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**Assessing social cognition  
using virtual reality and eye-tracking  
in the neurosurgical context**

MASTER THESIS

**André Filipe Sousa de Freitas**

INTERNATIONAL MASTER OF INTERACTIVE MEDIA DESIGN



UNIVERSIDADE da MADEIRA

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## Sumário

Durante uma cirurgia acordado ao cérebro, as diversas funções cognitivas são monitorizadas através de testes neuropsicológicos durante estimulações elétricas. O domínio da linguagem é o domínio mais testado neste tipo de cirurgia. Avaliar outras funções cognitivas durante este procedimento, apresentam inúmeras limitações, tais como, a criação e validação de tarefas tendo em conta as condições disponibilizadas durante a cirurgia. A realidade virtual permite a combinação de realismo com o controlo experimental necessário durante a avaliação cognitiva, o que conseqüentemente, permite inúmeras possibilidades de avaliar outras funções cognitivas mais complexas, tais como a cognição social. Caso a cognição social não seja avaliada corretamente, isto pode causar que a pessoa afetada apresente muitas dificuldade em manter e criar relações sociais, assim como afetar significativamente a sua capacidade de compreensão de interações sociais ou comportamentos indevidos em sociedade. Com esta pesquisa, adaptámos um instrumento de avaliação neuropsicológica da cognição social - o Edinburgh Social Cognition Test (ESCoT) - para a realidade virtual (VR), que denominámos CogMap para Cognição Social (CogMap-CS). Três estudos, com dois protótipos diferentes do CogMap-CS (interação com comandos físicos e rastreamento ocular) foram realizados com participantes saudáveis e pacientes que apresentavam lesões cerebrais ou crescimento de tumores cerebrais. Em geral, o CogMap-CS apresentou pontuações e feedback muito positivos, permitindo a recolha de mais informações sobre como podemos proceder para atingir o nosso objetivo final de validação clínica. No futuro, pretendemos implementar o CogMap-CS para ser utilizado durante cirurgias com paciente acordado ao cérebro e obter validação de profissionais de saúde e psicólogos na área de neuropsicologia.

**Keywords:** Cirurgia ao Paciente Acordado · Realidade Virtual · Traumatismo Cranio-Encefálico · Cirurgia de remoção de tumores, Rastreamento Ocular · Saúde

## Abstract

During Awake Brain Surgery (ABS), cognitive functions are monitored with neuropsychological tests during electrical stimulation. Language is the most tested domain. Assessing other higher cognitive functions imposes limitations primarily due to the challenges associated with tailoring neuropsychological tasks to the conditions of awake surgery. Virtual Reality (VR) can combine the realism of stimuli with the experimental control required during cognitive evaluation, offering possibilities of assessing other complex cognitive functions, such as the case of social cognition. If not assessed properly, this can cause the affected person to suffer from severe social detachment, hindering their ability to understand social interactions or social signals. Within this research, we have adapted a neuropsychological assessment instrument of social cognition - the Edinburgh Social Cognition Test (ESCoT) - to virtual reality (VR), which we have named CogMap for Social Cognition (CogMap-SC). Three studies, with two different prototypes of CogMap-SC (virtual reality controllers and eye-tracking) were conducted with healthy participants and traumatic brain injury/tumor patients. Overall, CogMap-SC presented very positive scores and feedback giving us more insight on how we can proceed to achieve our final goal of clinical validation. In the future, we intend to implement this VR application for use during an ABS and obtain validation from health professionals and psychologists.

**Keywords:** Awake Brain Surgery · Virtual Reality · Traumatic Brain Injury · Tumor Removal Surgery · Eyetracking · Health

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## Acronym list

**ABS** - Awake Brain Surgery

**TBI** - Traumatic Brain Injury

**BT** - Brain Tumor

**VR** - Virtual Reality

**ESCoT** - Edinburgh Social Cognition Test

**HTML** - Hypertext Markup Language

**CSS** - Cascading Style Sheets

**JSON** - JavaScript Object Notation

**UI** - User Interface

**CogMap-SC** - CogMap for Social Cognition

**SDK** - Software Development Kit

**3D** - Three Dimensional

**2D** - Two Dimensional

## 1 Introduction

Brain surgeries are generally undertaken on individuals who have experienced traumatic brain injuries (TBI) or brain tumor (BT) growths. Optimally, these surgeries are conducted with the patient in an awake state, facilitating real-time evaluation of cognitive functions that might be impacted during the procedure [1]. Cognitive evaluations are performed through brain mapping, which involves the identification and localization of various brain regions to ascertain their specific roles. This technique involves the application of electrical stimulation for no more than 5 seconds during the cognitive assessment, thereby temporarily inhibiting the targeted cognitive function. Unfortunately, patients often exhibit impairments in cognitive functions not associated with language post-surgery. This occurrence is predominantly attributed to a lack of comprehensive assessment tasks for intricate cognitive functions and operating room exigencies. The language domain, primarily evaluated through nomination tasks, is the most frequently assessed cognitive domain (Figure 1). Cognitive and movement domains are less assessed during ABS mostly because of difficulties adapting tasks to the surgical context and the 5-second stimulation interval [2, 3]. Nevertheless, other cognitive functions, such as social cognition, require consideration. Inadequate assessment of social cognition during awake brain surgery (ABS) can result in significant deficits in interpreting social cues and maintaining interpersonal relationships [4, 5].

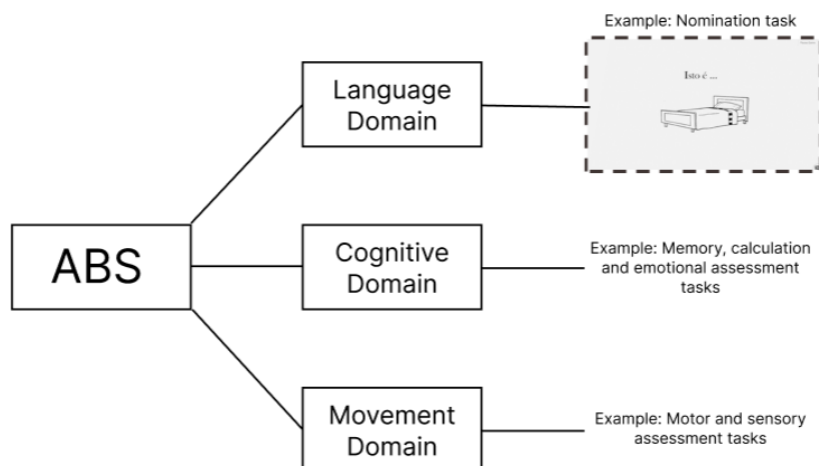


Figure. 1: ABS and different domains that require assessment

The integration of virtual reality (VR) within a surgical context facilitated the development of more sophisticated assessment tools [6]. These tools could incorporate 3D environments and human interactors without necessitating their physical presence, thus enabling participants to engage in more stimulating assessment and rehabilitation activities rather than being restricted to conventional paper-and-pencil tasks [7]. Serious VR games emerged as valuable instruments not only for raising awareness on specific topics but also for enabling clinicians and psychologists to devise more comprehensive assessment and rehabilitation tasks [8]. Nonetheless, psychologists required additional tools for creating immersive experiences. Consequently, eye-tracking technology demonstrated considerable potential in the healthcare sector [9]. Eye-tracking provided eye-gaze data that could be utilized to identify various psychological discrepancies and to comprehend attention deficits. This technology also enabled the replication of human-eye interactions within serious games.

Given these considerations, integrating both technologies would facilitate the development of more sophisticated games that disseminate comprehensive information while fully immersing the user in a three-dimensional environment. Applying these technologies within ABS would enable more intricate assessments, thereby reducing the likelihood of cognitive deficits.

In this thesis, we developed - CogMap for Social Cognition, or "CogMap-SC", an assessment tool incorporating virtual reality technology and eye-tracking capabilities for evaluating social cognition. This tool enables psychologists to perform more sophisticated assessments on various aspects of social cognition while simultaneously collecting data on patients' visuospatial search patterns, facilitating the detection of attention deficits.

## 1.1 Motivation

During my undergraduate studies, I had the opportunity to select a software or research company for a four-month internship. NeuroRehabLab was my facility of choice. A friend had introduced me to the lab, and I had read about some of their accomplishments. After an initial discussion with the principal investigator, I learned that their research primarily focused on neurological and psychological evaluations and rehabilitation. Initially, these topics appeared highly complex, and as someone with no prior experience in these fields, I believed I would never develop an interest in them. However, after four months, my perspective underwent a significant transformation. The

field of neuropsychology is exceptionally intriguing, characterized by numerous intricacies that demand considerable attention and effort. Consequently, I resolved to pursue a master's degree with NeuroRehabLab to delve deeper into neurological research. Awake Brain Surgeries (ABS) in Portugal remain relatively underdeveloped, relying on basic tasks for psychological assessments during brain mapping. This poses a risk during such procedures, as not all cognitive functions can be evaluated using these elementary tests. Therefore, we undertook the task of developing more comprehensive tasks to assess complex cognitive functions.

## 1.2 Previous Work

In collaboration with NeuroRehabLab, our efforts were directed toward the development of assessment tasks designed for use in ABS. By leveraging VR and eye-tracking technologies, we successfully devised three tasks aimed at evaluating the language domain within ABS (Appendix A). The HTC Vive Pro Eye was selected as the primary technology due to its capability to provide real-time eye data monitoring, while also enabling users to engage in tasks involving eye-tracking interactions. Although the task and its various features were fully developed, we were unable to carry out validation studies due to time constraints. Having completed this assessment task, we resolved to advance towards more intricate cognitive functions, as prior research has demonstrated a deficiency in such studies.

These initial explorations into the realm of ABS, clinical assessment, and technologies related to VR and eye-tracking, were instrumental in understanding the complex relationship between neurology and psychology. These insights further highlighted the need for enhanced evaluation tools within clinical assessments. As previously noted, the language domain has been the most extensively assessed cognitive domain. This focus has presented significant hurdles, as numerous other cognitive functions necessitate similar levels of attention. Building upon the preceding research, we pinpointed the cognitive functions in greatest need of attention and, in this case, prioritized social cognition.

## 1.3 Scientific Contributions

This thesis aims to yield substantial scientific contributions. To assess social cognition, it was necessary to select a previously validated social cognition tool, specifically, the Edinburgh Social

Cognition Test (ESCOT). This research includes usability studies and clinical case studies conducted over varying periods. These studies were carried out with local participants, necessitating the translation of the ESCOT into Portuguese. Additionally, this thesis provides the scientific community with design and technical specifications for the development of applications utilizing VR and eye-tracking technology, employing three distinct VR headsets: the HTC Vive Pro Eye, the Meta Quest 2, and the Meta Quest Pro. Lastly, it is anticipated that this thesis will enhance awareness regarding the necessity for more sophisticated assessment tools.

This thesis has further contributed to the dissemination of knowledge through the publication of two minor scientific articles in ABS.

- 1 - **"Development of virtual reality-based tasks for cognitive and emotion mapping during awake brain surgery for tumor resection: the CogMap system"** by Ana Lúcia Faria et AL (2022) - Poster I co-authored for a conference, featuring an eye-tracking application for ABS that included three tasks: Nomination task, Stroop Test and the Trail Making Test.
- 2 - **"Assessing social cognition using virtual reality in the neurosurgical context"** by André Freitas et AL (2024) - Poster and short paper I authored for a conference that featured the first prototype of CogMap-SC and a study with healthy participants.

Our most recent contribution has been accepted as a full paper at an esteemed international conference on health and social care. We are expected to present our findings and ensure the inclusion of our paper in the conference proceedings.

#### 1.4 Objectives

Taking into account what we discovered from our previous work, we realized that ABS focused mostly on the domain of language. This happened because of the difficulty in adapting to more complex assessment tasks in the context of ABS. ABSs are usually performed in very limited spaces where the use of technology becomes even more limited due to the clinical environment. As such, with the rise of VR, we saw an opportunity to create more complex tasks that would aid in assessing more complex cognitive functions. One very important cognitive function is social cognition, which if not properly assessed, could lead patients to suffer from severe depression, lack of understanding of social norms, and difficulty in creating and maintaining relationships. With this in mind, we set as our main objective for this thesis, to adapt a previously clinically validated

social cognition assessment task to VR and obtain its clinical validation. The combination of VR and eye-tracking technologies would further allow us to create immersive environments that would only require the use of a patient's eyes to interact. The coexistence of these two technologies would therefore aid us in the integration of VR and eye-tracking technologies in ABS procedures.

## 1.5 Requirements

A critical requirement for this project was the necessity of an assessment tool. For this purpose, we selected the clinically validated social cognition assessment test, the Edinburgh Social Cognition Test (ESCoT). Another significant consideration, that could potentially impact user immersion, was the environment and the manner of presenting and interacting with the diverse scenarios. Typically, the ESCoT is conducted utilizing a paper-and-pencil method, necessitating that our adapted VR application avoids inducing distress or causing discrepancies in task completion compared to the traditional method. One of the most significant obstacles was the recruitment of participants who had either suffered traumatic brain injuries or experienced tumor growth. Modifying the developed tasks to meet the varied physical and psychological needs of the participants necessitates extensive patience and rigorous research. Finally, given that our primary objective was to achieve validation of this tool during ABS, the most significant requirement was to observe and integrate the technology into ABS. As these procedures are infrequently performed within SESARAM, it would necessitate either awaiting the scheduling of such surgeries or seeking alternative countries where these clinical procedures are more routinely conducted.

## 1.6 Document layout

This thesis will commence with an introduction to related works pertinent to the research topic, providing a comprehensive understanding of the requisite requirements. Subsequently, a detailed exposition of the implementation process will be presented. This section of the document will encompass the translation and adaptation of the ESCoT into CogMap-SC then proceed with the development of two initial prototypes along with an extensive description of the technological and software tools employed. Following this, three studies essential for the validation of the previously developed prototypes will be disclosed. The thesis will culminate in a thorough analysis of the feedback and data obtained from these studies, which will be discussed, leading to a conclusion that encapsulates the entire work and a projection of the future prospects for CogMap-SC.

## 2 Literature review

### 2.1 Awake Brain Surgery and the assessment of complex cognitive functions

During Awake Brain Surgery (ABS), cognitive functions are monitored while a specific brain area receives direct electrical stimulation to inhibit its function. This procedure optimizes tumor resection within eloquent areas while minimizing the risk of permanent deficits [1]. Due to difficulties adapting cognitive assessment tasks to the operating room, ABS has been performed primarily in lesions involving language areas [2]. However, it is of great interest to further preserve complex cognitive functions to maintain patient functionality and quality of life [3]. For example, social cognitive deficits, which refer to the ability to perceive, interpret, and act on social information, are critical predictors of functional outcomes, affecting the ability to create and sustain interpersonal relationships. Although these abilities are central to the patient's functioning, they are under-assessed in the context of acquired brain injury in general [4]. The most recent edition of the Diagnostic and Statistical Manual of the American Psychiatric Association for Mental Disorders (DSM-5) introduced social cognition as one of the six core components of neuropsychological functioning alongside complex attention, learning and memory, executive function, and perceptual motor function, which could lead to a change in attention for this important domain. Social Cognition, as defined by Arioli et al. [5], consists of "a set of processes, ranging from perception to decision-making, underlying the ability to decode others' intentions and behaviors, to plan actions fitting with social and moral, besides individual and economic considerations.". This term encompasses many different topics regarding social cognition since it cannot be described by just one word. It addresses the topics of the nature of the human being, such as social perception, social understanding, and social decision-making, while also mixing with the morals imbued by society. Some paper and pencil tasks are available to assess these abilities, for example, ESCoT [10], TASCIT [11], and Reading the Mind in the Eyes [12]. However, these are limited in accuracy, sensitivity, validity, and means of presentation and interaction. Assessing social cognition in the context of ABS for tumor resection is very important but challenging, especially with operating room contingencies. However, with the arrival of new technologies, the creation of more complex assessment tools is becoming more and more feasible.

## 2.2 Virtual Reality and opportunities

The use of virtual reality for health purposes has been growing exponentially, allowing the creation of fictional environments to simulate or present real-life scenarios, leaving reality for a brief time or just making up scenarios that would otherwise be impossible to reenact in reality. Seeing this as an opportunity, several studies took advantage of this technology [6], using serious games and simulations of daily life situations as a means of assessment and intervention. There is a growing need for new neuropsychological assessment and intervention instruments, not only because traditional ones are becoming outdated and inadequate but also because there is an increasing number of people who need them. It would be needed a huge number of human resources to adequately respond to the needs of the growing number of acquired brain injuries (stroke, brain tumors, traumatic brain injuries...) and degenerative diseases (Alzheimer's, Multiple Sclerosis...) Technology can help these professionals to respond adequately to the needs of the patients.

For example, the development of serious games became a worldwide phenomenon that instigated many studies due to the many advantages of playing video games and how they affect a person's well-being. One study that goes into further detail about the gamification of rehabilitation was a study conducted by Silva [8]. This short study delved into how stroke victims require cognitive rehabilitation to improve their way of living and rehabilitate them into society. As such, they implemented Rehab&Play, featuring many different types of games related to the topics of attention, perception, and memory, created with the help of a rehabilitation software named Musiquence [13]. This short study presented very positive results, paving the way for the application to possibly be featured in other related studies or a more longitudinal study. This is but one example where gaming can be used for rehabilitation or assessment.

As virtual reality becomes a more prevalent and accessible technology, it was noticed that it can be a very functional tool for creating virtual environments and heightening the possibilities of creating serious games that stray further from the already existing means of assessment and intervention psychology. A great example of this is a study conducted by Mendes [7], that featured the implementation of two types of virtual environments: one that used abstract fractal geometries. In contrast, the other one used realistic natural landscapes, to compare perceived restorativeness and stress reduction. The possibility of using VR in this study allowed them to better immerse the participants in the environments and obtain better and much clearer results. This study concluded

that, despite some limitations, fractal-based abstract environments could be used for restoration purposes. Virtual environments can also be used to provide users with a simulation-type exercise. Faria and her colleagues [9] conducted a systematic review of over 70 studies, selected from approximately 363 in total, in which they identified that virtual reality greatly facilitates the creation of realistic scenarios. These created scenarios commonly replicated various locations within a household or typical daily environments frequented by individuals and were mostly used for ecologically valid simulations of daily tasks. However, despite the informative insights provided, many of the case studies reviewed suffered from insufficient participant numbers, thus hindering the full validation of this tool. Notwithstanding these challenges, virtual reality presents itself as an optimal candidate for the implementation of innovative cognitive mapping paradigms, due to its cost-effectiveness and the ease with which it integrates supplementary technologies, such as eye-tracking. As these technologies continue to advance, psychologists and researchers are allowed to devise novel methodologies for assessing an individual's social cognition in a manner that is more accessible, accurate, and ecologically valid. Several new technology-based assessment tools and methods have been developed; however, they necessitate thorough clinical validation and adaptation for interactive use, particularly in Applied Behavioural Science contexts. For instance, the Awareness of Social Inference Test (TASIT) [7] has been adapted into a VR-based format with 360° video footage, yet it still requires validation. It is anticipated by the authors that the VR-based TASIT will exhibit psychometric properties that are comparable or superior to the traditional version and that the purported enhanced level of social presence experienced in a virtual environment will lead to improved ecological validity.

