are common in adulthood, especially among older adults. The lifetime risk for brain or spinal cord malignancy is <1%, with the highest incidences in Australia, North America, and Northern Europe and the lowest in Africa.(Crocetti et al., 2012; *Key Statistics for Brain and Spinal Cord Tumors | American Cancer Society*, n.d.). In 2020, they affected 277,000 persons; the estimated number of cases in 2040 is 403,000, between 20 and 85 years old, affecting more males than women. The numbers are also alarming when we look at European data where it affected in 2022, 44200 individuals and the prevision to 2040 is to grow to 49750 persons (European Cancer Information System (ECIS), 2023; Global Cancer Observatory (GCO), 2023). We are referring to primary tumors of the central nervous system, which can be either benign or malignant and affect various components of the brain. The most common types are gliomas, which are the most frequent primary tumors in adults, including subtypes like (a)astrocytomas and glioblastomas, (b) gliomas of the cerebellum, brainstem, and optic nerve, germ cell tumors, and medulloblastomas and (c) meningiomas, those common tumors originating in the meninges, are the most prevalent in females and after 45 years of age (ECIS, 2023; GCO, 2023).

ABI and their therapeutic interventions can elicit cognitive challenges, with approximately one in four individuals reporting difficulties in cognition and learning due to the presence of a BT or its associated treatments (De Luca et al., 2016). These cognitive challenges encompass impediments in learning, thinking, concentration, problem-solving, planning, and decision-making. Social cognition (SC), denoting the capacity to comprehend social situations and respond appropriately, can also be compromised, leading to difficulties in discerning appropriate social behaviors, humor, and the potential loss of inhibition (De Luca et al., 2016).

Memory difficulties typically involve short-term memory, impacting the acquisition of new information and the recollection of recent events or conversations (De Luca et al., 2016). The consequences of these cognitive difficulties extend to communication skills, affecting the interpretation of body language, reading, writing, understanding numbers, and verbal expression. Perception, the process of assimilating and interpreting information from the environment, may be disrupted, leading to challenges in recognizing objects, understanding their functions, judging distances, and executing movements or tasks. Specific terms associated with perception difficulties, such as agnosia (impairment in identifying objects, people, words, and sounds) and apraxia (difficulty in executing movements or tasks despite understanding), underscore the multifaceted nature of cognitive challenges. These difficulties can contribute to visual problems and other perceptual deficits, significantly impacting an individual's ability to navigate daily life (De Luca et al., 2016).

Patients with ABI frequently exhibit not only compromised cognitive functions but also disruptions in SC and Theory of Mind (ToM). These disturbances can lead to social maladjustments, impacting the lives of the patients, their families, and their social networks (Maggio et al., 2022; Njomboro, 2017). SC involves processing information from various brain regions, including the frontopolar and dorsolateral-prefrontal cortices, insula cortex, and temporal areas. Up to 40% of individuals with ABI experience SC difficulties, resulting in lower empathy, trouble interpreting irony and sarcasm, diminished social abilities, and a lack of insight into their impact on others, leading to higher rates of social isolation (Lezak et al., 2012).

Damage to neural pathways and brain regions involved in social functioning underlies deficits and challenging behaviors in socio-cognitive interactions following TBI (Denny, 2021). Frontal and temporal areas are typically compromised due to the nature of TBI and the involved mechanical forces (Arioli et al., 2018). The amygdala, crucial for processing negative stimuli, may exhibit deficits in detecting negative facial expressions observed in ABI (Adolphs, 2009; Rosenberg et al., 2014).

The amygdala is crucial for SC, particularly in processing unpredictability and saliency in social stimuli. It codes stimulus salience, contributing to emotion recognition, social behavior perception, and reward learning. It responds differently to temporally unpredictable stimuli, emphasizing its sensitivity. Amygdala lesions reduce fear and timidity, linking it to social approach behavior. Essential functions include (a) emotion recognition, (b) social behavior modulation, (c) salience processing, (d) reward learning, and (e) memory consolidation. In summary, the amygdala's role in processing socially and emotionally relevant information highlights its significance in SC, influencing responses to ambiguous situations (Adolphs, 2010).

1.2 Social Cognitive Deficits

Most ABI affects the frontotemporal region, particularly in the ventromedial and orbital areas of the frontal lobe (Stuss, 2011). Consequently, about 60-80% of ABI patients also have deficits in SC (Weddell et al., 2006). These deficits refer to the ability to perceive, interpret, and act upon social information and are, as such, critical predictors of functional outcomes, affecting the ability to create and sustain interpersonal relationships.

The most recent edition of the American Psychiatric Association's Diagnostic and Statistical Manual for Mental Disorders (DSM-5 TR) introduced social cognition as one of six core components of neurocognitive function, alongside complex attention, executive function, learning and memory, language and perceptual–motor function. Paper-and-pencil tests routinely assess these neurocognitive deficits, which are limited in accuracy, validity, sensitivity and means of interaction (American Psychiatric Association, 2022).

SC encompasses a multitude of psychological domains of varying complexities, including ToM, recognition of emotions in others, empathy, moral judgments, pragmatic communication skills, and understanding of social norms (Henry et al., 2015; Love et al., 2015; Maggio et al., 2022). Several studies have indicated the benefits of psychological interventions in SC, particularly in recognizing emotions and exhibiting appropriate social behavior (Rodríguez-Rajo et al., 2022). Inaccurate assessment of facial emotions can adversely affect social responses, impacting communication, community integration, and quality of life (QoL) (Denny, 2021). These socio-cognitive abilities are pivotal in an individual's social adaptation and participation, influencing mental health and overall well-being (Pertz et al., 2020).

The neural foundations of SC involve intricate mental operations across cortical and subcortical regions, such as the prefrontal cortex (dorsomedial, ventromedial, and orbitofrontal areas), temporal lobe, inferior parietal lobe, and amygdala, rendering it particularly susceptible to disruption in cases of ABI (Maggio et al., 2022). A disrupted neuronal connectivity between the prefrontal cortex and the limbic system in ABI patients may lead to apathy, anhedonia, and social disinterest. Also, the interconnected neural networks facilitate the processing of basic and advanced social elements (De Luca et al., 2016). Frontal lobes play a pivotal role in SC, with damage resulting in inhibitions in emotional processing and inappropriate social activity. So, damage to regions involved in visual information processing leads to deficits in facial emotion recognition, indicating global impairments in SC (Arioli et al., 2018).

The "social brain," comprising key regions, is crucial for understanding and interpreting social information (Adolphs, 2009; Frith & Frith, 2007). Consequently, damage to these areas can compromise emotional, cognitive, and communicative capacities (Bosco et al., 2018; Frith & Frith, 2003; Rodríguez-Rajo et al., 2022). The subcomponents of SC can be delineated as socio-cognitive emotional processes (e.g., emotion recognition or affective empathy) and socio-cognitive processes (e.g., cognitive empathy and ToM). These components significantly influence our social behavior and impact SC (McDonald et al., 2014). “Challenging behaviors” identified in individuals with ABI (Kelly et al., 2008), such as verbal and physical aggression, perseverative behavior, sexually inappropriate conduct, wandering, inappropriate social behavior, and lack of initiation, pose significant obstacles to community reintegration. These behaviors also impact families and caregivers, with approximately half of caregivers reporting heightened stress levels (Kelly et al., 2008).

Self-awareness of deficits is vital as a predictor of social difficulties and treatment outcomes (Ownsworth & Clare, 2006; Toglia & Kirk, 2000). Lack of understanding may lead to inappropriate behavior, hampering behavior modification and treatment-seeking (Honan et al., 2019; Wallis et al., 2022). Denny (2021) reported that ABI participants struggle to differentiate correct and incorrect responses, especially in surprise and disgust, indicating impaired socio-cognitive skills post-ABI.

In traditional assessments and interventions, cognitive functions such as attention, memory, and language have historically taken precedence, neglecting the critical domains of SC and ToM (Njomboro, 2017). Despite their significant impact on daily life, these aspects have been overlooked because, depending on the affected brain regions, a patient may perform well in cognitive assessments while exhibiting substantial impairment in SC and ToM, particularly in decision-making and moral judgment (Maggio et al., 2022). Evidence suggests correlations between compromised cognitive functions, particularly executive skills such as working memory and inhibitory control, and difficulties observed in SC (Maggio et al., 2022). These impairments give rise to specific challenges by decelerating the patient's responses in daily activities, amplifying distraction, and fostering irritability. Interventions for attention deficits encompass a spectrum of strategies, ranging from basic tasks like utilizing flashcards to enhance fundamental attention skills to more intricate endeavors involving visual and verbal tasks to improve complex attention and working memory (De Luca et al., 2016). Cognitive rehabilitation training (CRT) based on cognitive-behavioral methods, mainly targeting planning, problem-solving, and executive deficits, may enhance cognitive functions (De Luca et al., 2023).

Individuals with impaired SC may display (a) social detachment, (b) isolation, (c) egocentrism, (d) disregard for social norms and conventions, (e) accelerated cognitive decline, and (f) increased risk of mortality (Rodríguez-Rajo et al., 2022). SC deficits are also associated with more significant challenges for caregivers, leading to increased family stress. Beyond obstructive social relationships, these difficulties interfere with employment and community roles (Rodríguez-Rajo et al., 2022). Research indicates that ABI patients may exhibit (a) diminished empathy, (b) social isolation, (c) difficulty grasping sarcasm and irony, (d) limited social competence, (e) reduced talkativeness and (f) maladjusted emotional expressions that can worsen, some of the burden caregivers endure (De Luca et al., 2016). Caregivers of ABI may also encounter challenges in sustaining meaningful social connections, securing or acquiring employment, and participating in societal contributions commensurate with their aspirations (Marsh et al., 2002; Wallis et al., 2022).

Social success hinges on decoding concealed beliefs, emotions, and intentions from others, known as the ToM (Premack, 1978). Challenges in mental state comprehension and disruptions to neural underpinnings lead to adverse outcomes, such as social isolation, friendlessness, and social demotivation, that are highly related to social isolation, psychiatric disorders, and mortality that can contribute to challenges in community reintegration and rehabilitation(De Luca et al., 2016; Dodell-Feder et al., 2020; Rodríguez-Rajo et al., 2022).

1.3 Assessment and rehabilitation of acquired brain injury patients: current methods

Assessing SC within the context of ABI poses several questions concerning the existing tools and their limitations. Commonly employed tools, such as The *Reading the Mind in the Eyes Test* (RMET) (Baron-Cohen et al., 2001), *The Awareness of Social Inference Test* (TASIT) (McDonald et al., 2003), *The Faux Pas Recognition Test* (Stone et al., 1998), The *Interpersonal Reactivity Index* (IRI) (Davis, 1983), the *Movie for the Assessment of Social Cognition* (MASC) (Dziobek et al., 2006) *The Strange Stories Test* (Jollife & Baron-Cohen, 1999) and The Edinburgh Social Cognition Test (ESCoT) (Baksh, 2017), are validated for clinical use. There are inherent limitations to these traditional paper-and-pencil assessments, which necessitates an exploration of the untapped potential and advantages Virtual Reality (VR) offers. For example, the widely used RMET faces assessment challenges tied to vocabulary, intelligence dependence, and culturally biased stimuli (Dodell-Feder et al., 2020).

Cognitive rehabilitation is designed to assist individuals in restoring typical functioning or compensating for cognitive deficits after an injury to the brain (De Luca et al., 2016). The primary objective of CRT is to empower individuals with ABI to attain their optimal level of well-being, minimizing the impact of their challenges in daily life and facilitating their return to various and more suitable life contexts (De Luca et al., 2023).

Cognitive rehabilitation techniques can be categorized into two primary classifications: conventional methods involving manual exercises conducted with a therapist and computer-assisted approaches known as computerized cognitive rehabilitation. Both categories employ cognitive strategies to retrain or alleviate deficits in various cognitive domains, including attention, concentration, visual processing, language, memory, reasoning, problem-solving, and executive functions (De Luca et al., 2016).

