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landeira@puc-rio.br
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Fonseca, Rochele Paz; Zimmermann, Nicolle; Cotrena, Charles; Cardoso, Caroline; Haag Kristensen, Christian; Grassi-Oliveira, Rodrigo
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Neuropsychological assessment of executive functions in traumatic brain injury: hot and cold components

Rochele Paz Fonseca, Nicolle Zimmermann,Charles Cotrena, Caroline Cardoso, Christian Haag Kristensen, Rodrigo Grassi-Oliveira

Pontifícia Universidade Católica-RS, Porto Alegre, RS, Brazil

Abstract

This study aims to compare the decision making process between patients with traumatic brain injury (TBI) and healthy controls. In addition, it also aims to identify dissociations and the frequency of deficits in executive functions (EF) tasks, that mainly assess decision making (DM – hot component) and inhibition (cold component), following TBI. The sample was comprised of 16 post-TBI adults aged between 18 and 68 years and of 16 healthy controls, matched by age and education. They were assessed by means of Iowa Gambling Task (IGT) for DM evaluation, Trail Making Task (TMT) and Hayling Test for inhibitory control assessment. There were no differences between groups regarding the performance on IGT, total and block scores. However, TBI patients preferred the disadvantageous decks, without learning evidence along the task. Seven patients showed a dissociation between deficitary DM on IGT *versus* accurate inhibition on Hayling Test and on TMT. Conversely, five patients presented a partial dissociation with deficit on IGT and on TMT, with an opposite performance in Hayling Test. Only three cases had deficits in all instruments. In this way, after a TBI a patient can keep a comparable performance on IGT. Moreover, as dissociations among hot and cold executive components were found, when they are associated they can aggravate each other.

Keywords: neuropsychological tests, executive functions, decision making, inhibition, traumatic brain injury

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Introduction

Executive functions (EF) can be considered a complex umbrella process that include plenty of subcomponents (such as initiation, inhibition, cognitive flexibility, shifting, switching, planning, speed of processing, decision making, among others) that work together towards goals accomplishment (Chan, Shum, Toulopoulou & Chen, 2008; Verdejo-García & Bechara, 2010). In neuropsychology, EF have received great investment for its complexity and multifactorial features, although its nature and components that integrate this mental function are still non-consensual (Elliott, 2003; Tirapu-Ustárroz et al., 2008). In this context, some authors proposed that EF can be divided into "cold" and "hot" processes. Components that demand greater use of rationality and logic, such as reasoning, planning, among others, are considered "cold", and those ones that involve emotion, such as decision making (DM), are considered "hot" (Ardila, 2008; Brock, Rimm-Kaufman, Nathanson, & Grimm, 2009; Chan et al., 2008).

Rochele Paz Fonseca, Nicolle Zimmermann, Charles Cotrena, Caroline Cardoso, Christian Haag Kristensen and Rodrigo Grassi-Oliveira, Faculdade de Psicologia, Programa de Pós-Graduação em Psicologia (Cognição Humana), PUCRS. Correspondence regarding this article should be directed to: Rochele Paz Fonseca. Phone: 55 51 3320-3500 ramal 7742. Email: rochele.fonseca@gmail.com

Neuropsychological assessment in individuals with traumatic brain injury (TBI) is a common necessity in all levels of severity of this disorder, since cognitive deficits have a great prevalence in its acute and chronic phases (Fork et al., 2005; Zgaljardic & Temple, 2010). Initially, linguistic and mnemonic assessment can represent the major demand, since aphasic and amnesic symptoms are more prominent. However, return to work and daily demands can require more detailed assessment of attentional and EF that are essential for tasks accomplishment (Clune-Ryberg et al., 2011). The role of neuropsychological assessment and interventions in this population is challenging since it is influenced by emotional and psychiatric characteristics that are present sometimes before and/or after the injury (Taylor, Kreutzer, Demm& Meade, 2010). With such regards, assessing EF in its different facets is very relevant for rehabilitation purposes (Milders, Ietswaart, Crawford & Currie,2008). Notwithstanding, very little is known about hot and cold EF in this clinical population.