### **2.3 Eye-tracking and capabilities**

During social interactions, people's eyes convey a wealth of information about their attention direction and emotional and mental states [14]. This encompasses the perception of gaze direction and its influence on the other person's perception and gaze-following behavior. Eye-tracking had its debut a few years before VR, allowing people to gather eye data and many other eye-related information, such as visuospatial search patterns to detect attention deficits. Taking advantage of the eye-tracking data, in a study by Suslow [15], it was possible to observe that people with clinical depression (or a more severe case of depression) presented an increase in attention maintenance on dysphoric stimuli. In contrast, a decrease in attention maintenance was observed on

more positive stimuli. This study allowed a better understanding of how depressed people explored different types of stimuli and how depression affected their behavior while doing so. Rehder & Hoffman's study [16] consisted of the usage of an eye-tracker to assess selective attention in category learning. The data collected by each participant provided very important eye data that, after being interpreted, showed that participants demonstrated, throughout the tasks, that they gained better capabilities in allocating their attention optimally. Many studies that feature eye-tracking focus on the gathering of attentional data, since gaze and other eye data are the best ways to obtain such data. A study conducted by Skinner [17] emphasized this by evaluating the reliability of using eye-tracking to assess attentional bias to threatening words in healthy participants. By presenting two words on a screen - a threat word and a control word, the participants were then asked to read the words until a timer concluded - the study managed to conclude that the participant's gaze would wander more towards control words rather than the threat words. Since eye-tracking is still not a very accessible tool, many researchers perform user experience studies, sharing best practices guidelines, as a way of helping and motivating other researchers that intend to conduct studies with eye-tracking [18–20]. Other areas of research that take advantage of eye-tracking features are, for example, 1) emotional design using anthropomorphisms to understand how much they can affect a person's emotional state [21]; 2) assessment of capabilities of reading maps (cartography) and individual's perception and cognition [22]; and 3) the effect of cognitive impairments in the process of decision making [23–25]. Over the last few years, eye-tracking has made its way into research. This technology provides researchers with many other means to evaluate attention span, visuospatial search patterns, and other related abilities. Researchers have been using this technology in their favor, utilizing the different possible measurements that could be captured with eye-tracking devices [26]. For example, gathering data on a patient's pupil dilation can provide knowledge about the difficulty of a task, mental effort, and neural gain. . As the technology evolved, eye-tracking and virtual reality headsets combined became a reality, once again stimulating several studies and introducing even more means of measuring dimensions of interest within neuropsychological assessment and intervention [27–37]. These two technologies were used in the operating room for ABS social cognition assessment, by Casanova and colleagues [30]. They evaluated the feasibility and safety of a VR headset with incorporated eye-tracking (a Tobii Pro VR Integration, an eye-tracking retrofitted HTC VIVE) to present a visuospatial and social VR experience to 15 patients with brain tumors near language and/or motor areas. The VR task was

developed with animated avatars to explore nonverbal language, empathy, and theory of mind. None of the patients experienced VR sickness, and the eye-tracking was functional, enabling the clinicians to analyze the patients' attention and explore the visual search patterns.

#### **2.4 Literature Review: Conclusion**

During awake brain surgery (ABS), cognitive functions are monitored via direct electrical stimulation, which optimizes tumor resection while minimizing the risk of permanent deficits. Initially concentrated on language areas, the adaptation of this method to complex cognitive functions such as social cognition is essential for preserving patient functionality and quality of life. Social cognition, which involves the perception, interpretation, and action upon social information, is insufficiently assessed yet critical for functional outcomes. Traditional assessment tools lack precision and ecological validity, prompting interest in novel methods such as virtual reality (VR) or multi-interface technologies such as Musiquence. VR can simulate real-life scenarios, thereby offering innovative and ecologically valid cognitive assessments, while Musiquence can provide flexibility and customization for the creation of complex cognitive assessment tasks related to many cognitive functions. When combined with VR, eye-tracking technology augments the collection of data pertaining to gaze and attention, thereby holding the potential to refine neuropsychological assessments, although it has not yet undergone thorough validation. Recent studies indicate that VR and eye-tracking can be safely integrated into ABS, facilitating the assessment of social cognition without adverse effects, and presenting a promising future for cognitive mapping and assessment methodologies.

### 3 Implementation

In this section, we delineate the various steps involved in the creation of CogMap-SC, complemented by a rationale for the design and technical decisions taken.

#### 3.1 Goals

Considering the collective body of work undertaken by our team and other scholars, we have delineated two objectives:

- Develop a VR-Eyetracking-based application that allows the assessment of social cognition through the usage of external visual stimuli;
- Validate the developed task during ABS with health professionals and psychologists.

These goals were chosen to consider all related work we found and what we understood was lacking in other related studies.

#### 3.2 Tools

The development of this task necessitated the utilization of various tools. The initial implementation involved adapting the ESCoT into the Portuguese language and transforming it into a more close-ended response format. Subsequently, CogMap-SC was developed and integrated into the Musiquence rehabilitation tool utilizing the Unity game development engine. The task demanded physical hardware capable of executing the VR-adapted task we devised. Consequently, three headsets were selected for their compatibility with the development of CogMap-SC: the HTC Vive Pro Eye, the Meta Quest 2, and the Meta Quest Pro, which were changed accordingly depending on the necessity. Each of these VR headsets necessitated distinct Unity Engine SDKs for their development and deployment. In addition to these SDKs, web development tools such as HTML, CSS, and JavaScript were employed for the initial prototype of CogMap-SC.

##### 3.2.1 The ESCoT

The ESCoT consists of ten scenarios in which each scenario features colored comic strips followed by five questions on topics of significant relevance in assessing social cognition.

### **3.2.1.1 General Interpretation**

This topic relates to how well the participant can read social behaviors or can address what is currently happening during a scenario [6]. Questions presented regarding this topic are for example: "Can you tell me what is going on in this video?" or "Could you provide a detailed explanation of what is happening in this comic strip?"

### **3.2.1.2 Cognitive Theory of Mind**

Cognitive Theory of Mind relates to the ability of the participant to dictate what are the intentions and beliefs of another individual [6]. Questions presented regarding this topic are for example: "What did the woman think that the policeman wanted?" or "What did the man think the woman wanted?".

### **3.2.1.3 Affective Theory of Mind**

Affective Theory of Mind, in contrast to the previous topic, relates to the capability of the participant to acknowledge what a person is feeling at the moment [6]. Questions presented regarding this topic are for example: "How did the woman feel after being fired?" or "How did the man feel after dropping his ice cream?".

### **3.2.1.4 Interpersonal understanding of social norms**

This topic, unlike the rest, relates more to the ability of the participant on being able to discern what is considered socially acceptable or not acceptable in a scenario featuring other people [6]. Questions that could be presented regarding this topic could be for example: "Did the women behave like everyone else would?" or "Did the man who was sitting down act according to what other people would do?".

### **3.2.1.5 Intrapersonal understanding of social norms**

Despite sharing a similar name to the previous topic, Intrapersonal understanding relates more to how the participant would behave in a certain situation [6]. Questions about this topic were, for example: "Would you have acted the same way as the woman in the cafe?" or "Would you have done the same thing as the man did?".

## **3.2.2 The ESCoT - Administration and scoring procedure**

These questions were all related to the comic strips shown previously, asking the participant about the different social behaviors displayed, possibly considered correct or incorrect, leaving

that judgment to the participant. They were then scored with values ranging from 0 to 3, zero meaning that no score was given to that answer, and three meaning that the given answer was the most correct. Every scenario followed the scoring template of 0 - 3 - 3 - 3 - 3 - 3 for the five questions and had a maximum score of 12, meaning that if the participant scored 12, he mentioned all the requirements in each question in that particular scenario. The questions that belong to the "General Interpretation" topic were not scored due to possible bias because of the following questions.

### **3.2.3 Adaptation of the ESCoT**

The ESCoT is noted for its incorporation of comic strips and open-ended questions, a consideration that was pivotal during the adaptation process. Consequently, we initiated the process by creating storyboards and adapting the comic strips to feature real-life agents and scenarios. By employing healthy, everyday individuals, we meticulously recreated the comic strips to ensure that the resultant videos accurately depicted the same situations and underlying principles.

#### **3.2.3.1 Adaptation of the ESCoT - Videos**

During the brainstorming phase, the concept of utilizing 360° videos to enhance user immersion was proposed. Nonetheless, this idea was ultimately abandoned due to the significant challenges associated with recording 360° videos in uncontrolled environments, which presented an array of unpredictable negative factors. The primary objective was to develop scenarios featuring fully animated 3D models; however, this endeavor demanded skills and time that were not available. Consequently, it was determined that the initial iterations of the application would employ 2D videos. The filming of these videos spanned three weeks, contingent upon the availability of actors and locations. Participants in these videos signed consent forms, and no personal names were disclosed. To achieve greater realism and immersion, uncontrolled environments were intentionally chosen, incorporating incidental elements such as bystanders and various forms of visual disturbances, including clouds, vehicles, and the presence of wild animals or insects. These settings were recorded using an iPhone camera on Madeira Island, with some scenarios taking place in coffee shops, restaurants, public parks, and bus stops. It is noteworthy that while certain videos serve as precise real-life representations of the comic strips, in several instances, we had to employ creative liberties. Notably, Scenarios 4 and 5 necessitated substantial modifications. The rationale behind

these alterations is explained later. Nevertheless, the contextual integrity and the underlying message of the comic strip were preserved.

### 3.2.3.2 Adaptation of the ESCoT - Questions

By adhering to the scoring criteria outlined in the ESCoT template for each scenario, we developed various options for CogMap-SC, ensuring the responses align with the range of possible scores attainable across different scenarios. Given that this adaptation is intended for use by Portuguese participants, the ESCoT and CogMap-SC were directly translated into Portuguese. For instance, for the initial question of the first scenario, the ESCoT employed this template to evaluate participant responses (Figure 2). If a participant's answer comprehensively fulfilled all requisite criteria, they would receive a score of 3 points for that question.

**Question 1: Cognitive Theory of Mind: What did the man think that the elderly woman wanted?**

Prompt ONCE if needed: *Can you tell me more about what you mean by that? / Can you explain that in a little bit more detail?*

		Additional notes
An answer that recognises that the elderly woman needs help with a specific activity and a contextual reason why she needs assistance. For example <i>help with her shopping because she looks like she is unable to pick it up herself/she has a walking stick so obviously has mobility issues</i>	3	
An answer that recognises that the elderly woman needs help with a specific activity. For example, <i>help with her shopping/her shopping to be picked</i> . No more than two points can be gained if the consequences of her age or situation is not explained <b>(prompt)</b>	2	
An answer that recognises that the elderly woman needs help. For example <i>his assistance/help</i> <b>(prompt)</b>	1	
An answer that does not recognise that the elderly woman needs help. For example <i>him to avoid stepping on her shopping</i> <b>OR don't know</b>	0	

Figure. 2: ESCoT scoring template for the 1st question of the 1st scenario

Contrarily, our adaptation of the CogMap-SC was designed to incorporate the question along with five possible answers, each with their own scores, about the video previously presented.

---

1. **O que é que a jovem estaria a pensar?**

- (a) Que deveria ajudar o idoso mas estava ocupada (3)
- (b) Que não tinha obrigação de ajudar (1)

- (c) Que outra pessoa poderia ajudar o idoso (2)
  - (d) Que cada um é responsável por si (1)
  - (e) Nada (0)
- 

In the subsequent section, we will outline each scenario and explain the principal distinctions in their video adaptations.

### 3.2.3.3 Scenario 1 - Helping the elderly

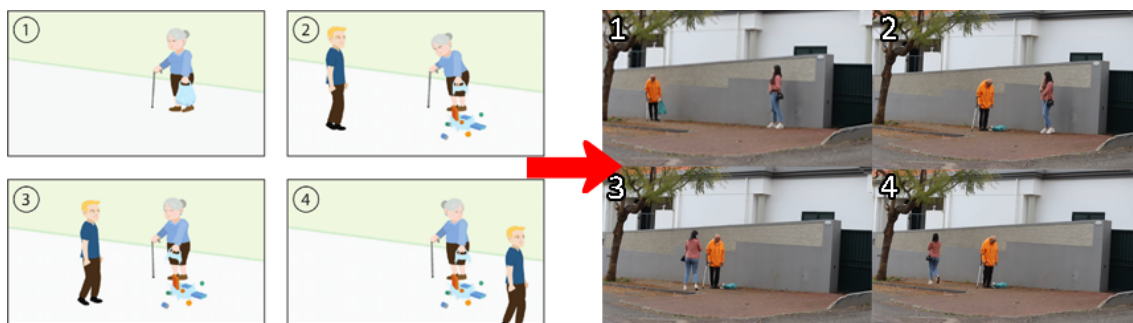


Figure. 3: Scenario 1 comic strip adaptation to video

The comic strip for this scenario (Figure 3) depicts an elderly woman standing on a sidewalk with a cane and a bag of groceries. After a brief period, a young man is observed walking past the elderly woman. Abruptly, the grocery bag collapses to the ground. The young man, exhibiting a lack of attention, walks past the woman without offering assistance. This scenario illustrates a social cue concerning empathy, perception, and aid towards the elderly. In alignment with this context, we recorded a video adaptation of the scene. The video portrays a young woman engaging in a phone conversation when an elderly man carrying a heavy plastic bag filled with groceries, and aided by a cane, passes by. Subsequently, the grocery bag falls to the ground. Rather than assisting the elderly man in retrieving the groceries, the young woman continues to walk away. The video concludes at this point.

The adapted questions related to Scenario 1 can be found in Appendix B.

### 3.2.3.4 Scenario 2 - Disobeying parking regulation

The comic strip for this scenario (Figure 4) illustrates a woman parking her vehicle on a yellow line, adjacent to a "no parking" sign, and subsequently leaving her vehicle unattended. Shortly



Figure. 4: Scenario 2 comic strip adaptation to video

thereafter, she returns to find a police officer standing by her car, issuing a fine for parking in a "no parking" zone. This scenario exemplifies a non-social cue associated with adherence to rules. Within this context, we produced a video adaptation. Due to the unavailability of a police officer for the role, we opted to re-enact the scenario with a construction worker. The video features a construction worker approaching a van that is improperly parked in a "no parking" zone. The vehicle's owner arrives, and the construction worker instructs him to remove the van immediately. The video concludes at this juncture. Despite the variance in actors and specific circumstances, the scenario underscores the significance of adhering to parking regulations.

The adapted questions related to Scenario 2 can be found in Appendix C.

### 3.2.3.5 Scenario 3 - Being considerate on the bus

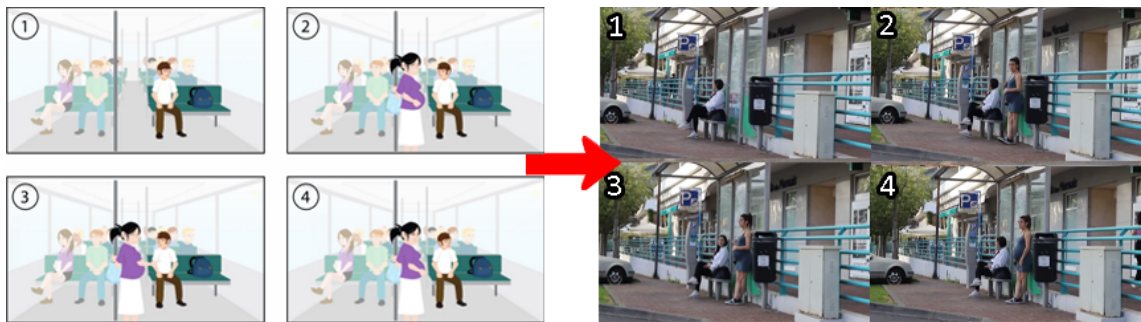


Figure. 5: Scenario 3 comic strip adaptation to video

The comic strip for this scenario (Figure 5) depicts the interior of a bus, where a man sitting down is highlighted. A pregnant woman subsequently appears in search of a seat. She approaches the seated man and requests that he relinquish his seat for her. He disregards the woman and remains seated. This scenario illustrates a social cue concerning empathy, compassion, and aiding pregnant women. With this context, we produced a video adaptation. Filming within the confined space of a bus presents substantial challenges, primarily due to the potential disruption caused by

numerous bystanders, which could complicate the filming process considerably. Consequently, we opted to record the same context at a bus stop. The video portrays a young woman seated on a bench at a bus stop; shortly thereafter, a pregnant woman arrives and requests her to remove her belongings from the bench. The seated woman ignores the request, leaving the pregnant woman standing. The video ends at this point. Although the setting differed, the fundamental principle remained consistent: individuals should recognize and exhibit consideration towards those with disabilities or pregnancies.

The adapted questions related to Scenario 3 can be found in Appendix D.

### 3.2.3.6 Scenario 4 - Cleaning up after your pet

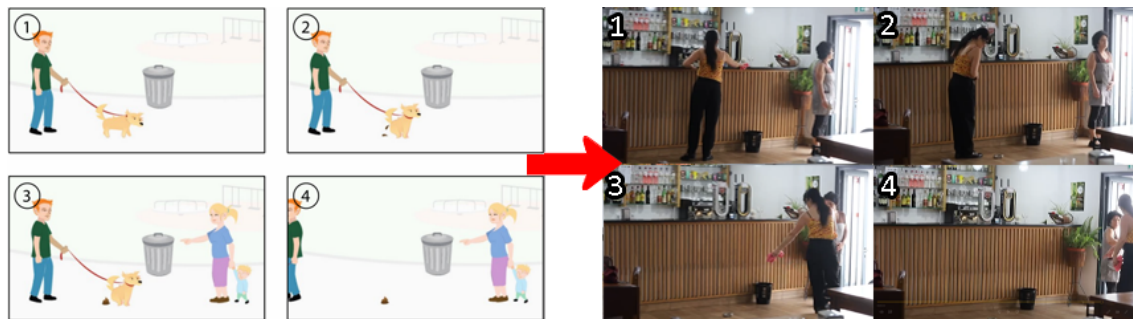


Figure 6: Scenario 4 comic strip adaptation to video

The comic strip for this scenario (Figure 6) illustrates a man walking his dog, which then defecates on the sidewalk. A woman accompanied by her child passes by and advises the man to clean up after his dog. The man, however, disregards her admonition and departs without addressing the mess. This scenario exemplifies a violation of social norms, highlighting the expectation that individuals should clean up after their pets. Building upon this context, we produced a video adaptation of the scenario. Due to constraints preventing the use of a dog in the video, we adapted the setting to an indoor environment. The video portrays a coffee shop server cleaning the counter while a woman stands nearby holding a paper napkin. Shortly thereafter, the woman discards the napkin onto the floor. The server reprimands the woman, insisting that she pick up the napkin. The woman, however, engages in a dispute with the server and eventually exits the shop without complying. The video then concludes. Although significant alterations were made to the environment and characters, the central message remains consistent: individuals should clean up after their own mess.

The adapted questions related to Scenario 4 can be found in Appendix E.

### 3.2.3.7 Scenario 5 - Assisting a neighbour

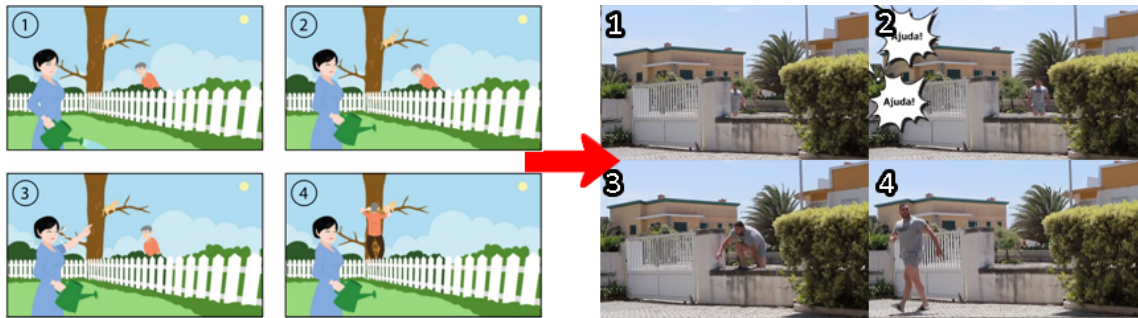


Figure. 7: Scenario 5 comic strip adaptation to video

The comic strip depicted in figure 7 illustrates a woman engaged in watering plants while a cat is precariously positioned on a tree branch and a man walks by. Abruptly, the cat begins to vocalize for assistance, prompting the woman to solicit the man's help. In response, the man vaults over the fence and ascends the tree to rescue the cat. This scenario exemplifies a non-social cue related to empathy and neighborly assistance. Consequently, we recorded a video adaptation of this scenario. Due to the impracticality of sourcing a cat trapped in a tree, the exact scenario could not be replicated. Thus, the video was adapted to a different setting while preserving the thematic essence of assisting one's neighbor. The video portrays a man walking past a house, followed by the appearance of speech bubbles indicating a call for help. Compelled by this cue, the man attempts to open the door but is unsuccessful, ultimately opting to scale the wall of the woman's residence to provide aid. The video concludes at this juncture. Although the element of an animal in distress was omitted, the narrative of neighborly assistance was maintained in the adaptation.