Conventional techniques entail therapist-guided manual exercises, while computerized exercises are designed as game-like programs to train cognitive skills. Computerized cognitive rehabilitation extends to memory training, attention, problem-solving, and job simulation and utilizes multimedia and informatics resources along with specific hardware systems and software. These systems encompass ad hoc programs that reactivate compromised neuropsychological functions (De Luca et al., 2016).

CRT following TBI confers significant advantages by augmenting functional outcomes beyond the scope of natural recovery mechanisms. Notably, traditional rehabilitation modalities, including physical, occupational, and speech therapies, are more frequently employed than psychological therapy in the early post-TBI stages or during the post-acute phase following severe TBI (Andelic et al., 2021). Consequently, a considerable proportion of patients may encounter unmet rehabilitation needs in the long term. The prevalence of rehabilitation utilization was 32—4% in the first year after TBI across European countries. Despite the acknowledged benefits of rehabilitation for individuals after TBI, only 15% of patients received outpatient rehabilitation, which is notably low considering the long-term rehabilitation needs evidenced in earlier studies (Andelic et al., 2021).

CRT emerges as a prospective approach for enhancing cognitive performance, especially in older adults (Brands et al., 2019). Scientific research has illustrated the beneficial effects of cognitive training on overall cognitive function and processing speed in healthy individuals. Additionally, positive outcomes have been documented in individuals with mild cognitive impairment, including enhancements in global cognitive function, episodic memory, and working memory (Brands et al., 2019; De Luca et al., 2023). Comparative analysis revealed that computerized cognitive training led to increased intraindividual variability in processing speed tasks compared to an 8-week sham exercise and cognitive training program (Brands et al., 2019).

1.4 Virtual reality to improve social cognition assessment and rehabilitation

Virtual Reality Technology (VRT) offers significant advantages in neurorehabilitation, primarily through its capacity to train impaired functions and stimulate neuron reorganization, maximizing motor learning and neuroplasticity. Additionally, it facilitates restoring and improving functions and abilities by engaging patients in a safe, non-threatening, yet realistic Virtual Reality Environment (VRE) (Naro & Calabrò, 2021). The versatility of VREs allows customization to individual patient needs, offering personalized feedback on performance. Moreover, VREs support cognitive training, enhancing patient motivation and enjoyment. VR lacks a singular definition but generally involves interactive simulations that immerse users in environments resembling real-world objects and events, providing a naturalistic experience (Weiss et al., 2006). Regardless of the definition, VR offers a simulated experience of a natural or imaginary environment. VRT implements VR using multimedia devices, comprising a multimedia display delivering sensory information (visual, auditory, and tactile) and a control device capturing user actions (motions, gestures, and speech) (Naro & Calabrò, 2021).

VR's utility extends to cognitive training, boosting patient motivation, and enhancing rehabilitation through task-oriented exercises, including exercise-based games or "exergames." Importantly, VR presents a cost-effective alternative to advanced rehabilitation therapies. It enables independent patient use and can be adapted for at-home use, particularly in telerehabilitation services, as seen with VR rehabilitation systems (Naro & Calabrò, 2021).

Additionally, enhancing ecological validity in interventions may boost adherence and transfer training gains to daily activities. To address this, computerized and VR applications with natural user interfaces offer an innovative, practical, and time-efficient solution in inpatient settings, especially with limited human resources. This makes them more realistic, interactive, and potentially more engaging and represents a promising intervention strategy for mitigating cognitive deficits (Faria et al., 2023). By recreating ecologically valid scenarios similar to real life, it becomes feasible to simulate interpersonal interactions without the pressures encountered in real-life contexts, thereby allowing for the generalization of results to everyday life (Maggio et al., 2022).

Specific emerging cognitive interventions, such as computer-based cognitive retraining (CBCR) and VR, may offer potential benefits for individuals with ABI because they provide a computer-generated environment that simulates various daily activities, presenting advantages over conventional care, particularly in simulating hazardous real-life tasks. VRE accurately measures individual performance and contributes to training memory functions and cognitive abilities. Rehabilitation in a VRE enhances central nervous system feedback, leading to augmented feedback and significant changes in neural plasticity, which is crucial for motor and cognitive function restoration (De Luca et al., 2016).

Between two to three years after injury, over half of the survivors of brain lesions continue to manifest cognitive deficits, report depressive symptoms, and display lower levels of social participation (e.g., work absenteeism, reduced autonomy in activities of daily living, negatively impacting their quality of life (Kapoor & Ciuffreda., 2017). In this context, early cognitive intervention for cognitive deficits emerges as a research priority at the scientific level (Câmara et al., 2022; Kapoor & Ciuffreda, 2017). VR training can facilitate the rehabilitation of attention processes in neurological patients and enhance other cognitive domains with a significant improvement in global cognitive functioning. The reactivation of brain neurotransmitter capacities, such as cholinergic and dopamine systems, through VR-based cognitive treatment, may contribute to these positive effects (Maggio et al., 2019).

Therefore, this study's primary objectives encompass the clinical validation of a more ecologically valid instrument to assess Social Cognition, a cognitive function significantly impaired in ABI. Additionally, the research aims to evaluate the impact of a general cognitive training intervention on specific cognitive domains (such as memory, attention, executive functions and social cognition), mood, and quality of life (QoL) in individuals with ABI.

2. Methodology

2.1 Inclusion criteria and procedure

The study was authorized by the SESARAM - Regional Health Service of Madeira ethics committee through Approval 10/2020 (Appendix A). The ABI participants were selected at the Neurosurgery service of Dr. Nélio Mendonça Hospital (SESARAM, EPE). In total, 13 patients who had a brain tumor or a TBI and were followed by the Neurosurgery service were selected. To be included, participants should possess literacy skills (at least two years of minimum schooling) and exhibit motivation to participate. As exclusion criteria, we had speech and comprehension impairments and severe depressive symptomatology.

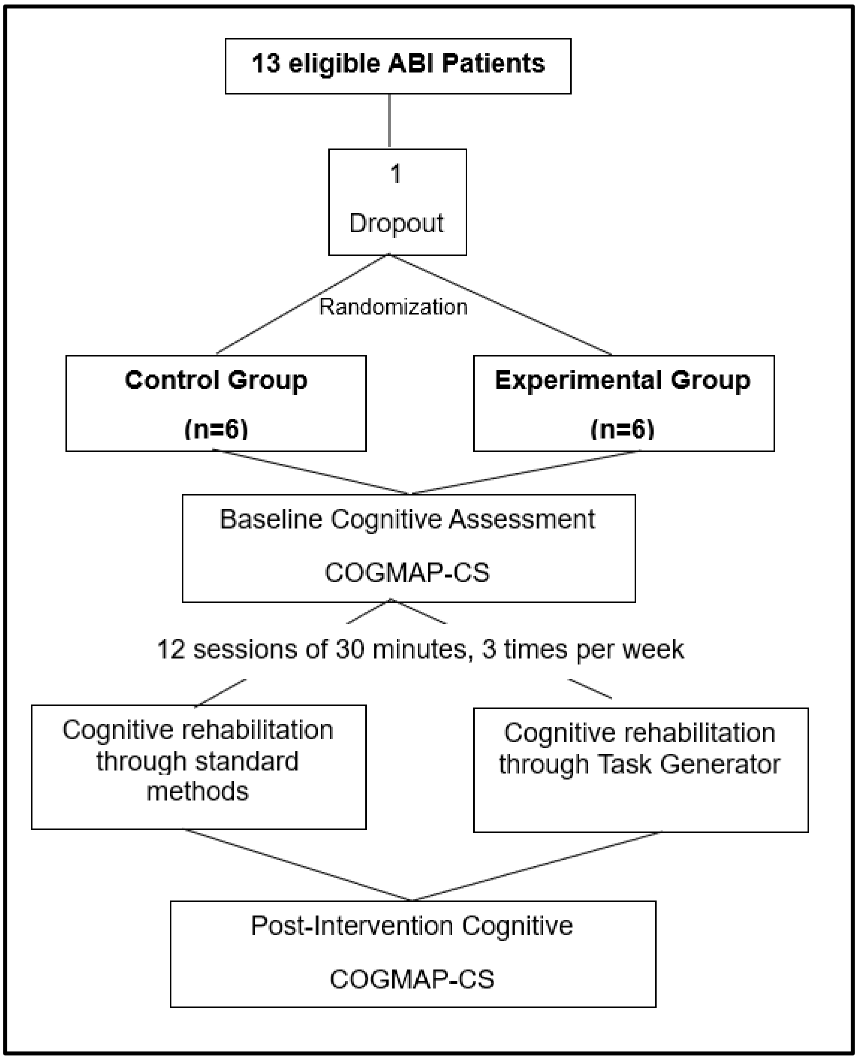
The 13 patients were randomly assigned 1:1 to two different clusters: seven to the experimental group (EG) and 6 to the treatment as usual group, named the control group (CG)(Fig. 1), using the Research Randomizer, an online platform that provides immediate random sampling and assignment (www.randomizer.org). All the participants gave informed consent before participation, and assessment and intervention performance data were anonymized according to the SESARAM ethical standards for research with humans.

2.2 Intervention protocol

The experimental group underwent a twelve-sessions intervention of 30 minutes, three times per week. The neuropsychological intervention sessions involved cognitive training in attention, executive functions, language, and memory with tablet-based activities using the *Task Generator (TG) 2.0.* (fig.1).

Figure 1

Study Protocol

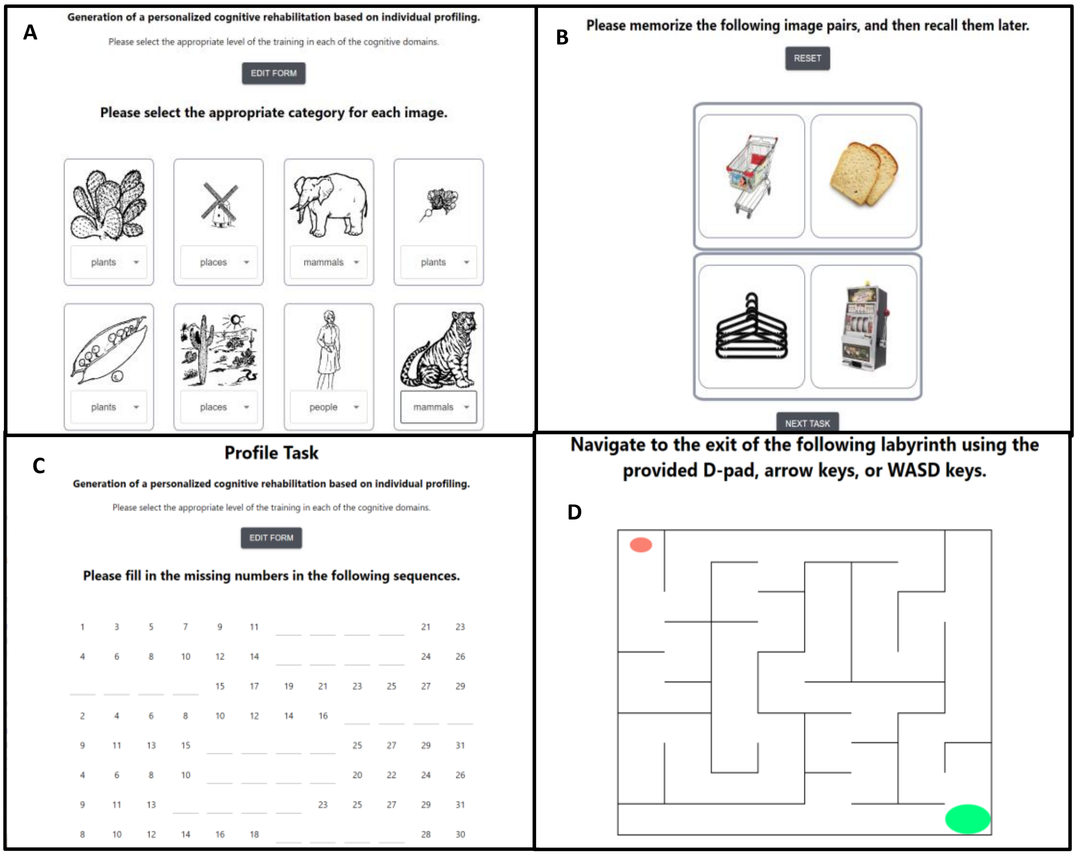


2.3 Task Generator 2.0

During the training sessions, patients in the EG worked under the supervision of a psychology intern. They used the TG, a tablet-based software designed to generate tasks automatically based on certain parameters set by the user, able to develop a personalized cognitive rehabilitation program consisting of 11 tasks: (a) cancellation, (b) numeric sequences, (c) problem resolution, (d) association, (e) comprehensive of contexts, (f) image pairs, (g) word search, (h) maze, (i) categorization, (j) memory of stories and (k) action sequencing, based on the influence of their distinct parameters on various cognitive domains, such as Attention, Memory, Executive Functions, and Language, and overall Difficulty, allowing professionals to tailor it to the specific needs of each patient.