Among the EF, DM process has been studied in neurological patients, as in TBI, and also in psychiatric patients, as in substance abusers (Bechara & Damásio, 2002). DM has been considered a "hot" EF, involving emotional process (Bechara, Tranel, & Damásio, 1996; Chan et al., 2008; Happaney, Zelazo, &Stuss, 2004). Neuropsychological research has been investigating DM processing based on the somatic marker hypothesis

(Damásio, 1996). This theory proposes that when a person needs to make a decision, he/she faces somatic sensations (somatic markers) that occurs in advance to real consequences of possible different alternatives. Those implicit markers act as emotional biocatalysts of DM in which distinct alternatives are evaluated emotionally based on somatic sensations that guide adaptive DM (Damásio, 1996). Ventromedial prefrontal cortex and its limbic system connections are considered key structures to DM process (Bechara et al., 1996). The Iowa Gambling Task (IGT) (Bechara, Damásio, Damásio & Anderson, 1994; Bechara, 2007) is one of the most internationally valued instruments for measuring emotion-based DM (Bechara et al., 1997; Bowman, Evans & Turnbull, 2005).

Studies on DM in neurological populations have been accomplished. The IGT has been considered a sensitive paradigm to assess aspects of executive dysfunctions after a TBI (Bonatti, Zamarian, Wagner, Benke, Hollosi, Strubreither & Delazer, 2008; Hanten, Scheibel, Li & Oomer, 2006; Levine, Black & Cheung, 2005; MacPherson, Phillips, Sala & Cantagallo, 2009; Wiederkehr, Barat & Dehail, 2005).

Another executive component frequently impaired in TBI patients when compared to healthy controls is inhibition (Dimoska-Di Marco, Kelly, Tate & Johnstone, 2011; Felmingham, Baguley & Green, 2004; Perlstein, Larson, Dotson & Kelly, 2006; Larson, Kaufman, Schmalfuss & Perlstein, 2007). Inhibition is an important executive ability that allows the individual to suppress, interrupt to or delay a usual and automatic behavior on behalf of a more complex and controlled processing (Aron, Robbins, & Poldrack, 2004). Studies suggest that TBI patients can present impairment in this executive function (Rao & Lyketsos, 2000; Dimoska-Di Marco et al., 2011). In the literature, some neuropsychological tools are more recognized for assessing with accuracy inhibition, such as bipartite paradigms, since at the first section they usually require more automatic processes; while at the second part, a similar paradigm is used with some differences, requiring then more controlled processing. Trail Making Test (TMT) (AITB, 1944; Sánchez-Cibillo et al., 2009) and Hayling Test (Burgess & Shallice, 1996; Chan et al., 2008) are frequently administered for such purpose. In the study of Draper and Ponsford (2008), 60 TBI patients showed an impaired performance in Hayling Test when compared to controls. Periàñez et al. (2007) administered TMT to evaluate inhibitory control and they also observed a lower performance of TBI patients compared to healthy controls. Therefore, this set of evidence suggests these tests are useful to contribute to the diagnosis of inhibition impairments in TBI population.

Among the few studies that had investigated DM and cold EF components in TBI patients, findings had been suggested an impaired profile in both aspects (Levine et al., 2005; Bonatti et al., 2008; Sigurdardottir, 2010). Bonatti et al. (2008) assessed TBI acute patients and healthy controls by means of IGT, TMT and a Go-NoGo task, among other paradigms. Impairment in both inhibitory control and DM was found in TBI patients when compared to controls. Conversely, Levine et al. (2005) performed a study with 71 TBI patients that were assessed through IGT and TMT, with an impaired performance in both instruments. Although these studies have been conducted aiming to investigate DM and inhibition components, as far as we know, no investigations had been conducted up to date towards an assessment of DM and verbal and visuospatial inhibition, including for example a paradigm like Hayling Test.

Regarding this non-sufficiently explored relationship among hot and cold EF post-TBI, more specifically between predominant verbal and visual inhibition and DM, this study aimed to compare the performance in IGT between TBI patients and healthy controls. In addition, it also aimed to verify the frequency of inhibition and DM deficits, looking for dissociations among these EF components.

