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Executive Functions in Relation to Impulsivity Following Traumatic Brain Injury

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Impulsivity is a common and debilitating sequela following traumatic brain injury (TBI) and should be assessed during the rehabilitation process. It is now accepted that impulsivity is a multidimensional construct and such a distinction may help in understanding the mechanisms underlying impulsivity and facilitate assessment. The goal of this study is to examine the link between impulsive behaviors and their underlying mechanisms in a TBI sample. Twenty-five TBI patients and twenty-four matched controls were administered performance tasks measuring prepotent response inhibition, resistance to proactive interference, and decision-making. Group comparisons show weaker performance on measures of inhibition and decision-making by the TBI participants. Finally, performance on the Modified Six Elements Task was associated with impulsive behaviors in everyday life as observed by treating clinicians. This study sheds light on the associations between executive functions and impulsivity in an acute rehabilitation setting.

Keywords: traumatic brain injury, impulsivity, inhibition, decision-making, performance task

L'impulsivité est une séquelle fréquente et handicapante qui mérite une évaluation suite à un traumatisme cranio-cérébral (TCC). Il est maintenant reconnu que l'impulsivité est un construit multidimensionnel, ce qui facilite la compréhension de ses mécanismes sous-jacents et son évaluation. L'objectif de cette étude est d'observer les liens entre les comportements impulsifs et les mécanismes sous-jacents auprès de personnes ayant subi un TCC en réadaptation. Vingt-cinq participants TCC et vingt-quatre participants contrôles appariés ont complété des tâches visant à évaluer l'inhibition de la réponse prédominante, la résistance à l'interférence proactive et la prise de décision. Des comparaisons de groupes indiquent une performance moindre chez les TCC aux tâches d'inhibition et de prise de décision. La performance au *Modified Six Elements Task* est associée aux comportements impulsifs dans la vie quotidienne tels qu'observés par les cliniciens. Cette étude permet d'éclairer les liens entre l'impulsivité et les fonctions exécutives dans un contexte de réadaptation aigüe.

Mots clés : traumatisme cranio-cérébral, impulsivité, inhibition, prise de décision, tâche de performance

Impulsivity is a common and debilitating sequela following traumatic brain injury (TBI) which has important consequences on the patients' rehabilitation process, social reintegration, and safety (Votruba et al., 2008). Indeed, impulsive post-TBI patients are more likely to display aggressive (Greve et al., 2001) or socially inappropriate (McDonald, Flanagan, Rollins, & Kinch, 2003) behaviors. They are also more at risk of accidents (Rapport, Hanks, Millis, & Deshpande, 1998). It is therefore generally accepted that the presence and the magnitude of impulsivity deserve to be assessed during the rehabilitation process.

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Three different methods can be used to assess impulsivity: questionnaires, performance tasks, and rating scales. Questionnaires allow a subjective assessment of impulsivity in multiple situations but are vulnerable to recall biases. Performance tasks are generally more objective and allow to measure the underlying mechanisms of impulsivity. However, they generally lack specificity and ecological validity since they rarely take into account the unpredictability of everyday life (Cyders & Coskunpinar, 2011). Finally, rating scales are ecologically valid since they are based on observations of actual behaviors but are costly and impossible to adapt to a diversity of situations.

In TBI patients, additional shortcomings can be noted for the methods described. Studies have demonstrated that these patients are often not aware of their difficulties (Bechara & Van der Linden, 2005) and consequently, impulsive behaviors can be underreported in questionnaires. As for informantrated questionnaires, they must be completed by someone close enough to be able to observe the patient's impulsivity, which can be a challenge in an inpatient rehabilitation setting. As for performance tasks, as mentioned earlier, they allow the assessment of underlying mechanisms. However, as of yet, those have not been identified in the TBI population.

The goal of the current study is to measure different executive functions in a post-TBI sample using performance tasks and see how these are related to impulsive behaviors. In other words, this study aims to test some underlying mechanisms in relation to impulsivity based on a theoretical model.

