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REY COMPLEX FIGURE TEST: VALIDATION STUDY IN TRAUMATIC BRAIN INJURY

Dissertação no âmbito do Mestrado em Neuropsicologia Clínica: Avaliação e Reabilitação, orientada pelo Professor Doutor Mário Manuel Rodrigues Simões e co-orientada pela Doutora Diana Filipa Dias Duro, apresentada à Faculdade de Psicologia e Ciências da Educação da Universidade de Coimbra.

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Título da Dissertação - *Teste da Figura Complexa de Rey: Estudo de Validação no Traumatismo Crânio-Encefálico*

RESUMO

INTRODUÇÃO: O teste da Figura Complexa de Rey (FCR; Rey, 1941) é um instrumento psicométrico com uma longa história no campo da (neuro)psicologia. Avalia, essencialmente, a memória visual, a capacidade viso-espacial/construtiva e o funcionamento executivo, algumas das funções cognitivas afetadas em casos de traumatismo crânio-encefálico (TCE). Esta ferramenta de avaliação tem sofrido alterações, podendo ser aplicada de acordo com diferentes versões que combinam tarefas para a sua realização, estando, entre as mais comuns, a fase de cópia e de evocação imediata do estímulo.

OBJETIVOS: Elaboração de um estudo de validação psicométrica e clínica em pessoas vítimas de TCE. Neste âmbito, pretende-se a exploração das propriedades psicométricas do teste da FCR, da capacidade discriminativa das suas pontuações e o estabelecimento de pontos de corte (PC).

MÉTODOS: A amostra total é composta por 60 participantes, divididos por dois grupos (Grupo TCE: n = 30, Grupo de Controlo: n = 30) emparelhados de acordo com a idade, escolaridade e género. O grupo clínico cumpre com os critérios de diagnóstico internacionais em vigor no estabelecimento hospitalar no qual os participantes foram consultados. O grupo de controlo é constituído por adultos saudáveis ativamente inseridos na comunidade, submetidos ao mesmo procedimento avaliativo previamente estipulado para o grupo clínico.

RESULTADOS: A pontuação da cópia e da evocação imediata da FCR diferiu significativamente entre o Grupo TCE e Grupo de Controlo, sendo o tamanho do efeito superior na tarefa que recruta a memória. A FCR apresentou correlações maioritariamente fortes e sempre estatisticamente significativas com critérios externos relevantes selecionados de acordo com a literatura (MMSE, MoCA, Localização Espacial, Código, Pesquisa de Símbolos, TMT-B, Stroop - condição cor/palavra, FVF, FVS) e recolhidos no mesmo período temporal que a mesma. Adicionalmente, revelou ter capacidade discriminativa, tanto na tarefa da cópia como na de evocação, alcançando-se pontos de corte com valores de especificidade superiores aos de sensibilidade.

CONCLUSÕES: O presente estudo apoia o facto da FCR poder ser uma medida útil do funcionamento executivo, para além de avaliar a memória e a capacidade viso-espacial/construtiva, algo a ponderar na escolha de protocolos de avaliação em doentes com TCE. A FCR apresentou uma sensibilidade razoável e uma especificidade boa, revelando também uma boa capacidade discriminativa, apontada como possível alvo de estudo em trabalhos futuros, face aos níveis de gravidade da condição clínica. Os resultados constituem um primeiro contributo na validação da FCR em adultos Portugueses com TCE, proporcionando avanços para a incrementação do seu uso na prática clínica.

Palavras-chave: traumatismo crânio-encefálico, avaliação neuropsicológica, Figura Complexa de Rey, validação clínica e psicométrica

Title of Dissertation - *Rey Complex Figure Test: Validation Study in Traumatic Brain Injury*

ABSTRACT

INTRODUCTION: The Rey Complex Figure test (FCR; Rey, 1941) is a psychometric instrument with a long history in the field of (neuro)psychology. It essentially assesses visual memory, visual-spatial/constructive capacity and executive functioning, some of the cognitive functions affected in cases of traumatic brain injury (TBI). This assessment tool has undergone changes and can be applied according to different versions that combine tasks for its implementation, the most common being the copying phase and immediate recall of the stimulus.

OBJECTIVES: Preparation of a psychometric and clinical validation study in patients suffering from TBI. In this context, the aim is to explore the psychometric properties of the RCFT, the discriminative capacity of its scores, and the establishment of cut-off points (CP).

METHODOLOGY: The total sample consists of 60 participants, divided into two groups (TBI Group: n = 30, Control Group: n = 30) paired according to age, education, and gender. The clinical group complies with the international diagnostic criteria applied at the hospital where the participants were consulted. The control group consists of healthy adults actively inserted in the community, undergoing the same evaluation procedure previously stipulated for the clinical group.

RESULTS: The RCFT copy and immediate recall scores differed significantly between the TBI Group and the Control Group, with the effect size being higher in the task that recruits memory. The RCFT showed mostly strong and always statistically significant correlations with relevant external criteria selected in accordance with the literature (MMSE, MoCA, Spatial Location, Digit Symbol-Coding, Symbol Search, TMT-B, Stroop - color/word condition, PVF, SVF) and collected in the same period. Additionally, it proved to have discriminative capacity, both in the copying and evocation tasks, reaching cut-off points with specificity values higher than sensitivity.

CONCLUSION: The present study supports the fact that RCFT can be a useful measure of executive functioning, in addition to assessing memory and visual-spatial/constructive capacity, something to consider when choosing assessment protocols in patients with TBI. The RCFT showed reasonable sensitivity and good specificity, also revealing a good discriminative capacity, identified as a possible target for study in future works, given the severity levels of the clinical condition. The results constitute a first contribution to the validation of RCFT in Portuguese adults with TBI, providing advances towards increasing its use in clinical practice.

Keywords: traumatic brain injury, neuropsychological assessment, Rey Complex Figure Test, clinical and psychometric validation

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Introduction

Traumatic brain injury (TBI) is a global public health problem that has an increasing incidence throughout the world (Roozenbeek et al., 2013), and is even considered the biggest public health problem in Western countries (Zaninotto, 2016). It often leads to long-lasting consequences (Stuss, 2011), with lifelong disability being common in those who survive (Roozenbeek et al., 2013). In Europe, for example, it is well known that TBI is the clinical condition that most contributes to the greatest number of years lived with disability (Polinder et al., 2007).

A major societal challenge is to effectively address the social and health-related issues that emerge from this condition. One such challenge is to validate neuropsychological measures that can assess and monitor the TBIs consequences, and thus ensure effective and timely rehabilitation programs. Thus, the main goal of the present study is to clinically validate the Rey Complex Figure Test (RCFT) in a Portuguese sample of TBI patients and healthy adults from the community. This is extremely important because there are no studies carried out in Portugal that specifically focus on RCFT in adults with TBI, and because RCFT evaluates one of the functions most commonly reported to be affected in these patients, the memory (Granacher, 2015; Vakil, 2005).

We begin by providing a theoretical framework on TBI and the importance of neuropsychological assessment in these cases. This is followed by a description of the RCFT and an explanation of the objectives of the study. We will then outline the procedures and materials used do validate the instrument. This section is followed by the presentation of the statistical analysis carried out and the results obtained. We then discuss the results considering current literature, with a reflection on the limitations of the work. We end with a conclusion that summarizes the study carried out. The references consulted to prepare the master's dissertation are listed below the conclusion.

Background

Concept of Traumatic Brain Injury

The term ‘traumatic brain injury’ (TBI) has replaced the former term ‘head injury’ (HI) as it better captures the relevance of the ‘brain’ in this condition (Roozenbeek et al., 2013). HI is a less specific and more old-fashioned term, which includes clinically evident injuries, of external cause, occurring on the face, scalp and calvarium (e.g., lacerations, contusions, abrasions, or fractures), which may or may not be associated with TBI (Bruns & Hauser, 2003). On the other hand, TBI injury is more properly defined as an alteration in brain function caused by an external force (e.g., bump, blow, jolt, or penetration to the head), whose outcome translates into a disruption of expected brain operation (Bruns & Hauser, 2003; Faul & Coronado, 2015; Menon et al., 2010).

The most common symptoms after TBI can be broadly grouped into four large groups, namely neurological, neurocognitive, behavioral, and emotional symptoms (Azouvi et al., 2017; Crowe, 2008). At the same time, the severity of a TBI may range from mild to severe, leading to different types of signs and symptoms (Faul & Coronado, 2015), such as irritability, anxiety, nervousness, lethargy, vomiting, headache, dizziness, fatigue, balance problems, sensitivity to noise and light, blurred vision, 'pressure in the head', poor concentration, difficulty thinking clearly, any period of observed or self-reported dysfunction of memory (amnesia) around the time of injury, a period of observed or self-reported transient confusion, altered level of consciousness, seizures, focal motor neurologic deficit, coma, or even death (Bruns & Hauser, 2003; Faul & Coronado, 2015; Gardner et al., 2020).