Methods

Participants

Eighteen adults (12 men and 4 women) with ages between 18 and 68 years who had suffered a closed TBI were recruited through outpatients records of hospitals from Porto Alegre, Rio Grande do Sul, Brazil. Participants were included in case they did not present moderate to severe aphasia, did not have less than two years of formal education, previous neurological or non-corrected sensorial disorders. All of them were Brazilian Portuguese native speakers. Two participants were excluded for not having completed the battery of assessment, leading to a final sample of n=16 TBI patients. Previous history or presence of psychiatric disorders were not excluded but instead characterized through clinical interview, as present or absent. Sociocultural, individual and clinical features of the clinical group can be viewed in Table 1. Neuropsychological assessment was performed after at least one month post-injury and time post-TBI varied from one to 50 months.

Control group consisted of sixteen non-brain damaged adults matched to each TBI case by age and education rates. By means of a t Test, groups did not differ from each other regarding age (p=0,370) or years of education (p=0,166). Those adults were recruited by convenience in workplaces and community centers. Inclusion criteria for the control group were absence of history of psychiatric or neurological disorders, of non-corrected sensorial deficits, of non-usage of anticonvulsive, antipsychotic and benzodiazepinic medication.

All information presented in Table 1 was obtained by means of self-report through a sociocultural and medical history questionnaire (Fonseca et al., 2012). More specifically, this questionnaire included questions about gender, age, education, socioeconomic status, frequency of reading and writing habits and handedness. The frequency of reading and writing habits was ranked from 0 (I never read) to 4 (I read everyday) for books,

Table 1. Demographic and clinical data of TBI and control groups

	Variables/Groups	TBI group		Control group	
		M	SD	M	SD
Demografic Data	Age	37.31	13.65	32.88	13.09
	Years of education	10.50	3.48	12.44	4.2
	Reading and writing habits	7.94	5.15	14.25	4.52
	Socioeconomic score	23.44	6.87	26.63	4.89
		Frequency			
		n (%)		n (%)	
	Sex				
	Male	12 (75.0)		9 (56.3)	
	Female	4 (25.0)		7 (43.8)	
	Handedness				
	Right	13 (81.3)		16 (100.0)	
	Left	3 (18.8)		–	
Clinical Data		M	SD	M	SD
	MMSE	24.3	3.82	28.87	1.36
		Frequency			
		n (%)		n (%)	
	Severity				
	Mild	6 (37.5)		–	
	Severe	10 (62.5)		–	
	Cause ofinjury				
	Motor vehicle	8 (50.0)		–	
	Fall	5 (31.25)		–	
	Sports	1 (6.25)		–	
	Others	1 (6.25)		–	
	Notspecified	1 (6.25)		–	
	Previous psychiatric disorders				
	Absence	9 (64.28)		0 (0.0)	
	Presence	5 (35.71)		0 (0.0)	

Note. MMSE = Mini Mental State Examination (Folstein, Folstein & McHugh, 1975, adapted for local population by Chaves & Izquierdo, 1992).

magazines, among others, with a total score of 16, and from 0 (I never write) to 4 (I write everyday) for letters, messages, among others, reaching a maximum of 12 points (Pawlowsky et al, 2012). In addition, handedness was verified by means of Edinburgh Inventory (adapted for local population by Fonseca et al., 2012), with a total score of 20.