Votruba et al.'s (2008) study assessed impulsivity using a multi-modal approach and compared these measures with *in vivo* observations, allowing for an ecological evaluation of impulsivity and different measures. Their findings identified the Trail-Making Test as a sensitive, but not specific, measure to motor impulsivity. However, the authors chose the performance tasks on the basis of frequency; consequently, no model of impulsivity was used in the selection of the measures administered to the participants. We wonder if the selection of measures based on a theoretical orientation and underlying mechanisms could strengthen the links between different means of assessment of impulsivity.

When it comes to a theoretical rationale, a review of the current post-TBI impulsivity literature (Kocka & Gagnon, 2014) showed that definitions vary significantly from one study to another: some definitions are narrow (e.g., choosing smaller immediate gratification instead of larger delayed reinforcers, which is an observable behavioral aspect of impulsivity) and some are broader (encompassing a multitude of dimensions and behaviors). In the current study, impulsivity is considered to be a multi-dimensional construct. Such a conceptualization has gained a significant amount of support in the current literature. Indeed, it is now generally accepted that impulsivity is a multifaceted construct and such a distinction may help in understanding their underlying mechanisms and specific dimensions.

Observing that patients with different lesions (i.e., damage to different areas of the frontal lobe) had different neuropsychological difficulties, Bechara and Van der Linden (2005) identified three different underlying mechanisms that come into play in decision-making and impulse control. The first mechanism, prepotent response inhibition, refers to the ability to voluntarily suppress the dominant response and appears to be linked to the more posterior area of the ventromedial prefrontal cortex. The second mechanism is resistance to proactive interference and it refers to the ability to resist the intrusion of information that is no longer relevant in the working memory. This mechanism seems to be linked to the lateral orbitofrontal and dorsolateral regions of the prefrontal cortex. The third mechanism is decision-making and it refers to the ability to make a choice after considering the consequences of that choice. This mechanism appears to be linked to the ventromedial prefrontal cortex. Each mechanism can be tested with different performance tasks, and the authors suggested links between them and the urgency, perseverance, and premeditation dimensions of the UPPS model, respectively.

The UPPS model (Whiteside & Lynam, 2001) is gaining a significant amount of support in the literature on impulsivity and is slowly making its way into the post-TBI literature as well. According to this model, there are four distinct dimensions to impulsivity: urgency, lack of perseverance, lack of premeditation, and sensation-seeking. Urgency refers to the tendency to engage in impulsive behaviors in emotional circumstances. Perseverance refers to the tendency to remain focused and the ability to complete a task that may be considered boring or difficult. Premeditation refers to the tendency to think and reflect on the consequences of an action before carrying it out. Sensation-seeking refers to an openness to trying new things that may (or may not) be dangerous and to the tendency to enjoy activities that are exciting. Smith, Cyders, Annus, Spillane, and McCarthy (2007) supported the validity and utility of using these four dimensions and demonstrated that they can not only be distinguished but can also help clarify different aspects of risky behaviors. Whiteside, Lynam, Miller, and Reynolds (2005) also demonstrated the validity of this model by showing that it could differentiate clinical groups (individuals with borderline personality disorders, pathological gamblers, and individuals with alcohol abuse problems) from controls with urgency being the most strongly associated with psychopathology. As for individuals who have suffered a TBI, Rochat, Beni, Annoni, Vuadens, and Van der Linden (2010) not only showed that the multifaceted nature of impulsivity also applies to this population, but also showed an increase in urgency, a lack of perseverance, and a lack of premeditation post-TBI.

Different authors tested and supported Bechara and Van der Linden's (2005) hypotheses amongst non-clinical populations. Indeed, urgency has been linked to prepotent response inhibition as measured by a Go/No-Go (GNG) task in which the participant must withhold a dominant response (Gay, Rochat, Billieux, d'Acremont, & Van der Linden, 2008). Lack of perseverance has been linked to task unrelated thoughts and proactive interference errors as measured by a modified GNG task aiming to generate task unrelated thoughts (i.e., a slower paced version of the GNG) and a Recent Negatives Task (Gay et al., 2008). Lack of premeditation has been linked to disadvantageous choices on the Iowa Gambling Task among college students (Zermatten, Van der Linden, d'Acremont, Jermann, & Bechara, 2005). The latter is a decision-making task in an ambiguous situation in which the participant is expected to learn which decks are more advantageous. However, other authors demonstrated different links between the UPPS dimensions and these mechanisms. Indeed, Billieux, Gay, Rochat, and Van der Linden (2010) showed an indirect relationship between prepotent response inhibition and urgency. More precisely, this study showed that a difficulty in inhibiting prepotent responses is linked to more disadvantageous choices which in turn is linked to urgency and problematic behaviors. Finally, a meta-analysis conducted by Cyders and Coskunpinar (2011), using the UPPS model and other models of impulsivity, showed that negative urgency, lack of perseverance, and lack of planning are all three related to prepotent response inhibition and that sensation-seeking is linked to delay in response.