Figure 2

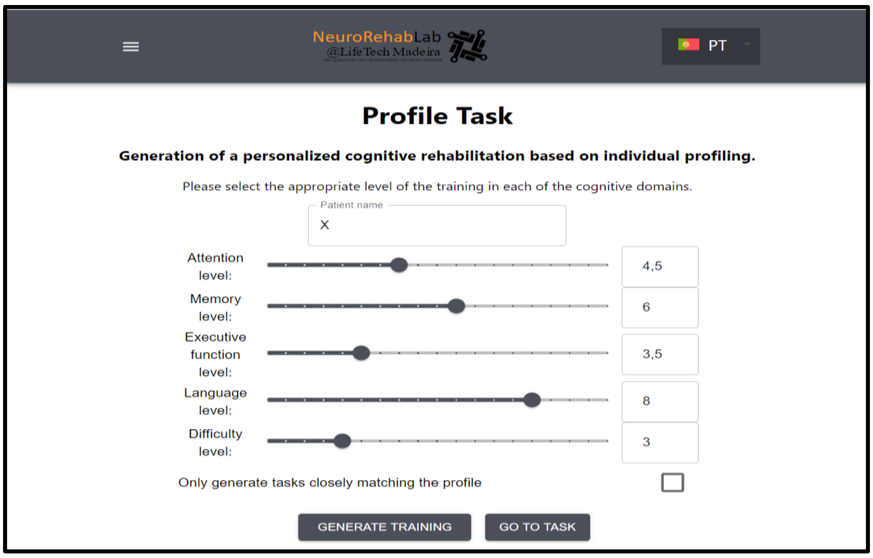
Examples of Task Generator exercises (A - Example of a categorization task, B- Example of a visual memory task, C- Examples of numeric sequences, D- Example of a Maze task)



The task can be rated on a scale from 1 to 10, and these values are retrieved from the values achieved at the different domains at the MoCA cognitive test (Freitas et al., 2010; Marcos, 2024; Nasreddine et al., 2005) and allow individual task parameterization.

Figure 3

Profile customization panel.



These principles offer a systematic, quantitative approach to task-specific cognitive demands, delivering highly adapted training programs to address individual deficits efficiently (Faria & Badia, 2015). The intervention for the CG consisted of traditional time-matched cognitive training. Paper-and-pencil tasks facilitate targeted interventions within specific cognitive domains, but their ecological validity may be limited.

2.4 Neuropsychological assessment

Following this intervention program, a post-intervention neuropsychological assessment was conducted to determine the effects of the intervention on the patient's general and SC. Upon analysis of the results obtained, the assessment battery allowed us to ascertain whether there are relationships between the variables under study. The neuropsychological assessment protocol is presented below, organized by domains of assessment.

2.4.1 Pre-morbid intelligence at Pre- Pre-Intervention: Irregular Word Reading Test (TeLPI)

The premorbid intelligence was measured using the Irregular Word Reading Test (TelPI) (Alves et al., 2012; 2018). The TeLPI estimates pre-morbid intelligence in individuals aged 25 or over. It consists of 46 words in Portuguese, with decreasing familiarity. It aims to evaluate crystallized intelligence and was developed to resist the effects of neurological dysfunction or injury, showing a relative insensitivity to cognitive decline (Alves et al., 2012; 2018).

The test has significant clinical advantages in evaluating loss of intellectual function after brain injury, and its use in assessing conditions of cognitive decline allows one to estimate the individual's previous cognition function. In addition, TeLPI is a short test that does not require prolonged concentration on the part of the subject. As it takes a minimum effort for the subject to read the words he recognizes aloud, the TeLPI is relatively little affected by lack of concentration or motivation (Alves et al., 2018).

2.4.2 General Cognition: Montreal Cognitive Assessment (MoCA)

The primary endpoint of the study was global cognitive functioning, as determined by the Montreal Cognitive Assessment (MoCA) adapted for the Portuguese version, which has excellent internal consistency, with a Cronbach's alpha coefficient of 0.94 (Gonçalves, 2021; Nasreddine et al., 2005; Simões et al., 2008). The MoCA's sensitivity to mild cognitive impairment makes it a useful tool for identifying cognitive deficits in ABI patients, allowing healthcare professionals to track changes in cognitive function and tailor interventions accordingly. It has been widely used internationally and has been found to be more sensitive than other scale tools in screening post-ABI cognitive impairment (An et al., 2021; Lim et al., 2016; Schiavolin et al., 2022). The utilization of the specified instrument requires approximately 10 to 15 minutes and evaluates several cognitive domains, including attention and orientation, memory, language, and visuospatial abilities.

2.4.3 Attention: Trail-Making Test (TMT)

The TMT is a widely recognized neuropsychological test that offers insights into visual search and scanning, selective and divided attention, processing speed, mental flexibility, and executive functions. In TMT A, participants are required to connect circles numbered from 1 to 25 sequentially. TMT B involves connecting alternating numbers (from 1 to 13) and letters (from A to L) in ascending order, thereby assessing task-switching capabilities (Cavaco et al., 2013; Reitan & Wolfson, 2004).

The Trail Making Test (TMT) evaluates visual search capability, graphomotor speed, and executive operation. It assesses selective attention, cognitive flexibility, planning, and sequencing. Usually, the completion time of Part B is used as an executive function index. Both parties' scores are calculated based on the time the participant takes to complete each task. It has been observed, however, that completion time increases with age (Marques, 2022; Reitan & Wolfson, 2004).

2.4.4 Attention: Toulouse-Piéron Cancellation Test

The Toulouse-Piéron Cancellation Test (TP) is a focused attention assessment regarding speed, accuracy, and fatigue resistance. It does not require specific knowledge and depends on the subject's ability to provide voluntary and targeted attention. In addition, the test allows one to observe the behavior and performance of the subject in tasks that require mental effort (Lima et al., 2023; Toulouse & Piéron, 1904). The task involves identifying three signs of a template containing eight types of squares. The original signs were used for sampling in a collective application in the adaptation study, according to the instructions. This test is used to evaluate the ability of selective and sustained attention, processing speed, fatigue resistance, and visual-perceptive ability. It encompasses two main indices: Work Efficiency and Dispersion Index (Lima et al., 2023; Toulouse & Piéron, 1904). The Portuguese adaptation of the test (Amaral, 1967) showed high reliability and validity. It counted on the participation of 3122 individuals over ten years of age, and the normative data for the Portuguese population were also established (Lima et al., 2023).

2.4.5 Executive Function: Frontal Assessment Battery (FAB)

The Frontal Assessment Battery (FAB) is a screening tool comprising six tests, notable for its brief administration time (5-10 minutes) and the absence of the need for any materials. It facilitates the evaluation of six dimensions: (a) Abstract thinking (similarities test), (b) Mental flexibility (phonemic fluency), (c) Motor programming (Luria's motor series), (d) Sensitivity to interference (antagonistic instructions), (d) Inhibitory control (go-no-go), and (e) Independence from the environment (suppression of grasp behavior). Each task corresponds to an activity controlled by the prefrontal cortex, rendering this test suitable for detecting executive dysfunction (Dubois et al., 2000; Lima et al., 2008).

2.4.6 Executive Function: Symbol Search Test of WAIS-III

The Symbol Search subtest (SS) is part of the Wechsler Adult Intelligence Scale - Third Edition (WAIS-III). Symbol Search is a measure of perceptual speed and visual-motor integration. In this subtest, two groups of symbols are presented: a target group with two symbols and a search group with five symbols. The subject must decide whether any of the symbols of the target group is present in the search group within 120 seconds. The test score is determined by the number of correct items that the examiner has completed within a defined period. This result is compared to the standards established for the population, considering the examiner's age, to determine their ability to complete the visual patterns (Wechsler, 1997).

2.4.7 Executive Function: Digit Symbol Test of WAIS-III

The WAIS-III (Wechsler Adult Intelligence Scale - Third Edition) Digit Symbol Test (DST) evaluates perceptual reasoning, processing speed, and visual discrimination skills. The test consists of a series of symbols or numbers corresponding to different codes. A set of numbers (one to nine) is presented in pairs, each with another symbol, forming a key. Using this key, the subject must match the symbols to the numbers within 120 seconds. The score in the WAIS-III Coding test provides information about the speed and accuracy of the perceived processing of the participant. In addition, the test can also help to evaluate attention skills, visual-motor coordination, and working skills in a visual context (Wechsler, 1997).

2.4.8 Memory: Verbal Paired Associates of WMS

The Verbal Paired Associates (VPA) is a subtest of the Wechsler Memory Scale and is a task used to evaluate episodic verbal memory, which is the ability to remember and retain verbal information in a specific context. The functions assessed include memory capacity for verbal and visual stimuli, including abstract and meaningful material, and the ability to remember both immediate and late (Wechsler, 1987). In this test, the examiner presents a list of word pairs, one of which is a target word, and the other is a word associated with it. Then, the participant is asked to remember the related word when the target word is presented again. During the test, the participant acquires knowledge of eight pairs of words, four of which are considered easy-to-learn associations, while the other four are considered more challenging (Wechsler, 2008). Performance in this task provides insights into the ability to encode, store, and retrieve verbal information in the participant's memory. Word pairs test is widely used in neuropsychological assessments to investigate possible verbal memory difficulties (Wechsler, 1987).

2.4.9 Quality-of-Life: World Health Organization Quality of Life Assessment-BREF (WHOQOL-Bref)

WHOQOL is a questionnaire that allows individuals to assess their quality of life subjectively. This instrument consists of 100 items covering six main areas: (a) Physical, (b) Psychological, (c) Level of Independence, (d) Social Relations, (e) Environment, and (f) Spirituality/Religion/Personal Beliefs. In addition, it includes 24 specific facets that explore more detailed aspects of each domain, along with a global indicator that represents an overview of the quality of life (Quality of Life overview) (Canavarro et al., 2006; Vaz Serra, 2006; WHOQOL Group, 1994). The WHOQOL-BREF was created as a reduced version, consisting of 26 questions, distributed in 4 areas: (a) physical, (b) psychological, (c) social relations and (d) environment. The Portuguese version was developed in 2006 and has good psychometric features. The WHOQOL-BREF quote is made using a Likert scale, on which each item is rated on a scale of 1 to 5, representing different levels of satisfaction or perception. To obtain the final score in each domain, the totals of each item belonging to the domain are added and converted on a scale of 0 to 100. The higher the score, the higher the quality of life perceived in the respective field (Vaz Serra et al., 2006; WHOQOL Group, 1998).

