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Executive functions assessment in post-traumatic brain injury adults

Avaliação das funções executivas em adultos pós traumatismo cranioencefálico

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Abstract

Objective
Executive dysfunction after traumatic brain injury may lead to reduced daily functionality due to direct damage to the frontal lobe or to disruption of its connections to other brain regions. This study aimed to compare the performance of adults with and without traumatic brain injury on executive functions tasks.

Method
The present study had a descriptive transversal design and included 43 participants divided into a clinical group (N = 23, age M = 34.3 [10.86]) and a control group (N = 20, age M = 38.3 [10.7]). The battery consisted of traditional instruments and the Ecological Hotel Task.

Results
A significant difference was found in the performance of the groups in the planning measures (number of tasks [t = -3.06; p < 0.01] and planning score [t = -3.06; p < 0.01]), highlighting the advantages of using both the traditional performance paradigms and the ecological tasks in neuropsychological assessment of executive functions.

Conclusion
Results suggested that the ecological task might discriminate better executive dysfunction, emphasizing the importance of using activities that simulate real-life situations of the participants.

Keywords: Brain injury, traumatic; Executive function; Neuropsychology

Resumo

Objetivo

A disfunção executiva após traumatismo cranioencefálico pode levar à diminuição da funcionalidade devido ao dano direto ao lobo frontal ou ao rompimento de suas conexões com outras partes do cérebro. Este estudo objetivou comparar o desempenho de adultos com e sem traumatismo cranioencefálico em tarefas de função executiva.

Método

O estudo apresenta delineamento transversal descritivo de análise quantitativa. Participaram 43 sujeitos divididos em grupo clínico (N =23, idade M = 34.3 [10.86]) e controle (N = 20, idade M = 38.3 [10.7]). A bateria foi composta por tarefas tradicionais de função executiva e a Tarefa Ecológica do Hotel.

Resultados

Encontrou-se diferença significativa na performance dos grupos nas medidas de planejamento (número de tarefas [t = -3.06; p < 0.01] e escore de planejamento [t = -3.06; p < 0.01]), reforçando a vantagem do uso de instrumentos tradicionais e ecológicos na avaliação neuropsicológica de funções executivas.

Conclusão

Os resultados sugerem que a tarefa ecológica pode discriminar melhor a disfunção executiva, reforçando a importância da utilização de atividades que simulem situações da vida real dos participantes.

Palavras-chave: *Lesões encefálicas traumáticas; Função executiva; Neuropsicologia*

Traumatic Brain Injury (TBI) is considered the primary cause of death and disability in young adults. Sixty-nine million individuals worldwide are estimated to sustain a TBI each year (Dewan et al., 2018). Its physical, cognitive, and emotional consequences have been extensively described (Johnstone et al., 2022). There is still a lack of statistical data in Brazil about this silent epidemy. Still, a few studies pointed out that the hospitalization rate was 65.54/100.000, the hospitalization period average was 5.74 days, and mortality rates was 10.27/100.000 between 2008 and 2019 (Carteri & Silva, 2021).

Another study that investigated data registered between 2008 and 2012 at the Brazilian Hospitalization Database (DATASUS) reported 125.000 hospital admissions due to TBI a year, and an incidence of 65.7 admissions per 100.000 inhabitants per year (Almeida et al., 2016). The same study found that hospital mortality was 5.1/100.000/year, and case fatality rate was 7.7%. Moreover, the age group 20–29 showed the highest mortality rate when compared to other age groups.

Takahashi et al. (2021) analyzed secondary data of hospital admissions for TBI, registered at DATASUS, between 2008 and 2019 to provide an overview of TBI epidemiology in all Brazilian states. Results showed that the Southeast (42.5%) and Northeast regions (25.8%) presented the major incidence of TBI, with more than a million cases of disability. They showed a trend toward an increase in the incidence of TBI, especially in young children (0–4 years old) and elderly groups (> 65 years old).

Magalhães et al. (2022) evaluated the sociodemographic and clinical characteristics of patients with TBI admitted to a public reference trauma center in Brazil and found that falls were the main cause of TBI.