The adapted questions related to Scenario 5 can be found in Appendix F.

### 3.2.3.8 Scenario 6 - Smoking in a prohibited area

The comic strip for this scenario (Figure 8) illustrates two women dining in a restaurant. A red sign at the top of the strip clearly indicates that smoking is prohibited on the premises. Nonetheless, the woman on the left proceeds to smoke a cigarette. The woman on the right, visibly disturbed by this behavior, calls for her attention and informs her that smoking is not permitted. This scenario exemplifies a violation of social norms, as it not only causes discomfort to those nearby but also breaches the establishment's regulations. Based on this context, we recorded a video adaptation of

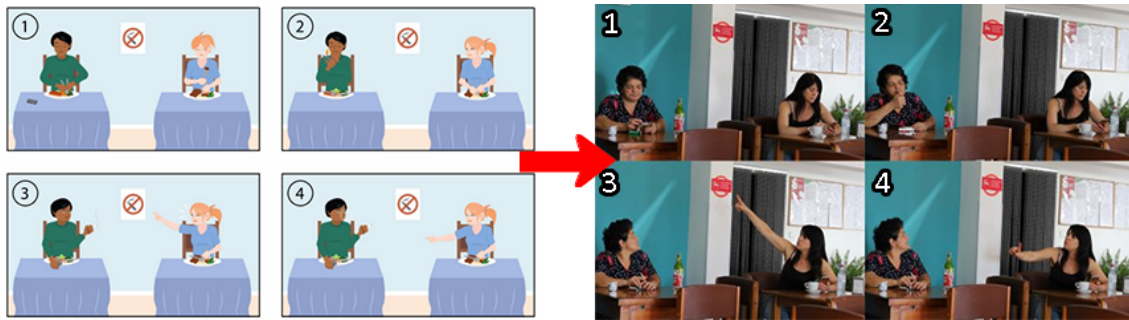


Figure 8: Scenario 6 comic strip adaptation to video

the scenario. The video depicts two women seated in a coffee shop. Shortly after, the woman on the left begins to smoke a cigarette. Mirroring the comic strip, the woman on the right exhibits distress over the situation and gestures towards the no-smoking sign above them. She then indicates that the woman must cease smoking within the coffee shop, at which point the video concludes.

The adapted questions related to Scenario 6 can be found in Appendix G.

### 3.2.3.9 Scenario 7 - Talking in the cinema

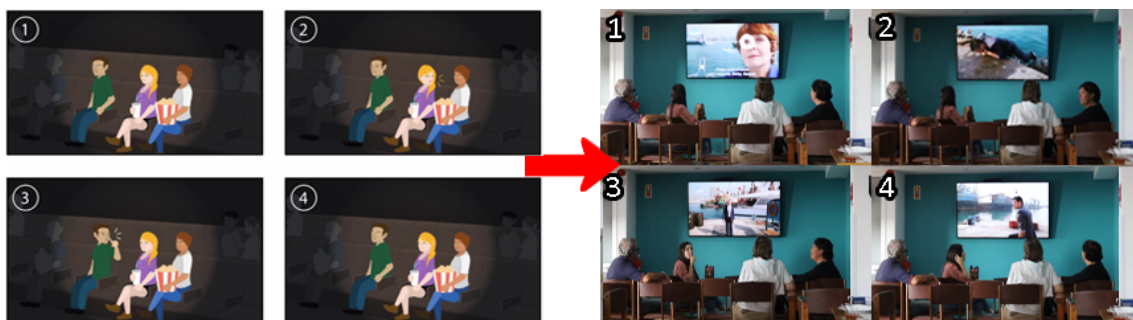


Figure 9: Scenario 7 comic strip adaptation to video

The comic strip for this scenario depicts (Figure 9) three individuals seated in a cinema. The two individuals on the right commence a conspicuous conversation, which disturbs the individual on the left. Consequently, he requests that the conversing individuals remain silent so he can focus on the movie. The individuals then cease their conversation and remain quiet. This scenario exemplifies a breach of social norms pertaining to respect and adherence to societal rules. Utilizing this context, a video adaptation was recorded. Since renting a cinema room was not feasible, an alternative and more manageable environment was chosen. Thus, the video portrays four individuals in a living room viewing a movie. After a period, the two women on the right begin conversing. Disturbed by this, the young woman seated at the front turns around and requests that the two women remain

silent to enable her to concentrate on the movie. The video subsequently concludes. Despite the alteration in the setting, the essence of the scenario, which involves disrespect and disturbance to others by talking in a cinema, was successfully preserved.

The adapted questions related to Scenario 7 can be found in Appendix H.

### 3.2.3.10 Scenario 8 - Serving a customer (non-social norm violation)

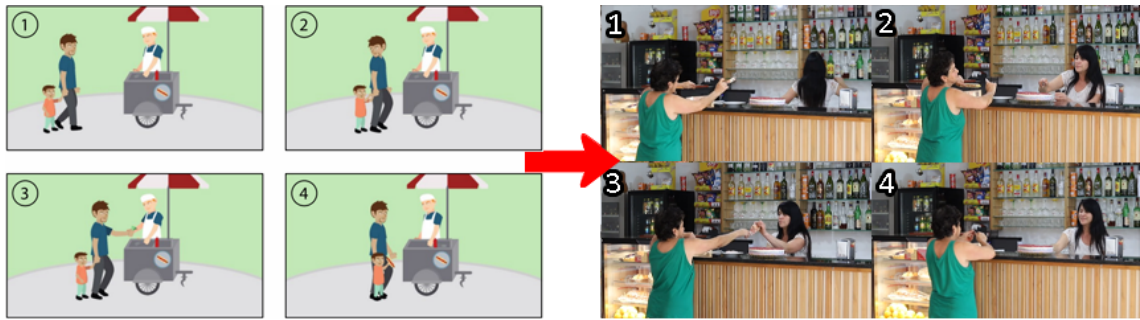


Figure. 10: Scenario 8 comic strip adaptation to video

The comic strip for this scenario (Figure 10) depicts a father and his child walking past a hot dog stand. The child requests a hot dog, to which the father consents. The owner of the stand subsequently prepares the hot dog and, following the father's payment, hands it to the child. Both appear satisfied with the interaction. This scenario exemplifies a non-social violation concerning respect and an owner delivering satisfactory service. Consequently, we recorded a video adaptation of this scenario. Due to the unavailability of a hot dog stand, we opted to film the video in a previously utilized coffee shop. The video portrays two women, namely a client and a server, within a coffee shop setting. The client requests a slice of dessert and a chocolate from the stand to her left. The server, gladly accommodating the request, provides the client with the ordered items. Subsequently, the client pays for the items and receives her change. Both participants appear content with the transaction, culminating the video. Although a hot dog stand is not featured, we effectively illustrated a positive business transaction between a customer and a business owner.

The adapted questions related to Scenario 8 can be found in Appendix I.

### 3.2.3.11 Scenario 9 - Skipping a bus queue

The comic strip for this scenario (Figure 11) begins by depicting a queue of individuals awaiting the arrival of a bus. Upon the bus's arrival, a woman in a purple t-shirt decides to cut ahead in the line. Despite the clear discontent expressed by the others regarding this breach of etiquette,

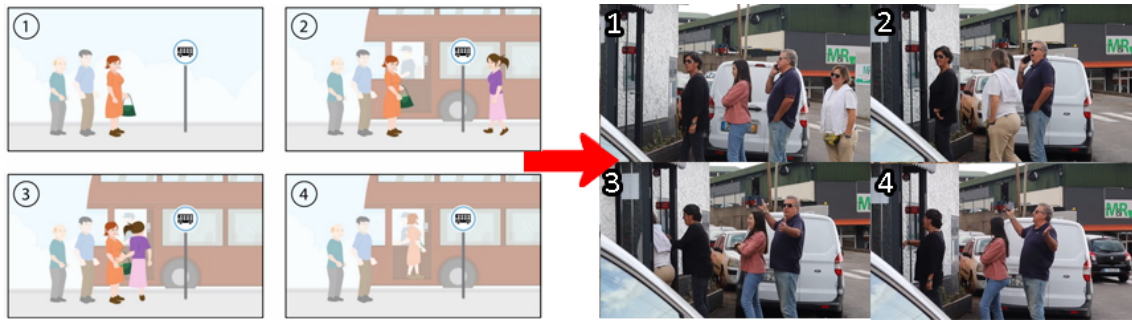


Figure. 11: Scenario 9 comic strip adaptation to video

they continue to board the bus. This scenario illustrates a transgression of socially imposed rules pertaining to queuing. In light of this context, we proceeded to record its video adaptation. To avoid any potential issues with public transportation, we opted to re-enact the scenario using a different context. Consequently, the video depicts individuals queuing to enter an establishment. After a brief period, the last individual in the queue decides to cut in front of everyone. The other individuals in the queue begin to argue, displaying their dissatisfaction with the woman who bypassed them. The video then concludes. Despite employing a different type of queue, we successfully conveyed the intended message of demonstrating a social rule violation associated with queue cutting.

The adapted questions related to Scenario 9 can be found in Appendix J.

### 3.2.3.12 Scenario 10 - Assisting a stranger

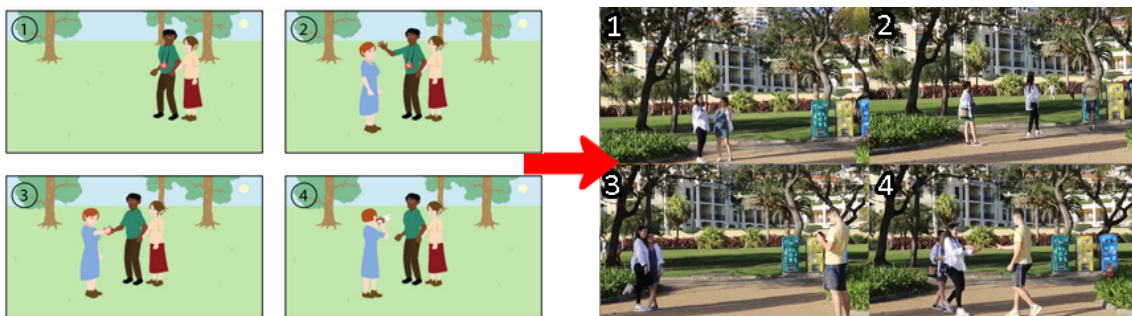


Figure. 12: Scenario 10 comic strip adaptation to video

The comic strip depicting this scenario (Figure 12) illustrates a couple taking a walk in a park, expressing a desire to take a photograph. A woman dressed in blue passes by, and the couple requests her assistance in taking their picture. She concurs and proceeds to use the couple's camera to capture the image. This scenario exemplifies a non-social violation concerning empathy

and extending help to a stranger by taking a photograph. With this context, we produced a video adaptation. In the video, two friends are seen strolling through a park. One of the friends wishes to capture the moment but realizes there is no one available to take the photo. Fortuitously, they notice a man passing by and solicit his help. The man consents and uses their phone to take the picture. Content with the photograph, they all part ways amicably. The video concludes thereafter.

The adapted questions related to Scenario 10 can be found in Appendix K.

### **3.2.4 The ESCoT - Conclusions**

Considering the prerequisites established prior to adapting the ESCoT, we successfully translated the ESCoT, along with its scoring templates and questions, into Portuguese. Additionally, we transformed the ESCoT's open-ended response format into a closed-ended format by providing predefined answer options. These questions and answers are essential for the development of the prototype of CogMap-SC. Furthermore, we converted the comic strips into 2D videos that depict the various scenarios illustrated in the comic strips. Although certain comic strip scenarios necessitated modifications for video recording, we preserved their contextual integrity and message. With these components completed, we were able to advance to the development phase of CogMap-SC.

## **3.3 Musiquence™**

Musiquence is a two-dimensional rehabilitation software that employs a presentation-style tool akin to PowerPoint for the creation and administration of assessment tests, offering extensive customization capabilities [11]. The software supports the incorporation of images, textual content, and audio files to develop diverse task types. Musiquence is structured into two primary components: the task interpreter and the editor.

### **3.3.1 Musiquence's Task interpreter**

Within this primary interface (Figure 13), users had the capability to link a user ID with the task they accomplished and specify the objective associated with the task's completion. In addition, Musiquence facilitated the utilization of various technologies for interaction purposes. Upon selecting the gear icon located in the top-left corner, a settings interface would appear, displaying the technologies that had been previously integrated and were available for selection. The technologies accessible in the version of Musiquence were as follows:



Figure. 13: Musiquence’s main menu task interpreter

- **Augmented Reality;**
- **Microsoft Kinect;**
- **Intel Realsense;**
- **Follow Mouse;**

Each of these technologies incorporated its own unique method of interaction. However, utilizing these technologies necessitated the possession of specific hardware for each option. The application was also equipped with a normal mode and a speed-run mode. In the normal mode, during tasks and between exercises, auditory feedback was provided to indicate whether the user had answered correctly or incorrectly. Progression to the subsequent exercise in this mode was contingent upon reaching the time limit or correctly answering the question. Upon the completion of the task, the user would receive a score and additional pertinent data regarding their performance. Conversely, the speed-run mode eliminated auditory feedback and the constraints on progressing to the next question. Regardless of whether the user guessed correctly or incorrectly, the task would continue to the next exercise. At the conclusion of the task, scores would be provided in a manner similar to the normal mode. Additionally, the main menu offered an exit button, a load activity button, and a button to access the task editor.

### 3.3.2 Musiquence’s Task editor

Activating the button to access the task editor displays the interface shown in figure 14 to the user.

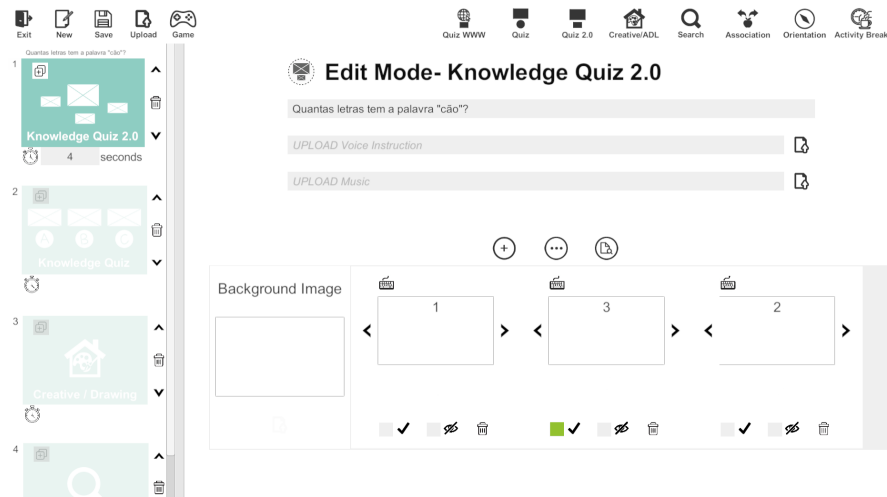


Figure. 14: Musiquence's Task editor

The interface depicted in Figure 7 enables users to generate tasks comprising an array of exercises, with the provision for an unrestricted quantity of exercises per task, contingent upon user preference. In addition to standard functionalities customary in creation tools, such as creating, saving, and loading files, Musiquence facilitates the development of eight distinct types of exercises.

- **Quiz WWW** - This exercise facilitates the incorporation of hyperlinks and the retrieval of their contents for a specific task. This exercise was developed by our team and not by the original creator of Musiquence; consequently, it is still in a trial phase. To ensure the proper functionality of the exercise, the user is required to construct the exercise by incorporating the web link within the question form.
- **Quiz** - This exercise consists of a straightforward question-and-answer format that does not permit alternative arrangements of the provided options. It represents a more basic iteration compared to Quiz 2.0, which offers extensive customization features.
- **Quiz 2.0** - This exercise facilitates varying the positional arrangements of potential options and permits the incorporation of background images to design more immersive activities.
- **Creative/ADL** - This exercise is specifically designed for use with certain technologies. To fully engage with this exercise, it is necessary to possess or use an Xbox Kinect. This exercise facilitates the development of intricate tasks encompassing drawing, creation, and various other enriching activities.

- **Search** - As suggested by its name, this activity encompasses the entirety of the screen with a white overlay, permitting the use of a magnifying glass solely for the identification of a particular option. This exercise facilitates the development of engaging search tasks.
- **Association** - This exercise enables the establishment of two distinct categories, within which users are required to accurately classify the specified option.
- **Orientation** - This type of exercise incorporates a watch and a calendar that display the current time and date. It facilitates the creation of exercises wherein the user must identify the current time of the day, the day of the week, or the present season.
- **Activity Break** - This form of exercise does not serve as a form of exercise per se; rather, it is predominantly utilized as a means to introduce a pause during the task.

In addition to this variety of exercises, Musiquence facilitates the incorporation of voice instructions and music through an import feature. Furthermore, for each exercise type, users have the option to import personal images for use during tasks. Musiquence employs a PowerPoint-like interface for displaying exercises within tasks, as previously mentioned. As illustrated in Figure 4 on the left side, users can select and access individual slides to modify their content, with the additional capabilities of duplicating and removing slides. If users wish for the application to conclude after a specified duration, they can use the watch button beneath the slide to set a timer that operates in seconds. Upon completing the task creation, users can press the save button in the top left corner to generate a JSON file, which can subsequently be utilized in Musiquence’s Task interpreter.

### 3.3.3 Why Musiquence?

Musiquence has provided a rehabilitation engine that can be utilized for the implementation of the adapted VR task. Over time, the adapted task is projected to encompass a broader range of scenarios beyond those presented in the ESCoT. Consequently, Musiquence, through its customization capabilities, would facilitate the generation of an unlimited array of social cognition assessment tasks for clinical evaluations. Conversely, utilizing Musiquence to develop this VR task would enable the platform to enter the 3D domain, thus paving the way for the creation of more intricate tasks featuring 3D models.

### 3.4 Unity

Unity is a game development engine that leverages object-oriented programming to facilitate the creation of video games. The primary incentive for selecting Unity lies in its user-friendly interface and extensive library of complimentary assets. Additionally, this game engine offers a substantial collection of virtual reality tutorials, which provide comprehensive instructions on developing and utilizing virtual reality applications. Unity employs C# as its programming language, which is widely regarded as an accessible language to learn.

Another significant motivation for using Unity was the pre-existing implementation of Musiquence within this engine. To effectively leverage Musiquence, the adoption of Unity was imperative. Nevertheless, the development of virtual reality (VR) applications required more than merely Unity itself.

### 3.5 Head mounted displays and SDKs

In the development of CogMap-SC, three distinct VR head-mounted displays were utilized: the HTC Vive Pro Eye, the Meta Quest 2, and the Meta Quest Pro. These VR headsets were acquired on loan from NeuroRehabLab. The Unity Engine offers an array of VR solutions, each VR headset mandates the use of a specific Software Development Kit (SDK). For instance, the HTC Vive Pro Eye demands the SteamVR SDK for the development and execution of applications within Unity. In contrast, the Meta Quest series of VR headsets (Meta Quest 2/Meta Quest Pro) can use either the inherently integrated XR Plugin from Unity or the Meta Quest All-in-one SDK, which provides numerous tutorials and code blocks for VR application development tailored to the Meta Quest. Due to these software constraints, it was necessary to create multiple iterations of the CogMap-SC tailored to the specific technologies being utilized.

### 3.6 WebView3D

In the initial prototype of CogMap-SC, this SDK facilitated the incorporation of a Chromium-based web browser in a Unity Canvas, enabling the presentation of videos, access to HTML files, and execution of JavaScript programs within Unity. These functionalities were crucial for the prototype, as they allowed the development of two primary components of CogMap-SC, which are

discussed in subsequent sections. This SDK takes advantage of the programming languages HTML, CSS and JavaScript for the presentation of the media.

### **3.7 HTML**

Hypertext Markup Language or HTML is the standard markup language for documents designed to be displayed in a web browser. It defines the content and structure of web content. This programming language is mostly comprised of code blocks that use open and close tags for implementation.

### **3.8 CSS**

Cascading Style Sheets or CSS is a style sheet language used for specifying the presentation and styling of a document written in a markup language such as HTML or XML. This programming language is mostly comprised of grouped up variables and attributes that provide HTML a better interface.