As mentioned earlier, few authors have studied the link between impulsivity and these underlying mechanisms as measured by performance tasks amongst a TBI sample. This is surprising, considering that post-TBI impulsivity, as mentioned earlier, is associated with deleterious outcomes, that TBIs are often associated with frontal lesions (McDonald, Hunt, Henry, Dimoska, & Bornhofen, 2010; Meythaler, Peduzzi, Eleftheriou, & Novack, 2001), and that executive functions are mostly supported by the frontal lobe. Furthermore, deficits in inhibition (Picton et al., 2007), planning (Fortin, Godbout, & Braun, 2003), and flexibility (Johnstone, Leach, Hickey, Frank, & Rupright, 1995) have been associated with TBI and all of these can possibly be linked to impulsivity. Similarly, studies have shown that patients with TBI present prepotent response inhibition impairments (Dimoska-Di Marco, McDonald, Kelly, Tate, & Johnstone, 2011; Gagnon, Bouchard, Rainville, Lecours, & St-Amand, 2006; Rochat, Beni, Annoni, Vuadens, & Van der Linden, 2013), proactive interference difficulties (Rochat et al., 2013), and weakened decision-making (Bonatti et al., 2008). Therefore, we believe that there is a gap in the literature as to the study of the link between these underlying mechanisms and post-TBI impulsivity.

In the present study, we aim to compare post-acute TBI survivors to controls on measures of prepotent response inhibition, resistance to proactive interference, and decision-making. We believe that the TBI participants will show weaker performances on inhibition and decision-making tasks (the GNG task, the Stop-Signal Task, the Iowa Gambling Task, the Nelson Task, the Modified Six Elements Task, the Trail-Making Test, and the Hayling Test) than the matched controls. Furthermore, we believe that these differences will not only be attributable to general cognitive impairment (as measured by the digit span). We will also examine the relations between performance tasks with impulsive behaviors in everyday life in an acute rehabilitation setting as reported by the patients' clinicians and nurses for the TBI survivors in our study. We expect that performance on the tasks will serve as a predictor of the frequency of impulsive behaviors in everyday life in the rehabilitation setting for the TBI participants. Indeed, we believe that if a person has difficulties with inhibition and decision-making skills, they will be reflected in their behaviors in everyday life, thus resulting in an increased frequency of observed impulsive behaviors.

Method

Participants

For the present study, 25 participants (16 males, 9 females; 16 French-speaking, 6 English-speaking, 1 Spanish-speaking, and 2 who have another primary language; 22 Caucasian, 2 African-American, and 1 of Asian descent) who had sustained a TBI were recruited from two rehabilitation centres in the greater Montreal area (Quebec, Canada). All participants were undergoing an intensive rehabilitation program. Table 1 shows sociodemographic information and lesion characteristics for the sample. Participants with Glasgow Coma Scale scores ranging from 13 to 15 had sustained brain injuries severe enough to require inpatient stay and rehabilitation. It should also be noted that injury severity was determined by the patients' physician. Patients were recruited based on the following inclusion criteria: 1) has suffered a traumatic brain injury; 2) at least three weeks post-TBI to ensure a stable medical condition; 3) the TBI occurred after the age of 16; 4) an ability to comprehend and to adhere to instructions; 5) in an acute phase of recovery; 6) undergoing an intensive rehabilitation program; 7) aged between 18 and 80 years. Exclusion criteria included: 1) a lack of functional English or French; 2) a diagnosis of aphasia or agnosia; 3) a diagnosis of hemineglect.