Procedures and instruments

All participants were assessed in clinical setting in silent and ventilated rooms and they signed a consent form approved by the Ethical Committee of the university (Protocols 10/05143 and 1679-09). They were assessed in randomized two different orders through the following neuropsychological instruments:

Iowa Gambling Task (Bechara et al., 1994; Bechara, 2007). A computer-based IGT version adapted to southern Brazilian population by Schneider and Parente (2006) was used. Moreover, this version of IGT showed reliability evidence in a Brazilian sample (Cardoso et al., 2010). In this task, the examinee chooses cards from four decks (A, B, C and D) along 100 trials. Each card results either in gain or gain and loss of money. From the four decks, two are advantageous (C and D) and they result in money gain with a low money loss long the run. The other two decks (A and B) are disadvantageous in a way that they result in short term greater gains, but more frequent losses. The task emphasizes the learning of reward and punishment associations, being an international reference for DM assessment (Bechara et al., 1994; Schneider-Bakos, Denburg, Fonseca, & Parente, 2010). To sum up, the main dependent variables derived from IGT are total score or net score *(C + D) – (A + B)*; block score *(C + D) – (A + B) for each* *segment or block of 20 cards;* frequency of deck choices and category of spared or impaired performance according to a cut-off point of -10, established by Bechara, Tranel and Damasio (2000) especially for brain-damaged samples.

Trail Making Test (AIT, 1944 adapted and normalized by Fonseca et al., in preparation). The instrument is composed by two parts. In Part A, participants must connect numbers randomly distributed in an A4 sheet; in Part B, numbers and letters are to be alternately connected; they are also distributed in a random order in an A4 sheet. Number of correct answers and errors were considered, such that maximum of correct answer is 24 and of errors there is no maximum amount established. Time for execution of each parte and the relationship between time for parts B versus A are also analyzed. In this task, components of planning and speed processing related to visual, perceptual and motor skills (parts A and B), as well as inhibition and switching (part B) are assessed.

Hayling Test (Burgess & Shallice, 1996 adapted by Fonseca et al., 2010; normalized by Fonseca et al., in preparation). This task is composed by phrases in which the last word is missing. So participants must complete it with a word that fits properly in the sentence (Part A – completing normally) and with a non-related word (Part B). Time and accuracy (maximum of 15 for quantitative scoring; maximum of 45 for quantitative-qualitative errors score of Part B) were measured. Components of initiation (part A), verbal inhibition (part B), and speed processing (two parts and relationship between time for part B versus part A) are assessed.

Statistical analyses

All descvriptive and inferential analyses were carried out at the Statistical Package for the Social Sciences (SPSS 17.0). A normal distribution was observed in both groups by means of the Kolmogorov-Smirnov Test. Mean comparisons between TBI and control groups was conducted by means of an independent samples t Test for DM variables (total and block scores on IGT) as well as for inhibition variables (Hayling and Trail Making Tests' accuracy and time). In order to compare the performance in each block of IGT between groups along the five segments, a mixed-ANOVA was conducted. Finally, aiming to investigate possible dissociations between deficits occurrence in DM and other cold EF, the Z score was calculated for Hayling Test and Trail Making Test variables); in addition, participants were classified on IGT as having non-impaired or impaired DM abilities based on the cut-off scores established by Bechara, Tranel & Damasio (2000).

Results

There was no difference between TBI (M=-6.88; SD=11.95) and control groups (M=-3.50; SD=25.67) at the total score of IGT (p=0.638) at the t Test. It could be noted a high standard deviation in both groups, mainly in controls, what might reflect heterogeneity in the sample. Groups were also compared regarding their performance in each block of 20 cards, as observed in Table 2. In Figure 1, the learning curve of each group can be viewed.

Based on Table 2, there were no significant differences in the analysis of each block separately. In addition, data presented on Figure 1 show that there are no differences between groups regarding their performance along IGT blocks (mixed ANOVA; p=0.446). In Figure 2, there is the frequency of group preferences for each of the four decks (A, B, C or D). Such analysis assesses if the most risky decks (A and B) or advantageous decks (C and D) were chosen.

Figure 2 suggests that the TBI group chose more risky decks (A and B), while controls preferred more frequently cards from the blocks B and D. In this way, there was difference between groups in deck A (p<0.001), with TBI patients choosing this risky deck more frequently (t Test). Table 3 shows groups' performance in inhibition tasks.

Results presented in Table 3 suggest that groups differ in measures of processing speed related to the inhibitory process (Time Part B - time Part A of the Hayling Test), in a way that TBI patients were slower than controls. Besides that, the errors variable of TMT - Part B was significantly different between groups, with an inferior performance of TBI patients.