2.4.10 Depressive symptomatology: Beck Depression Inventory (BDI – II)

The Beck Depression Inventory (BDI) (Beck et al., 1996), consisting of 21 items, is a method to assess the presence and intensity of depressive symptoms in individuals over 13 years of age. It was developed as an indicator of depressive symptoms and not as a clinical diagnostic tool. The administration of this instrument takes between five to ten minutes. It can be done during an interview, in writing or orally, individually or in a group. The person should choose between four and six sentences and select the one that best describes their mood "in the last two weeks," including the day the questionnaire is completed. The score of the latest version of the Beck-II Depression Inventory (BDI-II) (Beck et al., 1996) is calculated by adding the points assigned to each item responded to. Each item has a score value that varies from 0 to 3, reflecting the severity of the evaluated symptom. The total score is obtained by adding the points of each item, resulting in a value that can vary from 0 to 63. The interpretation of the total score of the BDI-II is based on established cutting points. These cutting points help to classify the level of depressive symptomatology presented by the individual. Generally, the following cutting points are considered: 0 to 13 - "minimum" depressive symptomatology; 14 to 19 - "light"; 20 to 28 - "moderate"; above 29 - "serious" or "severe."

The validation of BDI-II for the Portuguese population (Brochado, 2013) allowed us to adapt the study, determine the psychometric validity for this sample, and provide specific normative data for the Portuguese population. The psychometric validation allowed us to measure the internal consistency, the convergent and discriminating validity, and the instrument's factor structure. The results of this study provided evidence of the validity and reliability of BDI-II for the Portuguese population, thus allowing the appropriate use of this instrument to assess the presence and severity of depressive symptoms in that specific population (Brochado, 2013).

2.4.11 Social Cognition: CogMap-CS and ESCoT

CogMap–Social Cognition (CogMap-CS) refers to a set of social cognition tasks applied using a VRH. It is derived from the original Cogmap software and allows us to explore the advantages of using VR. It aims to integrate various SC tasks by presenting 10 video scenarios and associated questions that assess whether there is any deficit related to SC based on the ESCoT evaluation scenarios (Baksh, 2017).

The Edinburgh Social Cognition Test (ESCoT) is a measure of social cognition that assesses four key social cognitive abilities within the same test. These abilities include cognitive ToM, affective ToM, interpersonal understanding of social norms, and intrapersonal knowledge of social norms. The ESCoT consists of 11 dynamic, cartoon-style social interactions, each approximately 30 seconds long. Participants are presented with animations depicting various social scenarios and are then asked questions related to the context of each interaction (Baksh, 2017).

Applying the ESCoT tool allows assessing SC deficits, showing that patients with ABI exhibited significant improvements in SC when assessed with ESCoT after undergoing cognitive rehabilitation (Poveda et al., 2022). So, CogMap-Cs, as a virtual reality-based adaptation of this test, allows us to assess SC through interactive tasks presented in a VRE. The tool includes scenarios with video stimuli followed by questions related to social behaviors, cognitive ToM, affective ToM, and interpersonal understanding of social norms (as in the EsCoT). Participants interact with the tasks using VR controllers, such as pointing and shooting, or through eye-tracking technology (Freitas et al., 2024).

Figure 4

CogMap-CS setup

CogMap-CS offers a customizable experience where users can select different environments and interact with tasks in a more immersive and realistic manner and aims to provide a more engaging and effective way to evaluate SC compared to traditional paper-and-pencil tests (Fig. 5). In a validation study with healthy participants, CogMap-CS showed promising results, with most participants performing better on the VR-based tasks than on the paper-and-pencil versions and having positive feedback on usability, indicating that it is user-friendly and well-received by participants. The methodology aims to introduce SC tasks in an ecologically valid method (Faria et al., 2022).

2.4.12 Usability: System Usability Scale

Following the completion of the virtual reality-based intervention, the System Usability Scale (SUS) (Martins et al., 2015) was administered to evaluate participant satisfaction and the usability of the TG System. The SUS, a robust, technology-agnostic tool, facilitates the usability assessment of diverse interface technologies. It produces scores ranging from 0 to 100, where higher values signify enhanced usability: scores in the 90s are considered exceptional, those in the 80s are good, and scores in the 70s are deemed acceptable.

2.5 Statistical Analysis

All descriptive analyses were performed using IBM SPSS Statistics software (version 29.0) (IBM Corp., 2022). A significance criterion was set at $\alpha = .050$. Given the clinical sample and a limited number of participants, non-normality of distributions was assumed. Consequently, non-parametric tests were employed, specifically the Wilcoxon test (to assess intra-subject differences) and the Mann-Whitney test (to evaluate inter-subject differences).

The Reliable Change Index (RCI) was also used to determine the significance of changes in specific variables at the individual level. This is a statistical tool employed to ascertain the importance of changes in particular variables at the individual level, accounting for measurement error. This index quantifies the reliability and clinical relevance of observed changes, providing a robust method for evaluating the effectiveness of therapeutic interventions or programs. It is particularly useful in identifying meaningful change patterns in individuals rather than aggregate group changes. It facilitates the assessment of individual responses to treatment, indicating whether changes represent improvement, deterioration, or stability compared to baseline measurements. The utility of RCI is heightened in studies with small sample sizes, where conventional statistical approaches focusing on mean differences are less effective (Brazão et al., 2015; Jacobson & Truax, 1991; Zahra & Hedge, 2010). By focusing on individual outcomes, the RCI offers nuanced insights into the therapeutic impact, enhancing the evaluation of intervention efficacy. In this context, the Zahra RCI Calculator (https://www.daniel-zahra.com/publications) was applied to compute the RCI, determining significant clinical change post-intervention. The RCI considers a magnitude of 1.96 or greater in either direction as statistically reliable at the $p<.05$ level. This threshold indicates a significant change in the individual's scores that is unlikely to be due to measurement error or variability within the measure. An RCI value exceeding 1.96, within a 95% confidence interval, confirms a significant change. Interpretatively, an RCI greater than 1.96 suggests global improvement, values between -1.96 and 1.96 indicate no significant change, and values below -1.96 suggest global decline (Brazão et al., 2015). So, it scientifically means that A participant's change score exceeding 1.96 suggests a global improvement (GI), while a change score ranging between -1.96 and 1.96 indicates no significant change (NC). Conversely, a change score less than -1.96 signifies a global decline (GD), as elaborated in Table 8. Focusing on individual outcomes, the RCI offers nuanced insights into the therapeutic impact, enhancing the evaluation of intervention efficacy and digging into greater detail of change.

3. Results

3.1 Demographic Characteristics of the Sample

Participants from the EG had a median age superior (*Mdn*= 59, *IQR*= 37.5-77) to those of the CG (*Mdn*= 43.5, *IQR*= 38.5-52.8) but had a lower average of schooling years (Mdn= 7.5, IQR= 4-9.8) than the CG (*Mdn*= 10.5, *IQR*= 5.5-12). The EG had the same percentage of female and male persons (50%/50%) compared to the CG, which had a higher rate of males (83.3%/16.7%). Considering the type of ABI, all the EG samples 100% consisted of BT, and the CG had the same amount of BT and TBI (50%/50%); this group also shows a higher number of months after ABI (*Mdn*= 25, *IQR*= 14-53.3) than the EG (*Mdn*= 13.5, *IQR*= 8.3-21.3). Considering the Premorbid Intelligence at baseline, we can find higher values of Complete IQ, Verbal IQ and Achievement IQ at the CG (*Mdn*= 106, *IQR*= 92-116.5; *Mdn*= 107.5, *IQR*= 93.3-117.5; *Mdn*= 103.5, *IQR*= 92.5-112.5). Comparing with the values found at the EG (*Mdn*= 92.5, *IQR*= 75.8-111.5; *Mdn*= 94.5, *IQR*= 8.3-21.3; *Mdn*= 92.5, *IQR*= 8.3-21.3), as can be seen at Table 1.

Table 1

Demographic characteristics (presented as Medians and IQR) of both groups and differences between groups (MW)

	Experimental (*n* = 6)	Control (*n* = 6)	*MW*	*p*
Age	59 (37.5–77)	43.5 (38.5–52.8)	10.000	.199
Gender	Female = 50 %; Male = 50 %	Female = 16.7 %; Male = 83.3 %	12.000	.241
Schooling	7.5 (4–9.8)	10.5 (5.5–12)	12.000	.324
Type of ABI	Tumor= 50 %; TCI = 50 %	Tumor= 100 %	9.000	.056
Months post-ABI	13.5 (8.3–21.3)	25 (14–53.3)	10.000	.200
Premorbid Intelligence				
TELPI Total	27.5 (17.5–42)	35.(30–42.5)	13.000	.423
TELPI Complete IQ	92.5 (75.8–111.5)	106 (92–116.5)	12.000	.337
TELPI Verbal IQ	94.5 (8.3–21.3)	107.5 (93.3–117.5)	12.000	.337
TELPI Achievement IQ	92.5 (8.3–21.3)	103.5 (92.5–112.5)	12.000	.337

Note: p<.05 in bold

3.2 Global cognition: MoCA

When we analyze the results of the MoCA test (Table 2), we can see that there is in both groups a quantitative increase between the baseline and the post-intervention assessment Median values (pre-post *Mdn*= 2) [EG: *Mdn*=2.5; CG: *Mdn*=0.5]. There was a more significant increase in the total score of de EG (pre-post *Mdn*=2.5) [Pre: *Mdn*=22, *IQR*=16.5-23.3; Post: *Mdn*=24.5, *IQR*=17-29] than that observed in the CG (pre-post *Mdn*=0.5) [Pre: *Mdn*=26.5, *IQR*=20.8-27.5; Post: *Mdn*=27, *IQR*=22.5-27.5]. We can also observe that there is a statistically significant difference in the abstraction subtest of the MoCA in the EG between the two assessments (*W* (6) =-2.121, *p*=.034). The Mann-Whitney (MW) results indicate that there is no difference between the two groups.

Table 2

MoCA scores (presented as Medians and IQR) pre and post intervention with within-groups (W) comparisons and pre- to post-intervention difference with between-groups (MW) comparisons.

	Experimental (*n* = 6)				Control (*n* = 6)					
	Pre	Post	*W*	*p*	Pre	Post	*W*	*p*	*MW*	*p*
MoCA Total	22 (16.5–23.3)	24.5 (17–29)	-1.472	.141	26.5 (20.8–27.5)	27 (22.5–27.5)	-.531	.595	15.000	.626
Visuo-Spatial	15 (13–18)	18 (15–21.5)	-1.069	.285	18 (11–19.5)	18 (12.5–21)	-1.000	.317	15.000	.589
Naming	23 (20.5–26)	29 (25–29)	0.000	1.000	23 (20.5–26)	26 (21–26.5)	-.447	.655	14.000	.473
Attention	23 (20.5–26)	29 (25–29)	-1.414	.157	23 (20.5–26)	26 (21–26.5)	-1.518	.129	15.000	.604
Language	5 (2.5–6)	6 (4–7.5)	-.577	.564	6 (4–8)	5 (2.5–5.5)	-1.732	.083	14.000	.490
Abstraction	12 (7.5–14.5)	14 (13–15)	-2.121	**.034**	12 (7.5–13.5)	14 (7–15.5)	-.557	.564	15.000	.523
Orientation	22 (21.5–23)	24 (21–26)	-1.414	.157	19 (16–22)	21 (17–24.5)	-1.000	.317	17.500	.902
Delayed Recall	15 (14–16.5)	18 (16.5–18)	-.552	.581	14 (12–16.5)	16 (12.5–17)	-.966	.334	14.000	.510

Note1.p <.05 is indicated in bold.

3.2 Social cognition: CogMap-CS

Concerning the social cognition evaluated by the CogMap-CS (Table 3), we observe that there is a statistically significant difference in the EG between the two assessments (*W* (6) =-2.207, *p*=.027). There is also, in both groups, a quantitative increase between the baseline and the post-intervention assessment Median values (pre-post *Mdn*= 0.5) [EG: *Mdn*=4.5; CG: *Mdn*=4].

Table 3

COGMAP-CS scores (presented as Medians and IQR) pre and post intervention with within-groups (W) comparisons and pre- to post-intervention difference with between-groups (MW) comparisons.