### **3.9 JavaScript**

JavaScript or JS is a scripting language that enables you to create dynamically updating content, control multimedia, animate images, and develop web-related videogames. This programming language is mostly comprised of functions and the use of variables.

### **3.10 Prototyping: CogMap-SC with VR controllers**

Musiquence was constrained to utilizing three specific technologies: the Kinect for the XBOX, mobile tablets, and mouse input. While these technologies were noteworthy, they did not support the requirements of our project. Given that virtual reality (VR) predominantly operates within three-dimensional (3D) environments, it became necessary to comprehensively restructure Musiquence to facilitate the creation of 3D environments. This restructuring presented several challenges, particularly because the Musiquence engine required a mechanism to execute the constructed tasks within a VR headset. Consequently, the prototype development began with the construction of a 3D environment featuring a central white canvas to display tasks. Musiquence traditionally employed a white canvas affixed to the screen for task display. To accommodate this

within VR, Musiquence’s connection to its existing white canvas was redirected to the 3D environment’s white canvas, effectively enabling task display in a 3D setting. Subsequently, the system lacked user interaction with the 3D environment’s white canvas. To address this, we incorporated the HTC Vive Pro Eye and the development SDKs provided by VALVE, which manufactures these VR headsets, to implement a point-and-shoot interaction method. This method was also extended to the Meta Quest series of VR headsets, requiring integration with Unity SDKs. This interaction method utilizes VR controllers to target the activity canvas and execute selections via the trigger button. This led to the development of the initial prototype (Figures 15 and 16).

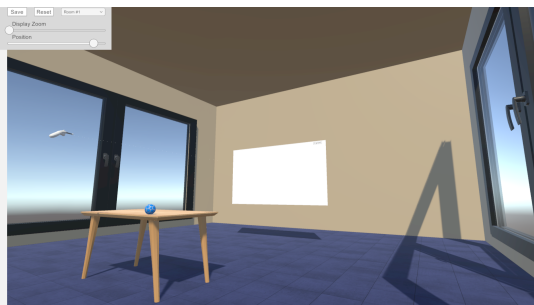


Figure. 15: First CogMap-SC’s prototype

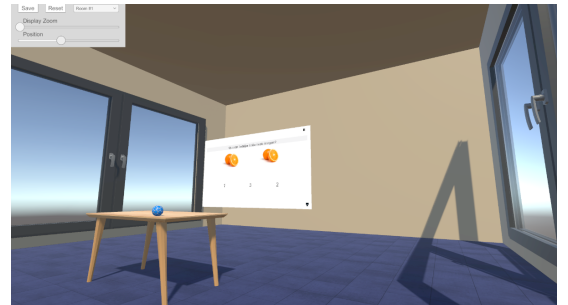


Figure. 16: CogMap-SC showcasing a Musiquence task

To ensure user comfort and avoid overstimulation within the VR environment, a minimally designed room was developed, incorporating only a table and exterior windows. Given that Musiquence could offer a range of solutions to address our issue, it was imperative to preserve the integration between the Musiquence engine and the 3D environment. Therefore, we retained the display for the activity and employed a point-and-shoot interaction method (Figure 17).

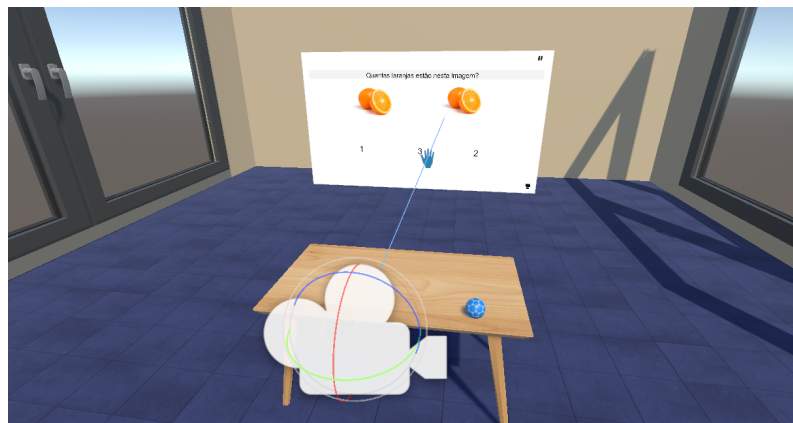


Figure. 17: CogMap-SC’s interaction method

The figure illustrates the environment and the manner in which the activity is to be completed utilizing only the virtual reality controllers; specifically, through pointing and pressing a button as the means of interaction. To enhance customization, we introduced the capability to enlarge the activity canvas and position it further from the participant. In this initial iteration of the prototype, all activities created by Musiquence could be loaded and executed using the VR headset within this environment. Prior to the actual implementation of CogMap-SC, we sought to offer clinicians and potential users of this application increased customization options for the environment. Accordingly, five additional environments comprising furniture and various other miscellaneous items were developed for selection. These environments had been pre-validated and were designed to resemble typical living rooms to avoid overstimulating the patients/participants (Figure 18).

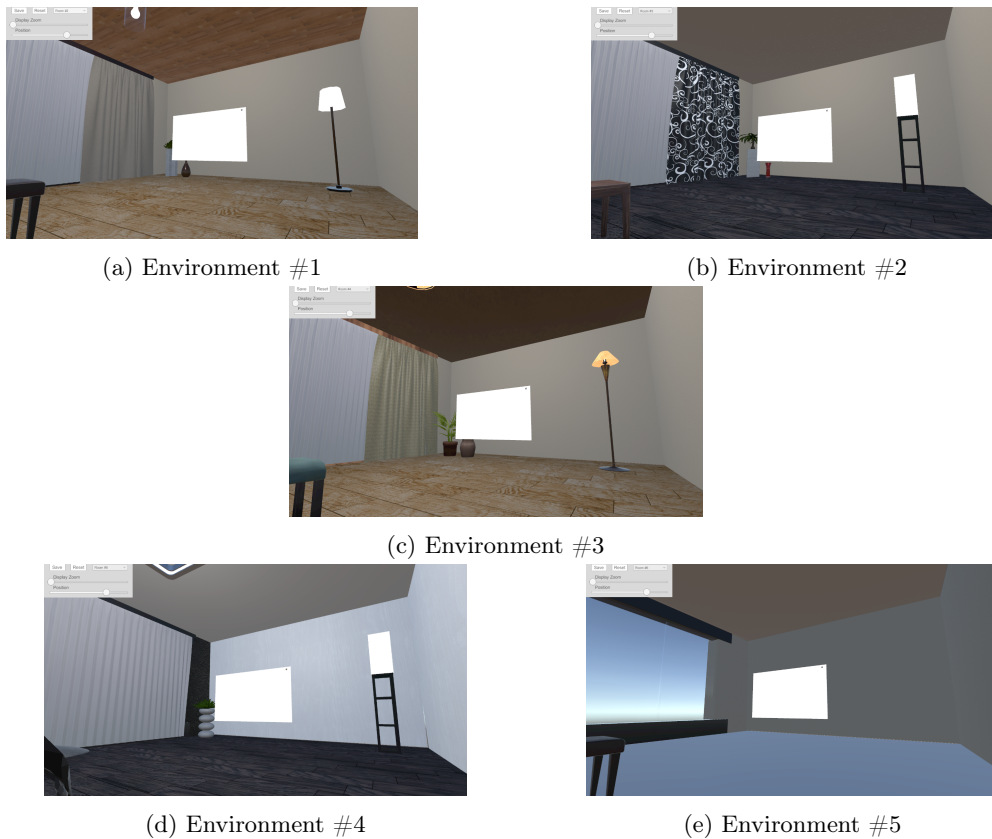


Figure 18: Extra environments added for customization

During the development phase, Musiquence was unable to incorporate videos within the assessment task as these tasks were constructed using JavaScript Object Notation (JSON) files, which did not support video input. This limitation posed a significant challenge given our intention to integrate videos for CogMap-SC. JSON files are characterized by a structured combination of data

and variables that facilitate easy access and readability by computer programs. To avoid delays in development, we opted to utilize a Hypertext Markup Language (HTML)/Web viewer SDK for Unity to display the videos and corresponding questionnaires, **WebView3D** (Figure 19).



Figure. 19: 3DWebView's Logo

With the help of this tool and previous knowledge of front- and back-end web development, we created a JavaScript creator and a JavaScript interpreter.

### 3.10.1 JavaScript Creator - Forms

As previously discussed, CogMap-SC comprises ten scenarios in which participants are required to watch a video and subsequently complete a corresponding questionnaire. The primary function of this JavaScript tool was to facilitate the creation of customized social cognition assessment tasks. Consequently, the "creator" tool is designed as a straightforward HTML form, enabling participants to upload a video and then formulate questions based on their preferences (Figure 20).

This form is fully translated into Portuguese and facilitates the creation, modification, and saving of social cognition assessment tasks in JSON format. This functionality enables users to execute their scenario tasks by loading the JSON file generated in Musiquence with the JavaScript interpreter. If the user opts to load an existing file, a window will prompt the participant to select a pre-existing JSON file. This action will import the data from the selected file, which contains the questions, possible answers, and corresponding scores. To add a new question, the user must complete the field labeled "Questão:" and subsequently press the "Adicionar Opção" button the required number of times to add options. If excess options are added inadvertently, the "Remover Opção" button can be used to remove the most recently added option. Each option includes a score box, allowing the participant to assign a value between 0 and 3 to each answer. Upon finalizing

**FORM CREATOR**

Editar Formulário:  
Carregado com Sucesso

Escolher ficheiro Cenário1.json

Criar Formulário:  
Cenário 1

Escolher ficheiro Nenhum ficheiro selecionado

Escolha um vídeo antes de continuar

Questão:

Adicionar Opção Remover Opção Guardar Pergunta Criar Formulário

**Questão 1: Pode dizer-me o que aconteceu no vídeo?**

- Um idoso e uma jovem caminham na estrada
- Uma jovem encontra-se a falar ao telemovel
- Um idoso ia a caminhar e deixou o saco cair (1)
- Uma jovem passou por um idoso que precisava de ajuda e ignorou-o (2)
- Um idoso ia a caminhar e deixou cair o saco e foi ignorado pela jovem (3)

Editar Apagar

**Questão 2: O que é que a jovem estaria a pensar?**

- Nada
- Que não tinha obrigação de ajudar (1)
- Que cada um é responsável por si (1)
- Que outra pessoa poderia ajudar o idoso (2)
- Que deveria ajudar o idoso, mas estava ocupada (3)

Editar Apagar

**Questão 3: Como acha que o idoso se sentiu?**

- Raiva
- Alegria
- Nenhum

Figure. 20: Web-based social cognition assessment task creator

the question and its options, pressing the "Guardar Pergunta" button will append the created question to the list displayed below. In case of an input error within a question, the "Editar" and "Apagar" buttons enable the user to modify or delete the question, respectively. Ultimately, to save the questionnaire, the user can click the "Criar Formulário" button to store a JSON file at the specified location in the form-creation application.

To utilize the formulated CogMap-SC task, the user must load the JSON file into Musiquence, which will then execute the task with the assistance of the JavaScript Interpreter.

### 3.10.2 JavaScript Interpreter

The WebView3D SDK facilitated the integration of web-based content within Unity, enabling interoperability between Unity's programming language, C#, and the web development language, JavaScript. The interpreter was required to present the video, permit the participant to advance to the questionnaire, and proceed to the subsequent scenario. This task was relatively straightforward to implement by leveraging the HTML programming language in conjunction with Cascading Style Sheets (CSS) (Figure 21).

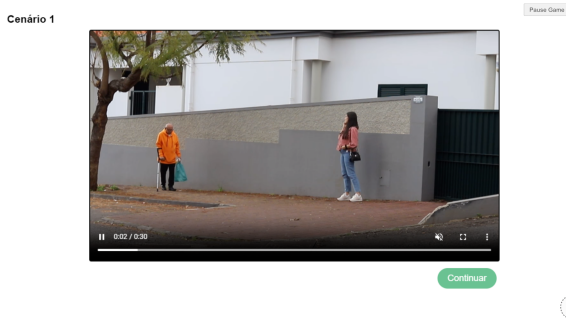


Figure. 21: JavaScript Interpreter - Video showcase

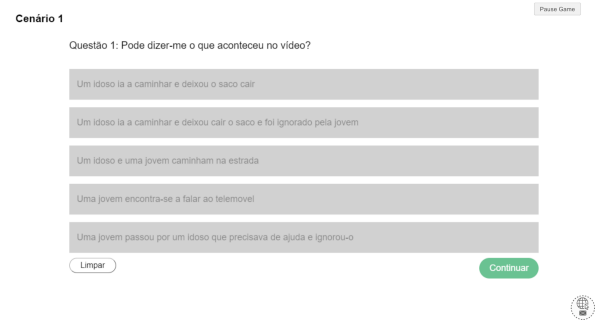


Figure. 22: JavaScript Interpreter - Questionnaire showcase

The JavaScript interpreter was required to read the JSON file with the task and present the data in HTML. With the use of WebView3D SDK that same HTML would then be presented to the user. In more detail, the video would play on the middle screen with the possibilities of full-screen, replay, and rewind. Whenever the participant was ready to continue, the button in the right-lower corner could be pressed to proceed to the questionnaire.

After pressing the button, the user would be redirected to a page featuring a question and five possible answers (Figure 22). The only way for the user to continue with the task was to select one of the five options. After selecting the one that the user found to be more complete or correct, the task would continue. If by mistake the user pressed the wrong option, pressing the button "Limpar" would reset the selected option and allow reselection. After the five questions, regarding the different topics of social cognition, pressing the continue button would advance the user to the next scenario, until the task was fully completed. After completion of CogMap-SC, to save the individual answers the user provided, the Unity Engine would send a log message to JavaScript and save a text file with the questions, answers and related scores, indicating that the activity was over and Musiquence could terminate that same activity. With this, the first prototype of the CogMap-SC was created, which featured 3D environments for the 2D-based Musiquence, the HTML + CSS + JavaScript form creator for the cognitive assessment tasks, the task interpreter and virtual reality controller interactions.

### 3.10.3 Conclusions

Utilizing the aforementioned tools, we initiated the development of the initial prototype of CogMap-SC. Consequently, we successfully created two integral components: a Javascript Creator and a Javascript Interpreter. These tools proved to be indispensable for the functionality of

CogMap-SC. The Javascript Creator facilitated the formulation of specific scenarios, while the Javascript Interpreter established the necessary connection between Musiquence and the Web-View3D SDK. The initial prototyping demonstrated considerable promise, prompting us to conduct two subsequent usability studies. These studies provided valuable insights into the aspects that required further refinement, as discussed in subsequent sections.

### 3.11 Prototyping: CogMap-SC with eye-tracking

During awake brain surgery (ABS), patients are restricted from performing rapid hand movements and head tilts to ensure that surgeons can perform the procedure without any impediments. Incorporating a VR headset alongside VR controllers poses significant challenges in this context. Consequently, we have opted to enhance CogMap-SC by integrating an alternative mode of interaction: eye-tracking. This method of interaction not only facilitates task participation, but also allows the exclusive use of the VR headset during the surgical process.

#### 3.11.1 Prototype changes

Overtime, Musiquence suffered quite drastic changes related to its design and functionalities. As such, it could now accept videos into its JSON files simplifying the process of creating new social cognition assessment tasks and completing them.

We began by removing the 3D Webview SDK and transforming CogMap-SC into a Unity Native application. All of the previously utilized HTML and JavaScript code was scrapped except for the JavaScript form creator, which could still be used for creating new tasks. Making use of Unity's button and 2D design technologies we designed an interface that was accessible, intuitive and that featured bigger buttons for easier interactions (Figures 23 and 24).



Figure. 23: CogMap-SC's updated video interface

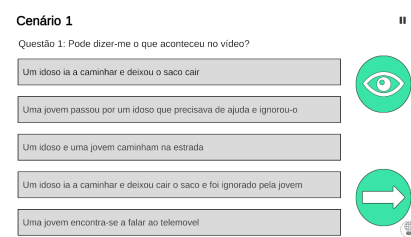


Figure. 24: CogMap-SC's updated questionnaire interface

Using Musiquence’s color scheme, we reworked CogMap-SC into a more aesthetically pleasing task that functioned better than the first prototype. The feedback provided by the initial two studies was also taken into account and we adapted it into the following changes.

### 3.11.1.1 CogMap-SC 2.0 - Video Interface

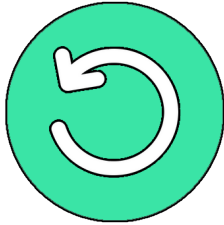


Figure. 25: Restart video button

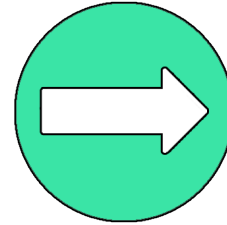


Figure. 26: Continue button

The CogMap-SC now includes an updated video interface, which, similar to the initial prototype, displays the video centrally on the screen; however, it has incorporated two additional buttons while eliminating non-essential features. In the revised version, users are able to press the button on the left (Figure 25) to replay the video or the button on the right (Figure 26) to advance to the questionnaire section. The decision to streamline the interface was informed by substantial user feedback, which suggested that individuals occasionally found the interface overwhelming or had difficulty in making selections. Adhering to effective eye-tracking methodologies, the buttons were designed to be sufficiently large to ensure efficient user selection even with minimal eye movement. To maintain the integrity of previously collected data and avoid the necessity to revalidate the task, none of the videos from the previous version of the CogMap-SC were altered or updated. All the assets within the new video interface were custom-designed by our team and their designs were chosen from clinically validated icons.

### 3.11.1.2 CogMap-SC 2.0 - Questionnaire Interface

The questionnaire interface also faced some design changes regarding the color scheme and some other added functionalities.

The questions pertaining to each scenario would now be displayed in the top right corner of the screen, while the corresponding answers would be positioned directly below them (Figure 39). In the default, unselected state, the answer background would feature a white color; upon selection, this background would change to a teal-like green that adheres to Musiquence’s color scheme. Additionally, the text color was altered to a more distinct black. Two pivotal buttons

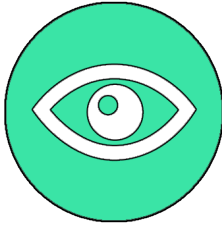


Figure. 27: Rewatch video button

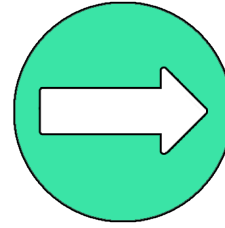


Figure. 28: Continue button

were incorporated: one for rewatching the video (Figure 27) and another for proceeding to the subsequent question (Figure 28). When activated, the button with the eye icon will navigate the user back to the video interface, permitting a review of the scenario's video without forfeiting progress in the questionnaire. On the other hand, the button with the arrow icon will advance the user to the next question within the scenario, and upon reaching the final question, will redirect to the video interface of the subsequent scenario.

### 3.11.2 Interaction changes

Unlike the point-and-shoot interaction of the first prototype of CogMap-SC, eye-tracking would impose some more complex hardware and software requirements. One big limitation of the HTC Vive Pro Eye is its portability. Despite having great performance and eye-tracking capabilities, this VR headset requires two elevated base stands for tracking that are quite heavy and impractical. For use during ABS, this could cause some difficulties during surgery, so we needed a hardware solution. The Meta Quest 2 which we used for previous studies had great portability but no eye-tracking capabilities whatsoever. As such, we decided to invest in another VR headset. The Meta Quest Pro is a significant upgrade to the Meta Quest line of existing VR headsets, with an increase in comfortability, while adding facial and eye-tracking functions.

With the Meta Quest Pro secured, we proceeded to the implementation of the eye-tracking functionalities in the newest version of the CogMap-SC. The interface for the new functionalities was already implemented, but we required a way to press a button using only eye-tracking. This interaction was possible to achieve using the All-in-One Meta Quest XR SDK. This SDK offered customization and eye-tracking interaction with the use of XR Ray Interactors and UI elements, much like the point-and-shoot interaction. However, implementing this interaction was not as simple as pressing a button. The Meta Quest Pro despite being an upgrade in hardware, presented very little documentation regarding its software use. This caused some complications and required

us to extensively research other research works that featured this technology. Much like us, other researchers showcased some type of disappointment with what was provided in the All-in-One Meta Quest XR SDK. One big limitation of this SDK was that the eye-tracking and its interactions only worked for one of the eyes, either the left or the right one. The only way to select which eye would be chosen for tracking was to pick it before opening the application. This could cause some limitations especially if a participant showcased visual impairments or discrepancies in one specific eye.