When analyzed together, results from the analysis of deficits through Z score in tasks of hot and cold EF demonstrated that seven patients presented dissociations in the performance of the IGT, showing deficits, and a normal performance on TMT and Hayling Test. At the same time, five cases presented a deficitary performance in IGT and in TMT, followed by a normal performance in Hayling Test. As far as the greater frequency of patients with an impaired DM could be associated to the greater frequency of severe TBI patients in the clinical group, an additional analysis was conducted: no differences between subgroups of mild and severe TBI patients were found regarding the frequency of deficit

Table 2. Performance of each group in IGT blocks

		M (SD)	t	p value
Block1	TBI	-3.63 (5.62)	-0.227	0.82
	Controls	-3.13 (6.81)		
Block 2	TBI	0.38 (6.24)	-0.056	0.95
	Controls	0.50 (6.42)		
Block 3	TBI	-0.50 (3.05)	-0.640	0.53
	Controls	1.13 (9.68)		
Block4	TBI	0.00 (3.09)	0.984	0.33
	Controls	-2.88 (11.26)		
Block5	TBI	-1.13 (3.79)	-0.863	0.39
	Controls	0.88 (8.45)		

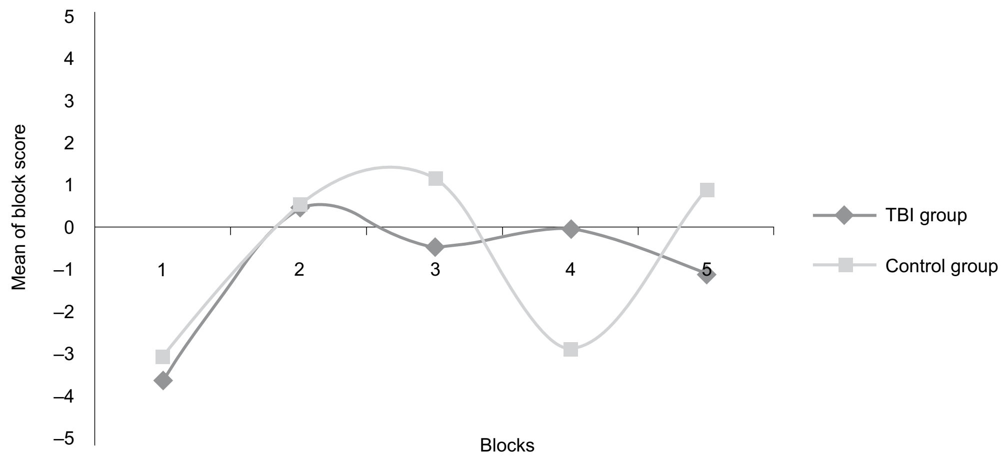

Figure 1. Group performance along blocks.