Depending on the severity, TBI induces immediate neuropathological effects that, in the mildest form, may be transient, but as severity increases, neural damage and degeneration result (Bigler, 2013). Research suggests that up to 10% of victims with mild TBI (i.e., the less severe form) may present persistent behavioral and neuropsychological symptoms 1 year after the injury and, in some cases, even lifelong disability (Bruns & Hauser, 2003; Faul & Coronado, 2015).

Epidemiology, Incidence and Mechanisms

Every year the world literature on TBI increases, covering new epidemiological findings from many regions (Tagliaferri et al., 2006). This condition is prevalent in both low- and high-income countries, affects people of all ages (Koskinen & Alaranta, 2008), and constitutes a critical public health and socio-economic problem throughout the world (Peeters et al., 2015), being a major cause of morbimortality, often with permanent disability (Dias et al., 2014).

Even so, for more than 30 years, TBI is called the 'silent epidemic' (Miller, 1986) since the consequences arising from TBI are usually not immediately visible and victims are not very forthcoming in complaining about what they feel (Koskinen & Alaranta, 2008). Despite the dramatic repercussions, especially for survivors (Santos et al., 1998), there is an underestimation of its incidence, as well as a lack of awareness regarding its impact (Koskinen & Alaranta, 2008).

A systematic review (Tagliaferri et al., 2006), which covered 14 European countries between the years 1980 and 2003, indicated an average incidence of 235 cases per 100.000 per year, with most countries reporting an incidence rate of approximately 150 to 300 cases per 100.000 inhabitants. A further analysis (Peeters et al., 2015), with data from 16 countries in Europe from the period 1990-2014, revealed a higher estimated average incidence rate of 326 per 100.000. It turns out that estimates usually only include patients with TBI admitted to hospitals, leading to an underestimation of mild TBIs (e.g., those who were not medically assisted or who were only seen in the emergency room) and an overestimation of more severe TBIs (Bruns & Hauser, 2003).

Globally, in terms of gender, TBI is more frequent in men (Santos & Agrela, 2019; Santos et al., 2003), with a ratio of 2.2:1 being found between 1999 and 2012 in Europe (Peeters et al., 2015). The uniformly greater risk in male population, finds the highest proportions relative to women in adolescence and young adulthood (Bruns & Hauser, 2003), however, it is a difference that has been attenuated in recent years (Santos & Agrela, 2019).

According to the literature, the mechanisms, or external causes of TBI, vary depending on the development of the country and its situation at the time they were studied (Abou-Abbass et al., 2016). Different studies conducted in Europe (Hukkelhoven et al., 2012; Peeters et al., 2015; Santos & Agrela, 2019; Tagliaferri et al., 2006) point to two main causes, road traffic crashes (most common in young adults) and falls (most common in elderly and children; Peeters et al., 2015). In Portugal, the results are consistent with those observed in other countries, with falls being behind the highest number of TBI cases, probably due to the improvement in road safety issues and by the growth rate of the elderly population (Dias et al., 2014).

Traumatic Brain Injury Classification

Multiple classifications are available, namely by level of severity, level of consciousness, post-injury mental state and location of injury (Granacher, 2015). Among the various possible systems, historically, the Glasgow Coma Scale (GCS) has been the most widely used clinical TBI classification (Bruns & Hauser, 2003; Shah & Kelly, 2003).

The GCS is based on the patient's responses in three parameters - eye opening, verbal response and motor response to various stimuli. Through interaction with the TBI victim, a score is assigned to each component. The score corresponds to the sum obtained in each of the three parameters, which can vary from three points (if the patient does not respond in any of the three components), to fifteen points (if the patient manages to open his eyes spontaneously, talk in a guided manner and obey motor commands). The scoring system implies that lower scores are indicative of a higher degree of severity, therefore, most often, a score < 9 is considered severe TBI, 9 to 12 is considered moderate, and 13 to 15 is considered mild (Granacher, 2015).

Information regarding the period of loss of consciousness and the period of post-traumatic amnesia can be combined with the information provided by the GCS. According to the fifth edition of Diagnostic and Statistical Manual of Mental Disorders (DSM-5), a loss of consciousness of less than 30 minutes is associated with a mild TBI, between 30 minutes and 24 hours with a moderate TBI, and more than 24 hours with a severe TBI. On the other hand, post-traumatic amnesia of less than 24 hours is frequently reported in mild TBI, from 24 hours to 7 days in moderate cases, and more than 7 days in severe cases (American Psychiatric Association, 2014).

Typology of Traumatic Brain Damage and Secondary Injury

Lesions that arise as a primary consequence of trauma occur through direct contact and/or through acceleration-deceleration forces, and may be focal, diffuse, or both (Baxendale et al., 2019). Focal injuries include skull fracture, contusions, lacerations, hemorrhages, and hematomas (e.g., extradural hematoma, subdural hematoma, subarachnoid hemorrhage, intraparenchymal hemorrhage and intraventricular hemorrhage; Silver et al., 2018). Diffuse injuries include diffuse axonal injury (Silver et al., 2018), ischemic brain injury and brain swelling (Granacher, 2015).

Furthermore, TBI is not a static clinical condition, as it involves a dynamic process of brain changes. Secondary injuries occur and refer to brain damage caused by events after to the primary insult (Baxendale et al., 2019), with emphasis on vascular failure, intracranial hypertension, brain shift and herniation (Granacher, 2015). The presence of these secondary processes in cases of TBI considerably increases the probability of developing long-term neuropsychological sequelae after injury, having a cumulative impact, i.e. the more injuries the brain suffers, the less likely is a complete neuropsychological recovery (Baxendale et al., 2019).

Disability

As already mentioned, the true consequences of TBI go beyond the dynamics of their occurrence or fatality (Majdan et al., 2017). In addition to the very high number of deaths from TBI, including in Portugal (Santos & Agrela, 2019), it is necessary to note that with modern medicine and the progress of techniques for treating TBI victims, the survival rate of patients is increasing, which leads to an equal increase in the number of survivors with cognitive impairment (Bigler, 2008).

Even mild TBIs, associated with cognitive deficits related to a temporary inability to adequately allocate neural resources in response to cognitive demands resulting from neural disorders and structural injuries, can, in chronic cases, persist for more than 10 years after the injury (Rajesh et al., 2017). Although the recovery time from a mild TBI varies, around 50% of subjects report symptoms three months after the traumatic injury (Sawchyn et al., 2000), and in around 7% to 15% of cases, these symptoms can even become persistent (Hall et al., 2005).

A prospective longitudinal study (Jourdan et al., 2016) involving 147 patients who suffered a TBI, concluded that, 4 years after the occurrence, 46 of the 147 patients (32%) had severe disability, 58 (40%) a moderate disability and only a minority of 40 patients (28%) achieved a good recovery. In general, although almost 80% were independent in carrying out simple activities of daily living, around 40-50% needed help with outdoor or organizational activities and only 36% declared to have some professional activity. In fact, in 2017, Majdan et al. verified that TBI was a cause of 8.1 million of years lived with disability in 16 European countries.

It is increasingly clear that TBI is a complex condition, a chronic progressive disease that incorporates long-term cognitive problems (Azouvi et al., 2017; Jourdan et al., 2017; Maas et al., 2022; Pavlovic et al., 2019). Long-term follow-up reveals that up to 50% of patients with TBI show visible deterioration on advanced neuroimaging (Prince & Bruhns, 2017), a deterioration that is accompanied by poorer performance on neuropsychological measures when compared to healthy subjects (Horneman & Emanuelson, 2009). Subjective memory complaints, problems with attention and concentration, problems with changing focus, changes in executive functioning, including difficulties in multitasking, working memory and processing speed, are among the typical cognitive symptoms in concussion condition (Boyd, 2014).

Patients end up suffering as the changes they experience prevent the natural continuation of their social and professional life, and adversely affect their own and their families' quality of life (Jourdan et al., 2017; Santos & Agrela, 2019). However, it is important to mention that it is possible to intervene in this scenario. Early referral for neuropsychological assessment can help identify non-organic and remediable factors to optimize recovery after TBI (Baxendale et al., 2019). Indeed, it has been proven that specific community re-entry services may be useful for preventing long-term patient deterioration (Jourdan et al., 2017). The focus of post-TBI rehabilitation/intervention needs to include, not just physical, but also cognitive aspects (Pavlovic et al., 2019). To this end, a prior neuropsychological assessment is mandatory.