Worldwide, automobile accidents are the primary cause of brain injury among adolescents and young adults age group, and usually, it is related to the use of alcohol. Long-term follow-up studies of people living with TBI have shown that, even after mild brain injuries, neuropsychiatric and neuropsychological consequences can still interfere with social participation and perception of well-being (Guerrette & McKerral, 2023).

Executive dysfunction can be one of the most frequent and disabling sequelae after TBI as it directly interferes with planning and performing the activities of daily living (Engel et al., 2019). Executive Functions (EF) can be defined as a set of high-level cognitive processes that, in an integrated way, allow the individual to achieve goals, assess the efficiency of behaviors, solve problems, leave ineffective strategies in favor of more efficient ones, and inhibit behaviors (Friedman & Miyake, 2017).

A neuropsychological assessment is usually recommended as it can provide important information about the cognitive, emotional, and behavioral changes that frequently lead to functional limitations. A multi-method evaluation can determine neuropsychological rehabilitation needs as patients seldom report problems due to deficits in self-awareness (Dromer et al., 2021).

There is a wide range of neuropsychological measures for the EF's assessment, most of which have a long history and great scientific recognition (Harvey, 2019). However, the abstract nature of many formal tests may differ from the executive skills required in everyday activities. Psychometric measures may differ in how the steps that make up a test are far removed from daily life demands. Thus, assessing a patient with brain injury only through psychometric measures may not estimate the nature and the degree of difficulty that they present when performing daily tasks (Doherty et al., 2015).

Therefore, it is recommended that the neuropsychological assessment include ecological tasks that provide similar scenarios to the patient`s daily life, being able to predict their performance in the real-world (Renison et al., 2012). Studies after TBI highlight the importance of using tasks whose performance is evaluated through real situations that allow the professionals to observe the underlying difficulties (Rand et al., 2018).

This research aimed to investigate components of EF in adults after TBI, with an emphasis on planning. The specific objectives were to compare the performance of adults with and without TBI on EF instruments that assess planning and to investigate whether there is an association between performance in different EF tasks using psychometric and ecological tools.

Method

Participants

A total of 43 adults participated: 23 with TBI and 20 controls without a history of neurological conditions. Inclusion criteria for the Clinical Group (CG) were ages between 18 to 59 y.o., four years of formal education, and at least two months from the onset of the lesion. The injury time ranged from 5 to 152 months (M = 42.61, SD = 41.94). Individuals with movement impairments in the upper limbs, `as deficits in fine movements with the dominant hand, were excluded. Participants with TBI were recruited from different public hospitals in the south of Brazil. The Non-Clinical Group (NCG) was recruited from the community. The CG and NCG were matched for age (CG average age 34.3 years (SD = 10.86) / NCG average age 38.3 (SD = 10.7), years of education (YoE), and the ratio of women to men. The groups did not differ significantly about age (t = -1.21; p = 0.23) and education (t = -0.85; p = 0.40).

Instruments

The following instruments were used to investigate inclusion criteria and sample characteristics: Questionnaire of demographic, clinical, and neuropsychological data for TBI patients

(elaborated by authors); Mini Mental Scale Examination (Folstein et al.,1975, adapted by Chaves & Izquierdo, 1992); Oral and Written Comprehension subtests of the NEUPSILIN (Fonseca et al., 2009).

The battery of neuropsychological instruments was chosen considering the scientific value of the tasks. The following tests were used to study the research questions: Prospective Memory and Verbal Fluency subtests of the NEUPSILIN (Fonseca et al., 2009); Verbal Fluency Semantic subtest of the *Bateria Montreal de Avaliação da Comunicação* (MAC) (Fonseca et al., 2008); Wisconsin Card Sorting Test – 48 cards (Zimmermann et al., 2015); Patient Competency Rating Scale (PCRS) (Zimmermann et al., 2014) Family and client versions. Tower subtest Delis-Kaplan Executive Functions System (D-KEFS) (Delis et al., 2001); The Hotel Task (Cardoso et al., 2015).