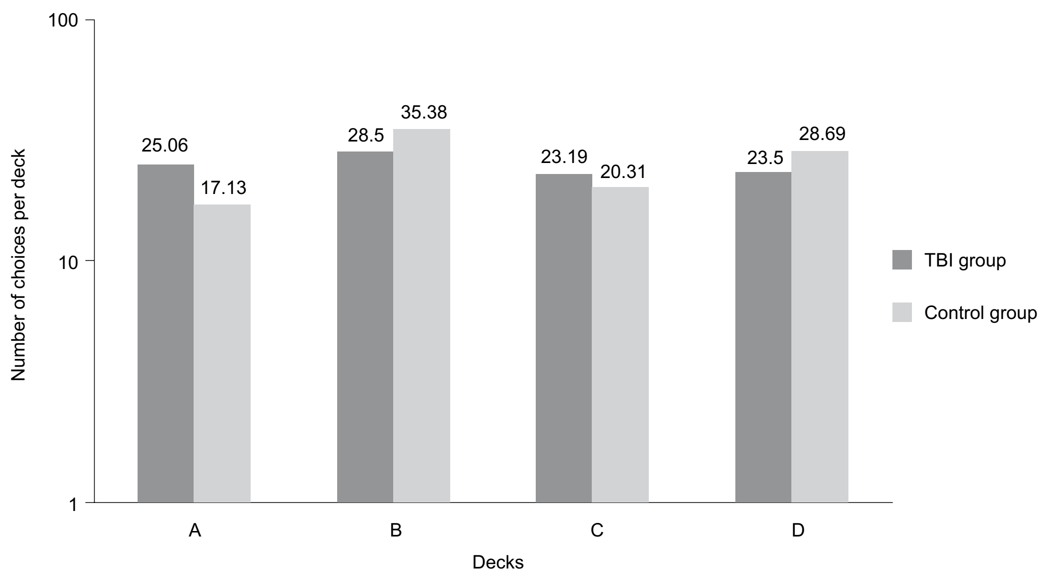

Figure 2. Group preferences for each of the four IGT decks.

in IGT, or in Hayling Test or in TMT (Fisher's Exact Test, p>0.05). Severe TBI patients presented 50% more deficits in all neuropsychological tests compared to the milder group.

Discussion

Findings from this study suggested that TBI patients' global performance on the IGT, as a group, did not differ from DM processing in healthy controls. Even though there was no difference in the block score either, a greater peak of learning could be observed at healthy controls. In spite of the fact that control group changed its performance in block 4, these participants may have preferred more risky cards looking for gaining more money in this segment, as well as for checking the hypothesis of the advantageous and disadvantageous decks. When it comes to the TBI group, it was not possible to observe a learning curve through the task, but a constant curve from block two to five. Conversely, in another study, healthy individuals initiated selection of advantageous decks from 30 cards on, while clinical samples generally showed an inability to choose advantageous decks (Dunn, Dalgleish & Lawrence, 2006). In this way, in our study, TBI patients preferred disadvantageous decks (A and B), followed by a significant difference between groups in deck A.

When interpreted together, these findings suggest that in spite of nonsignificant differences between groups in the total score, TBI patients presented a more risk taking behavior. A study of Van Noordt & Good (2011) did not find differences between controls and mild TBI patients for self-report. However, injury severity was inversely related to DM performance, such that as injury status increased, quality of this EF processing decreased. Authors pointed out the great heterogeneity of cognitive deficits post-mild TBI. In this context, such findings can partly explain results of the present study regarding the absence of significant differences between groups in the total and block scores. Nevertheless, we highlight the preference of the TBI group for the disadvantageous

Table 3. Performance of groups in TMT and in Hayling Test

	Tasksvariables	Groups	M	SD	F	p
Hayling Test	Time B/time A	TBI	4.42	4.08	3.120	0.099
		Controls	2.64	0.93		
	Qualitative Errors Part B (/45)	TBI	19.00	10.18	0.249	0.054
		Controls	12.19	8.98		
	Correct answers Part A (/15)	TBI	14.69	0.60	0.789	0.741
		Controls	14.75	0.45		
	Errors Part A (/15)	TBI	0.31	0.60	2.248	0.495
		Controls	0.19	0.40		
	Correct answers Part B (/15)	TBI	7.44	3.18	0.011	0.088
		Controls	9.60	3.64		
	Errors Part B (/15)	TBI	7.88	3.05	0.158	0.067
		Controls	5.63	3.63		
	Time Part B - time Part A	TBI	61.93	52.16	6.531	0.018
		Controls	26.22	17.98		
TrailMaking Test	Errors Part A	TBI	0.13	0.34	1.454	0.559
		Controls	0.06	0.25		
	Correct answers Part B (/24)	TBI	22.69	3.11	15.026	0.112
		Controls	24.00	0.00		
	Time Part B - time Part A / time Part A	TBI	2.00	1.66	0.813	0.457
		Controls	1.56	1.50		
	Time Part B/time Part A	TBI	3.26	1.66	1.843	0.218
		Controls	2.56	1.50		
	Errors Part B	TBI	3.63	4.43	19.980	0.017
		Controls	0.63	0.81		

deck A, what might be associated to the prevalence of 62.5% of severe TBI in the sample.