Memory, Executive Function and Visuo-spatial/Constructive Abilities

Memory dysfunction is one of the most (if not the most; Granacher, 2015; Vakil, 2005) commonly reported complaint by patients and their relatives following TBI (Azouvi et al., 2017), which makes it the study target of several researchers (Vakil, 2005). For example, in the prospective study by Jourdan et al. (2016) mentioned above, it was found that, 4 years after the injury, memory failures were the most frequent complaints, reported by 67.5% of patients. Zec et al. (2001), studying a longer period after injury (10 years) found that mean index scores for the Wechsler Memory Scale–Revised were < 1 SD of norms for all memory indices. A later study by Horneman and Emanuelson (2009) that evaluated the remaining sequelae also 10 years after the occurrence of a TBI, found that the TBI group presented impaired performance in verbal learning and memory, and slightly compromised performance in visual memory, when compared to the control group. In the same line of reasoning, Carlozzi et al. (2013) found that patients with severe TBI performed worse than controls on all types of verbal or visual memory tasks. So, although verbal memory has been assessed more thoroughly than visual memory, research shows that both memory modalities are sensitive to TBI (Vakil, 2005).

Additionally, given the vulnerability of the frontal lobes and brain networks prior to TBI, patients who survive TBI often exhibit deficits in executive functions (Stuss, 2011). Executive functions are a form of supraordinate neurobehavioral systems and have been conceptualized in different ways (Granacher, 2015). Gouveia e Fabrício (2004) concluded that impairments of executive functions affect mental flexibility, planning, self-monitoring, and problem solving. Dennis et al. (2001) documented that individuals with TBI presented difficulties with executive function in tests of executive performance, such as inhibition, planning and behavioral regulation. According to Horneman and Emanuelson (2009), victims of TBI presented impairment in executive function, especially in the areas of attention, working memory and mental flexibility. In a broader analytical perspective, Azouvi et al. (2016) directly compared the sensitivity of traditional executive function tests in TBI patients with the Behavioral Dysexecutive Syndrome Inventory questionnaire and found that, of the 54 patients evaluated, executive function deficits were found in the majority (87%).

On the other hand, visuo-spatial and visuo-constructive capacity is a cognitive domain not so widely studied, but essential to perform daily tasks, such driving vehicles, households (including preparing meals), read maps, use a computer, among others (Granacher, 2015). While memory deficits are common among the different types of TBI, impairment of visual-spatial and visuo-constructive capacity becomes more evident in cases of contusions or hematomas, who sustain traumatic brain injury sufficient to produce tissue-based brain injury (Levin et al., 1990; Levin et al., 1991). Visual-spatial skills are usually assessed by paper-and-pencil drawing exercises (e.g., drawing circles, triangles, three-dimensional cubes, intersecting pentagons, a clock with the hands at a certain time) or by manual manipulation of three-dimensional cards or blocks to make a series of drawings. Compromised patients, when drawing two- or three-dimensional figures, often omit elements of the figure being copied, round off corners, lose the shape of the figure, and are unable to draw alternate figures (Granacher, 2015). Honerman and Emanuelson (2009) found that a group of patients with TBI had a compromised performance in the visuo-spatial and visuo-constructive functional domains, compared to a control group, due to significant difficulties in copying the drawing measured by the Rey-Osterrieth Complex Figure and difficulties in manipulating objects evaluated by Block Design.

Neuropsychological Assessment

Clinical neuropsychology is an applied science that focuses on the behavioral expression of brain dysfunction (Lezak et al., 2012). The main reason for its development took place in the first half of the 20th century, due to the First World War. Large-scale neuropsychology programs were justified by the need to screen and diagnose surviving military personnel with brain injuries and behavioral disorders, as well as their subsequent rehabilitation (Homskaya, 2001).

Educational psychologists were pioneers in the development of tests to measure the concept of intelligence. Since then, experts in mental measurement have produced a myriad of examination techniques, some of which have been incorporated into the canon of neuropsychological testing (Barr, 2017). Society's acceptance of these tests has led to a proliferation of large-scale statistics-dependent testing programs, which has provided neuropsychology with an understanding of mental abilities from a normative perspective (Lezak et al., 2012).

Likewise, neuroscientists have discovered the usefulness of psychological techniques when studying brain-behavior relationships (Bilder, 2011). Currently, in the 21st century, the development of dynamic imaging techniques has provided psychological constructs with the neurological foundations that support the analysis and understanding of the multifaceted, unique, and often altered behavioral presentations of patients with brain injury (Friston, 2009). However, neuropsychology offers what neuroimaging techniques cannot – the ability to detail how the injury affects the psychological state of the patient (Bigler, 2001), the mastery of applying qualified and technical knowledge of brain-behavior relationships, improving the quality of life of patients (Pearson et al., 2018).

As a clinical science, neuropsychology has been evolving naturally. There is an emerging evolution that translates into a gradual sensitivity of different health professionals (e.g., neurologists, neurosurgeons) to the practical problems of identification, assessment, care, and treatment of patients with brain injuries, requiring the help of a formal request for neuropsychological assessment (Lezak et al., 2012).

The multiplicity of existing clinical conditions constitutes a challenge for neuropsychologists who aim to meet the assumptions for which the assessment instruments were designed and, jointly, assess patients at levels appropriate to their unique characteristics. Faced with this issue, it is not possible to have guarantees and certainties of principles, to maintain immutable techniques, and not to benefit from tampering with procedures as scientific research and experience accumulate (Lezak et al., 2012). Each neuropsychological assessment brings the promise of new insights into the functioning of the brain, with flexibility, curiosity and inventiveness being fundamental precursors to the practice of neuropsychology (Lezak, 2002). In this sense, this master's dissertation aims to contribute to the expansion of scientific literature by taking the first steps in the study of RCFT in cases of Portuguese adults with TBI (the concrete objectives will be specified below).

Rey Complex Figure Test

The RCFT assesses a very diverse set of cognitive processes. In addition to being mainly pointed out as a test that assesses constructive visuo-spatial skills and visual memory (Sherman et al., 2023), its performance also recruits aspects of executive functioning, such as planning, organization and problem solving (Mitrushina et al., 2005; Sherman et al., 2023; Watanabe et al., 2005).

The RCFT was originally developed by Rey in 1941 with the aim of assessing visuo-spatial perception and visual memory in patients with brain injuries (Lezak et al., 2012). Since then, it has had a long history in the field of neuropsychology (Simões et al., 2011) and was recently recognized as the second most used psychological test by 21.40% of a sample of 1383 Portuguese psychologists who responded to a survey about the most used assessment instruments in Portugal (Simões et al., 2023).

The RCFT has been used as an assessment tool in different age groups, namely in children (e.g., Anderson & Catroppa, 2005), adolescents (e.g., Silva, 2017), adults (e.g., Smith et al., 2007) and elderly people (e.g., Bravo, 2013). In addition to carrying out studies on healthy populations (Bravo, 2013; Caffarra et al., 2002; da Silva et al., 2004; Foss et al., 2010; García-Herranz et al., 2022; Mós & Espirito-Santo, 2016; Silva, 2017; Tremblay et al., 2015; Tsatali et al., 2020; Vicente et al., 2021; Wilson & Batchelor, 2015), its applicability extends to pathological and/or more specific cases, with its use being noted for the evaluation of institutionalized elderly people (Ventura & Espirito-Santo, 2015), patients with multiple sclerosis (Pires & Espírito-Santo, 2019), subjective cognitive decline, mild cognitive impairment (multiple domain), Alzheimer's disease (Bigler et al., 1989; Javorsky, 1999; Tsatali et al., 2022), ischemic vascular dementia, human immunodeficiency virus (Javorsky, 1999), attention deficit/hyperactivity disorder (Watanabe et al., 2005), epilepsy (Frank & Landeira-Fernandez, 2008; LeMonda et al., 2022; McConley et al., 2008; Watanabe et al., 2005), aneurysm (Diamond & DeLuca, 1996), psychiatric patients (Elderkin-Thompson et al., 2004; Lee et al., 2022) and for the detection of malingering and suspect effort (Blaskewitz et al., 2009; Sherman et al., 2002; Suhr et al., 1997). As such, multiple works are also carried out in the TBI (e.g., Busch et al., 2005; Mangum et al., 2021; Meyers & Rohling, 2004; Rigon et al., 2016; Schwarz et al., 2009; Suhr et al., 1997; Zaninotto, 2016), and the evaluation using the RCFT has served to document neuropsychological functioning after TBI (Ashton et al., 2005; Bigler et al., 1996; Honan et al., 2015; Leininger et al., 1990; Sigurdardottir et al., 2015), assess cognition after surgical intervention (Coelho, 2020), analyze the results of neuropsychological rehabilitation programs (Morais, 2014; Seniow et al., 2003), monitor the clinical condition and investigate remaining long-term sequelae (Anderson & Catroppa, 2005; Beauchamp et al., 2011; Clarke et al., 2012; Muscara et al., 2008; van Heugten et al., 2006).