	Experimental (*n* = 6)				Control (*n* = 6)					
	Pre	Post	*W*	*p*	Pre	Post	*W*	*p*	*MW*	*p*
COGMAP-CS	84.5 (0–93.5)	89 (8.5–96)	-2.207	**.027**	93.5 (67.8–101.3)	69 (58–78)	-1.490	.136	10.000	.199

p <.05 is indicated in bold

There was a more significative increase in the total score of de EG (pre-post *Mdn*=4.5) [Pre: *Mdn*=84.5, *IQR*=0-93.5; Post: *Mdn*=89, *IQR*=8.5-96] than that observed in the CG (pre-post

Mdn=4) [Pre: *Mdn*=93.5, *IQR*=67.8-101.3; Post: *Mdn*=97.5, *IQR*=84.8-106.5]. Analyzing the MW results, we can see that there is also no difference between the two groups.

3.3 Attention: TMTA, TMTB and TP

When analyzing the results of the tests used to assess Attention (Table 4), we observed improvements in all tests within the EG, including a reduction in time spent (seconds) completing both tests of the TMT[(A: pre-post *Mdn*=-23.11s) [Pre: *Mdn*=88.2, *IQR*=69-154.7; Post: *Mdn*=65.1, *IQR*=54.7-106.9]; (B: pre-post *Mdn*=-110.31s) [Pre: *Mdn*=300, *IQR*=232.6-300; Post: *Mdn*=176.5, *IQR*=108.3-287.6] enhancements in the total scores of TP(pre-post *Mdn*=1.35) [Pre: *Mdn*=5.65, *IQR*=0.6-10; Post: *Mdn*=7, *IQR*=1.95-11.9], increased work efficiency (pre-post *Mdn*=13.5) [Pre: *Mdn*=55.5, *IQR*=5.8-99; Post: *Mdn*=69, *IQR*=15.3-118.3], and a decrease in the dispersion index measured in this test (pre-post *Mdn*=-10.58) [Pre: *Mdn*=20.05, *IQR*=4.4-107.8; Post: *Mdn*=9.47, *IQR*=2.9-62.3].

In the CG, despite favorable outcomes such as reduced time to complete both TMT tests [(A: pre-post *Mdn*=-4.81s) [Pre: *Mdn*=37.41, *IQR*=29.9–60.2; Post: *Mdn*=32.61, *IQR*=27.3–53.9]; (B: pre-post *Mdn*=-13.19s) [Pre: *Mdn*=98.61, *IQR*=89.7–169.6; Post: *Mdn*=85.42, *IQR*=61.9–145.9] and improvements in work efficiency (pre-post *Mdn*=27) [Pre: *Mdn*=138, *IQR*= 62.8–166; Post: *Mdn*=165, *IQR*=75.8–201.3], and TP total scores (pre-post *Mdn*=2.85) [Pre: *Mdn*=13.7, *IQR*= 6.4–16.7; Post: *Mdn*=16.55, *IQR*=7.7–20.2, as well as an escalation in the dispersion index measured by the TP (pre-post *Mdn*=4.38) [Pre: *Mdn*=14.97, *IQR* =11.4–25.8; Post: *Mdn*=19.32, *IQR*=9.6–52.8].

We noted statistically significant differences in the pre-and post-test measurements of the TMT A in the EG (*W* (6) = -1.992, *p*=.046). In the CG, there were also statistically significant differences between baseline and post-intervention assessments at TMT B (*W* (6) = -1.992, *p*=.046). In TMT Part A, there are also statistically significant differences between the two groups (*W* (6) = 4.000, *p*=.025).

Table 4

TMT and TP scores (presented as Medians and IQR) pre and post-intervention with within-groups (W) comparisons and pre- to post-intervention difference with between-groups (MW) comparisons.

	Experimental (*n* = 6)				Control (*n* = 6)					
	Pre	Post	*W*	*p*	Pre	Post	*W*	*p*	*MW*	*p*
TMT A	88.2 (69–154.7)	65.1 (54.7–106.9)	-1.992	**.046**	37.41 (29.9–60.2)	32.61 (27.3–53.9)	-.314	.753	4.000	**.025**
TM A errors	.00 (0–0.5)	.000-0)	-1.000	.317	.00 (0–0.8)	.00 (0–0.8)	-1.000	.317	18.000	1.00
TMT B	300 (232.6–300)	176.5 (108.3–287.6)	-1.483	.138	98.61 (89.7–169.6)	85.42 (61.9–145.9)	-1.992	**.046**	6. 000	.055
TMT B errors	4 (3–4)	.00 (.0–2.5)	-1.444	.149	.00 (.0–4)	.00 (.00–1.75)	-.447	.655	17.500	.924
TP_Total	5.65 (0.6–10)	7 (1.95-11.9)	-1.892	.058	13.70 (6.4–16.7)	16.55 (7.7–20.2)	-.943	.345	7.000	.078
TP_WE	55.5 (5.8–99)	69 (15.3–118.3)	-1.753	.080	138 (62.8–166)	165 (75.8–201.3)	-.943	.345	7.000	.078
TP_DI	20.05 (4.4–107.8)	9.47 (2.9–62.3)	-.943	.345	14.97 (11.4–25.8)	19.32 (9.6–52.8)	-.524	.600	11.000	.262

p <.05 is indicated in bold

3.4 Memory: VPA

The Verbal Paired Associates (VPA) recognition values (Table 5) indicate that in spite of not having any statistically significant difference in the W or MW ($p \geq .05$), we can observe that in both groups, there is a quantitative improvement between the baseline and the post-intervention assessment Median values (pre-post *Mdn*= 0.5) [EG: *Mdn*=6; CG: *Mdn*=6.5], with a higher value on the CG.

Table 5

Verbal Pair WMS retention and recognition scores (presented as Medians and IQR) pre and post-intervention with within-groups (W) comparisons and pre-to post-intervention difference with between-groups (MW) comparisons

	Experimental (*n* = 6)				Control (*n* = 6)					
	Pre	Post	*W*	*p*	Pre	Post	*W*	*p*	*MW*	*p*
Verbal Pair Word Rec	7.5 (0–16)	11.5 (6–24.5)	-.674	.500	7 (4–19.8)	13 (5.3–27)	-.632	-.527	17.000	.872

p <.05 is indicated in bold

3.5 Executive Function: FAB, DST and SS

In all the tests related to this cognitive domain, we can see in Table 6 that there is, in all three, a quantitative increase between the baseline and the post-intervention assessment Median values in the EG (Coding: pre-post *Mdn*= 5.5) [Pre: *Mdn*=23.5, *IQR*=7.5-35.8; Post: *Mdn*=29, *IQR*=14.8-40], (Symbol: pre-post *Mdn*= 2) [Pre: *Mdn*=12, *IQR*=8.3-17.3; Post: *Mdn*=14, *IQR*=10-21.3], (FAB pre-post *Mdn*=5) [Pre: *Mdn*=10.5, *IQR*=7.5-3.8; Post: *Mdn*=16, *IQR*=11.8-17.3]. We can also observe that there is a statistically significant difference in the coding test in the EG between the two assessments (*W* (6) =-2.207, *p*=.027). At the CG, there is only a slight increase in the FAB test (CG pre-post *Mdn*= 0.5) [Pre: *Mdn*=16.5, *IQR*=11-17.3; Post: *Mdn*=17, *IQR*=14.5-18]. In the two other tests there is a small decrease (Coding pre-post *Mdn*=- 0.5) [Pre: *Mdn*=46.5, *IQR*=29-57; Post: *Mdn*=46, *IQR*=32.5-59.3], (Symbol pre-post *Mdn*= 2) [Pre: *Mdn*=23.5, *IQR*=17-28; Post: *Mdn*=21.5, *IQR*=16-29.5]

Table 6

Coding and Symbol Search WAIS and FAB scores (presented as Medians and IQR) pre- and post-intervention with within-groups (W) comparisons and pre- to post-intervention difference with between-groups (MW) comparisons.

	Experimental (*n* = 6)				Control (*n* = 6)					
	Pre	Post	*W*	*p*	Pre	Post	*W*	*p*	*MW*	*p*
Coding	23.5 (7.5–35.8)	29 (14.8–40)	-2.207	**.027**	46.5 (29–57)	46 (32.5–59.3)	-1.051	.293	9.000	.148
Symbol Search	12 (8.3–17.3)	14 (10–21.3)	-1.476	.140	23.5 (17–28)	21.5 (16–29.5)	- .680	.496	7.500	.092
Fab Total	10.5 (7.5–13.8)	16 (11.8–17.3)	-1.892	.058	16.5 (11–17.3)	17 (14.5–18)	-1.841	.518	13.000	.411

p <.05 is indicated in bold

3.6 Depressive Symptomatology: BDI-II

When we examine the total results of the BDI-II (Table 7), we can see that there is a decrease in the depressive symptomatology at the EG and a slight increase in the CG (EG: *Mdn*=-2; CG: *Mdn*=4) [(EG Pre: *Mdn*=13.5, *IQR*=8.5-23.3; Post: *Mdn*=11.5, *IQR*=3.5-22.3); (CG [Pre: *Mdn*=3.5, *IQR*=1.5-12.5; Post: *Mdn*=7.5, *IQR*=2.8-11.3]. Despite these differences, it can be observed that the values related to depressive symptomatology, both in the pre-and post-test, are consistently lower in the control group.

Table 7

BDI scores (presented as Medians and IQR) pre and post intervention with within-groups (W) comparisons and pre- to post-intervention difference with between-groups (MW) comparisons.

	Experimental (n = 6)				Control (n = 6)					
	Pre	Post	*W*	*p*	Pre	Post	*W*	*p*	*MW*	*p*
BDI Total	13.5 (8.5–23.3)	11.5 (3.5–22.3)	-1.105	.269	3.5 (1.5–12.5)	7.5 (2.8–11.3)	-1.084	.279	14.500	.575

p <.05 is indicated in bold

3.7 Quality-of-Life: WHOQOL-BREF

Analyzing the results of the WHOQOL-BREF test (Table 8), we can observe that there are no changes at the CG. Still, in the EG, we can see a relevant increase in the perception of QoL between the baseline and the post-intervention assessment Median values (pre-post *Mdn*= 7) [Pre: *Mdn*=95, *IQR*=84.3-98.5; Post: *Mdn*=102, *IQR*=89-112.3]. We can also see that there is a statistically significant difference in the EG between the two assessments (*W* (6) =-1.192, *p*=.046). Although there were no changes in the pre-and post-test medians at the CG, an analysis of the interquartile differences reveals a greater dispersion in the collected data [Pre: *Mdn*=99, *IQR*=95.8-100.3; Post: *Mdn*=99, *IQR*=89.8-102.3], as can be seen at Table 7.

Table 8

WHOQOL-BREF scores (presented as Medians and IQR) pre and post intervention with within-groups (W) comparisons and pre- to post-intervention difference with between-groups (MW) comparisons.

	Experimental (n = 6)				Control (n = 6)					
	Pre	Post	*W*	*p*	Pre	Post	*W*	*p*	*MW*	*p*
WHOQOL-BREF	95 (84.3–98.5)	102 (89–112.3)	-1.192	**.046**	99 (95.8–100.3)	99 (89.8–102.3)	-.943	.345	12.500	.378

p <.05 is indicated in bold

3.8 Reliable Change Index

Scientifically, the RCI means that a participant's change score exceeding 1.96 suggests a global improvement (GI), while a change score ranging between -1.96 and 1.96 indicates no significant change (NC). Conversely, a change score less than -1.96 signifies a global decline (GD), as elaborated in Table 9. Focusing on individual outcomes, the RCI offers nuanced insights into the therapeutic impact, enhancing the evaluation of intervention efficacy and digging into greater detail of change.