In general, our findings are corroborated by other investigations that evaluated DM in TBI patients through the IGT and they also showed an impaired performance when compared to controls (García-Molina et al., 2007). Among those studies, TBI patients failed to learn through the five blocks of the IGT. This data characterizes a failure in the DM processing based on the somatic marker hypothesis assessed through the task (Bonatti et al., 2008; Sigurdardottir et al., 2010). It could also be observed in Figure 1, in which TBI group did not present a typical learning, even though there was no significant differences in the mixed ANOVA, maybe due to sample size by group. Except for one TBI patient, other patients were impaired in the task, this finding is in agreement with previous research (Levine et al., 2005; Sigurdardottir et al., 2010). We hypothesize that there might be a tendency of differentiation of groups depending on the severity of trauma and of sample size.

Among the studies that controlled lesion site in TBI, performance seemed to be influenced by lesions that affected neural circuitary involved in DM process. However, contradictorily, recent investigations pointed out that lesions that not prefrontal ventromedial (Fujiwaraet al., 2008; MacPhersonet al., 2009) orfrontal(Levine et al., 2005) present an impaired performance in the instrument. In this context, our sample was composed by four patients with lesion exclusive to the frontal lobes and another areas, four patients with exclusive lesions in the frontal lobe, four patients with damages in other brain areas and four with no diagnosed brain damage. Therefore, even though it was not a direct aim of this study, our findings suggested that even with a reduced sample of 16 patients in comparison to the healthy controls group, there was a tendency of deficits in the TBI group independently of the lesion site. Those studies suggest perhaps that our results might not be specifically related to frontal damages described in the literature.

Dissociation of deficits analysis has important contributions for theoretical and clinical fields. The first dissociation (patients with an impaired performance in IGT and normal performance in TMT and Hayling Test) might be explained in terms of hot and cold distinct components of the EF, while the dissociation between thw two inhibition assessment tasks could be explained through a dissociation of verbal and non-verbal inhibitory abilities, requiring different demands on the executive system. Three cases presented deficits in all tasks showing impaired hot and cold EF. This could be explained according to previous studies that had shown association of deficits of DM and inhibitory control assessed by both IGT and TMT (Bonatti et al., 2008; Levine et al., 2005) and general studies with inhibitory control with verbal and non-verbal input assessed by Hayling test (Draper &Ponsford, 2008) and TMT

(Periàñezet et al., 2008) respectively. Only one mild TBI patient did not present deficits in any task. In this case, we emphasize the heterogeneity of the mild TBI neuropsychological deficits (37, 5% of our sample). In general, our results are in compass with general studies that showed distinct impairments of EF in TBI patients (Dimoska-Di Marco, Kelly, Tate & Johnstone, 2011; Felmingham, Baguley & Green, 2004; Perlstein, Larson, Dotson & Kelly, 2006; Larson, Kaufman, Schmalfuss & Perlstein, 2007).

Besides the known heterogeneity of TBI population, another limitation of this study may be taken into account. Five patients had a previous history of psychiatric disorder, not specified by the general self-report questionannaire. Even though, plenty of studies have been showing that psychiatric disorders pre-TBI are prevalent (for example, Whelan-Goodinson, Ponsford, Johnston & Grant, 2009), in studies with larger samples this factor should be more controlled or further investigated.

This preliminary comparative study between TBI and control groups can contribute to a better understanding of the relationship among different hot and cold EF after this neurological disorder. In this context, our findings contribute to the notion that hot and cold EF can be in some cases associated or dissociated in TBI patients. This is possibly due to the marked heterogeneity of this sample. Interpretation of these initial findings should take into account some caveats of this study, such as small sample size and heterogeneity of the clinical sample. For future studies, we suggest cluster or comparative analysis including stratified samples of TBI patients regarding lesion site, severity, psychiatric profile, medication use and measures of functionality. With a greater sample size, regression analysis could be also conducted followed by the traditional and relevant neuropsychological analysis of deficits frequency, as far as the comprehension of cognitive dissociations is one of the main targets of clinical and cognitive neuropsychology.

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