Despite this limitation, for this prototype we implemented the interaction using only the left eye. In order to "press" a button during the task, the participant would be asked to look attentively without blinking at the option they desired for 0.5 seconds. This would trigger a select function and interact with the Unity UI as a mouse input, allowing the participant to complete the task without having to use VR controllers.

### **3.11.3 Limitations eye-tracking**

As previously stated, utilizing single-eye tracking could potentially result in issues contingent upon the participants; however, for this prototype, it was deemed sufficient. In addition, eye-tracking presents other inherent limitations. The Meta Quest Pro incorporates an integrated mechanism to accommodate the use of glasses with the VR headset. However, participants could not wear their glasses during the eye-tracking study due to the interference caused by the lenses on the glasses with the camera technology utilized by the Meta Quest Pro for eye-tracking, rendering the tracking ineffective. This posed a significant challenge for CogMap-SC, given its extensive reliance on text. If participants were unable to read text positioned too close or too distant from their eyes, all collected data from that participant would have to be invalidated, primarily due to potential reading miscomprehension affecting their responses. Furthermore, eye-tracking remains a precarious and imprecise technology, susceptible to issues at critical moments. This unreliability could also result from inadequate eye-tracking calibration, which is mandatory. Before each eye-tracking intervention, the Meta Quest Pro required calibration using VR controllers. This calibration process, which involved the user following a dot in a white space to collect eye data, was relatively straightforward. The principal issue with this calibration is its susceptibility to become unstable or undone over time, depending on the environment. Although calibrating the eye-tracking system

prior to the ABS procedure would not pose a challenge, ensuring the calibration remained precise and stable presented a significant concern.

Despite these limitations, we were positive that with future CogMap-SC implementations, we would be able to overcome these impediments.

### **3.12 Implementation - Conclusion**

The creation of these prototypes required a lot of validation throughout its development as well as attention to detail. Due to its nature, these prototypes would need to take into account the user's needs more than anything else. The first prototype focused more on the validation of the adapted task. Adapting the ESCoT, an open-ended questionnaire assessment tool, to a VR environment also required us to create our own close-ended questionnaires so that the adaptation could be used successfully. However, visual stimuli for the ESCoT would not fit into our final design of the prototype, so, video stimuli with human interactors were created. The second prototype, on the other hand, was a step further into the final interaction method of the adapted task. The use of eye-tracking was taken into account since it would heavily simplify the first prototype's point-and-shoot interaction focusing primarily on the patient's eyes rather than their hand/wrist movement. In order to perceive if the changes we made to these prototypes and interaction methods were correctly implemented, we conducted many studies with healthy and traumatic brain injury or brain tumor patients. These aided us in understanding what we should take into account for further implementations of the task as well as, obtaining a clinical validation of the CogMap-SC.

## 4 First Study: Healthy Participants with controllers

To verify the validity of the CogMap-SC prototype, a study was conducted involving healthy participants. This investigation also served to gather feedback on the interactions and design choices implemented.

### 4.1 Methodology

Considering CogMap-SC is a VR-adapted test of the "paper-and-pencil" task of ESCoT, to check validity, we determined that the best way to do so would be to test both tasks and compare results. This comparison study would enable us to understand better if both versions assess the same thing and are equivalent. The study would consist of two major components: we would have participants complete the open-ended ESCoT and then require participants to complete the CogMap-SC version, in a counterbalanced order to mitigate learning effects. None of these versions were going to be timed. The ESCoT was completed according to the official testing standards in a relaxed and calm manner with two human interactors, the participant and the researcher. However, we conducted a Portuguese-translated version of the ESCoT. We printed out all of the official ten scenario comic strips and questioned the participants regarding each scenario. Each of their answers received a score between zero and three, depending on how complete and concise their answers were. Due to the ESCoT's open-ended nature, we followed a template provided by the official creators, indicating what different topics should be addressed in the participant's answer.

Conversely, CogMap-SC was performed using the HTC Vive Pro Eye or the Meta Quest 2 (depending on which was available at the time). The participant was requested to wear the headset and use only the VR controllers to complete the task. During the task, if any interaction issues or doubts came up, the participant could pause the task and ask for guidance. However, no questions regarding the context of the video could be asked, since it could influence the participant's answers. Much like the ESCoT, each of the CogMap-SC answers featured a predetermined score between zero and three, depending on the question. In both versions, all scenarios shared the same context, with some minor differences in the environment and actors. After finishing the task, the participant would be required to answer a questionnaire - System Usability Scale (SUS) [38] - to obtain more feedback on the CogMap-SC. This first phase of the study would also serve as a way to test the usability of the CogMap-CS with a specific interaction in mind, in this case, a point-shoot type

of task using the virtual reality remotes as a means of input. With the protocol completed, we proceeded to the sampling phase.

#### 4.1.1 System Usability Scale (SUS)

The SUS is a very straightforward questionnaire that aims to collect generalized data for the usability of a specific task/technology. It features 10 questions, each related to general aspects of the application. When completing the SUS, the participants must rate each question within an interval range of 1 to 5, 1 meaning "Completely disagree" and 5 meaning "Completely agree". After gathering feedback data from each participant, the scores obtained are gathered and compared. Generally speaking, an average score of 68 on the SUS is deemed very good usability for that certain application/technology. All the questions shown in the SUS questionnaire were translated into Portuguese.

#### 4.1.2 Sample

We set a minimum goal of 20 participants to obtain a concrete validation of CogMap-SC. For this first study, we concluded that these requirements were the most indicated:

- Ages between 18 to 60;
- Gender is not important;
- Healthy participants with no psychological or physical discrepancies;
- Participants had to be able to move their arms (even if minimal movement);
- Ability to understand and read Portuguese;

With everything in order, we set out to search for possible participants. Most of the participants were obtained through colleagues and family members, without any possible bias. Those participants who indicated any visual or health discrepancy at the time of participation in the study were deemed invalid and removed from the data set.

In compliance with the sampling requirements, we conducted 20 studies with twenty healthy participants. Within this cohort, 16 participants were between the ages of 18 and 30, comprising 11 women and 5 men, while 4 participants were between the ages of 31 and 60, including 3 women and 1 man. The studies were carried out in a controlled environment, involving only the participant

and the administrator that supervises the test. The age distribution of the 20 participants resulted in a mean of 26.5  $\pm$  9.1 years old.

## 4.2 Results

All statistical analyzes were performed with SPSS software (version 29, SPSS Inc., Chicago IL, USA). Subsequently, the score for each participant was collected for both methods and finally compared.

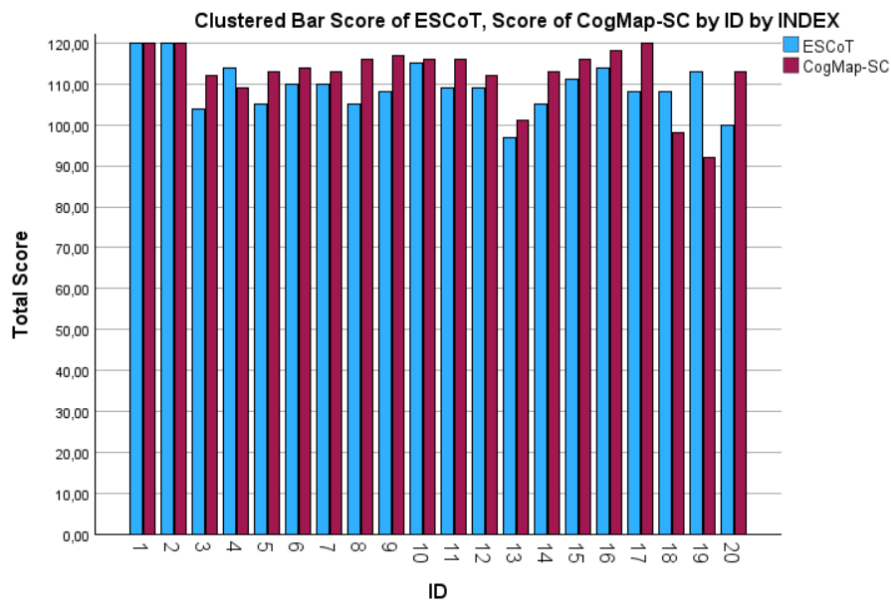


Figure. 29: Scoring obtained for each participant in the two methods

**Figure 29** presents the total scores obtained in the 10 scenarios for each participant, with 120 being the highest possible score. It is noticeable that most of the participants scored above 100 in both methods, indicating that throughout the different topics on social cognition, these participants did not show many discrepancies with respect to their social cognition. The VR task presented an average score of approximately 112.5, whereas the ESCoT method presented an average score of approximately 109.7. By comparison, both methods presented very positive scores and only showed a difference in average scores of 2,75.

To better evaluate the questions shown in all different topics of assessment of social cognition, we decided to organize the scores obtained in each different scenario by their topic and compare

them between the two types of task: CogMap-CS and ESCoT. The scores presented were obtained by adding all the participant’s scores for each question in each scenario.

	Cognitive Theory of Mind		Affective Theory of Mind		Interpersonal understanding of social norms		Intrapersonal understanding of social norms	
	CogMap-SC	ESCoT	CogMap-SC	ESCoT	CogMap-SC	ESCoT	CogMap-SC	ESCoT
Scenario 1	49	58	60	49	54	54	54	59
Scenario 1	51	51	60	45	60	53	54	60
Scenario 3	54	48	60	51	60	58	60	60
Scenario 4	49	50	60	54	51	56	54	60
Scenario 5	52	57	60	52	57	55	48	57
Scenario 6	46	51	54	54	60	57	60	60
Scenario 7	48	47	57	45	60	56	60	60
Scenario 8	57	55	60	52	60	56	60	60
Scenario 9	49	56	54	55	60	55	60	60
Scenario 10	57	59	60	52	60	57	60	60
Total Score	512 / 600	532 / 600	585 / 600	509 / 600	582 / 600	557 / 600	570 / 600	596 / 600

Table 1: Table regarding all of the scores in each topic

**Table 1** shows each participant’s performance per topic. In Cognitive Theory of Mind, paper and pencil scored **higher** with an average of 54.2, versus VR’s 51.2. In Affective Theory of Mind, VR scored **much higher** with 58.5, versus paper and pencil’s 50.9. For Interpersonal understanding of social norms, VR scored **higher score** with 58.2, versus paper and pencil’s 55.7. In Intrapersonal understanding of social norms, paper and pencil scored **almost perfect** with 59.6, versus VR’s 57. Comparing the scores from the pilot study allowed us to better assess each participant’s performance. Scores were calculated by subtracting the maximum possible score from their actual scores, providing a clearer comparison between the CogMap-SC and paper and pencil tasks. In this comparison, 2 participants performed equally in both tasks (10%), 15 performed better in CogMap-SC (75%), and 3 performed better in the paper and pencil task (15%).

### 4.3 Internal Consistency

To assess the **internal consistency** of scores from CogMap-SC and ESCoT, we use the Cronbach Alpha (CA) test for reliability, providing a value between 0 and 1. Higher values indicate better internal consistency. [39] We calculate CA for both types of tests.

### 4.3.1 Cronbach's Alpha - CogMap-SC

After organizing scores for each participant in every scenario, we calculated the CA value. We obtained an alpha value of **0.8**, indicating **very good** internal consistency for CogMap-SC, since  $0.95 > \alpha \geq 0.7$  [39]. To get a higher  $\alpha$  value, removing a specific question's scores is necessary. If scores related to the Cognitive Theory of Mind question in scenario 6 were removed,  $\alpha$  would increase by 0.011.

### 4.3.2 Cronbach's Alpha - ESCoT

After calculating the CA for CogMap-SC, we did the same for ESCoT, organizing scores for each participant in every scenario, resulting in an alpha value of 0.696, which is a **reasonable** value. This value is close to the minimum preferred value of 0.70, indicating good internal consistency ( $0.95 > \alpha \geq 0.70$ ) [39]. To increase this value and improve internal consistency, we would need to remove the question about Affective Theory of Mind in scenario 1, raising the value of  $\alpha$  to 0.742.

We cannot fully assume that a higher  $\alpha$  value means more internal consistency since it is influenced by the number of items, with more items increasing the coefficient value [39]. After scoring 40 questions per task and removing questions with zero variance, we ended up with 32 questions for ESCoT and 20 for CogMap-SC.

## 4.4 Usability Tests

Regarding CogMap-CS usability, participants filled out an adapted System Usability Scale (SUS) [38] questionnaire after each VR task session. This quick and straightforward tool collects user experience data. The application averaged a score of 90 among 20 participants, exceeding the good score threshold of 68 (Figure 30).

The SUS ranges from values between 0 and 100, meaning that we obtained a **very positive** score throughout the 20 participants, indicating that the VR activity of CogMap-CS is seen as simple to use and aesthetically pleasing, as per SUS standards. Regarding the participant's feedback on the VR task, many displayed satisfaction with the task's easy to use and responsive nature. It was also mentioned that they felt very immersed in the environment. In contrast, others presented suggestions about the application's minor interactions, sharing their experience with similar activities and how changing them could benefit user experience. The videos displayed in each scenario

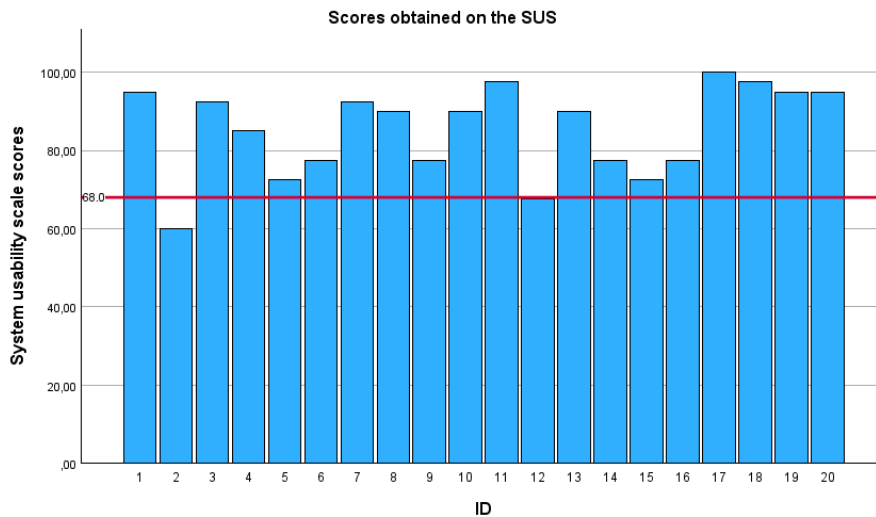


Figure. 30: SUS scores obtained

were also victim of constructive criticism. While the majority of the videos showcased their desired context, some videos were too abstract to be able to identify any context. This was the case of cenario 4, where the participants were required to identify a woman asking for help from her house and a man trespassing the woman’s house to provide her assistance. Most participants were confused since in the video, the man is clearly able to open the garage door but closes it without going through it. Another faulty aspect of this scenario, was the lack of facial expressions from the man, indicating distress, so as to know what was happening to cause the woman to be screaming for help.

#### 4.5 Conclusions

With this first study, we were able to validate CogMap-SC with twenty healthy participants. This collected feedback helped us to understand whether the developed task was ready for a first clinical case study and what issues it had during its prototype. Understanding what works and what does not was essential in this first phase. If the feedback provided during this pilot study was not positive/convincing, we would be required to accommodate the changes developed before progressing into a second study.

## 5 Second Study: TBI and Tumor Participants with VR controllers

The first prototype presented very good feedback from healthy participants. Despite that, since our main goal was to adapt a clinically validated social cognition assessment task to VR, before proceeding, we wanted to validate this developed task with patients with traumatic brain injury (TBI) or brain tumor-related (BT). During this time, a relevant study was about to start in SESARAM, where another researcher would utilize traditional assessment tests in conjunction with a digital rehabilitation software (Task Generator 2.0) for a duration of 8 weeks. This related study could be beneficial for our own goals, as participants shared the same requirements of our study, patients with TBI and BT.

### 5.1 Methodology

The primary aim of this second study was to gather clinical feedback on the usability and validity of CogMap-SC and to examine the potential correlation between social cognition and other cognitive functions. The research question formulated was: "Does rehabilitation of other cognitive functions enhance social cognition?" For each participant, the study commenced with an initial session where various cognitive abilities such as memory recall, pattern recognition, mathematical calculations, and motor activities were assessed. Concurrently, the CogMap-SC assessment was also conducted. The Meta Quest 2 was utilized for its portability. Participants were then instructed to wear the VR headset and complete the task exclusively using the virtual controllers. Ten scenarios accompanied by related questionnaires were administered. Similar to the previous study, participants were permitted to seek assistance with the technology and navigation of the task but were precluded from questioning the scenario context to ensure unbiased responses.

The CogMap-SC assessment would be conducted within a controlled environment devoid of external stimuli. Figure 31 illustrates the physical setting in which participants will perform the task and, as observed in the previous study, this task would not be subject to time constraints. Participants reserve the right to withdraw from the study at any time without any repercussions; should a participant be unable to complete the task, their participation would be considered invalid. Upon completion of the task, participants would engage in a rehabilitation program for a specified duration. Following the rehabilitation period, participants would be asked to attend a final assessment session, akin to the initial one, and to complete the CogMap-SC once more. The



Figure. 31: Physical environment for the CogMap-SC

study would subsequently reach its conclusion. The results would provide crucial feedback, enabling a comparative analysis of the results between the first and final sessions. With the protocol for the second study finalized, we deliberated on the prerequisites for prospective participants.

### 5.1.1 Sample

Due to the lack of patients with TBI or related to BT, we decided to obtain as many as possible. With this in mind, we still had a few requirements that needed to be met:

- Ages between 18 to 70;
- Gender was not important;
- Participants had to have suffered from TBI or BT-related issues.
- Participants had to be able to move their arms (even if minimal movement);
- Ability to understand and read Portuguese;

Considering the nature of these participants, extra care would have to be taken to not cause physical or mental straining. With these requirements in mind, we were fortunate enough to obtain participants from previous surgical procedures (performed in SESARAM) that required rehabilitation. Most of these participants shared some similarities in behaviors or cognitive functions, but all were able to maintain a conversation and presented no complex mental or physical disabilities.

From the available participants, we managed to obtain thirteen case studies. However, due to complications during the assessments, two participants were invalidated and one chose to drop out.

In the end, we obtained ten valid case studies. From the pool of participants, 1 was aged between 18 and 30 years old (1 male) and 9 were between the ages of 31 and 70 (2 female and 7 male). For the ages, we obtained a mean value of 45,4 +- 11.1. This value of standard deviation indicates that the data we gathered is dispersed in comparison to the mean.

## 5.2 Results

Much like the previous study, we compared both pre-rehabilitation and post-rehabilitation.

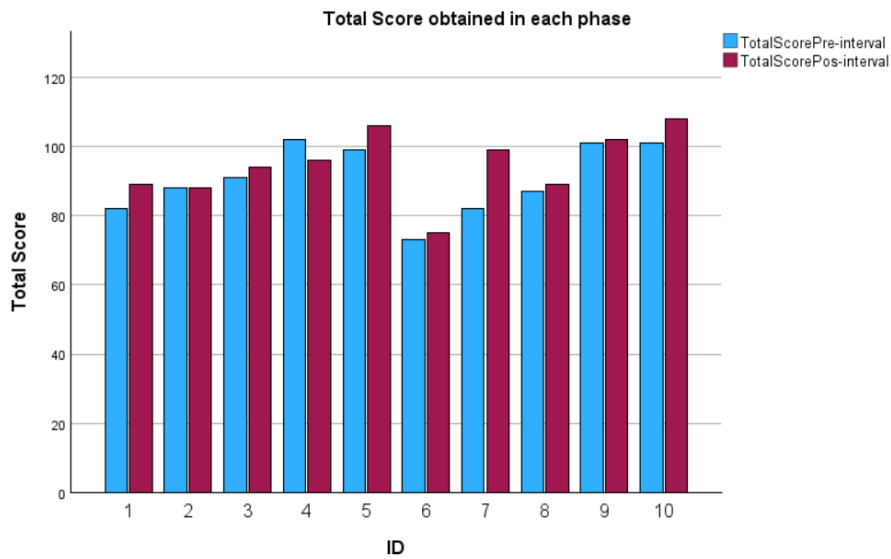


Figure. 32: Scoring obtained for each participant pre-rehabilitation versus post-rehabilitation

Figure 32 shows the total scores of each participant across ten scenarios, with a maximum score of 120. Most participants improved between their first and final sessions (8 participants - 80%), while others showed decreases (2 participants - 20%). The scores suggest some participants have social cognition issues related to social awareness or environmental perception. Positively, average scores increased from 90.6 (pre-rehabilitation) to 94.6 (post-rehabilitation). To evaluate topic-specific differences in social cognition, we compared the scores in each scenario between the first and final sessions by summing all participants' scores for each question.