In his first version, Rey (1941) advocated the use of a copying task, followed by a recall task, administered 3 minutes later. Subsequently, Osterrieth (1944) proceeded to its standardization, developing a scoring system, and presenting normative data for 230 children and adults, from 4 to 60 years old. For this reason, the stimulus and paradigm of Rey's original complex figure may be referred to as the "Rey-Osterrieth Complex Figure", to encompass the contributions of both authors (Meyers & Meyers, 1995).

Over time, several administration procedures have been used and reported by different professionals. In this way, a copying trial can be administered, followed by one or two recall trials (i.e., immediate recall, which can be done immediately after the copying task or 3 minutes later, and/or delayed recall, where the time interval varies from 15 minutes to 1 hour after the copy task) and, optionally, followed by a recognition task (Meyers & Meyers, 1995). Additionally, in terms of the graphic representation itself, some authors maintained the color system initially proposed by Rey for drawing up the figure (i.e., 5 or 6 colored pencils), to capture organizational and sequential aspects of performance, such as in the Boston Qualitative Scoring System version (i.e., use of 4 to 6 markers; Stern et al., 1999) and Developmental Scoring System (i.e., use of 5 felt-tip pens; Bernstein & Waber, 1996). Others (e.g., Meyers & Meyers, 1995), in turn, believe that this tactic can be problematic for the evaluated ones, since it introduces undesirable questions in the test, such as the possibility of distraction, the influence of fine motor skills and perception, and additional time to finish the drawing.

The original figure combines several segments, which intersect each other, forming various geometric shapes (i.e., rectangle, circle, square, triangle, rhombus). It was conceived to have a final structure complex enough to require analytical and organizational skills, without retaining an obvious meaning, but at the same time, being easy to graphically create (Simões et al., 2011). Alternative stimulus figures were also developed, essentially to meet the need for equivalent forms to perform repeated tests (Lezak et al., 2012; Meyers & Meyers, 1995; Sherman et al., 2023). Some examples are the Taylor Figure (Taylor, 1979), Modified Taylor Figure (Hubley & Tremblay, 2002) and the 4 Complex Figures from the Medical College of Georgia (Lee et al., 1989).

The scoring systems have also undergone changes over time. Extending to a more qualitative analysis, with the aim of investigating organizational results and configurational strategies, focusing not only on the final product, but also on the process, the Developmental Scoring System for the Rey-Osterrieth Complex Figure (Bernstein & Waber, 1996), mentioned earlier, assesses organization, style, accuracy, and errors. In the same sense, the Rey Complex Figure Organizational Strategy Score (Anderson et al., 2001) scores drawings according to their organizational strategy, also considering the reproduction sequence. On the other hand, the Boston Qualitative Scoring System (Stern et al., 1999), considered the most comprehensive system, divides the figure into three hierarchical elements (i.e., Configuration, Groupings and Details), counting each according with its presence, accuracy, and placement. Even so, the most used scoring system in clinical practice is possibly the 36-point system, developed by Osterrieth (1944) and widely disseminated in Lezak et al. (2012). This scoring procedure divides the figure by 18 units that refer to specifically detailed areas of the stimulus. Each unit is rated from 0 to 2 according to accuracy and placement, on a four-point scale (i.e., 0, 0.5, 1 and 2), with a maximum score of 36 points possible, as the name implies (Meyers & Meyers, 1995).

The RCFT was initially shown to be sensitive to TBI cases as a measure of visuo-spatial/constructive ability (Osterrieth, 1944) and visual memory (Brooks, 1972). In this way, it is important to study the psychometric qualities of the RCFT in a Portuguese sample, expanding the studies in this specific type of patients, so that it is a powerful work tool to be used in clinical assistance with the aim of documenting short and long-term deficits in this population, assisting in planning appropriate rehabilitation programs and evaluating their effectiveness, as well as the effectiveness of other clinical interventions (e.g., surgical treatments).

Objectives

The present study aims to validate the RCFT for the Portuguese population considering its use in the clinical group with TBI. More specifically, we explored the psychometric properties of the RCFT (i.e., through concurrent validity), analyzed comparatively the cognitive performance of the study groups (i.e., Control Group *vs.* TBI Group) and determined the respective diagnostic accuracy (i.e., through the establishment of optimal cut-off points).

Methodology

Sample Characterization

Participants for the clinical group (i.e., TBI Group) were recruited from consultation at the Department of Neurosurgery, Traumatic Brain Injury Unit at CHUC (*n* = 13) and at Neuropsychological Assessment Consultation (Director: Prof. Mário R. Simões) at the Center for the Provision of Services to the Community (CPSC; Centro de Prestação de Serviços à

Comunidade) of FPCE-UC (*n* = 17). Regarding data collected at CHUC, the patients were referred upon a detailed collection of self-reported history and report from reliable informant. All patients underwent through a medical exam by a neurosurgeon or neurologist, carried out complementary diagnostic exams (e.g., structural imaging exams varying from case to case) and made a comprehensive neuropsychological assessment (described in the following two sections). The final diagnosis was established by the agreement of a multidisciplinary teamwork based on international criteria. Regarding the participants assessed at the CPSC of the FPCE-UC, all data from a previously constructed larger database were aggregated, which coincided with the neuropsychological assessment established at CHUC, to extend the sample with the condition that all participants had been subject to the same baseline neuropsychological assessment. The inclusion criteria included (a) Portuguese as a native language, (b) age ≥ 18 years, (c) documented evidence of TBI, and (c) ability to complete the study protocol. The exclusion criteria comprised (a) illiteracy, (b) history of previous TBI, (c) evidence of pre-existing physical, neurological, psychiatric, or developmental disturbance and (d) present or history of alcoholism or drug abuse.

The Control Group was composed by healthy people actively inserted in the community (*n* = 30). All participants were volunteers aged between 20 and 78 years. Recruitment was carried out by pairing with the TBI Group previously recruited for the study, considering the variables gender, age, and education. The techniques used for this purpose were convenience sampling (i.e., contact with people who are easily accessible) and snowball sampling (i.e., the individuals selected to be studied invited new participants from their network of friends and acquaintances). The inclusion criteria comprise (a) Portuguese as a native language; (b) absence of current history of psychiatric or neurologic disease; (c) no significant motor, visual or auditory deficits with a possible negative influence in cognitive performance; (d) taking no medication with significant interference in cognitive function; and (e) no present or history of alcoholism or drug abuse. The exclusion criteria included (a) illiteracy; (b) functional deficits with influence in daily living autonomy; (c) performance’s values outside of the normative range by age and educational level in Mini Mental State Examination (MMSE; Folstein et al., 1975; Freitas et al., 2015c) and Montreal Cognitive Assessment (MoCA; Freitas et al., 2011; Nasreddine et al., 2005), that is, 1.5 standard deviations (SD) below the mean value (M), indicating possible cognitive impairment; and (d) presence of severe depressive symptomatology according to the Beck Depression Inventory II (BDI-II; Oliveira-Brochado et al., 2014). These neuropsychological tests will be described in Procedures and Materials.

Procedures

TBI Group

Patients from the Traumatic Brain Injury Unit of the Department of Neurosurgery at CHUC were referred to undergo an extensive neuropsychological assessment. The reason for the referral could be the need for a first assessment to document the deficits, subsequent assessments to monitor the clinical condition and/or evaluation after surgical intervention. For this study, only patients with a GCS of 15 at the time of discharge from the trauma unit were included; the same criteria were applied to ambulatory patients. The assessment to which they were subjected was identical to that mentioned below in the Control Group, except for some tests that were withdrawn after joining with the CPSC sample and which, therefore, were not included in the statistical analysis nor considered in the present study (this procedure allowed CHUC, CPSC, and healthy community participants to complete the same neuropsychological tests). The participants evaluated at the CPSC at FPCE-UC were part of a larger database collected over the years, which included individuals with different pathologies evaluated with a wide range of tests. For this purpose, all patients whose diagnosis was TBI and who had been evaluated under the same conditions as the other TBI victims of the hospital complex were filtered from the same database. The TBI Group (i.e., CHUC and CPSC participants) included all patients diagnosed with TBI, regardless of the assigned classification or typology.