Table 9

Reliable Change Index

Outcome measures	Categories	EG (n=6)		CG (n=6)	
		n	%	*n*	%
MoCA	GI	3	50	1	17
	NC	1	17	3	50
	GD	2	33	2	33
COGMAP-CS	GI	1	17	1	17
	NC	5	83	4	67
	GD	0	0	1	17
TMT					
TMTA	GI	2	33	0	0
	NC	3	50	3	50
	GD	1	17	3	50
TMT B	GI	3	50	0	0
	NC	2	16,5	6	100
	GD	1	16,5	0	0
TP					
Work Efficiency	GI	0	0	1	17
	NC	5	83	4	67
	GD	1	17	1	17
Dispersion Index	GI	1	17	2	33
	NC	3	50	3	50
	GD	2	33	1	17
Total Score	GI	0	0	0	0
	NC	4	67	5	83
	GD	2	33	1	17
WMS					
Verbal Pair Recognition	GI	1	17	1	17
	NC	3	50	2	33
	GD	1	17	3	50
WAIS III					
Coding	GI	1	17	1	17
	NC	5	83	3	50
	GD	0	0	2	33
Symbol Search	GI	1	17	0	0
	NC	4	67	3	16,5
	GD	1	17	3	50
FAB	GI	2	33	1	17
	NC	3	50	5	83
	GD	1	17	0	0
BDI	GI	2	33	1	16,5
	NC	2	33	1	16,5
	GD	2	33	4	67
WHOQOL-BREF	GI	0	0	0	0
	NC	5	83	4	67
	GD	1	17	2	33

Note. EG = experimental group; CG = control group; GI = Global Improvement; NC = No Change; GD = Global Deterioration. These values are at a confidence interval of 95%

4. Discussion

Cognitive interventions can lead to enhancements in social skills as patients better understand social cues and norms. Improved performance on cognitive tests, especially those related to ToM and understanding social norms, correlates with better social interactions and functionality. As cognitive functions improve, particularly those involving the processing and interpretation of social information, individuals with ABI can navigate social situations more effectively (Poveda et al., 2022). A significant proportion of patients with mild to moderate TBI experience persistent somatic, cognitive, and emotional symptoms that may hinder their ability to return to work and return to their social circle (Howe et al., 2017); what makes this subject so relevant to invest, because it affects the individual not only on their cognitive difficulties but also at a macro level, in the way he interacts with all the people that surround him.

Cognitive rehabilitation programs, therefore, often include training focused on SC to help individuals better understand and respond to social situations. This includes recognizing emotional expressions, understanding social cues, and improving communication skills. It is proven that individuals can recover cognitive functions such as attention and processing speed, are better able to follow conversations, understand social nuances, and respond appropriately in social settings (Togher et al., 2023). Bechi and colleagues (2022) also affirm that other skills, such as IQ and executive functions, might partially compensate for deficiencies in cognitive and social abilities, functioning as a cognitive-metacognitive reserve, as we also can infer from the pre-morbid IQ differences of both groups. Therefore, if social cognitive skills are improved through specific training, they may no longer require support from this reserve (Bechi et al., 2022).

CR, which focuses on facial emotion recognition and situational emotional recognition and reaction, can enhance the ability to recognize emotional reactions and facial expressions and improve SC (Halder & Samajdar, 2021). There is also a significant connection between CR, cognitive improvement, enhancement in social skills, and changes in neuroimaging. Magnetic Resonance Imaging (MRI) revealed significant changes in brain connectivity after CRT, particularly involving the cerebellum and cerebellar networks, documented through functional connectivity measures.

These neuroimaging findings provide a biological basis for the cognitive and social improvements observed, indicating that CRT can lead to measurable changes in brain structure and function (Moore et al., 2020). The neural correlates of cognitive improvement following CRT include increased activations in various brain regions, especially in frontal (including prefrontal), occipital, and anterior cingulate areas during working memory and executive tasks. Additionally, improved functional connectivity is observed after CRT, suggesting a neuroplastic effect of therapy through mechanisms of functional reorganization. CRT can have a positive impact on social functioning, including the development of problem-solving strategies and improvements in memory functions. Additionally, CRT focusing on SC has been found to enhance neural activity in the frontal, parietal, and limbic regions, which are important for SC (Isaac & Januel, 2016), and often the areas affected, especially in TBI.

Cognitive rehabilitation can have a positive effect on improving cognitive domains and social skills in individuals with ABI (Faria & Badia, 2015; Maggio et al., 2022). CRT techniques, such as computer-based and VR interventions, have been shown to be useful in improving cognitive functioning in patients with ABI thereby also enhancing SC. VR interventions have a higher potential to improve patients' motivation, enjoyment, and engagement in the rehabilitation process, which are important factors in successful rehabilitation. These interventions provide everyday life simulated environments that can help patients practice and develop their social skills and SC (De Luca et al., 2016).

4.1 Primary Outcomes

In the within-groups analysis, we can observe that the cognitive intervention with TG 2.0 led to an improvement in all cognitive domains, in accordance with the scientific literature (De Luca et al., 2018; Matsui et al., 2009) in both groups. The expected outcomes, such as treatment effectiveness, may have been affected by the time after the lesion, the pre-morbid IQ, and years of schooling (De Geus et al., 2024).

When we analyzed the results of the reliable change index, we couldn’t find previous studies that associated cognitive training after ABI using this index value. Despite that, the results were presented verifying individual differences that can indicate any global improvement or decrease in every cognitive domain that can predict the efficacy of the neurocognitive rehabilitation training applied.

In the general cognition assessment, we have a greater improvement in the total score intra-subject at the EG. We also verified in this group a statistically significant difference in the abstraction subtest between pre- and post-intervention. These results were according to the previous test made using a TG, which indicated that it leads to an overall improvement in general cognition after its use (Faria & Badia, 2015).

When we analyze the differences in groups at baseline, we can't find any significant statistical difference between EG and CG. Still, the second group presented a higher Median value at baseline. Upon individual analysis, Table 9 reveals that 50% of participants in the EG exhibited reliable change post-intervention. In contrast, 50% of participants in the Control Group (CG) did not demonstrate any reliable change following the intervention.

Concerning the topic of our study, social cognition, assessed by the Cogmap-CS, we only found a statistical difference between baseline and post-intervention in the EG, which indicates that an improvement in general cognition can lead to improvements in social cognition and social skills, functional independence, performance in daily activities, and community participation as referred in previous studies (Nott & Chapparo, 2020). There was not found any significant difference between the groups, and it was observed a reliable change only at 17% of the individuals in both groups and 83% of those of the EG presented no change after the cognitive training.

Concerning attention values in all tests applied, we find that there is only a significant difference within groups on the TMT A, which can be related to the specific nature of this test.

Neuroplasticity is enhanced in CRT through attention-enhancement techniques to facilitate cognitive recovery, particularly in attention. Attention process training, a systematic exercise strategy, improves the regulation of attentional functions. By engaging in activities requiring various types of attention—such as sustained concentration, selective attention, and split attention—patients stimulate their brains to adapt and reorganize neural circuits responsible for attention. The repetitive nature of these activities induces neuroplastic changes, gradually enhancing attentional capacities. CRT methods leveraging neuroplasticity, including memory training, cognitive remediation, and attention enhancement, demonstrate the brain's ability to adapt and recover cognitive skills (Zotey et al., 2023).

Having that in mind, we observed that in the attention domain, there were significant differences between the two groups at baseline, with a higher increase in EG post-intervention, with a statistical difference at the TMT A test that indicates that there was an improvement at the aspects of sustained attention reflecting their cognitive processing capacity and visuomotor coordination (Marques, 2022; Reitan & Wolfson, 2004), as was observed by previous studies(Faria et al., 2020), that demonstrates that CRT has shown both process-specific and general beneficial effects on attention, with improvements sustained over follow-up periods (Faria et al., 2020; Lezak et al., 2012).

However, there was a statistical difference between the results pre- and post-intervention at the TMT B at the CG, which indicates that there was an alteration in the capacity for cognitive alternation and executive control (Marques, 2022; Reitan & Wolfson, 2004).

There was also a reduction in the time spent to complete the tests but an increase in the Toulouse Piéron Dispersion Index (DI) in this group, which can indicate greater variability in task performance, suggesting difficulties in sustaining attention, maintaining consistent cognitive effort, or managing cognitive load efficiently. Such variability can indicate impaired executive functions commonly affected by ABI. Additionally, fluctuations in performance may reflect cognitive fatigue, a condition where cognitive stamina is compromised, leading to increased variability. This is particularly relevant in ABI. If the test or task measuring the dispersion index targets specific cognitive functions like memory, attention, or processing speed, a rise in dispersion might indicate deterioration or lack of improvement in these areas (Lezak et al., 2012; Lima et al., 2023).

In the TMT A, we observed that 50% of the CG exhibited a significant general improvement, in contrast to only 33% of the EG. For the TMT B, the CG showed a complete improvement in results, as verified through the RCI, while 50% of the experimental group demonstrated significant improvement. Regarding the TP, we noted a 50% reduction in the overall dispersion index value in both groups.

We also observed an increase in memory at CG. It was expected that there could be a significant improvement in verbal memory also at the EG, as shown in previous studies (Faria et al., 2020) because CRT techniques leverage the brain's remarkable neuroplasticity to enhance cognitive function following brain damage. Memory training and CRT methods employ targeted treatments to improve memory and overall cognitive abilities. This process strengthens memory consolidation and neuronal connections, enhancing the brain's ability to retrieve information over time. Computer-based cognitive training programs represent another form of cognitive rehabilitation that capitalizes on neuroplasticity. Through repeated exposure to mental challenges, individuals gradually improve their performance in these tasks due to reinforced neural networks and enhanced cognitive processes, exemplifying the brain's ability to adapt and remodel itself (Zotey et al., 2023), as was proceeded in the EG.

Between both groups, there wasn't any significant difference statistically and even no noteworthy difference at the Median values.

In the VPA test, we observed a 17% improvement in the participants from both groups but a 50% reduction in the overall value of RCI at the CG.

Concerning the executive functions, there is only a statistical difference at the EG between baseline and post-intervention at the coding test. Still, we can see that there is a quantitative increase in both groups, which can confirm the literature that affirms that the combined cognitive and psychological interventions effectively improve cognitive functions, such as attention, memory, and executive functions. This improvement at the impairment level highlights the direct impact of CRT on cognitive abilities. Furthermore, when there is an investment in cognitive and emotional functioning, these improvements inherently support better social interactions. Enhanced cognitive functioning enables individuals to process better and respond to social cues, while improved emotional regulation helps manage social interactions more effectively (Davies et al., 2023). No other statically differences were found in the other tests within groups or between groups.

At the coding test, we observed a significant improvement of 17% among participants from both groups, but 83% of the CG showed no change in RCI values. In the Symbol Search test, there was a general improvement of 17% in the EG and a significant reduction in 50% of the individuals in the CG. For the Frontal Assessment Battery (FAB), a general improvement was noted in 33% of the EG, while 83% of the CG showed no variation in RCI values.

Cognitive stimulation, whether traditional or computerized, enhances general cognitive functioning, memory, orientation, and praxis in older adults. Optimal results are achieved with long-term sessions lasting 45 minutes each. These sessions particularly benefit memory, executive functions, and verbal fluency. Participants aged 75 years or younger experience more significant improvements in general cognitive functioning, memory, orientation, language, and praxis compared to those older (Gómez-Soria et al., 2023). Considering this study, we can inquire that if we had longer time sessions, there could be any better improvement than those gathered.

The study of Nott and Chapparo (2020) about cognitive strategy use in adults with ABI informs that there are significant implications for developing personalized interventions for these people. Understanding the specific cognitive strategy profiles of these individuals allows for the tailoring of interventions to address areas of difficulty, such as perception, recall, planning, and performance. This personalized approach can enhance the effectiveness of rehabilitation programs. Identifying the cognitive strategy used by individuals with ABI enables the design of interventions that address deficits more precisely, potentially leading to improved rehabilitation outcomes and quality of life.