Table 2 illustrates the accumulative values of each topic to demonstrate the participants' performance in their respective tasks. Regarding the topic of Cognitive Theory of Mind, we observed a decrease in total scores by 2 points, from 195 to 193 between sessions, with average scores for both sessions being 19.5 and 19.3, respectively. In the context of Affective Theory of Mind, an

	Cognitive Theory of Mind		Affective Theory of Mind		Interpersonal understanding of social norms		Intrapersonal understanding of social norms	
	Pre-results	Post-results	Pre-results	Post-results	Pre-results	Post-results	Pre-results	Post-results
Scenario 1	15	8	30	30	18	24	27	27
Scenario 1	15	17	18	18	21	21	18	18
Scenario 3	20	21	24	30	24	27	30	30
Scenario 4	23	24	15	18	27	27	24	27
Scenario 5	21	22	24	27	21	24	24	27
Scenario 6	20	16	15	24	27	27	24	21
Scenario 7	20	23	9	12	24	24	30	27
Scenario 8	25	23	27	24	21	24	21	27
Scenario 9	8	10	24	21	27	30	27	27
Scenario 10	28	29	30	30	30	30	30	30
Total Score	195 / 300	193 / 300	216 / 300	234 / 300	240 / 300	258 / 300	255 / 300	261 / 300

Table 2: Table regarding all of the scores in each topic for the second study

increase of 18 points is evident from the initial session to the final session, with scores rising from 216 to 234 and average scores of 21.6 and 23.4, respectively. Pertaining to the topic of Interpersonal Understanding of Social Norms, a marked increase in scores is observed, culminating in an increase of 18 points from 240 to 258, with average scores for the sessions being 24 and 25.8, respectively. Lastly, concerning Intrapersonal Understanding of Social Norms, a slight increase of 6 points is noted, from 255 to 261, with average scores of 25.5 and 26.1 for the sessions. Upon comparing the obtained scores, it is discernible that of the four topics, three exhibited an increase in scores from the first to the final sessions of the study. In this sample of 10 participants, it can be inferred that rehabilitating other cognitive functions led to an enhancement in social cognition, albeit modestly.

### 5.2.1 Internal Consistency

As a way of assessing the **internal consistency** of the scores obtained by the participants before and after rehabilitation, we used Cronbach's Alpha.

### 5.2.2 Cronbach's Alpha - Pre-rehabilitation

After organizing the scores for each participant in every scenario, we calculated Cronbach's Alpha (CA). This sample consisted of 34 items. The obtained  $\alpha$  value was **0.510**, indicating that the internal consistency of the pre-rehabilitation scores was **poor**, with the value falling within the range  $0.6 > \alpha \geq 0.5$  [39]. To achieve a higher alpha value, removing a specific question and its corresponding scores is necessary. By removing the scores related to the question on the Affective

Theory of Mind in scenario 6, the alpha value would increase to 0.607, thereby slightly improving internal consistency.

### 5.2.3 Cronbach's Alpha - Post-rehabilitation

Immediately after determining the CA for the scores obtained in the first session, we proceeded to calculate the value of  $\alpha$  for the scores obtained in the final session. Unlike the previous sample, this sample contained 33 items. Similar to the previous results, the value of  $\alpha$  obtained was **0.572**, indicating that the internal consistency of this sample is **poor**, given that its value falls between 0.5 and 0.6 [39]. Despite being somewhat higher than the pre-rehabilitation CA value, this  $\alpha$  value is still considered poor for internal consistency. To achieve a higher  $\alpha$ , it would be necessary to remove a specific question and its scores. Specifically, if the scores related to the question concerning the Affective Theory of Mind in scenario 4 were removed, the  $\alpha$  value would increase to 0.639, which would improve the internal consistency to a "questionable" level instead of "poor".

### 5.2.4 Spearman's Correlation

			ScorePre	ScorePos
Spearman's rho	ScorePre	Correlation Coefficient	1,000	,670*
		Sig. (2-tailed)	.	,034
		N	10	10
	ScorePos	Correlation Coefficient	,670*	1,000
		Sig. (2-tailed)	,034	.
		N	10	10

\*. Correlation is significant at the 0.05 level (2-tailed).

Figure. 33: Spearman's Correlation coefficient and significance

To measure the correlation between the two data samples (pre and post-rehabilitation scores) we decided to use Spearman's Correlation (Figure 33). Taking into account the total scores of all the participants, it was possible to observe that there was a **positive** correlation between the two samples,  $r(10) = .670$ ,  $p = .034$  [40].

## 5.3 Usability & Feedback

Due to time constraints, we were unable to ask participants to complete an SUS questionnaire, as was done in the previous study, to collect feedback on its usability. However, during the final

session with each participant, we conducted a brief formal interview to identify the aspects of CogMap-SC that were effective and those that were not. In general, the application was perceived as intuitive and successful in achieving its objectives. However, there were minor interactions that led to some discomfort. For example, some participants had limited wrist and finger mobility, which occasionally made pressing the small "continue" button or navigating the VR controllers challenging. Another identified issue concerns the background coloring of the questionnaire section of CogMap-SC. Some participants were reported to have difficulty reading the text due to the bright white color of the text against a background that featured a non-contrasting shade of gray. The size of the different buttons was also another issue, as most of them presented as very small in the VR headset view. Many participants were unhappy with the inability to rewatch the video after proceeding to the questionnaires, given that most of the time the participants could not remember some aspects of the videos. Another big aspect of the usability of this task was the basic nature of it. Although some participants enjoyed using the VR headset, other participants mentioned that they suffered minor headaches, dry eyes, and nausea while performing the task. These symptoms subsided after completing the task or after taking a short break, but it was something to take into account for future implementations and possible design changes that could be required. However, when eye-tracking was mentioned as a potential interaction method in a future version of CogMap-SC, all participants expressed significant interest, and some even questioned the timeframe for the widespread availability of this technology.

#### **5.4 Conclusions**

With this second study in patients with TBI and TB, we were able to better understand what was missing in CogMap-SC and what we could improve. Despite having a small sample of participants, we were also able to confirm that social cognition can be successfully improved while rehabilitating unrelated cognitive functions. CogMap-SC was one step closer to achieving clinical validation; however, further adjustments were needed, particularly if our primary objective was to integrate this task into ABS.

## 6 Third Study: Healthy Participants with eye-tracking

With the latest CogMap-SC prototype implemented, we wanted to validate this new interaction method before introducing it into a clinical setting. Accordingly, we set out to conduct a usability study featuring healthy participants and CogMap-SC's new interaction method. Alongside it, another study would be done on a previous work created by us. This previous work was mentioned above and never got the opportunity to be validated with the participants. The VR Trail Making Test was developed by us and featured two possible exercise scenarios, in which participants would be required to follow a pattern of numbers or alternating numbers and letters using only their eyes. Together, these two studies would provide us with feedback on how eye-tracking could be used as a means of assessing and evaluating patients. The primary objectives of this study were to achieve validation for the newly developed CogMap-SC and to obtain validation for the VR Trail Making Test for comparable purposes.

### 6.1 Methodology

Given that the primary objective of this study is centered around usability, it was imperative to enlist a substantial number of participants to ensure robust validation. The study is structured in three distinct sections. Initially, participants are required to complete the Meta Quest Pro eye-tracking calibration, a necessary step due to individual variations in ocular characteristics. Following this preliminary phase, the study proceeds with participants engaging in five scenarios of the CogMap-SC, with ample time and guidance provided as needed. Since usability is the primary focus, the participant responses during the CogMap-SC were largely unrecorded. Upon completion of the CogMap-SC, a formal interview is conducted to gather comprehensive feedback on the application's usability. Subsequently, participants are asked to complete three separate questionnaires. To acquire additional insights into the task's usability, three clinically validated usability tests were utilized:

- 1 - The **User Experience Questionnaire** - to evaluate the user experience throughout the completion of the task [41];
- 2 - The **NASA Task Load Index (NASA-TLX)** - to evaluate the workload requirement of the task [42];
- 3 - The **System Usability Scale** - for a general comprehension of the usability of the task [38];

After completing these questionnaires, the participant would proceed to the final section. In this final section, we would validate the VR Trail Making Test by asking the participant to complete the test in the shortest amount of time possible. The participant would start with an example of the first pattern featuring just numbers, with no timed constraints. Right after that, we would proceed with the timed exercise where the participant would have to go through ten markers. Posterior to this timed exercise we would proceed to the next pattern of numbers and letters, start with an example, and finalize the test with the final timed exercise with ten markers. Finally, the participants would be instructed to complete the three questionnaires related to the task they had just completed. After responding to these questionnaires, the study would be completed.

### 6.1.1 User Experience Questionnaire

Despite being a very long questionnaire, the User Experience Questionnaire provides us with an extensive array of feedback that very precisely describes what the participant thought about the experience of completing the task. This questionnaire is divided into four major topics:

- **Utility** - this topic contains questions related to how useful the task is;
- **Ease of learning** - this topic features questions related to how easy to learn the different interactions of the task are.
- **Ease of use** - this topic contains questions related to how easy to use the task is;
- **Satisfaction** - this topic features questions related to how satisfied the user was during and after completing the task.

Each of these topics has the purpose of portraying how the participants felt about the experience itself. At the end of this questionnaire, an open-ended section is provided in which the participant could share some positive or negative aspects of the experience. For every question, the participant would be required to choose a score between 0 and 7, with 0 meaning "Completely Disagree" and 7 meaning "Completely Agree". The data collected from each participant would then be grouped and organized to obtain a consensus on that specific question or topic. All of the questions shown in the User Experience questionnaire were translated into the Portuguese language.

### 6.1.2 NASA-TLX

The NASA-TLX is another usability questionnaire that aims to quantify and measure the workload requirements of a specific task. It is divided into six major topics:

- **Mental Demand** - how much thinking, deciding, or calculating was required to perform the task;
- **Physical demand** - the amount and intensity of physical activity required to complete the task;
- **Temporal demand** - the amount of time pressure involved in completing the task;
- **Effort** - how hard does the participant have to work to maintain their level of performance;
- **Performance** - the level of success in completing the task;
- **Frustration level** - how insecure, discouraged, or secure or content the participant felt during the task;

Unlike the User Experience Questionnaire, the NASA-TLX instructs participants to rate their score on an interval scale ranging from low (1) to high (20). After collecting data from all participants, the calculation for the real workload score is obtained by multiplying the square selected by the participant by 5. This will provide us with a score between 0 and 100. If a topic gets a score close to 100, it means that in that specific topic, the workload was very intensive; and if it were to obtain a score close to 0, it means the specific topic's workload was not stressful/not very intensive. All of the questions in the NASA-TLX questionnaire were translated into Portuguese.

### 6.1.3 Sample

For a first validation, we ideally wanted to gather as many participants as possible. Our sampling requirements were very simple:

- Ages between 18 and 60;
- Gender is not important;
- Healthy participants with no psychological or physical discrepancies;
- Ability to understand and read Portuguese;

With these requirements in mind, we started our search for possible participants. Most of the participants collected were colleagues and students from our campus. Similarly to the pilot study, if health discrepancies were shown during these studies, the data obtained from these participants would become invalid.

We were able to conduct ten case studies with 10 participants whose ages ranged from 21 to 35 years old (6 male and 4 female). All of these sessions were conducted in a controlled environment with only the participant and the researcher in charge. Throughout the ages of the 10 participants, we obtained a mean value of  $25.8 \pm 2.8$ . This value indicates that the data we collected has a very low dispersion and is very close to the average age.

## 6.2 Results

All statistical analyzes were performed using SPSS software (version 29, SPSS Inc., Chicago IL, USA). Since this study featured three sections with two different tasks, we will present both the results and the analysis for each task. We begin with the newest version of CogMap-SC.

### 6.2.1 CogMap-SC - User Experience Questionnaire

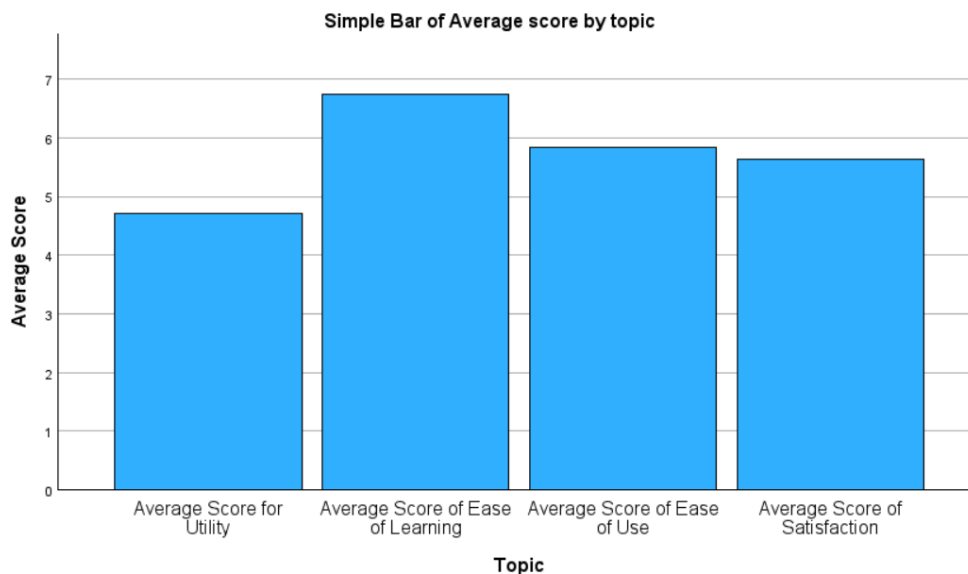


Figure. 34: User experience questionnaire average scores divided by topics

From the figure (Figure 34), it is possible to observe that overall CogMap-SC obtained very satisfactory scores regarding each topic. On the first topic, some users felt that CogMap-SC was not very useful outside of its context. Despite this, following the participant's feedback, CogMap-SC was seen as very easy to learn and use, and most participants were satisfied with this version and its interaction. The average scores and standard deviations for each topic are the following:

- **Average Score for Utility** presented an average score of 4.71 +- 0.7.
- **Average Score of Ease of Learning** presented an average score of 6.75 +- 0.4.
- **Average Score of Ease of Use** presented an average score of 5.84 +- 0,8.
- **Average Score of Satisfaction** presented an average score of 5,63 +- 0,9.

Overall, the average scores were very positive, indicating that this new CogMap-SC version provided a positive experience with respect to its use. The standard deviation values were very low, indicating that the scores were not very dispersed and close to their average score. In account of the open-ended section, most of the negative feedback we collected mentioned the lack of support for glasses users; sometimes the interaction method of holding the gaze for selection could cause some eye dryness; and there was no indication whatsoever that the video had ended. We also received a substantial amount of positive feedback, with many users praising eye-tracking as an excellent means for individuals with limb paralysis to interact with software applications. In addition, users reported that the application was very responsive and user-friendly.

### 6.2.2 CogMap-SC - NASA-TLX

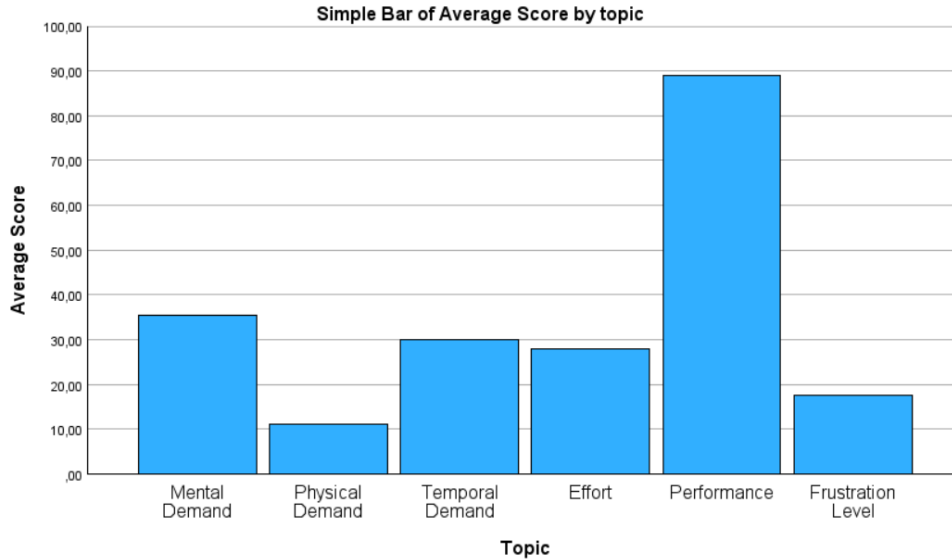


Figure. 35: NASA-TLX average scores divided by topics

From the previous graph (Figure 35), we can identify that CogMap-SC presented very low levels of workload regarding the many different topics. Regarding mental demand and physical demand, both of these topics presented very low average scores indicating that the task was not

very mentally and physically demanding. It is still important to notice that the participant deemed CogMap-SC more mentally than physically demanding. As for temporal demand, the participants indicated that CogMap-SC did not present much time pressure involved. Most of the participants indicated that they did not put much effort into the completion of the task, because they felt there was no need for it. This would explain the low average score behind the topic of effort. Performance-wise, most if not all participants believed their performance was above excellent which is why the performance topic presents such a high average score. Finally, the participants also indicated that CogMap-SC did not cause them much frustration. This is possible to observe in the average score for the topic of frustration level.

The concrete average scores and their standard deviation for each topic are the following:

- **Mental Demand** presented an average score of 35.5 +- 22.3.
- **Physical Demand** presented an average score of 11 +- 7.7.
- **Temporal Demand** presented an average score of 30 +- 22.85218.
- **Effort** presented an average score of 28 +- 18.7.
- **Performance** presented an average score of 89 +- 6.1.
- **Frustration** level presented an average score of 17.5 +- 13.4.

The overall workload evaluated for CogMap-SC was quite low, indicating a positive aspect for this task. However, the obtained standard deviation values show that within each topic, the scores were quite scattered, suggesting that there were many differing opinions on some topics.

### 6.2.3 CogMap-SC - SUS

The graph (Figure 36) showcases the total scores each participant obtained after completing the SUS questionnaire. Overall, it is evident that CogMap-SC achieved an exceptionally positive score, with the lowest score recorded being 75. This suggests that CogMap-SC is perceived as an application with very good usability. As previously highlighted, an average score above 68 signifies that the application/technology offers good usability. The average score achieved by all participants in the SUS was 89.5, further validating the previous claim. It also presented a standard deviation of 7.24569, indicating that the values were dispersed but not by a large amount.