Control Group

The evaluation protocol was composed by two cognitive screening tests, MMSE (Folstein et al., 1975; Freitas et al., 2015c) and MoCA (Freitas et al., 2011; Nasreddine et al., 2005), one psychopathological test, BDI-II (Beck et al., 1996; Oliveira-Brochado et al., 2014), and a wide spectrum of neuropsychological tests that assess diverse domains, highlighting, due to its importance for the present study, the Rey Complex Figure Test (RCFT; Meyers & Meyers, 1995; Rey, 1941), Stroop Test (Fernandes, 2012; Golden et al., 1978), Trail Making Test forms A and B (TMT-A and TMT-B; Cavaco et al., 2013b; Reitan & Wolfson, 1995), subtest Spatial Location of the Wechsler Memory Scale third edition (WMS-III; Wechsler, 2008b), Phonemic Verbal Fluency (PVF; letters "M" and "R") and Semantics (SVF; category "Animals"; Cavaco et al., 2013a; Thorndike & Lorge, 1944), subtests Digit Symbol-Coding, Digit Span and Symbol Search of the Wechsler Adults Intelligence Scale third edition (WAIS-III; Wechsler, 2008a) and Toulouse and Piéron Cancellation Test (TP; Amaral, 1967; Baeta, 2002; Lima et al., 2023; Toulouse et al., 1904). The evaluation procedure was implemented individually, in a quiet place accessible to the respondent (e.g., home or office), and took about an hour and a half to complete. The assessment instruments applied are consistent with those previously chosen to assist patients with TBI at CHUC and, simultaneously, with which most CPSC respondents were evaluated.

Materials

In this section we will describe the main tests used for the purpose of this study, targets of statistical analysis to obtain the results later presented and used, in part, to determine the inclusion or exclusion of participants.

Rey Complex Figure Test (RCFT)

The RCFT (Meyers & Meyers, 1995; Rey, 1941) was used according to the administration procedure of Meyers and Meyers (1995) and with the 36-point scoring system originally developed by Osterrieth (1944). For the study, only the copying and immediate evocation phase (i.e., after 3 minutes) will be considered. Therefore, each participant was asked to observe the figure carefully and to copy it the best they could using pencil and eraser. Three minutes later and without prior notice, the evocation of the figure was requested.

Mini Mental State Examination (MMSE)

The MMSE (Folstein et al., 1975; Freitas et al., 2015c) is a cognitive screening instrument that provides a general idea of the assessed person's cognition, evaluating six domains: (a) orientation, (b) repetition, (c) verbal recall, (d) attention and calculation, (e) language, and (f) visual construction. It is a test that is easy and quick to administer (i.e., 5-10 minutes), all items are dichotomous (i.e., 0 = *error* and 1 = *correct answer*) and the total score ranges from 0 to 30 points. Consequently, higher scores correspond to better cognitive performances (Freitas et al., 2015a).

Montreal Cognitive Assessment (MoCA)

The MoCA (Freitas et al., 2011; Nasreddine et al., 2005) is also a brief cognitive assessment test, especially designed to assess milder forms of cognitive decline. This instrument assesses six cognitive domains: (a) executive function; (b) visuospatial ability; (c) short-term memory; (d) language; (e) attention, concentration, and work memory; and (f) temporal and spatial orientation. Its protocol consists of a single page, the administration time is about 10-15 minutes and the final score varied from 0 to 30 points. Higher scores correspond to better cognitive performances (Freitas et al., 2015b).

Stroop - Color and Word Test

The Stroop Test (Fernandes, 2012; Golden et al., 1978) is a measure of selective attention constructed according to the Stroop paradigm (Espirito-Santo et al., 2015). It is made up of three different conditions, all timed to be performed within 45 seconds. In the first task, the subject must read as fast as he can the words (i.e., blue, green, red) that are repeatedly presented on a card, counting the total number of words read correctly and self-corrected in the 45 seconds timed. In the second task, under the same rules, the subject must name as quickly as possible the colors (i.e., blue, green and red) of a series of groups of "X" presented. In the last task, the subject must do exactly the same as in the previous task, but instead of a series of groups of "X" the three words from the first task are presented with the ink color of the second task incongruent to the automatic reading response (Fernandes, 2012). Thus, this instrument mainly assesses the ability to inhibit irrelevant information, the ability to suppress a behavioral response tendency, cognitive flexibility, and processing speed (Sherman et al., 2023).

Trail Making Test A & B

The TMT (Cavaco et al., 2013b; Reitan & Wolfson, 1995) is a neuropsychological assessment instrument consisting of two parts – A and B. In the TMT-A, the subject must join in an increasing way and as quickly as possible a sequence of numbers (i.e., from 1 to 25) randomly distributed on a sheet of paper. In TMT-B the procedure is the same, but the letters of the alphabet are added and to successfully complete the task the subject must alternate between the numbers in ascending order and the letters in alphabetical order. The two tasks are timed separately and the shorter the time recorded to complete the task, the better the result. This test provides information on attention, visual exploration, hand-eye coordination, processing speed, sequencing, cognitive flexibility, and executive function (i.e., switching between sequences exclusively assessed by part B; Cavaco et al., 2013b).

Spatial Location

The Spatial Location subtest is part of the WMS-III (Wechsler, 2008b), which mainly assesses episodic declarative memory, since new and contextualized information is shown to the subject by the test situation, requiring him to learn and recover it. This test requires the use of a Corsi board with 10 cubes so that the subject reproduces, pointing to the blocks, series of different amplitudes in direct and reverse direction. The more series the subject repeats correctly, the higher his score and the better his performance. It mainly evaluates attention, due to the need to understand and repeat simple information, and working memory, since it is necessary to remember and manipulate information received visually in the short term. Spatial

Location is considered an isomorph or a non-verbal equivalent of the Digit Memory subtest referred to below (Wechsler, 2008b).

Phonemic Verbal Fluency and Semantic Verbal Fluency

PVF and SVF (Cavaco et al., 2013a; Thorndike & Lorge, 1944) are measures of non-motor processing speed, language production, executive functions, and memory (Greenaway et al., 2009). Verbal fluency tests are brief neuropsychological assessment tools, with relatively simple administration and scoring procedures. In SVF, the subject is asked to say the largest number of animals that he can remember within 1 minute. In PVF, the subject is asked to mention as many words as possible starting with the letter "M" and "R" (the same procedure was performed with the letter "P" when carrying out the MoCA; Freitas et al., 2011; Nasreddine et al., 2005). The final score corresponds to the number of words spoken in each category within the time limit, which means that a higher score corresponds to a better performance (Cavaco et al., 2013a).

Digit Symbol-Coding

The Digit Symbol-Coding subtest is part of the WAIS-III (Wechsler, 2008a), is included in the Performance Intelligence Quotient and contributes to the Processing Speed Index (Sherman et al., 2023). In this subtest, the subject must associate numbers to symbols and correctly memorize these associations, to perform the task as quickly as possible (Simões, 2002). The final score corresponds to the number of symbols that the subject was able to associate correctly for 120 seconds, so a higher result translates into a better performance. Through this test it is possible to assess attention, short-term non-verbal memory, working memory, motor and thinking speed (Sherman et al., 2023; Wechsler, 2008a).

Digit Span

Digit Memory is another WAIS-III subtest (Wechsler, 2008a), but it is included in the Verbal Intelligence Quotient and is part of the Working Memory Index (Sherman et al., 2023). In this test, the subject must listen and repeat a sequence of numbers of different amplitudes in direct and reverse direction. The score reflects the number of correctly mentioned sequences, as such, the higher it is, the better the subject's performance in this task. As previously mentioned, and similarly to the Spatial Location subtest, it mainly assesses attention and working memory (Simões, 2002; Wechsler, 2008a).

Symbol Search

Like Digit Symbol-Coding, Symbol Search is a subtest of WAIS-III (Wechsler, 2008a) present in the Performance Intelligence Quotient and in the Processing Speed Index (Sherman et al., 2023). This test recruit's perceptual discrimination capacity, depending on the visual attention and working memory of the subject (Simões, 2002). The subject must mark, line by line, for 120 seconds, confirming or denying, the repetition of a target symbol among the others. The more lines correctly marked, the better the result (Wechsler, 2008a).

Toulouse and Piéron Cancellation Test

The TP (Amaral, 1967; Lima et al., 2023; Toulouse et al., 1904) is a psychometric tool that assesses selective and sustained attention, processing speed and visual-perceptual skills, encompassing two main indices, Work-Efficiency (WE) and Dispersion-Index (DI). It consists of a sheet of paper with 25 lines, totaling 40 squares per line, different from each other due to the orientation of the lines that accompany them, randomly directed according to the wind rose. The task has a total time of 10 minutes during which the subject must identify and mark the squares that match the three target squares presented at the top of the sheet. The subject is instructed to work as fast as he can and to go through each line only once, always from left to right. For each line, the hits, errors, and omissions are counted to calculate the mentioned indices. Better performances on the TP are a combination of high scores in TP-WE with lower scores in TP-DI (Baeta, 2002; Lima et al., 2023).