Procedures

The present study had a descriptive transversal design. Recruitment of the clinical group was done through telephone contact. The research objectives were presented to the participant or family member and an invitation to participate was made. The control group was formed by volunteers from the general community. Students and university employees and government officials from a city in southern Brazil participated.

Interested people who met the inclusion criteria were evaluated in a clinic at a university in southern Brazil. In the first session all research procedures were informed, as well as the reading and signing of the informed consent, approved by the Ethics Committee (Register nº 1229.154.11.10), in line with the Resolution 196/96 of the National Health Council.

After providing informed consent, participants responded a structured interview and a screening assessment, and if included in the groups, the assessment interview was scheduled.

Statistical Analysis

Data were analyzed with IBM®SPSS® (version 20.0). Significance level was considered if $p \leq 0.05$. The performance of the clinical and control groups in the neuropsychological tests was compared by the *t*-test for independent samples after verifying the normality of the data. Pearson`s correlation was used to verify the relationship between the performances by the different instruments.

Results

The TBI group (CG) presented an average age of 34,3 years (*SD* = 10.86) and the NC 38.3 (*SD* = 10.7) years ($t[42] = -1.21$; $p = 0.23$). The CG had an average of 10.74 (*SD* = 3.11) years of education and the NCG 11.70 (*SD* = 4.18), the differences between the groups was non-significant ($t[42] = -0,85$; $p = 0.40$). The MMSE scores were an average of 25.30 (*SD* = 4.10) for the CG and 27.95 (*SD* = 2.01) for NCG that indicated that participants were not in the dementia range. However, significant differences were found between groups scores on the MMSE ($t[42] = -2.74$; $p = 0.01$).

The majority of the TBI group (90%) was diagnosed with a severe injury level, showed loss of consciousness for more than 24 hours, and was in a coma between 6 and 55 days (*M* = 24.0, *SD* = 14.73). The TBI group time since injury varied between 5 and 152 months (*M* = 42.61, *SD* = 41.94), and 56% of this group were injured in a motor vehicle accident. Additional clinical information is provided in Table 1.

Table 1
Characteristics of the clinical group

Clinical characteristics	*n*	*M*	*SD*	%
Time since injury (months)	23	42.61	41.94	
Time of coma (days)	13	24.00	14.73	
Cause of the injury	23			
Vehicle accident				56.52
Violence (fight or assault)				26.09
Fall				13.04
Sports practice				4.35
Injury hemisphere	16			
Right hemisphere				31.25
Left hemisphere				18.75
Bilateral				50
Injury location	16			
Frontal				25
Parietal				6.25
Fronto-temporal				12.5
Temporo-parietal				18.75
Occipto-parietal				6.25
Generalized (+3 lobes)				12.5
Diffuse Axonal Injury				18.75

Neuropsychological Assessment – Executive Function Performance

Table 2 shows the group's performance at the Tower subtest – D-KEFS. The *t*-test for independent samples presented no significant differences between TBI and NC groups. However, the TBI group's overall performance was lower than the NC group. There were fewer correct items, more movements, a more extended time to finish the task, lower reaction time for the first movement, and more rule violations in the TBI group.

Regarding the performance of the groups in the other EF tasks, they differed significantly in the tasks of prospective memory, semantic verbal fluency, and WCST. Table 3 presents all results.

Table 2
Group's performance at the Tower subtest – Delis–Kaplan executive function system

Measure	Clinical Group (*n* = 23)		Control Group (*n* = 20)		*t*	Sig	Cohen's *d*
	M	*SD*	*M*	*SD*			
Correct items	7.30	2.20	7.80	1.64	-0.83	0.41	0.258
Total of movements	172.09	97.91	163.25	64.26	0.34	0.73	0.107
Total completion time (sec)	720.74	321.68	632.75	265.35	0.97	0.34	0.299
Total time of 1st movement (sec)	28.48	18.16	31.00	25.41	-0.38	0.71	0.114
Number of rules violated	3.39	4.46	2.65	3.66	0.59	0.56	0.181