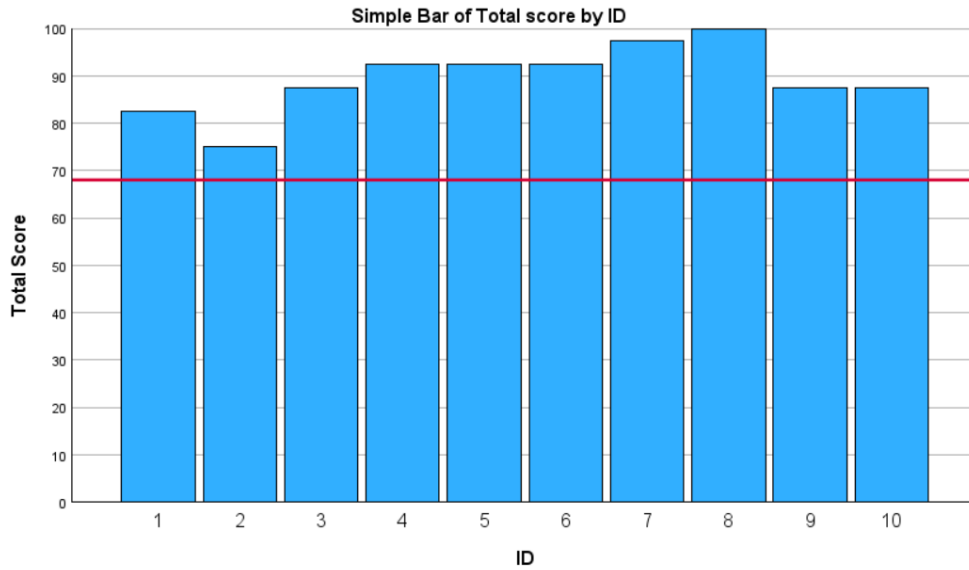


Figure. 36: SUS scores obtained from each participant

Using the feedback from these questionnaires, we then proceeded to analyze the responses associated with the Trail Making Test section.

#### 6.2.4 VR Trail Making Test - User Experience Questionnaire

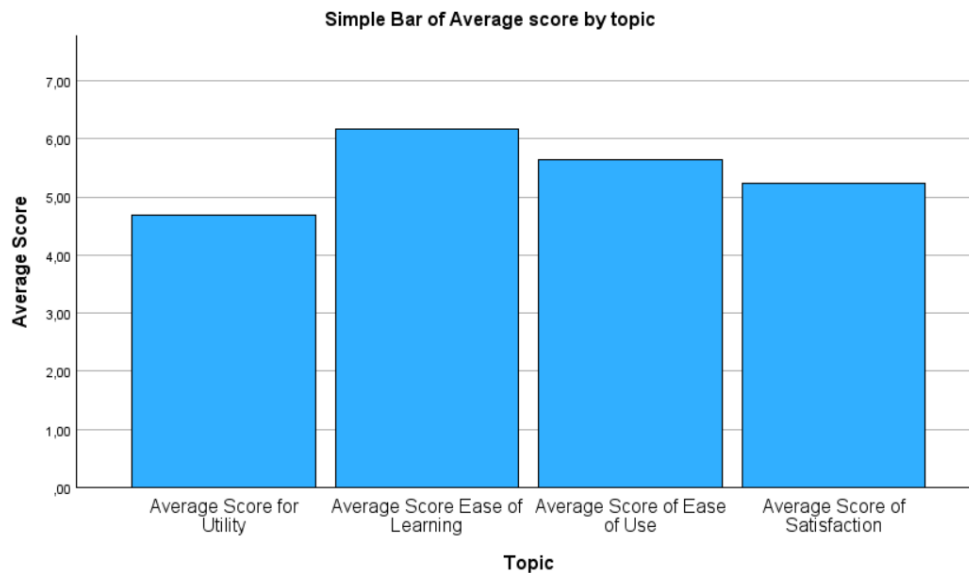


Figure. 37: User experience questionnaire average scores divided by topics

From the previous graph (Figure 37), we were able to discern that participants enjoyed the experience of completing the test. In the first topic, most of the participants thought that the test

was useful in some extremely specific clinical scenarios, while others believed that it was more of a game rather than a clinical assessment tool. However, most of the participants indicated that the task was simple enough to efficiently learn the different aspects without much difficulty. This therefore implied that the application was considered easy to use. Ultimately, for the final topic of satisfaction, the VR Trail Making Test presented an average score above 5, revealing that most of the participants enjoyed completing the task. The exact average scores and their standard deviations are as follows:

- **Average Score for Utility** presented an average score of 4.68 +- 1.2.
- **Average Score of Ease of Learning** presented an average score of 6.18 +- 1.0.
- **Average Score of Ease of Use** presented an average score of 5.63 +- 1.4.
- **Average Score of Satisfaction** presented an average score of 5.24 +- 1.2.

The majority of the average scores regarding the experience of completing the task were very positive. Additionally, the low values of the standard deviation indicate that the scores for each participant were very close to the overall average, reflecting minimal dispersion. In the open-ended section, several participants mentioned negative aspects, particularly discomfort with the eye-tracking calibration and the time it took to proceed to the subsequent point after hovering above the previous point. Nevertheless, many participants also stated that the task was fun, responsive, and very simple to use, amongst other positive comments.

### 6.2.5 VR Trail Making Test - NASA-TLX

From the graph (Figure 38), we can identify that the VR Trail Making test demonstrated very low levels of workload on the various NASA-TLX topics. Both mental and physical demands exhibited very low average scores, suggesting that the task was neither mentally nor physically taxing. However, it should be noted that the participant found the task more mentally demanding than physically. Regarding temporal demand, the participants reported that this task imposed some levels of time pressure, but nothing out of the ordinary. Most of the participants indicated that they did not exert much effort in completing the task, perceiving it as unnecessary, which explains the low average score in the effort category. Performance-wise, most of the participants believed that their performance was above average, resulting in a high average score for the performance

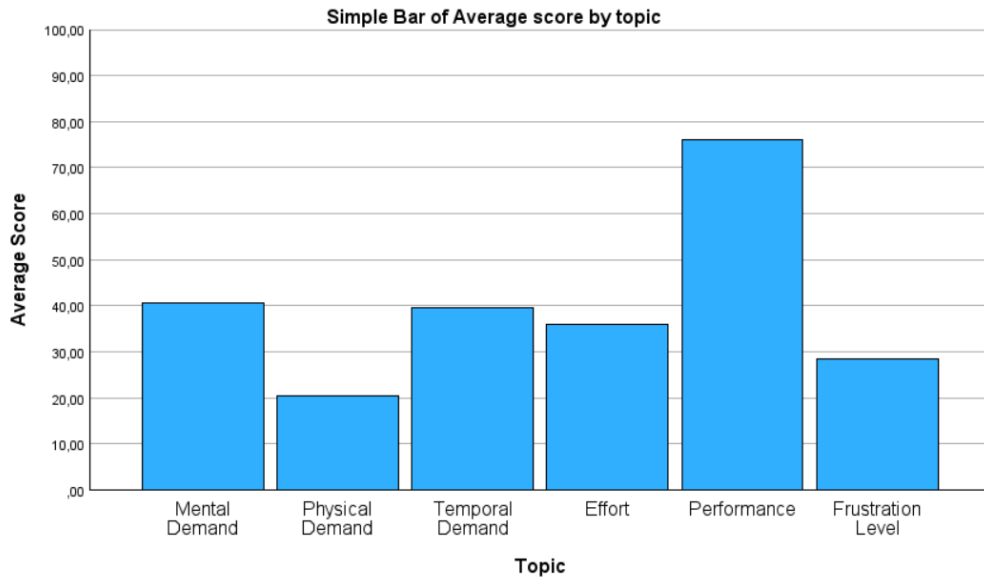


Figure. 38: NASA-TLX average scores divided by topics

topic. Lastly, participants indicated that the VR Trail Making did not cause much frustration, as reflected in the low average score for the frustration level topic.

The specific average scores and their standard deviations for each topic are as follows:

- **Mental Demand** presented an average score of 40.5 +- 35.5.
- **Physical Demand** presented an average score of 20.5 +- 22.8.
- **Temporal Demand** presented an average score of 39.5 +- 36.2.
- **Effort** presented an average score of 36 +- 32.5.
- **Performace** presented an average score of 76 +- 24.1.
- **Frustration Level** presented an average score of 28.5 +- 25.4.

The overall workload evaluated for the VR Trail Making Test was relatively low, highlighting a positive aspect of the task. However, the standard deviation values obtained were quite high, indicating that the scores within each topic were quite dispersed, suggesting a wide range of opinions on most topics.

### 6.2.6 VR Trail Making Test - SUS

The graph (Figure 39) illustrates the total scores obtained by each participant after completing the SUS questionnaire. In general, it is clear that the VR Trail Making Test secured a favorable

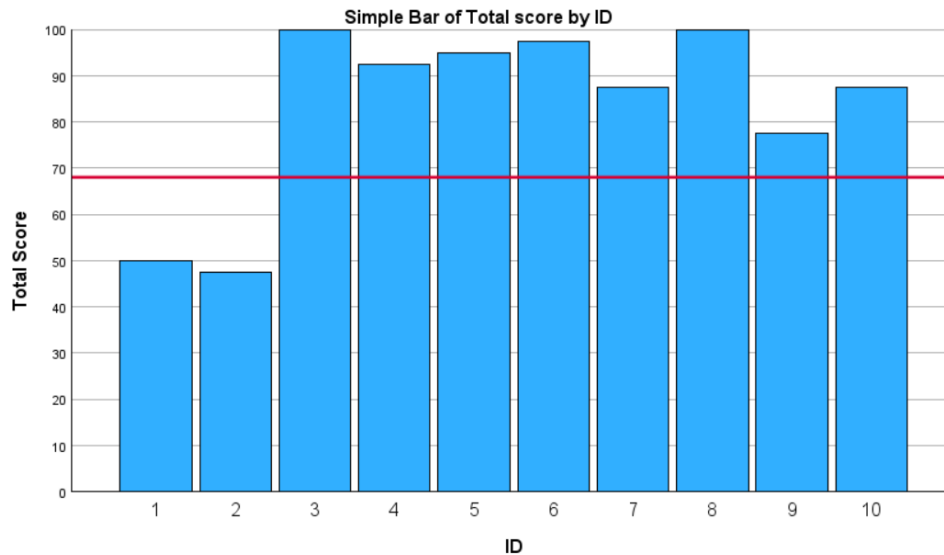


Figure. 39: SUS scores obtained from each participant

average score, although the lowest recorded score was 47.5. This implies that the task is considered to be an application with good usability. As mentioned earlier, an average score above 68 indicates good usability in an application or technology. The average score obtained by all participants in the SUS was 83.5, strengthening this assertion. The standard deviation was 19.55050, demonstrating a wide variance in scores. However, this significant standard deviation value suggests that the participants had markedly diverse opinions.

After obtaining the participant's feedback on both of these tasks, we concluded the third study.

### 6.3 Conclusions

In general, both tasks scored positively on usability. The updated version of CogMap-SC with the eye-tracking interaction was accepted and validated within the sample of participants and provided us with very important information about how the usability of eye-tracking could be used in the future. The VR Trail Making Test also presented very positive scores and useful information on the use of eye-tracking to complete assessment tasks, although compared to CogMap-SC, it obtained higher workload scores and lower usability scores.

### 6.4 Methodology: Conclusion

In this section, we detailed the steps necessary for adapting the social cognition assessment task to virtual reality. Regrettably, we cannot comprehensively validate these tasks due to the limited

sample size. Ideally, we would have involved more participants, but time constraints prevented us from doing so. Other than this, some participants indicated that not being able to use glasses was something that annoyed them. This could have been an influencing factor in some of the answers given by the participants. Nevertheless, the feedback we obtained will be invaluable for future applications and research involving eye-tracking technologies and interactions. Furthermore, we utilized the last study as an opportunity to gather feedback on a previously developed eye-tracking test, the VR Trail Making Test, obtaining positive scores regarding its usability and experience.

## 7 Discussion

A lot of work and research was put into ABS and assessment tools. However, most of them feature the assessment of the language domain. Other studies that delved into more complex cognitive assessments usually use more traditional-type tasks to achieve this goal. The use of VR and eye-tracking is still a work in progress, but we believe that one step at a time is the right way to integrate these technologies into a more surgical context.

Throughout the work previously shown in the last sections, we achieved one of our main goals: adapting a social cognition test to VR. The choice of the social assessment test, ESCoT, helped guide us to what type of task we should aim to develop. However, CogMap-SC had to go through many iterations so that we could achieve our main goal. The first interaction method of a point-and-shoot-type task helped us understand what limitations had to be imposed in future implementations.

In the first study, we conducted with healthy individuals, CogMap-SC received positive scores and feedback, confirming it was a step in the right direction. Regardless, many factors made us rethink some of the design choices for the first prototype. Given the excellent usability scores received by CogMap-SC, we felt confident in conducting the second study, this time with TBI and BT patients.

The second study was our most critical as it involved real-life clinical patients. Through this study, we gained a deeper understanding of the significance of the interaction method. Observing participants' struggles with the VR controllers and the task UI buttons was both heartbreaking and eye-opening. Though participants found the VR headset enjoyable, many struggled with precise movements. This indicated that a redesign and change in interaction method should be done before proceeding.

Given that our final goal was to validate this tool in ABS, eye-tracking became the most essential component of the CogMap-SC. The last study we conducted showed how much of a difference eye-tracking could make regarding interaction. The vast majority of the participants indicated that they enjoyed the experience of completing the task using only their eyes. It is also important to notice that some participants completed CogMap-SC with both interaction methods. These ended up preferring eye-tracking due to how innovative and easy to use it was.

With this final prototype concluded, we are ready to proceed to the next step by conducting a final study with the latest prototype on TBI and BT patients. Nevertheless, considering that social cognition is infrequently examined within surgical contexts, this study is likely to elevate awareness regarding its significance.

## 7.1 Constraints and Limitations

Throughout our efforts, we have accomplished a lot. However, much of our work suffered changes due to increasing constraints and limitations. During brainstorming ideas for the adaptation of the ESCoT, many design ideas had to be scrapped. The primary reason for this was the lack of skills required to execute certain choices, coupled with the fact that other designs demanded more time than what was available to us. As mentioned previously, one of our first design choices utilized 360° videos, which in theory would be perfect for what we wanted to accomplish. However, given the immersive nature of CogMap-SC, we had to ensure that the user would focus on the main context of the scenario instead of his surroundings. We attempted to maintain this philosophy while recording, but ended up giving up since most if not all videos had distracting elements that could negatively influence results. On the other hand, 3D models and animated environments would be ideal, but due to time constraints, we would not be able to create them without requesting an extension of time limitations.

The first study provided us with very useful information. However, the sample size of 20 participants could negatively affect our results. This was also the case for the second study. A significant challenge in conducting studies involving clinical patients is the recruitment process, as patients frequently decline participation due to time constraints or a lack of willingness to take part. Another constraint in working with clinical patients is that we must adapt our process to the needs of each patient. For example, one of our invalidated case studies featured an older woman who had many cognitive and memory deficiencies. During our conversations with her, she would frequently fixate on an arbitrary spot in the room and become momentarily unresponsive. After a brief period, questions about her well-being were met with positive responses. During the completion of CogMap-SC, the participant exhibited highly erratic head movements. Upon inquiry regarding her ability to perceive the 3D environment and comprehend the task, she affirmed that she could. However, after a few attempts, she was asked about the content of the video she had just viewed and was unable to recall any of it. This instance exemplifies the necessity for further attention,

as well as additional research and prototyping, to adequately address her needs. Nevertheless, we succeeded in recruiting a sufficient number of willing and valid participants who offered invaluable feedback.

Regarding the last study, we obtained a lot of valuable feedback. However, as previously mentioned, the low sample size negatively affected the validation of this tool. Eye-tracking is a technology that shows a lot of promise but also requires very extensive research and care. Using eye-tracking with TBI and BT patients will require an ever higher level of care since a lot of the patients we encountered during the second study presented minor eye movement issues.

Our major obstacle regarding using CogMap-SC during ABS is the limitations the technology presents. The HTC Vive Pro Eye facilitates highly responsive and delay-free eye-tracking; however, it is lacking in terms of portability. Due to the limited space in a surgical environment, setting up this VR headset could cause some constraints. The Meta Quest Pro, on the other hand, features more portability but a more difficult calibration setup and less responsiveness. A significant drawback of the Meta Quest Pro, as previously noted, is the potential for its calibrated eye-tracking to become progressively unreliable over time or to fully lose calibration if it is not utilized for repeated/extensive periods.

## 8 Conclusion

In this thesis we were able to identify the many shortcomings that prevailed among clinical assessments of cognitive functions during clinical examinations or ABS. Identifying these was essential for the selection of social cognition as the cognitive function to evaluate. Moreover, we were able to adapt an already validated social cognition assessment, the Edinburgh Social Cognition test, in the Portuguese language, as well as VR and eye-tracking (CogMap-SC). In addition to this, we were able to validate two interaction methods: the point-and-shoot-type interaction and the eye-tracking interaction.

Three studies were conducted that allowed us to gather feedback on CogMap-SC. These studies featured over 30 healthy participants ranging from 19 to 60 years of age and over 13 patients with TBI and BT ranging from 23 to 70 years of age. Most of the healthy participants in these studies were family members, colleagues or randomly chosen students of the University of Madeira. In contrast, the patients we conducted studies with were provided by the Neuropsychological department in SESARAM. In general, most of the feedback collected from these studies was positive, helping us to take one step forward towards our final goal of clinical validation.

Furthermore, a task developed before this paper, incorporating the trail-making test and eye-tracking, was also validated with healthy participants. This validation was aimed at facilitating the introduction of the task into clinical settings for the detection of attention deficits or as a potential means of patient relaxation.

In conclusion, this project required meticulous attention to detail and exceptional care due to its implications for health. We believe that this work adheres to the standards of the scientific community and constitutes a significant contribution to understanding how virtual reality and eye-tracking can beneficially influence clinical evaluations related to social cognition, among others.

CogMap-SC still has some limitations. To achieve our final goal of clinical validation, we firmly believe that another study is needed with patients with TBI and BT. This final study would then allow us to understand how eye-tracking would function in a more clinical setting, and help us in adapting the tool taking into consideration the patient's needs.

In addition to the proposed final study, CogMap-SC would greatly benefit from enhancements in its system. Rather than employing videos as visual stimuli, implementing 3D models with ani-

mations within more immersive environments could significantly improve the outcomes, while also offering more engaging tasks for the participants. The use of realistic videos, despite offering a more realistic methodology, is substantially constrained by the innate limitations of human and actor portrayals, as well as the challenges associated with the search for props necessary to construct these scenarios.

As of now, CogMap-SC is very limited in social cognition scenarios. In the future, this application could branch out and adapt other known social cognition tests into its application, allowing a bigger and broader range of showcases of social events and social rule violations.

Ultimately, CogMap-SC exhibits significant potential within the surgical context. Investing in additional research and development efforts would broaden the scope for researchers, thereby improving the understanding of the utility of VR and eye-tracking technologies in facilitating clinical assessments.

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This work was featured in one conference: SEGaH (Serious Games and Applications for Health) as a poster. In the future, this work will be featured and presented in HCist (Internal Conference on Health and Social Care Information Systems and Technologies) as a full paper.

This work was able to be completed with the help of the following organizations and collaborators.

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- Madeira N-LINCS
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## 9 Appendix

### 9.1 Appendix A - First Contribution

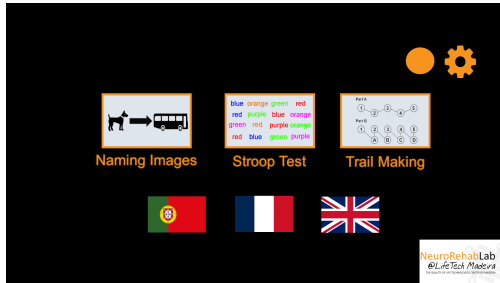


Figure. 40: CogMap's main menu

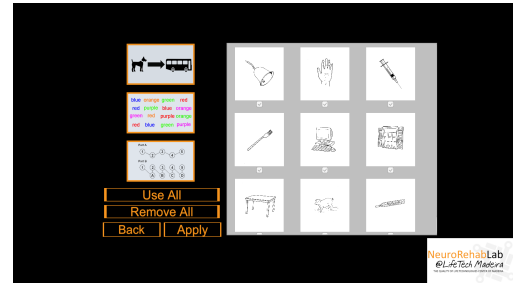


Figure. 41: CogMap's customization

This contribution had its first appearance during my bachelor's degree. Our main goal was to adapt three existing and validated tasks to virtual reality (VR) to be used during ABS for assessment (Figure 1 and Figure 2). This application would then utilize eye-tracking technology for data collection, pattern recognition, and collection of possible attention deficits. For use during ABS, psychologists needed to have the ability to view the same content as the patient within the VR headset, as well as receive visual feedback indicating the elapsed time of 5 seconds. Consequently, a dual-display functionality was integrated, enabling the use of a VR headset in conjunction with an auxiliary monitor displaying supplementary information. This additional information was concealed from the patient to reduce the potential for inconsistencies. The Naming Images task (Figure 3) presented a prevalidated databank of black and white images that the psychologist could select from. Afterward, the patient had to nominate what they were seeing in the image so that the psychologist could proceed. Eye-tracking data in this task was merely used for data gathering. The Stroop test task (Figure 4) shared some similarities to the naming images task, but instead of nominating what the patient was seeing, they would be required to nominate the color in which the word presented was. These words were generated at random, and eye-tracking was only used for data collection. Lastly, the Trail Making test (Figure 5) was a test task that was not developed to be used for official ABS assessments, but more as a relaxation tool in between assessments. This task featured 2 patterns: one consisting of just numbers (1-2-3-4-...) and the other featuring a combination of numbers and letters (1-A-2-B-...). In this task, the user had to connect the markers

using only their eyes. This was the only task present in the CogMap that featured an actual eye-tracking interaction.