The control group of 24 participants was recruited from the community to match the TBI participants on gender, age, and education. Exclusion criteria included: 1) a history of TBI; 2) a lack of functional English or French.

Table 1

Sociodemographic Information and Injury Characteristics of Participants

ID	Age	Gender	Years of education	Time post injury (days)	Injury severity	GCS	Cause	Injury location
1	31	Male	12	60	Severe	7	MVA	L sylvian SAH, L temporal edema, diffuse cerebral edema, L fronto-temporal + periorbital contusions
2	22	Female	13	73	Severe	6	MVA	Interpeduncular fossa SAH, IVH, R frontal + temporal contusions, DAI
3	23	Male	18	71	Mild complex	14	MVP	L+R temporal contusions, subfalcine SDH
4	22	Male	6	82	Moderate	9	MVA	L sylvian SAH
5	27	Male	18	81	Moderate	15	Fall	R+L SDH, L EDH
6	69	Female	16	109	Mild complex	15	MVA	L parieto-occipital SDH
7	47	Female	16	29	Moderate	14	MVA	R frontal SAH, L fronto-parietal-temporal SAH
8	58	Male	11	86	Moderate	14	Assault	L+R frontal SDH, L+R frontal hygromas, skull fracture
9	75	Male	16	107	Moderate	15	Fall	L SDH, L+R parietal SAH, diffuse cerebral edema
10	28	Male	18	134	Severe	5	MVA	L+R frontal contusions, DAI
11	18	Male	11	25	Severe	5	MVP	R EDH, R SDH, multiple skull fractures
12	34	Male	16	102	Severe	3	Fall	R SDH, R+L SAH, L temporal skull fracture
13	60	Male	11	49	Moderate	7	MVA	R parietal SAH, R temporal contusions, R+L frontal hygromas, DAI
14	55	Male	11	149	Severe	10	MVA	R parietal SAH, R basal ganglia stroke
15	39	Male	18	59	Mild complex	14	Fall	R temporal contusion, L parietal skull fracture
16	62	Female	12	35	Moderate	14	MVP	R fronto-temporal SAH, interpeduncular fossa SAH, R+L frontal contusions, R temporal contusions, R fronto-temporal SDH, L frontal SDH, interhemispheric cerebral edema
17	35	Female	13	213	Severe	7	MVC	L SDH, L EDH, L temporal contusions, L+R SAH, R temporal skull fracture, brainstem haemorrhage
18	76	Male	16	73	Moderate	13	Fall	R frontal SAH, R frontal contusions
19	68	Female	16	42	Mild complex	14	Fall	L occipital SAH, R frontal IPH, R frontal+ temporal contusions, small contusions on R+L frontal lobes and R temporal lobe, R SDH, R sylvian SAH
20	57	Female	11	85	Severe	5	MVC	Bilateral SDH, Bilateral SAH
21	68	Male	16	100	Moderate	9	Fall	L frontal SDH, L + R SAH, R frontal contusions
22	78	Male	6	103	Mild complex	n/a	Fall	SDH, R+L frontal hygromas
23	51	Female	9	45	Mild complex	10	Explosion	R+L SDH, contusion on L frontal lobe, frontal SAH

ID	Age	Gender	Years of education	Time post injury (days)	Injury severity	GCS	Cause	Injury location
24	62	Male	12	46	Moderate	15	Fall	R+L fronto-temporal SDH, R+L fronto-temporal SAH, multiple contusions
25	79	Male	9	80	Moderate	13	Fall	R+L frontal SAH, R frontal SDH, R+L frontal contusions, L temporal contusions

Note. GCS = Glasgow Coma Scale; MVA = motor vehicle accident; MVP = motor vehicle versus pedestrian; MVC = motor vehicle versus cyclist; L = left; R = right; SDH = subdural haemorrhage; SAH = subarachnoid haemorrhage; EDH = epidural haemorrhage; IPH = intraparenchymal haemorrhage; IVH = intraventricular haemorrhage; DAI = diffuse axonal injury.