4.2 Secondary Outcomes

We observe that in the EG, there is a decrease in depressive symptomatology and an increase in the perception of quality of life, with a significant difference between pre- and post-intervention in this domain. In the CG, although there was a light decrease, there are overall higher values than the EG in both assessment moments. CRT and related psychological treatments can enhance these areas, supporting the well-being of patients with cognitive impairments, with benefits extending across multiple domains (Lezak et al., 2012).

We need help finding the difference between groups when we analyze the values of de BDI-II or WHOQOL-BREF. For the BDI-II, an equal percentage of EG participants (33%) showed improvement and a decrease in overall RCI values. In comparison, 67% of the CG exhibited a greater reduction in this index score.

As verified by Davies and collaborators (2023), interventions that combine cognitive and psychological elements address not only isolated cognitive or emotional impairments but also aim to improve broader aspects of life, such as social interactions and overall quality of life. Improved cognitive functions facilitate enhanced social participation and activity by enabling individuals to engage more effectively in their social roles and activities. This underscores the importance of a holistic approach in rehabilitation, considering the interconnectedness of cognitive functions and social skills (Davies et al., 2023).

Both cognitive processes and emotional responses must be considered in cognitive therapy, showing the interconnectedness of CRT, cognitive improvement, and the enhancement of social skills. Cognitive treatment not only corrects distorted thinking but also emphasizes understanding and processing emotions. It helps individuals identify troubling emotions and the automatic thoughts that accompany them, aiding in CRT by enhancing clear and less distressful thinking. As individuals become adept at identifying and modifying automatic thoughts, they experience cognitive improvements, such as better problem-solving skills, reduced cognitive distortions, and enhanced decision-making capabilities (Reilly, 2000).

Cognitive therapy improves cognitive flexibility by elucidating the link between situations, thoughts, and emotional responses. As patients learn to interpret and respond to emotions effectively, they also improve their handling of social interactions, including managing social anxiety, interpreting social cues accurately, and responding appropriately in social settings. The training integrates emotional and cognitive processing, emphasizing the role of emotions in the therapeutic process. Addressing these emotions is essential for the patient's cognitive and emotional development and for improving interpersonal skills and social interactions (Reilly, 2000).

A longer, combined intervention associated with the feeling of having someone taking care of them, helping overcome cognitive difficulties, and not feeling abandoned could bring better results for future studies and the enhancement of positive emotions and general well-being. Even if there were no major differences in the assessments, we could affirm that the use of tablet-based intervention can not only facilitate the application at any place, with no use of other material but also enables the engagement and motivation of the patients.

4.3 Study Limitations

The primary limitation of this study was undoubtedly the sample size and the short duration of the intervention, which did not allow for more robust results and may have led to potential sources of error or biases. The condition of not having internet at the intervention places led to the creation of an App prototype of TG 2.0, which involved initial problems during training sessions that were solved iteratively with the informatics team. Additionally, the varying time intervals post-injury could have also interfered with the study outcomes.

The results may have been influenced by the therapeutic relationship, particularly in two cases that exhibited major deficits in the social cognition component. Compensatory strategies were then employed, tailored to each participant's profile, with these two participants requiring more intensive supervision from the psychology intern.

4.4 Future Studies

Future research should investigate the synergistic effects of combined cognitive and psychotherapeutic interventions to develop multidimensional treatment protocols for ABI patients. By focusing on both mental and emotional aspects, rehabilitation programs can more effectively support patients in recovering from cognitive deficits, thereby improving their quality of life, ultimately leading to more successful long-term outcomes. Furthermore, integrating a broader array of cognitive, functional and emotional l outcomes with the RCI analysis would provide a more comprehensive understanding of the intervention's impact. A larger sample with a smaller time lapse after the lesion could reveal stronger results, as it would capitalize on spontaneous recovery. Also, the use of VR both in assessment and rehabilitation should be considered as its potential in simulating real-life scenarios with ecological validity that can be better generalized to real-life performance in everyday tasks.

5. Conclusion

Increased cognitive variability can manifest as inconsistency in social interactions, making it challenging for individuals to keep up with conversations, follow social cues, or respond appropriately due to fluctuations in cognitive processing. These cognitive fluctuations can hinder consistent participation in social activities, leading to reduced social engagement and difficulties in maintaining relationships, potentially causing social withdrawal.

Considering the study results, TG 2.0 had a notable impact on various cognitive domains and aspects of social cognition. This underscores the importance of individualized and contextualized approaches to the assessment and intervention for adults with ABI. Such approaches enable an understanding of how brain injury and specific cognitive difficulties affect an individual's ability to engage in daily activities. This understanding is essential for planning personalized interventions aimed at improving functional independence and community participation.

An adapted approach identifies each client's cognitive strengths and weaknesses, which is vital for developing specific and effective intervention strategies. Furthermore, understanding the unique context of each individual, including their characteristics and goals, ensures that interventions are tailored to their needs, as seen with TG 2.0. This may include employing context-based metacognitive approaches, such as context-sensitive behavioral supports, cognitive orientation for occupational performance, and multicontextual approaches, which can also be achieved with RV. TG 2.0, with the possibility of adapting task parameters and difficulty levels based on patient performance, allows for personalized training that can enhance cognitive functions and positively influence social cognition.

In summary, the individualized and contextualized approach in the assessment and intervention for adults with ABI is essential to ensure that interventions are effective and targeted to the specific needs of these patients. The study's findings validate the clinical utility of the CogMap-SC to assess social cognition and demonstrated the beneficial impact of TG 2.0 on various cognitive domains and social cognition. These results highlight the potential for TG 2.0 to support ABI patients in improving their cognitive functions, mood, and quality of life, ultimately aiding in their social reintegration and overall well-being.

By addressing the objectives of this study—clinical validation of an ecologically valid instrument to assess social cognition and evaluating the impact of a cognitive training intervention on specific cognitive domains (such as memory, attention, executive functions, and social cognition), mood, and quality of life—we provide evidence that TG 2.0 is a promising tool for enhancing cognitive and social outcomes in individuals with ABI and should lead to further and broader scientific studies.

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Appendices

Appendix A: *Informed Consent*

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Consentimento Informado, Esclarecido e Livre para Participação em estudos de Investigação

Identificação do Investigador: Raquel Susana Sá Pereira de Vasconcelos

Título do estudo: Avaliação e intervenção da cognição social através da realidade virtual na lesão cerebral adquirida

Enquadramento: Tese de Mestrado em Psicologia Clínica, da Saúde e do Bem-Estar

Explicação do estudo:

Este estudo tem como objetivo principal desenvolver e validar clinicamente novas tarefas para avaliar e intervir na cognição social, função cognitiva significativamente afetada na Lesão Cerebral Adquirida (LCA). Será realizado um estudo longitudinal controlado e randomizado para avaliar o impacto de uma intervenção neuropsicológica de 12 sessões (com a duração de 30 minutos) com foco na dimensão da cognição social. Antes e após a intervenção será realizada uma avaliação neuropsicológica multidimensional (desempenho cognitivo, humor e qualidade de vida e funcionalidade), onde estará inserida uma tarefa de avaliação da cognição social a ser validada clinicamente com esta população. Para além de tarefas papel-e-lápis, serão utilizadas tarefas em *tablet* e óculos de realidade virtual com *eye-tracking*.

Como objetivo secundário pretende-se avaliar o contributo de eventos traumáticos ao longo da vida para o perfil neuropsicológico dos participantes, nomeadamente ao nível da Cognição Social.

A bateria de testes de avaliação, permitirá após análise dos resultados obtidos, aferir se existem então relações entre as variáveis em estudo. Os instrumentos de avaliação a serem utilizados serão:

- O *MoCA – Montreal Cognitive Assessment*, para avaliar a cognição geral, pois permite avaliar diversos domínios cognitivos (visuoespacial/executivo, nomeação, memória, atenção, linguagem, abstração, recordação atrasada e orientação (Nasreddine et al., 2005; Simões et al., 2008).
- O *TMT- Trail Making Test,* que nos fornece informações acerca de pesquisa visual, digitalização, velocidade de processamento, flexibilidade mental e funções executivas (Marques, 2022; Reitan & Wolfson, 2004).
- O teste de *Toulouse-Piéron Cancellation Test (TPCT)*, será utilizado para avaliar a atenção seletiva/sustentada, velocidade de processamento e habilidades visuo-perceptivas (Lima et al., 2023; Toulouse & Piéron, 1904).
- A *FAB – Frontal Assessment Battery*, que permite avaliar a flexibilidade mental, conceptualização, programação motora, sensibilidade à interferência, controlo inibitório e autonomia ambiental (Dubois et al., 2000; Lima et al., 2008).
- O teste de pesquisa de símbolos e o teste de código da *WAIS-III* - Wechsler Adult Intelligence Scale–III para avaliar a velocidade de processamento e a atenção(Wechsler, 1997).
- O teste de pares de palavras, da WMS-III - Wechsler Memory Scale-III (Wechsler, 1945, 1987).
- O teste de leitura de palavras irregulares (TeLPI) para determinar o nível de inteligência pré-mórbida (Alves et al., 2017).
- O *WHOQOL - Quality Life Assessment* para avaliar a qualidade de vida do paciente em quatro domínios: Físico, Psicológico, Ambiente e Relações Sociais (Vaz Serra et al., 2006; WHOQOL Group, 1998).
  - O *BDI – Beck Depression Inventory*, para avaliar a sintomatologia depressiva (Beck et al., 1996; Brochado, 2013).
- O *CogMap_CS, (Faria et al., 2022)* para avaliar a Cognição Social e a Teoria da Mente.
- Serão também efetuadas uma entrevista estruturada onde constarão dados sociodemográficos e clínicos e uma entrevista de avaliação de objetivos, com vista à identificação dos objetivos de reabilitação dos participantes, a *Goal Atainment Scale* (Kiresuk & Sherman, 1968; Sotero & Relvas, 2014).

Os trabalhos de investigação vão decorrer no Serviço de Neurocirurgia do Hospital Dr. Nélio de Mendonça sob orientação da Dra. Mónica Nóbrega, em articulação om a Prof. Ana Lúcia Faria da Universidade da Madeira. Os participantes do estudo serão recrutados no Serviço de Neurocirurgia e alocados ao grupo de controlo ou experimental de acordo com uma sequência obtida no *Research Randomizer* (http://randomizer.org). Os dados recolhidos relativamente à avaliação e intervenção de cada participante serão anonimizados e incinerados após 5 anos.

Condições e financiamento:

O estudo está autorizado pela comissão de ética do SESARAM- Serviço Regional de Saúde da RAM, através do parecer 10/2020 e está inserido no LifeTech Madeira – Quality of Life Technologies Centre of Madeira. Os recursos tecnológicos serão cedidos, pelo grupo NeuroRehablab, da Universidade da Madeira e da ARDITI, e incluem a plataforma MUSIQUENCE, (onde serão desenvolvidas as tarefas), e os óculos de realidade virtual HTC VIVE Pro Eye. Estes recursos são financiados pelo projeto projeto MACBIOIDI (INTERREG program MAC/1.1.b/098).

Anonimato e confidencialidade:

A participação neste estudo é voluntária e não envolve quaisquer riscos. Os dados recolhidos serão utilizados exclusivamente para o estudo acima descrito, assegurando-se a proteção de dados e anonimato dos participantes, sendo atribuído para tal um código para cada participante. Todos os contactos serão efetuados em ambientes onde se assegurará a privacidade e confidencialidade dos utentes participantes. A equipa de investigação estará sempre disponível para esclarecer qualquer dúvida e os participantes podem recusar ou desistir de participar a cada momento do processo. Quaisquer questões poderão ser dirigidas para:

Raquel Vasconcelos - 2062211@student.uma.pt

Este projeto estará em conformidade com os seguintes procedimentos no que diz respeito ao tratamento de dados pessoais:

- Os dados não serão recolhidos sem autorização. Antes do recrutamento, todos os voluntários serão informados verbalmente e por escrito sobre os pormenores do ensaio a ser realizado, incluindo qualquer risco envolvido. Todos os pacientes assinarão um Consentimento Informado (em anexo) antes da participação no ensaio;
- Nomes, datas de nascimento e outros dados sensíveis e passíveis de identificação serão encriptados para proteger a privacidade do paciente e dos dados recolhidos;
- A informação recolhida será utilizada apenas para o propósito do projeto e não será retida para outros fins;
- Nenhuma informação pessoal será tornada pública ou cedida a terceiros;
- Serão aplicados controlos técnicos estritos para garantir que a informação não seja disponibilizada inadvertidamente a organizações de marketing direto ou outras terceiras entidades.