Table 3
Performance in executive function tasks

Task / Measure	Clinical Group (*n* = 23)		Control Group (*n* = 20)		*t*	Sig	Cohen's *d*
	M	*SD*	*M*	*SD*			
WCST nº of items administered	46.04	3.45	43.55	4.38	2.04	0.04*	0.632
WCST nº of categories completed	3.87	2.01	5.05	1.40	-2.26	0.02*	0.681
WCST total of correct items	29.13	9.16	34.05	8.08	-1.86	0.07	0.570
WCST total of errors	16.91	11.29	9.50	10.63	2.20	0.03*	0.676
WCST Failure to maintain set	0.78	1.20	0.65	0.81	0.42	0.68	0.127
WCST Perseverative errors	11.70	8.72	7.20	9.36	1.63	0.11	0.497
WCST Non-perseverative errors	5.17	3.53	2.30	2.32	3.20	< 0.01*	0.497
Prospective memory	1.35	0.71	1.95	0.22	-3.83	< 0.01*	1.142
Phonemic verbal fluency (F)	9.09	5.81	11.25	4.41	-1.36	0.18	0.419
Semantic verbal fluency	15.26	5.70	20.80	5.68	-3.18	< 0.01*	0.819

Note: *$p < 0.05$.

Performance on the Hotel Task

After comparing TBI and NC groups' performances on the Hotel Task, results indicated a significant difference in their performance on the two measures that assess planning skills: number of tasks performed, planning score, and prospective memory score. The correct answers analysis of each task showed that the TBI group had a significantly lower score in the Foreign Coin Task, the Brochure Task, and the Menu Task compared to the NC group. Considering the time spent on each task, the TBI group spent significantly less time on the Brochure Task than the NC group. Table 4 shows the scores and the statistical results.

Table 4
Performance on the Hotel Task

Hotel Task	Clinical Group (n = 23)		Control Group (n = 20)		t	Sig	Cohen's d
	M	*SD*	*M*	*SD*			
Nº of tasks performed	3.35	1.53	4.45	0.76	-3.06	< 0.01*	0.917
Planning Score	5.70	3.06	7.90	1.52	-3.06	< 0.01*	0.917
Wake up guest	1.17	0.94	1.95	0.22	-3.85	< 0.01*	1.143

Note: *p < 0.05.

Correlation between EF measures

As shown in Table 5, Pearson's correlation coefficient investigated the relationship between the EF tasks. The analysis showed a high magnitude and positive correlation between semantic fluency and the Hotel Task, considering Cohen`s parameters (1998).

Table 5
Pearson's correlation between executive functions tasks

Measure	1	2	3	4	5	6
1. Total Moves (n = 23)						
Pearson	–					
Sig.	–					
2. Semantic fluency (n = 23)						
Pearson	0.364	–				
Sig.	0.088	–				
3. WCST N cat complete (n = 23)						
Pearson	-0.050	0.071	–			
Sig.	0.821	0.749	–			
4. WCST correct items (n = 23)						
Pearson	0.019	-0.013	0.931**	–		
Sig.	0.932	0.953	0.000	–		
5. Plan Score (n = 23)						
Pearson	0.007	0.711**	-0.029	-0.166	–	
Sig.	0.974	0.000	0.895	0.449	–	
6. N tasks (n = 23)						
Pearson	0.007	0.711**	-0.029	-0.166	1.000**	–
Sig.	0.974	0.000	0.895	0.449	0.000	–

Note: **high-magnitude and significant correlation

Patient Competency Rating Scale

All participants answered the Patient Competency Rating Scale (PCRS) self-report measure of awareness of deficits in daily activities, and family and significant others of the TBI group also filled out the questionnaire. Comparing the different scores found between patients and their families is thought to be a good measure of the patient's self-awareness of functional deficits, and these differences were calculated.

The mean score for the control group was 76.00 points (*SD* = 5.78), while the clinical group obtained 67.09 (*SD* = 11.18) points. The maximum scale score is 80.00 points, indicating the absence of self-awareness of the difficulties. The *t*-test for independent samples showed a significant difference between the groups (t = -3.35; p = 0.002), suggesting that the participants of the NCG noticed themselves as less compromised in daily activities when compared to the clinical group.