Beck Depression Inventory II

The BDI-II (Beck et al., 1996; Oliveira-Brochado et al., 2014) assesses the presence and severity of depressive symptoms through the response to 21 items. For each item, 4 to 6 sentences are presented, and the subject must choose the one that best describes the way he has been feeling during the last two weeks, including the day of the assessment. The scores on each of the 21 items range from 0 (i.e., no symptoms) to 3 (i.e., severe symptoms) and it is possible to obtain scores divided into three factors: (a) cognitive, (b) affective, and (c) somatic. The defined cut-off scores are: 0 to 13 = *minimal symptomatology*, 14 to 19 = *mild depression*, 20 to 28 = *moderate depression*, and more than 29 points = *severe depression* (Beck et al., 1996).

Statistical Analysis

Statistical analysis was performed using version 25 for Windows of the IBM Statistical Package for the Social Sciences (SPSS). Descriptive statistics were used to characterize the sample at a sociodemographic level, in global cognition and, specifically, in terms of performance in two RCFT tasks. The existence of statistically significant differences between subgroups (i.e., Control Group and TBI Group) was analyzed using the *t* test for independent samples, Wilcoxon-Mann-Whitney test or chi-squared independence test. The choice of the parametric or non-parametric test was based on the nature of the variables and the assumptions of normality and homoscedasticity, verified by the Kolmogorov-Smirnov test or Shapiro-Wilk test and the Levene test, respectively. In the presence of statistically significant differences, the effect size was calculated using Cohen's d, when both groups had similar SD and the same sample size, Hedges' g, when the sample sizes were different, and Pearson's r, when the non-parametric version was used. The effect size classifications were interpreted considering Cohen's (1988) proposal. Concurrent validity was determined using Pearson's correlation coefficients between the RCFT and external criteria considered acceptable (i.e., measures of memory, executive function, and visuo-perceptual/spatial/constructive capacity), with data observation based on the parameters defined by Cohen (1988). The diagnostic accuracy of the RCFT in cases of TBI patients was assessed with the receiver operating characteristics (ROC) curve analysis and the indicative values of Hosmer and Lemeshow (2000) were considered for the results of the area under the ROC curve (AUC). The optimal cut-off points were determined by Youden index formula (Youden, 1950; with the Excel add-in), where higher Youden index indicating maximization of the sensibility and specificity. For each cut-off point was calculated the sensitivity (i.e., probability for subjects with disease to have a positive test), specificity (i.e., probability for subjects without disease to have a negative test), positive predictive value (PPV; i.e., probability of disease in subjects who have a positive test), negative predictive value (NPV; i.e., probability of the classification ‘without disease’ in subjects who have a negative test) and classification accuracy (i.e., probability of correct classification of subjects with or without disease).

Results

Sociodemographic Characterization of the Study Sample

The present study's sample was composed by 60 participants, subdivided into 30 participants of the Control Group and 30 participants of the TBI Group. After analyzing the nature of the variables and the assumptions of normality and homoscedasticity, the chi-squared independence test, the *t* test for independent samples and its non-parametric version, the Wilcoxon-Mann-Whitney test, were applied to verify the existence of differences between Control Group and TBI Group in terms of age, education, and gender. As expected, due to the previously mentioned sample pairing, there were no statistically significant differences (or independence was verified) between the two subgroups in these variables.

Table 1 presents sociodemographic characterization of the study sample and the values of the statistical analysis carried out to evaluate the differences between Control Group and TBI Group.

Table 1

Sociodemographic Characterization and Differences of the Study Groups

	Total sample	Control group	TBI group	Differences between control and TBI groups
n	60	30	30	60
Age				$t(58) = .008, p = .993$
M ± *SD*	45.5 ± 15.1	45.4 ± 15.7	45.5 ± 14.7	
[Min-Max]	[20-78]	[20-78]	[20-72]	
Education				$U = 449.50, p = .994$
M ± *SD*	9.2 ± 4.3	9.3 ± 4.2	9.2 ± 4.5	
[Min-Max]	[1-17]	[4-17]	[1-17]	
Gender				$\chi^2(1) = .073, p = .787$
Female (%)	21 (35%)	11 (36.7%)	10 (33.3%)	

Note. n = number of participants in each condition; *M* = mean; *SD* = standard deviation; Min = minimum; Max = maximum; *t* = independent samples *t* test; *U* = Wilcoxon-Mann-Whitney test; χ^2 = chi-squared independence test; *p* = statistical significance.

Cognitive Characterization of Groups

To characterize the global cognitive performance of participants and evaluate differences between the Control Group and TBI Group in this performance, Table 2 presents the results of each group in MMSE, MoCA, Stroop, TMT A & B, Spatial Location (WMS-III), PVF, SVF, Digit Symbol-Coding (WAIS-III), Digit Span (WAIS-III), Symbol Search (WAIS-III) and TP, in matched sample.

Statistically significant differences were found between Control Group and TBI Group in all neuropsychological tests performed, always indicating that the Control Group achieved a higher cognitive performance than the TBI Group; except in the TP-ID test which, although the pattern of cognitive performance was the same, there were no statistically significant differences verified (see Table 2 for this analysis).

Table 2

Characterization and Differences of the Global Cognitive Performance of the Matched Groups

	Total sample	Control group	TBI group	Differences between control and TBI groups
MMSE				$U = 130$, $p < .001$, $r = .643$
M ± *SD*	27.2 ± 4.4	29.6 ± 0.67	24.8 ± 5.3	
[Min-Max]	[8-30]	[27-30]	[8-30]	
n	60	30	30	
MoCA				$U = 91.50$, $p < .001$, $r = .686$
M ± *SD*	22.5 ± 5.8	26.1 ± 3.3	18.9 ± 5.6	
[Min-Max]	[2-30]	[16-30]	[2-26]	
n	60	30	30	
Stroop				
Word				$t(48) = -4.949$, $p < .001$, $g = 1.428$
M ± *SD*	79.9 ± 23.1	90.7 ± 16.7	63.6 ± 22.1	
[Min-Max]	[3-119]	[57-119]	[3-91]	
n	50	30	20	
Color				$t(48) = -3.557$, $p = .001$, $g = 1.027$
M ± *SD*	60.3 ± 15.4	66.0 ± 11.4	51.8 ± 17.0	
[Min-Max]	[2-87]	[43-87]	[2-72]	
n	50	30	20	

	Total sample	Control group	TBI group	Differences between control and TBI groups
Stroop				
Word/Color				*t*(48) = -3.057, *p* = .004, *g* = 0.883
M ± *SD*	34.6 ± 11.4	38.4 ± 9.2	29.1 ± 12.3	
[Min-Max]	[1-60]	[18-60]	[1-51]	
n	50	30	20	
TMT				
Part A				*U* = 72, *p* < .001, *r* = .722
M ± *SD*	56.4 ± 71.5	26.3 ± 9.5	86.4 ± 91.9	
[Min-Max]	[13-515]	[13-49]	[26-515]	
n	60	30	30	
Part B				*U* = -123.50, *p* < .001, *r* = .606
M ± *SD*	122.9 ± 94.4	77.5 ± 64.6	171.5 ± 97.9	
[Min-Max]	[33-360]	[33-360]	[47-360]	
n	58	30	28	
Spatial Location				*U* = 150, *p* < .001, *r* = .567
M ± *SD*	13.4 ± 4.3	15.7 ± 3.2	11.0 ± 4.1	
[Min-Max]	[1-20]	[8-20]	[1-20]	
n	59	30	29	
Verbal Fluency				
Phonemic				*t*(58) = -4.787, *p* < .001, *d* = 1.236
M ± *SD*	28.9 ± 14.9	36.8 ± 14.3	21.0 ± 10.9	
[Min-Max]	[0-77]	[15-77]	[0-41]	
n	60	30	30	
Semantic				*t*(58) = -7.857, *p* < .001, *d* = 2.029
M ± *SD*	19.0 ± 7.9	24.7 ± 5.9	13.4 ± 5.3	
[Min-Max]	[3-33]	[13-33]	[3-22]	
n	60	30	30	