Por favor, leia com atenção esta informação. Se achar que algo está incorreto ou que não está claro, não hesite em solicitar mais informações.

Se concorda com a proposta que lhe foi feita, queira assinar este documento.

Assinatura de quem pede consentimento:

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Declaração de Consentimento do Participante

Eu,____declaro ter lido e compreendido este documento, bem como as informações verbais que me foram fornecidas pela/s pessoa/s que acima assina/m. 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 fins científicos e publicações que delas decorram e com as garantias de confidencialidade e anonimato que me são dadas pelo/a investigador/a.

Assinatura legível e manuscrita:

____

Data:____/____/ _______

Appendix B: *Survey Questionnaire*

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Dados Demográficos

1. **Género**

Preencher com uma cruz.

Masculino: ☐

Feminino: ☐

Outro: ______________________

2. **Idade:**

Preencher com uma cruz.

30 até 39 ☐

40 até 49 ☐

50 até 59 ☐

60 até 70 ☐

Superior a 70 ☐

3. **Profissão:______________________**

4. **Habilitações Literárias**

Preencher com uma cruz.

1.º Ciclo do ensino básico (4 anos de escolaridade): ☐

2.º Ciclo do ensino básico (6 anos de escolaridade): ☐

3º Ciclo do ensino básico (9.º ano): ☐

Ensino Secundário (12.º ano) Outro: ☐

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Dados Clínicos

5. Como se encontra a capacidade visual?

Preencher com uma cruz.

Pouca visibilidade	☐	☐	☐	☐	☐	Boa visibilidade
	1	2	3	4	5	

6. Como se encontra a capacidade auditiva?

Preencher com uma cruz.

Pouca audição	☐	☐	☐	☐	☐	Boa audição
	1	2	3	4	5	

7. Como se encontra a mobilidade?

Preencher com uma cruz.

Pouca mobilidade	☐	☐	☐	☐	☐	Boa mobilidade
	1	2	3	4	5	

8. É capaz de se permanecer sentado(a)?

Preencher com uma cruz.

Com muita dificuldade	☐	☐	☐	☐	☐	Sem dificuldade
	1	2	3	4	5	

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9. Sabe ler?

Preencher com uma cruz.

Sim ☐

Não ☐

10. Sabe escrever?

Preencher com uma cruz.

Sim ☐

Não ☐

11. Presença de diagnóstico médico?

____

12. Medicação atual:

Antidepressivos _______

Ansiolíticos__________Outras:________________________________

13. Consumo de substâncias: Álcool _______; Tabaco _______; Outro __________

14. Lesão Cerebral Adquirida

Data de ocorrência: _________/__________/___________

Tipo: _____________________Localização: __________________________

15. Terapia Ocupacional ou Fisioterapia

A beneficiar de TO ou FT: SIM__ NÃO__

Se **NÃO -** Terminou há: Menos de 2 Meses __ Mais de 2 Meses__

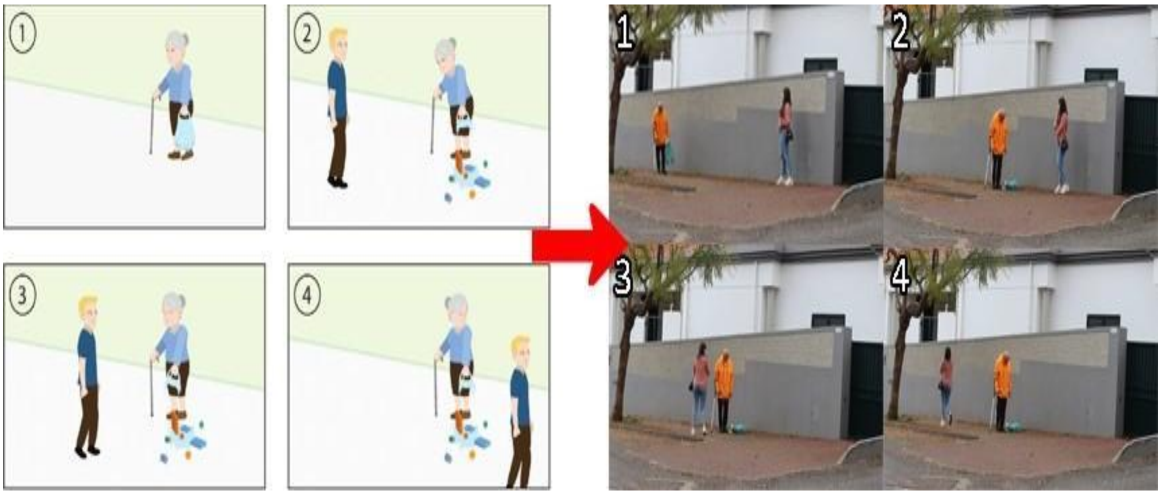
Se **SIM -** Local:_________________ Terapeuta:__________________________

Frequência: 1x por semana__ 2x por semana__ 3x ou + por semana__

Appendix C: *Images of EsCot assessment*

Figure 5

Images retrieved from EsCoT assessment transcribed by movie style at the CogMap-CS



Appendix D: *CogMap environment, examples of scenarios and questions*

Figure 6

CogMap-Cs adjustable environment

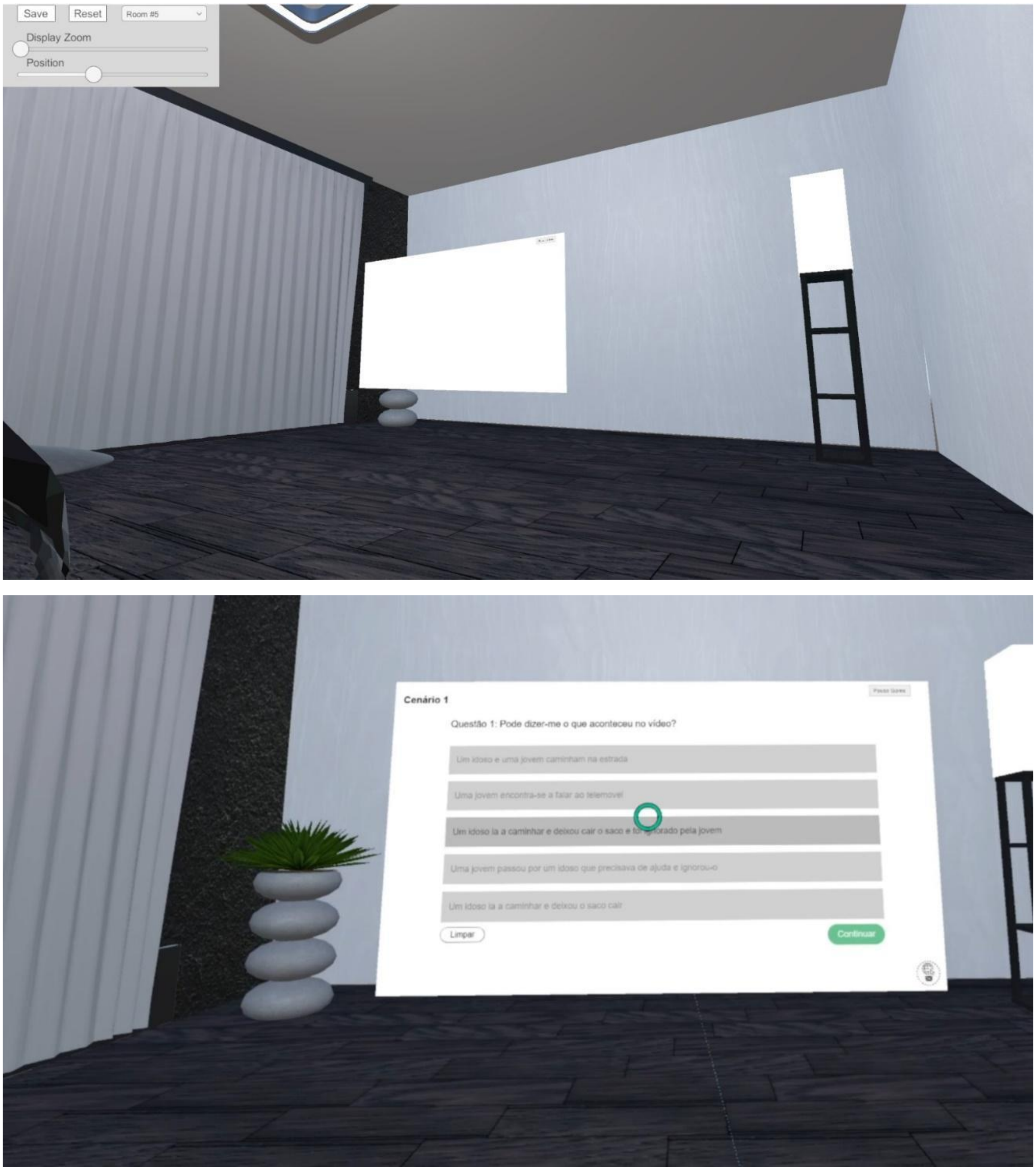


Figure 7

Example of CogMap-CS scenarios

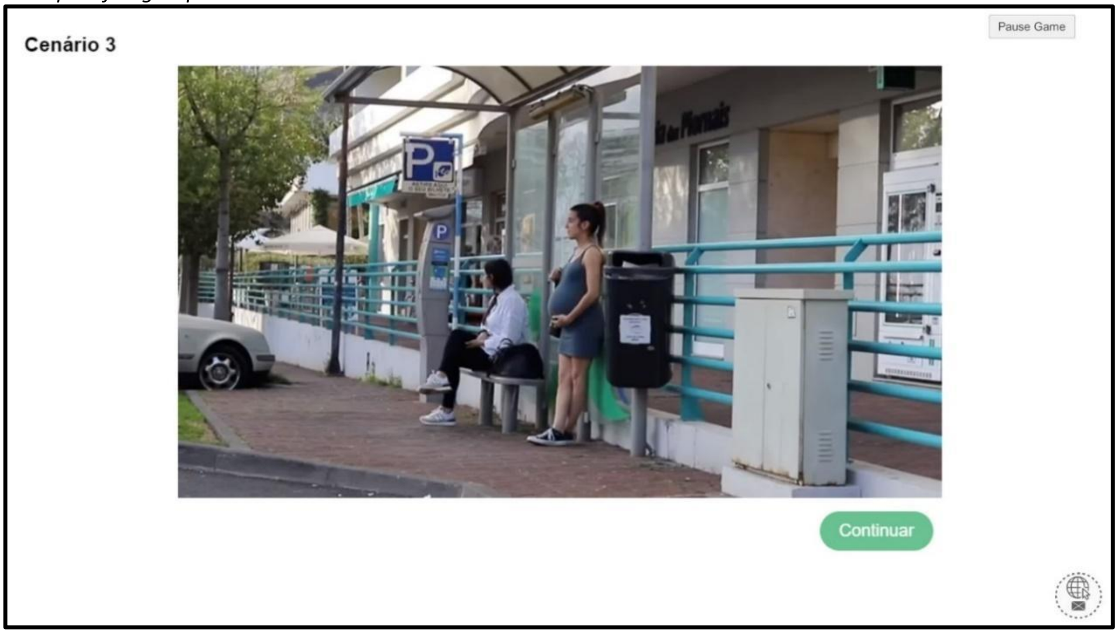


Figure 8

Example of questions of CogMap-CS