Measures

Performance tasks. Performance tasks for the present study were selected based on a theoretical rationale. Indeed, the following tasks were used as a measure of one or the other underlying mechanisms to the urgency, perseverance, and premeditation dimensions as suggested by Bechara and Van der Linden (2005). Exceptionally, the digit span task described below was added as a general measure of cognitive impairment. Indeed, this task implies no inhibition and was simply added to make sure that the TBI group did not differ from the control group on measures that are not related to the underlying mechanisms of interest (i.e., general impairment).

It should be noted that, when possible (i.e., for the GNG and stop signal tasks), coefficients of variation (CoV; Duchek et al., 2009) were obtained for each participant by dividing the standard deviation by the reaction time (RT) for each go trial (*SD*/*M*). This allowed us to obtain a measure of intra-individual variability and is considered to be a measure of general cognitive performance related to sustained attention. Indeed, conducting such an analysis allows to determine if fatigue may explain some of the results.

Go/No-Go. The GNG (Robertson, Manly, Andrade, Baddeley, & Yiend, 1997) is a computer task that requires dominant response inhibition. In this task, the participant must respond to one type of stimulus and withhold the response when a rare stimulus appears on the screen. To ensure that the persons who have sustained TBI have sufficient delays to perform this task successfully, a 500 ms inter-stimulus delay was fixed. Mean RTs on successful Go trials and the number of omission and commission errors were measured for the present study.

Emotional Stop-Signal Task. The Stop-Signal Task (SST; Verbruggen & De Houwer, 2007) is a classic response inhibition paradigm. Like the GNG, the SST is a computer task that requires dominant response inhibition. However, in this task the participant has to classify two different types of stimuli (left or right arrows) and must withhold a response whenever a stop signal (a sound) is presented. Therefore, the participant is required to retract a selective response (Rubia et al., 2001). In this study, we used a modified version of the SST to include emotional stimuli. This also allows to see if the patient's performance is altered in the presence of a more aversive emotional stimulus (e.g., anger). Therefore, each trial was preceded by a fixation cross, followed by a picture of a face which showed either a neutral or an angry emotion, and by the cue ''<<'' or ''>>''. In 25% of the trials, the cue was followed by a tone. Participants were asked to determine if the arrows were pointing left (<<) by pressing the *C* key on the keyboard or right (>>) by pressing the *V* key on the keyboard and to withhold their response in trials in which a tone followed the cue. A tracking procedure was used: stop-signal delays (SSDs; i.e., the delay after which the tone is emitted following the cue) began at 250 ms and varied depending on the performance of each subject. More precisely, a successful inhibition is associated with an increase of 50 ms on the next stop trial and an unsuccessful inhibition is associated with a 50 ms decrease. Also, the emotional stimuli were counterbalanced between participants.

Stop-signal reaction times (SSRTs) were measured and used for the analyses in this study. To estimate the SSRTs, we used the integration method because it has been demonstrated as more precise and less susceptible to show between-group differences where there are none. With this method, SSRTs are estimated by taking into account the RT distribution and the probability of responding in stop trials instead of assuming that the SSRT corresponds to the subtraction of the mean stop-signal delay from the mean RT as it is the case with the mean method (for a thorough explanation, refer to Verbruggen, Chambers, & Logan, 2013). We also estimated the SSRTs for each block separately as recommended by Verbuggen et al. (2013) in order to reduce the risk of underestimation due to strategic slowing. Similarly, we excluded the trials in which participants slowed their response by more than three standard deviations than the mean of the previous trials.

Hayling Test. The Hayling Test (Burgess & Shallice, 1997) is a task of response generation and response suppression, or salient verbal response inhibition. The participant is asked to complete fifteen sentences with the word that is expected and then to complete fifteen different sentences with a word that does not make sense and, consequently, to suppress the dominant word. In the second condition, penalties are given whenever the participant completes the sentence without inhibiting the salient response. The Hayling Test calls for dominant response inhibition. Penalty scores (number of penalties) were used in this study.