	Total sample	Control group	TBI group	Differences between control and TBI groups
Digit Symbol-Coding				*U* = 149.50, *p* < .001, *r* = .564
M ± *SD*	47.6 ± 23.6	60.6 ± 20.4	34.1 ± 18.9	
[Min-Max]	[5-93]	[26-93]	[5-73]	
n	59	30	29	
Digit Span				*U* = 138.50, *p* < .001, *r* = .588
M ± *SD*	13.4 ± 4.6	16.0 ± 3.8	10.8 ± 3.7	
[Min-Max]	[2-25]	[9-25]	[2-18]	
n	59	30	29	
Symbol Search				*t*(57) = -5.925, *p* < .001, *g* = 1.543
M ± *SD*	22.3 ± 11.2	29.1 ± 8.2	15.4 ± 9.6	
[Min-Max]	[2-46]	[16-46]	[2-30]	
n	59	30	29	
TP				
WE				*t*(56) = -3.882, *p* < .001, *g* = 1.020
M ± *SD*	142.6 ± 70.7	173.8 ± 60.4	109.2 ± 66.2	
[Min-Max]	[-16-307]	[60-307]	[-16-250]	
n	58	30	28	
DI				*U* = 333.50, *p* = .178
M ± *SD*	21.0 ± 24.8	15.7 ± 11.7	26.6 ± 33.0	
[Min-Max]	[2.2-164]	[3.5-42.9]	[2.2-164]	
n	58	30	28	

Note. *n* = number of participants in each condition; *M* = mean; *SD* = standard deviation; Min = minimum; Max = maximum; *t* = independent samples *t* test; *U* = Wilcoxon-Mann-Whitney test; *p* = statistical significance; *r* = Pearson's r; *g* = Hedges' g; *d* = Cohen's d. PVF presents the total result of the letters "P", "M" and "R". Spatial Location and Digit Span subtests present the total results for forward and backward sequences.

Psychometric Properties of RCFT

Concurrent Validity

The concurrent validity was performed through the Pearson correlation between the RCFT and some measures of visual memory and working memory (i.e., subtest Spatial Location, Digit Symbol-Coding, Symbol Search), executive functions (i.e., TMT-B, Stroop word/color condition, PVF, SVF), and visuo-perceptive/spatial/constructive ability (i.e., MoCA's visuo-spatial domain - cube and clock, MMSE's visuo-spatial domain - crossed pentagons, subtest Symbol Search). The correlations found between the RCFT tasks and the measures proposed for analysis were all statistically significant, considering a significance level of 5%. On the other hand, the correlations turned out to be mostly large according to Cohen (1988), who considers values between .10 and .29 indicative of small correlation, values between .30 and .49 indicative of medium correlation, and values between .50 and 1.0 interpreted as signs of large correlation. These indicators are detailed in Table 3.

Table 3

Concurrent Validity Between RCFT Tasks and Relevant External Criteria

RCFT	Copy			Evocation		
	r	*p*	Interpretation	*r*	*p*	Interpretation
MMSE's visuo-spatial domain	.713	< .001	large	.352	< .001	medium
MoCA's visuo-spatial domain	.687	< .001	large	.687	< .001	large
Stroop Word/Color condition	.669	< .001	large	.529	< .001	large
TMT-B	-.730	< .001	large	-.579	< .001	large
Spatial Location	.686	< .001	large	.679	< .001	large
Verbal Fluency						
Phonemic (total)	.634	< .001	large	.544	< .001	large
Semantic	.649	< .001	large	.681	< .001	large
Digit Symbol-Coding	.657	< .001	large	.701	< .001	large
Symbol Search	.659	< .001	large	.650	< .001	large

Note. r = Pearson correlation values; *p* = statistical significance; Interpretation = classification of correlation values according to Cohen (1988).

Differences Between Groups in RCFT Performance

According to the objectives of the present study, were tested the differences between the matched groups in RCFT performance. Table 4 presents the performance of the groups in the RCFT, specifically in the task of copying and immediate recall, and the statistical analysis used to test the differences. The results suggested significant statistical differences between Control Group and TBI Group in the copy and evocation of the RCFT, with the TBI Group consistently underperforming.

Table 4

Characterization and Differences of the RCFT Performance of the Matched Groups

	Total sample	Control group	TBI group	Differences between control and TBI groups
n	60	30	30	60
RCFT – Copy				*U* = 139, *p* < .001, *r* = .597
M ± *SD*	31.0 ± 6.3	34.1 ± 2.5	27.9 ± 7.4	
[Min-Max]	[5-36]	[24.5-36]	[5-36]	
RCFT – Evocation				*t*(58) = -5.360, *p* < .001, *d* = 1.384
M ± *SD*	17.7 ± 9.4	23.1 ± 7.6	12.3 ± 8.0	
[Min-Max]	[0-34]	[6.5-34]	[0-26.5]	

Note. n = number of participants in each condition; *M* = mean; *SD* = standard deviation; Min = minimum; Max = maximum; *t* = independent samples *t* test; *U* = Wilcoxon-Mann-Whitney test; *p* = statistical significance; *r* = Pearson's r; *d* = Cohen's d. RCFT – Evocation corresponds to immediate evocation, i.e. the realization of the figure 3 minutes after the copying phase.

Validity and Diagnostic Accuracy of RCFT

Receiver operating characteristics (ROC) curve analysis were calculated to measure the diagnostic accuracy of the RCFT to distinguish TBI patients from healthy adults. Graphic representations of the ROC curves are delivered in Figure 1. The results suggest the occurrence of a statistically significant curve and good discriminating power in both, the copy task (AUC = .846, *SE* = .051, *p* < .001, 95% CI [.746 - .945]) and the evocation task (AUC = .827, *SE* = .053, *p* < .001, 95% CI [.722 - .931]).

Table 5 presents the optimal cut-off points for maximum accuracy according to Youden’s index, and the respective values of sensitivity, specificity, positive predictive value (PPV), negative predictive value (NPV), and classification accuracy.

Figure 1

ROC Curve of the RCFT Copy and Evocation Task (Respectively) Considering the TBI Group

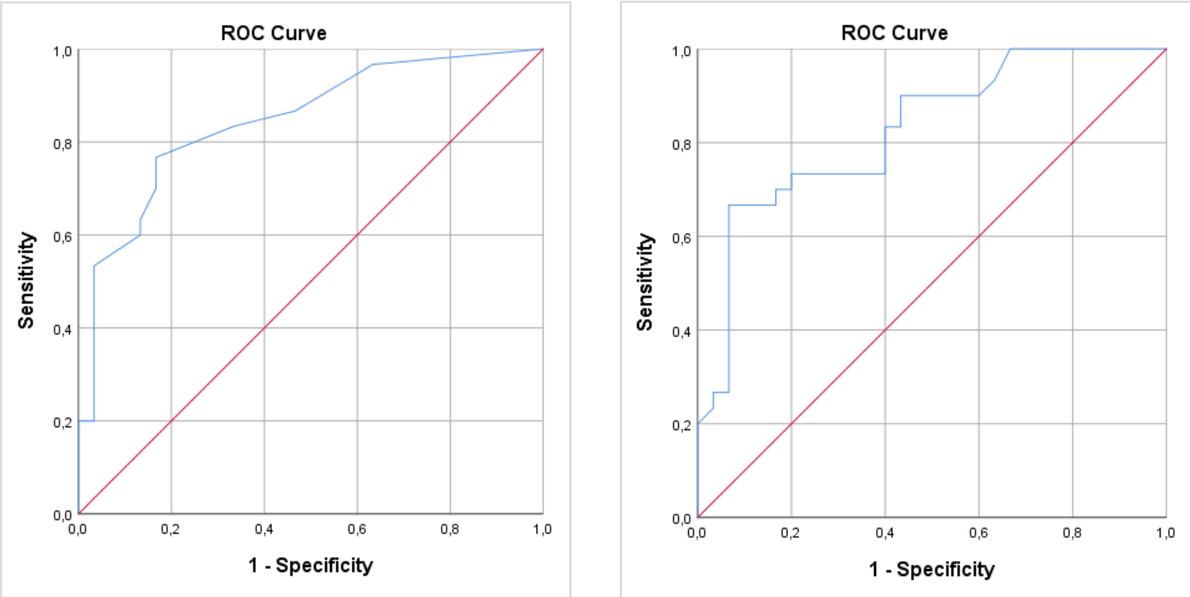

Table 5

ROC Curve Analysis

RCFT	Cut-off	AUC	Sensitivity	Specificity	PPV	NPV	Classification Accuracy
Copy	< 32	.846	70	83	83	70	75
Evocation	< 14	.827	67	93	90	72	78

Note. Values of sensitivity, specificity, PPV, NPV and classification accuracy were expressed in percentage. Cut-off points indicate the minimum score required for presence of signal.