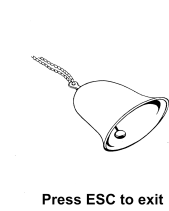


Figure. 42: Nomination task interface for psychologist



Figure. 43: Stroop Test task interface for psychologist

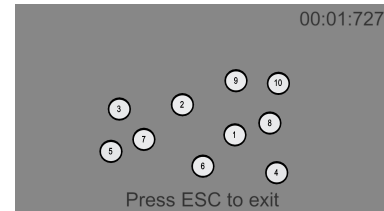


Figure. 44: Trail Making Test interface for psychologist

## 9.2 Appendix B - Scenario 1 (ESCoT and CogMap-SC)

- **General Interpretation** - "Pode dizer-me o que está acontecer nesta história, a começar pela primeira imagem e acabar com a última?"
- **Cognitive theory of mind** - "O que é que o homem pensou que a idosa queria?"
- **Affective theory of mind** - "Como é que a idosa se sentiu no fim da animação?"
- **Interpersonal understanding of social norms** - "O homem da animação comportou-se como as outras pessoas devem comportar-se?"
- **Intrapersonal understanding of social norms** - "Teria agido da mesma forma que o homem na animação?"

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### 1. Pode dizer-me o que aconteceu no vídeo?

- (a) Um idoso e uma jovem caminham na estrada (0)
- (b) Uma jovem encontra-se a falar ao telemóvel (0)
- (c) Um idoso ia a caminhar e deixou cair o saco e foi ignorado pela jovem (3)
- (d) Uma jovem passou por um idoso que precisava de ajuda e ignorou-o (2)
- (e) Um idoso ia a caminhar e deixou o saco cair (1)

### 2. O que é que a jovem estaria a pensar?

- (a) Que deveria ajudar o idoso, mas estava ocupada (3)

- (b) Que não tinha obrigação de ajudar (1)
- (c) Que outra pessoa poderia ajudar o idoso (2)
- (d) Que cada um é responsável por si (1)
- (e) Nada (0)

3. **Como acha que o idoso se sentiu?**

- (a) Raiva (0)
- (b) Tristeza (3)
- (c) Alegria (0)
- (d) Nojo (0)
- (e) Medo (0)

4. **Perante a situação a jovem fez o que a maioria das pessoas faria?**

- (a) Sim (0)
- (b) Não (3)

5. **Agiria da mesma forma que a jovem?**

- (a) Sim (0)
- (b) Não (3)

---

**9.3 Appendix C - Scenario 2 (ESCoT and CogMap-SC)**

- **General Interpretation** - "Pode dizer-me o que está acontecer nesta história, a começar pela primeira imagem e acabar com a última?"
- **Cognitive theory of mind** - "O que é que a mulher pensou que o polícia queria?"
- **Affective theory of mind** - "Como é que a mulher se sentiu no fim da animação?"
- **Interpersonal understanding of social norms** - "O polícia na animação comportou-se como as outras pessoas devem comportar-se?"

– **Intrapersonal understanding of social norms** - "Teria agido da mesma forma que o policia na animação?"

---

**1. Pode dizer-me o que aconteceu no vídeo?**

- (a) Estava uma carrinha estacionada e alguém solicita que a carrinha seja retirada (1)
- (b) Uma carrinha externa à obra encontra-se estacionada nas cargas e descargas e o responsável da obra solícita que seja retirada (3)
- (c) O responsável da obra solícita que a carrinha seja retirado do estacionamento sem motivo aparente (2)
- (d) Uma carrinha encontra-se devidamente estacionada e um individuo solicita que seja retirada (0)
- (e) Dois homens discutem sem motivo aparente (0)

**2. O que acha que estaria a pensar o proprietário da carrinha?**

- (a) O estacionamento era apropriado (0)
- (b) Poderia estacionar nas cargas e descargas temporariamente (2)
- (c) Não causaria transtorno a ninguém estacionar nas cargas e descargas (3)
- (d) Aquele era o local mais apropriado para estacionar a carrinha (0)
- (e) Tinha conhecimento da proibição de estacionamento das cargas e descargas, mas que ninguém o repreenderia (1)

**3. Como acha que o proprietário da carrinha se sentiu?**

- (a) Raiva (3)
- (b) Tristeza (0)
- (c) Alegria (0)
- (d) Nojo (0)
- (e) Medo (0)

**4. O responsável da obra agiu como a maioria das pessoas?**

(a) Sim (3)

(b) Não (0)

**5. Agiria da mesma forma que o responsável da obra**

(a) Sim (3)

(b) Não (0)

---

**9.4 Appendix D - Scenario 3 (ESCoT and CogMap-SC)**

- **General Interpretation** - "Pode dizer-me o que está acontecer nesta história, a começar pela primeira imagem e acabar com a última?"
  - **Cognitive theory of mind** - "O que é que o homem pensou que a mulher queria?"
  - **Affective theory of mind** - "Como é que a mulher se sentiu no fim da animação?"
  - **Interpersonal understanding of social norms** - "O homem na animação comportou-se como as outras pessoas devem comportar-se?"
  - **Intrapersonal understanding of social norms** - "Teria agido da mesma forma que o homem na animação?"
- 

**1. Pode dizer-me o que aconteceu no vídeo?**

(a) Uma grávida chega a paragem de autocarros (1)

(b) Os lugares encontram-se ocupados na paragem de autocarros, chega uma grávida e a pessoa que lá está não cede o lugar nem retira as suas coisas (3)

(c) Estão duas pessoas à espera do autocarro (0)

(d) Uma grávida encontra-se de pé porque ninguém lhe cede o lugar (2)

(e) Está uma pessoa a chegar a uma paragem de autocarros (0)

**2. O que acha que estaria a pensar a grávida a pensar?**

- (a) Que chegaria e lhe cederiam o lugar (3)
- (b) Que estava a ser ignorada pela jovem sentada (2)
- (c) Que a jovem tinha a obrigação de lhe ceder o lugar (1)
- (d) Que teria de aguardar de pé (0)
- (e) Que a gravidez não lhe dá prioridade sobre os outros (0)

3. **Como acha que a grávida se sentiu?**

- (a) Raiva (3)
- (b) Tristeza (3)
- (c) Alegria (0)
- (d) Nojo (0)
- (e) Medo (0)

4. **Terá a jovem que estava sentada agido da forma que a maioria das pessoas agiria?**

- (a) Sim (0)
- (b) Não (3)

5. **Agiria da mesma forma que a pessoa que estava sentada?**

- (a) Sim (0)
  - (b) Não (3)
- 

### 9.5 Appendix E - Scenario 4 (ESCoT and CogMap-SC)

- **General Interpretation** - "Pode dizer-me o que está acontecer nesta história, a começar pela primeira imagem e acabar com a última?"
- **Cognitive theory of mind** - "O que é que o homem pensa que a mulher quer?"
- **Affective theory of mind** - "Como é que a mulher se sente no fim da animação?"

- **Interpersonal understanding of social norms** - "O homem na animação comportou-se como as outras pessoas devem comportar-se?"
  - **Intrapersonal understanding of social norms** - "Teria agido da mesma forma que o homem na animação?"
- 

**1. Pode dizer-me o que aconteceu no vídeo?**

- (a) Uma mulher atira lixo para o chão (1)
- (b) Uma mulher atira lixo (1)
- (c) Uma mulher atira lixo para chão e a responsável do estabelecimento chama-a à atenção (3)
- (d) Uma mulher é chamada à atenção por atirar lixo para o chão (2)
- (e) Uma mulher põe o lixo no caixote do lixo (0)

**2. O que é que a mulher pensou?**

- (a) Que podia atirar o lixo para o chão (1)
- (b) Que estava a atirar o lixo para um local apropriado (0)
- (c) Que a responsável pelo estabelecimento não iria reparar que tinha atirado lixo para o chão (3)
- (d) Que a responsável pelo estabelecimento não iria chamar à atenção por atirar lixo para o chão (2)
- (e) Que é normal atirar lixo para o chão (1)

**3. Como acha que a mulher se sentiu?**

- (a) Raiva (3)
- (b) Tristeza (0)
- (c) Alegria (0)
- (d) Nojo (0)
- (e) Medo (0)

4. **A responsável pelo estabelecimento agiu da forma que a maioria das pessoas agiria?**

(a) Sim (3)

(b) Não (0)

5. **Agiria da mesma forma que a responsável do estabelecimento?**

(a) Sim (3)

(b) Não (0)

## 9.6 Appendix F - Scenario 5 (ESCoT and CogMap-SC)

– **General Interpretation** - "Pode dizer-me o que está acontecer nesta história, a começar pela primeira imagem e acabar com a última?"

– **Cognitive theory of mind** - "O que é que o homem pensou que a mulher queria?"

– **Affective theory of mind** - "Como é que a mulher se sente no fim da animação?"

– **Interpersonal understanding of social norms** - "O homem na animação comportou-se como as outras pessoas devem comportar-se?"

– **Intrapersonal understanding of social norms** - "Teria agido da mesma forma que o homem na animação?"

1. **Pode dizer-me o que aconteceu no vídeo?**

(a) Um jovem entra na sua casa (0)

(b) Um jovem salta o muro de uma casa (1)

(c) Um jovem não consegue abrir o portão da sua casa e salta o muro (2)

(d) Estava alguém a pedir socorro e um jovem salta o muro em auxílio (3)

(e) Um jovem encontra-se a fazer desporto (0)

2. **O que é que o homem estaria a pensar ao ouvir a mulher pedir socorro?**

(a) Que deveria entrar na casa e ajudar a todo o custo (3)

- (b) Que deveria chamar o 112 (1)
- (c) Que outra pessoa passaria e ajudaria (0)
- (d) Que deveria de ajudar de imediato (2)
- (e) Que não tinha a obrigação de ajudar (0)

**3. Como acha que a mulher se sentiu ao ser ajudada?**

- (a) Raiva (0)
- (b) Tristeza (0)
- (c) Alegria (3)
- (d) Nojo (0)
- (e) Medo (0)

**4. O jovem que saltou o muro agiu da forma que a maioria das pessoas agiria?**

- (a) Sim (3)
- (b) Não (0)

**5. Agiria da mesma forma que o jovem que saltou o muro?**

- (a) Sim (3)
  - (b) Não (0)
- 

**9.7 Appendix G - Scenario 6 (ESCoT and CogMap-SC)**

- **General Interpretation** - "Pode dizer-me o que está acontecer nesta história, a começar pela primeira imagem e acabar com a última?"
- **Cognitive theory of mind** - "O que é que a mulher de verde pensa que a mulher de azul quer?"
- **Affective theory of mind** - "Como é que a mulher de azul se sente no fim da animação?"

- **Interpersonal understanding of social norms** - "A mulher de verde na animação comportou-se como as outras pessoas devem comportar-se?"
  - **Intrapersonal understanding of social norms** - "Teria agido da mesma forma que a mulher de verde?"
- 

**1. Pode dizer-me o que aconteceu no vídeo?**

- (a) Uma mulher acende um cigarro (1)
- (b) Uma mulher é repreendida por estar a fumar (3)
- (c) Uma mulher aponta para um sinal de "proibido fumar" (2)
- (d) Duas mulheres estão a fumar no café (0)
- (e) Uma mulher está a fumar e é incomodada por outra (0)

**2. O que é que a mulher de cabelo comprido estaria a pensar?**

- (a) Que a mulher de cabelo curto devia de apagar o cigarro (3)
- (b) Que queria que a mulher de cabelo curto fosse embora (0)
- (c) Que a mulher de cabelo curto não estava a ver o sinal na parede (2)
- (d) Que a mulher de cabelo curto devia de continuar a fumar (0)
- (e) Que o sinal de "proibido fumar" estava visível a todos (1)

**3. Como acha que a mulher de cabelo comprido sentiu?**

- (a) Raiva (3)
- (b) Tristeza (0)
- (c) Alegria (0)
- (d) Nojo (0)
- (e) Medo (0)

**4. A mulher de cabelo curto agiu da forma que a maioria das pessoas agiria?**

- (a) Sim (0)

(b) Não (3)

5. **Agiria da mesma forma que a mulher de cabelo curto?**

(a) Sim (0)

(b) Não (3)

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**9.8 Appendix H - Scenario 7 (ESCoT and CogMap-SC)**

- **General Interpretation** - "Pode dizer-me o que está acontecer nesta história, a começar pela primeira imagem e acabar com a última?"
  - **Cognitive theory of mind** - "O que é que as mulheres pensaram que o homem queria?"
  - **Affective theory of mind** - "Como é que o homem se sentiu no fim da animação?"
  - **Interpersonal understanding of social norms** - "As mulheres na animação comportaram-se como as outras pessoas devem comportar-se?"
  - **Intrapersonal understanding of social norms** - "Teria agido da mesma forma que as mulheres na animação?"
- 

1. **Pode dizer-me o que aconteceu no vídeo?**

(a) Uma jovem pede silêncio (2)

(b) Várias pessoas conversam durante a visualização de um filme (3)

(c) Várias pessoas assistem um filme em silêncio (0)

(d) Uma jovem pede para assistir um filme (0)

(e) Várias pessoas assistem a um filme (1)

2. **O que é que a jovem estaria a pensar?**

(a) Que queria que as pessoas parassem de falar (2)

(b) Que queria assistir o filme em silêncio (3)

(c) Que estava muito barulho (1)

(d) Que as pessoas estavam a distrai-la do filme (0)

(e) Que as pessoas estavam ser mal-educadas (0)

**3. Como acha que a jovem se sentiu?**

(a) Raiva (3)

(b) Tristeza (0)

(c) Alegria (0)

(d) Nojo (0)

(e) Medo (0)

**4. As pessoas que conversavam agiram da forma que a maioria das pessoas agiria?**

(a) Sim (0)

(b) Não (3)

**5. Agiria da mesma forma que as pessoas que conversavam?**

(a) Sim (0)

(b) Não (3)

**9.9 Appendix I - Scenario 8 (ESCoT and CogMap-SC)**

- **General Interpretation** - "Pode dizer-me o que está acontecer nesta história, a começar pela primeira imagem e acabar com a última?"
- **Cognitive theory of mind** - "O que é que o vendedor de cachorros quentes pensou que o pai queria?"
- **Affective theory of mind** - "Como é que o pai sente-se no fim da animação?"
- **Interpersonal understanding of social norms** - "O vendedor de cachorros quentes comportou-se como as outras pessoas devem comportar-se?"
- **Intrapersonal understanding of social norms** - "Teria agido da mesma forma que o vendedor de cachorros quentes?"

**1. Pode dizer-me o que aconteceu no vídeo?**

- (a) Uma mulher está no café (2)
- (b) Uma cliente faz um pedido no café (3)
- (c) Duas mulheres conversam no café (1)
- (d) Uma cliente não paga os produtos que pediu (0)
- (e) A mulher de branco oferece algo à mulher de verde (0)

**2. O que é que a cliente estaria a pensar no final do vídeo?**

- (a) Que quer ser servida pela vendedora (1)
- (b) Que tem fome e quer ser servida (0)
- (c) Que está satisfeita com o atendimento (2)
- (d) Que precisa pagar os produtos que pediu (3)
- (e) Que preferia ser servida por outra pessoa (0)

**3. Como acha que a cliente se sentiu com o serviço da vendedora?**

- (a) Raiva (0)
- (b) Tristeza (0)
- (c) Alegria (3)
- (d) Nojo (0)
- (e) Medo (0)

**4. A vendedora agiu da forma que a maioria das pessoas agiria?**

- (a) Sim (3)
- (b) Não (0)

**5. Agiria da mesma forma que o/a vendedora?**

- (a) Sim (3)

(b) Não (0)

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### 9.10 Appendix J - Scenario 9 (ESCoT and CogMap-SC)

- **General Interpretation** - "Pode dizer-me o que está acontecer nesta história, a começar pela primeira imagem e acabar com a última?"
  - **Cognitive theory of mind** - "O que é que a mulher de roxo pensa que a mulher de laranja quer?"
  - **Affective theory of mind** - "Como é que a mulher de laranja sente-se no fim da animação?"
  - **Interpersonal understanding of social norms** - "A mulher de roxo na animação comportou-se como as outras pessoas devem comportar-se?"
  - **Intrapersonal understanding of social norms** - "Teria agido da mesma forma que a mulher de roxo?"
- 

#### 1. Pode dizer-me o que aconteceu no vídeo?

- (a) Várias pessoas aguardam numa fila (1)
- (b) A mulher de branco não aguarda pela sua vez na fila (3)
- (c) A mulher de branco aguarda pela sua vez na fila (0)
- (d) A mulher de branco pede para passar à frente na fila (0)
- (e) A mulher de branco entra em conflito com as pessoas da fila (2)

#### 2. O que estariam a pensar as pessoas que aguardavam na fila?

- (a) Que a ordem de chegada numa fila deve ser respeitada (1)
- (b) Que a mulher de branco não tem prioridade para passar à frente na fila (3)
- (c) Que a mulher de branco deve aguardar pelo seu lugar (2)
- (d) Que a mulher de branco devia pedir licença para passar à frente (0)
- (e) Que ninguém deve passar à frente numa fila sem justificação (0)

3. Como acha que as pessoas que aguardavam na fila se sentiram?

- (a) Raiva (3)
- (b) Tristeza (0)
- (c) Alegria (0)
- (d) Nojo (0)
- (e) Medo (0)

4. A mulher de branco agiu da forma que a maioria das pessoas agiria?

- (a) Sim (0)
- (b) Não (3)

5. Agiria da mesma forma que a mulher de branco?

- (a) Sim (0)
- (b) Não (3)

### 9.11 Appendix K - Scenario 10 (ESCoT and CogMap-SC)

- **General Interpretation** - "Pode dizer-me o que está acontecer nesta história, a começar pela primeira imagem e acabar com a última?"
- **Cognitive theory of mind** - "O que é que a mulher pensou que o casal queria?"
- **Affective theory of mind** - "Como é que o casal sentiu-se no fim da animação?"
- **Interpersonal understanding of social norms** - "A mulher que está a tirar a fotografia na animação comportou-se como as outras pessoas devem comportar-se?"
- **Intrapersonal understanding of social norms** - "Teria agido da mesma forma que a mulher na animação?"

1. Pode dizer-me o que aconteceu no vídeo?

- (a) Um jovem passeia no parque (1)

- (b) Um jovem é abordado por duas raparigas (2)
- (c) Duas raparigas conversam com um conhecido (0)
- (d) Duas raparigas pedem ajuda para tirar uma fotografia (3)
- (e) Três amigos encontram-se no parque (0)

**2. O que é que o jovem pensou?**

- (a) Que as raparigas queriam conversar (0)
- (b) Que as raparigas queriam uma foto (3)
- (c) Que as raparigas queriam cumprimentá-lo (0)
- (d) Que as raparigas precisavam de ajuda (2)
- (e) Que as raparigas precisavam de indicações (1)

**3. Como acha que as raparigas se sentiram?**

- (a) Raiva (0)
- (b) Tristeza (0)
- (c) Alegria (3)
- (d) Nojo (0)
- (e) Medo (0)

**4. O jovem que tirou a foto agiu da forma que a maioria das pessoas agiria?**

- (a) Sim (3)
- (b) Não (0)

**5. Agiria da mesma forma que o jovem?**

- (a) Sim (3)
  - (b) Não (0)
-