The most important measure evidenced by the PCRS is the discrepancy between the scores obtained by TBI patients and their family members. In the present study, the average score of family members was 56.30 (*SD* = 22.56), while the clinical group was 67.09 (*SD* = 11.18). This difference was considered significant (t = 2.05; p = 0.04) and suggested the presence of anosognosia in the clinical group.

There were no significant differences on mean scores in Oral (t[42] = 0.09; p = 0.92) and Written Comprehension (t[42] = -1.10; p = 0.28) scores between groups.

Discussion

The TBI group showed similar demographic and clinical characteristics to the TBI population generally described: 91% were males, the mean age of 30,22 (9.26) years, and 56% of injuries related to motor vehicle accidents.

Performance of groups in EF tasks

The comparative analysis of the groups' performance in Tower D-KEFS did not significantly differ between the clinical and control groups. Different tower tasks are widely used in neurological populations, including TBI, and the literature presents conflicting data about the results (Cockburn, 1995). Specifically, in adults after TBI, studies show that when compared to a control group, TBI patients perform a significantly higher number of movements and need more time to complete the task than people without injury (Chan & Manly, 2002). Despite the lack of statistical significance in the present study, the clinical group also performed more movements and had a more extended task completion time than the controls, indicating the hypothesis that there is an impairment in the planning function after TBI.

Carlin et al. (2000) compared people's performance with prefrontal cortex damage and healthy controls in the Tower of London. The results indicated a significant difference in the number of movements performed and the total time to complete the test. However, there was no significant difference in the number of correct items, violet rules, and reaction time. Cockburn (1995) administered the Tower of London to 20 subjects after severe TBI and compared them to a control group (n = 25). The scores indicated that the test did not discriminate between the two groups. These studies corroborate the results found in the present research.

The control group violated fewer rules than the clinical group. The ability to follow the rules is an essential component of the task that deserves investigation as it provides data related to the ability of self-monitoring and inhibitory control (Yochim et al., 2009; Zorick et al., 2021). Perhaps the most significant demand related to the tower task is the ability to "look ahead." Completing the task with the fewest possible moves, within a time limit and without violating rules, require the capacity for abstraction and mental planning, which allow the development of a strategy that remains in working memory and helps solve the problem (Carlin et al., 2000).

The other EF tasks used to assess the participants' performances, and the prospective memory assessment results differentiated the groups. These findings corroborate other studies which emphasize that the ability to remember to act in the future may be impaired after TBI (Cores et al., 2010).

The clinical group performed worse on verbal fluency tasks. Previous studies have shown that the TBI population has limited word production in these activities (Chaurasiya et al., 2021). The semantic verbal fluency task discriminated the groups. Tzadok et al. (2022) also found similar results when evaluating adults with TBI. The semantic verbal fluency task is more sensitive to identifying deficits in lexical access, verbal inhibition, semantic memory, and processing speed in TBI (Tzadok et al., 2022).

The results obtained in the WCST revealed that they differed in the measures of the quantity of administered items, completed categories, total errors, and non-perseverative errors. The analysis indicated that the TBI group had the worst performance in all measures evaluated by the test. These data corroborate previously conducted studies with adults after TBI (Hang et al., 2011).

Performance of groups on the Hotel Task

The absence of ecological validity in numerous neuropsychological instruments, widely reported in the literature, contributed to the choice of using an ecological task in this research. The Hotel Task was chosen considering its complexity. It is a 15-minute task, that is longer than most tasks proposed in the neuropsychological assessment context. In addition, it presents 5 tasks that demand different cognitive domains and executive subcomponents (Cardoso et al., 2015).

The Hotel Task provides an assessment of planning. The three most relevant measures considered in the analysis of results were the number of tasks performed, the planning score (based on deviation from the ideal time), and the number of times the participant remembered to wake up the guests.

The groups differed significantly in the three measures mentioned above, indicating that the control group could perform the Hotel Task with better performance. The TBI group had an average of 3.35 (*SD* = 1.53) tasks performed out of five. It means that people after TBI were unable to organize themselves and administered the available time of 15 minutes to go through the five proposed activities. The prospective memory measure also differentiated the groups. Manly et al. (2002) found similar results when using the Hotel Task with the brain injury group. The mean number of hotel tasks performed was 4.10 (*SD* = 0.88) for the TBI group, while the mean in the NCG was 4.96 (*SD* = 0.20) tasks.