Discussion

The validity of neuropsychological measures should be tested to ensure the quality of the neuropsychological assessment process (Sherman et al., 2023). The main objective of this study was to validate the RCFT for TBI patients as a measure of visual memory, visuo-perceptual/spatial/constructive capacity, and executive functioning, some of the cognitive functions most affected and with greatest impact on patients suffering from this condition (Granacher, 2015; Stuss, 2011; Vakil, 2005).

The analysis of group differences in patients' cognitive status corroborated the extensive literature on remaining global deficits in patients with TBI. The wide range of neuropsychological assessment measures applied and analyzed made it possible to confirm that patients with TBI present a consistently lower cognitive performance than healthy participants, having had weaker performances in the majority of tests carried out, namely in attention tests (selective and sustained), visual exploration, perceptual discrimination, hand-eye coordination, sequencing, processing and motor speed, language, memory (working memory, visual and verbal short-term memory), visuo-spatial/constructive capacity and executive functioning (inhibitory control, cognitive flexibility, alternation, update, planning, organization, problem solving). The effect size analysis revealed that these differences were all high or very high, reaching values above 0.5 and, sometimes, above 1.0 (Cohen, 1988). Thus, we found what other authors advocated (e.g., Andriessen et al., 2011; Leathem et al., 1996; Sigurdardottir et al., 2015; Stuss, 2011), that TBI is a complex trauma associated with multiple cognitive and functional consequences, with regular generalized brain damage.

Within the psychometric field, as expected, there were statistically significant correlations between the two RCFT tasks (i.e., copy and evocation) and all tests proposed for this analysis, which is an indicator of concurrent validity (i.e., the RCFT is significantly and highly correlated with other measures of related constructs, considered acceptable in the literature, and obtained in the same period). Strong correlations, according to Cohen (1988), obtained between the RCFT and measures of executive functioning, reinforce the fact that RCFT is a measure not only of visual memory and visuo-spatial/constructive capacity, but that it also recruits the frontal lobe, encompassing executive functioning, to execute the drawing. In this sense, Somerville et al. (2000) using the previously mentioned Boston Qualitative Scoring System (BQSS), tested the relation between the five BQSS scores (i.e., Fragmentation, Planning, Neatness, Perseveration and Organization) and four measures of executive functioning, namely the Wisconsin Card Sorting Task-Perseverative Responses (WCST; Heaton, 1981), TMT-B (Reitan & Wolfson, 1985), Controlled Oral Word Association-Total (COWA; Benton, 1968) and Similarities subtest of the Wechsler Adult Intelligence Scale – Revised (WAIS-R; Wechsler, 1981), finding that BQSS scores were significantly related to performance on traditional neuropsychological tests that measure various aspects of executive functioning. Even though the results are not consistent in this sense (e.g., see Elderkin-Thompson et al., 2004), the present study supports the fact that RCFT may be a useful measure of executive functioning.

In respect of performance in the RCFT, the TBI Group obtained significantly lower results when compared to the Control Group. When analyzing the magnitude of the statistical difference, we found that it was greater in the evocation task compared to the copy task, something that would be expected according to the literature that announces a pattern of cognitive deficits that are essentially accentuated at the level of memory and executive functions in this clinical condition (e.g., Boyd, 2014; Granacher, 2015; Hunter et al., 2022; Meulemans & Séron, 2004; Stuss, 2011; Vakil, 2005), unlike visuo-spatial/constructive deficits that occur mainly in more specific cases of contusions or hematomas, which sustain traumatic brain injury sufficient to produce brain tissue damage (e.g., Levin et al., 1990; Levin et al., 1991), as mentioned at the beginning. Still, as the deficits are often generalized and as the copying task requires not only visuo-spatial/perceptual/constructive capacity, but also planning and problem-solving skills, the size of the effect in this task was high.

Regarding diagnostic accuracy, the results confirmed that the RCFT can be a good instrument to distinguish the performance between healthy adults and patients with TBI, according to the values stipulated by Hosmer and Lemeshow (2000), since the AUC value was greater than 0.8, but less than 0.9. The data obtained suggests that, if chosen randomly, approximately 85% of clinical cases in the copy task and approximately 83% of clinical cases in the evocation task will present worse scores than non-clinical cases in the RCFT.

It was also possible to verify that the specificity values of both RCFT tasks were higher than the sensitivity value, which suggests that the test is better for determining a negative diagnosis knowing that the patient does not have the disease, than a positive diagnosis knowing that the patient has the disease. It can be concluded that the copy task and the evocation task have good predictive capabilities in terms of specificity, presenting values above 80%, and reasonable predictive capabilities in terms of sensitivity, obtaining values between 50% and 80% (Marôco, 2018).

Among all classifications, RCFT correctly classified 75% of cases in the copy task and 78% in the evocation task (i.e., classification accuracy, the probability of correct classification of subjects with or without disease). However, it is important to highlight the careful use of RCFT in TBI population since that the results obtained in the section designated for this purpose indicate some likelihood to have false negative cases. This is because in both the copying task and the evocation task, in 60 cases, 11 were false negatives, that is, 11 people who suffered a TBI obtained a classification above the cut-off point stipulated for both tasks. This means that a person can be misclassified, if they do not present values corresponding to the cognitive pattern of TBIs in the RCFT, when in fact they have suffered a TBI. This event can be justified by the fact that the sample contains TBIs with different degrees of severity and with different evolution times. Knowing that, especially in cases of mild TBIs, recovery can occur completely and even within a period of months after injury (Maas et al., 2008), the possibility of these cases being present in the sample and having an influence on the results must be considered.

Limitations

In addition to what has already been exposed, some limitations should be mentioned. First, the TBI Group was considered globally due to the small sample size. It is known that this clinical condition has many particularities, depending on the severity of the lesion, its location and the type of external mechanism that caused it (Granacher, 2015), variables that were not controlled in the present study. Consequently, it is important to be careful when generalizing the results demonstrated here, since in addition to the fact that global cognitive sequelae are known, the differentiation of TBI according to some of the classification mechanisms will be useful to infer more accurately, due to the type of manifestations associated with them (Junqué et al., 2001). In this sense, future studies that have the possibility of working with a larger sample could even study the optimal cut-off points depending on the severity levels of the injury (e.g., mild, moderate and severe), contributing to the use of RCFT not as a diagnostic tool (it does not serve this purpose), but as an assessment of the severity of the damage, something initially planned for this master's dissertation but unaccomplished due to time restrains.

On the other hand, the clinical group is made up of a collection in two different settings and at different periods, unified for convenience. For this reason, adjustments had to be made to use only neuropsychological assessment instruments common to both subgroups. This process caused us to lose some information and we chose to only study the copying and immediate evocation tasks of the RCFT, when there are already more complete versions that include the delayed evocation task (e.g., 30 minutes after copying) and recognition (e.g., see Meyers & Meyers, 1995), that allow access different aspects of cognition, important in patients with TBI (e.g., recognition trial can operate as an examination of test motivation through analyses of test profiles and rare recognition mistakes, an analysis to consider in patients who are going to undergo a neuropsychological assessment to obtain a medical certificate of multipurpose disability).

Conclusions

The present work demonstrates the importance of the administration of the RCFT in TBI patients, according to its role in assessing deficits in visual memory, visuo-spatial/constructive ability, and executive functioning. The main objective was to contribute to the extension of the literature on RCFT in TBIs, making it a more valuable tool in the psychological and psychometric field in Portuguese adult's victims of this clinical condition. The RCFT proved to be an instrument sensitive to executive functioning and can even be used as a test that recruits and evaluates it, something proven through concurrent validity and estimated through the high effect size observed in the copying task. In this way, its use can provide valid information on a broader field of cognitive functioning, something useful to consider when choosing a protocol that should tend to be brief, due to the fatigue inherent in TBI victims. Furthermore, the RCFT demonstrated to be a valid instrument for distinguishing the cognitive pattern of these patients in comparison with healthy adults in the community, and its use in discriminating different levels of severity of TBIs should be considered in future studies, allowing the RCFT to be a clinical useful tool to be used alongside GCS, period of loss of consciousness and the period of post-traumatic amnesia.

The results of this master's dissertation support the fact that TBI is an embrittlement condition that requires intervention from the field of neuropsychology. Therefore, neuropsychological assessment in general, and specifically using RCFT in these cases, is essential, as it allows to identify the cognitive changes that arise from the injury, as well as the functions that remain preserved, what will be fundamental in order to elaborate a rehabilitation program that promotes a greater degree of autonomy, socioeconomic reintegration and an increase in the patient's quality of life, simultaneously helping to respond to the social and health problems resulting from this condition (Muñoz-Céspedes & Paúl-Lapedriza, 2001).

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