The discrepancy between Tower D-KEFS and Hotel Task results suggests the hypothesis that ecological tasks may be more sensitive to EF deficits, including planning. The literature shows that structured tasks, like most neuropsychological instruments, favor the performance of the participants, as they usually indicate the beginning and the end of the task and defined rules (Dawson et al., 2009). The demand for organization, planning, and self-regulation in real-life activities is hugely more complex than the demand for experimental tasks. The degree of structuring of tasks present in neuropsychological tests may mask the investigation of strategy skills (Gouveia et al., 2007).

As seen in the Hotel Task, the absence of commands to execute the task contributed to the deficit in time management, sequence of actions, and identifying when the activity requirement was satisfied, showing the commitment to planning after TBI.

Correlation between EF measures

The results indicated a significant correlation only between the semantic verbal fluency task and the Hotel Task, which can be explained by the ecological component present in the semantic fluency task, evident when the participant uses the subcategory strategy. The qualitative analysis of this task allows us to observe whether the examinee used the clustering strategy or not.

The lack of correlation between the other tasks corroborates other studies reported in the literature. Regarding the tower task and the WCST, Cockburn (1995) did not find a significant correlation between the Tower of London (total score) and the WCST perseverative errors. In a non-clinical population study, Souza et al. (2001) also found no significant correlation between the WCST and the Tower of London Test.

The absence of correlation between the Tower D-KEFS and the Hotel Task indicates that this assessment is dissociated despite both tasks evaluating the planning component. The tower task is considered more structured than the ecological task may justify this dissociation.

PCRS – Self Awareness Estimate

A comparison of the scores obtained by the patient's version and by the version of his informant indicated that patients had a higher total score. This result suggests that the group of people after TBI considered themselves less committed to activities of daily living, which involve executive, attentional and mnemonic components than their informants consider them. The difficulty of self-awareness of deficits after TBI is widely described in the literature (Ownsworth et al., 2019), and the results found in this study corroborate with these findings.

The moderate and significant correlation between the family member's version and the Hotel Task indicates that this version of the PCRS is sensitive to identifying EF impairment. As expected, the patient's version showed no correlation with any EF task confirming the presence of anosognosia in this population.

Conclusion

This study aimed to analyze and compare the performance of the clinical group (TBI) and the control group in EF tasks. Specifically, in the investigation of the planning component performed, it was observed that although the clinical group showed worse performance in planning tasks, the Tower D-KEFS were not statistically significant in this sample. On the other hand, the Hotel's ecological task results, which also investigates planning skills, showed a significant difference between the groups. These findings confirm the hypothesis that instruments with ecological validity may be more sensitive in the investigation of EF.

One of the limitations of this research was the heterogeneity of the sample. Unlike most studies found, any diagnosis of TBI was included in this sample. This choice was made due to the difficulty still present in most major medical centers in the country related to neuroimaging exams. Even with a report that guaranteed TBI diagnosis, many patients included in this research did not present specific data on the lesion.

The strength of this study is the use of an ecological task, which made it possible to compare the participants' performances in the execution of different modalities of neuropsychological tasks. The results of this comparison emphasize the need to use ecological tasks in the context of acquired

brain injury and provide an identification of the nature of the deficits. In the case of planning, the findings of the ecological task showed that the clinical group had significant difficulties in carrying out poorly structured planning tasks, that is, those that do not provide environmental feedback and therefore are considered close to everyday activities. Unfortunately, ecological tasks in research and clinic are still uncommon in Brazil. This lack may be related to the difficulties of elaboration, administration, and interpretation of these tasks, which are laborious, long, and more complex when compared to conventional neuropsychological instruments.

Finally, this study offers a clinical and experimental contribution to professionals who work and research the consequences of TBI, especially about the planning component, emphasizing the importance of using activities that simulate real-life situations of the participants. The results presented in this research can contribute to developing new rehabilitation approaches.

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