Nelson Task. The Nelson Task (Nelson, Reuter-Lorenz, Sylvester, Jonides, & Smith, 2003) is a recent-probes task and calls for the inhibition of proactive interferences in working memory. In this task, a fixation point is presented for 500 ms, followed by a 1500 ms blank, a 500 ms presentation of four lowercase letters followed by a 3 seconds blank before an uppercase letter is presented in the middle of the screen. The participant is asked to determine whether the probe (uppercase letter) was among the lowercase letters presented in the block of stimuli associated to that trial by pressing on either the *C* (positive) or *V* (negative) keys on the keyboard. There are 96 positive trials and 96 negative trials. The negative trials can be divided into four categories: *Unfamiliar*, in which the probe was neither the stimulus nor the probe in the two previous trials; *Familiar*, in which the probe was a stimulus in the previous trial, but not the one before; *Highly Familiar*, in which the probe was a stimulus in both previous trials; and *Response Conflict* in which the probe was a positive probe in the previous trial. To successfully complete the task, the patient must therefore inhibit the proactive interferences of the previous trials. It is expected that the higher the familiarity, the harder it will be to inhibit. Reaction times for the different conditions were assessed for this study.

Iowa Gambling Task. The Iowa Gambling Task (IGT; Bechara, Damasio, Damasio, & Anderson, 1994) is a computer task in which the patient is placed in an ambiguous situation where he/she is asked to select cards from four different decks. Two of those decks offer big pay-offs but even bigger losses. The two other decks offer small pay-offs with smaller losses. Therefore, the strategy to adopt is to opt for small, yet constant gains. There are 100 trials in this task and strategic patients are expected to choose the deck somewhat randomly in the first trials and to choose the decks that offer smaller pay-offs (and smaller losses) in the latter trials. The IGT is a task that requires decision-making. The number of times the participant chose an advantageous deck minus the number of times the participant chose a disadvantageous deck was used for the analyses. This measure, however, only takes into account the last 40 trials in order to allow participants to have enough time to understand which decks are better than others.

Modified Six Elements Task. The Modified Six Elements Task (SET) is part of the Behavioral Assessment of Dysexecutive Syndrome battery (Wilson, Evans, Alderman, Burgess, & Emslie, 1997). It aims to assess planning and decision-making (Norris & Tate, 2000). In this task, the participant is asked to organize his/her work in order to do at least part of all six subtasks (two arithmetic tasks, two image recognition tasks, and two story-telling tasks) within a ten-minute time frame without doing two subtasks of the same category one after the other. A total profile score is calculated by considering the number of attempted subtasks and the number of broken rules. Points are also deducted if the participant spends more than nine minutes and thirty-one seconds on a single subtask. Therefore, a higher total profile score indicates a better performance. This task calls for planning and decision-making. The total profile score was used for the analyses in this study.

Delis-Kaplan Executive Function Systems Trail-Making Test. The Delis-Kaplan Executive Function Systems Trail-Making Test (DKEFS TMT; Delis, Kaplan, & Kramer, 2001a) is a modified version of Partington's Trail-Making Test (Brown & Partington, 1942). It is a visual-motor sequencing task measuring flexibility of thinking, and it also gives information about impulsivity in a non-verbal task (Swanson, 2005). The DKEFS TMT is composed of five conditions: visual scanning, number sequencing, letter sequencing, number-letter switching, and motor speed. The number-letter switching condition is the one that assesses flexibility of thinking, and the other four conditions allow a better understanding of the results obtained.

Scaled scores are obtained for each condition of the DKEFS TMT based on a normative sample. This test has a good internal consistency and validity (Delis, Kaplan, & Kramer, 2001b). In this study, we used this task as a measure of cognitive flexibility since it was the only measure associated with impulsivity in Votruba's study (Votruba et al., 2008). Scaled scores for the different conditions were used in the analyses below.

Digit Span. This test is part of the Weschler Adult Intelligence Scale, third edition (WAIS-III; Wechsler, 1997) and is a measure of working memory. There are two conditions to this test: the forward and the backward digit span. In the forward condition, the participant is asked to repeat the numbers in the same order as the examiner. In the backward condition, the participant is asked to repeat the numbers backwards. A score is obtained for each condition: the longer the sequence, the higher the score is. In the current study, the Digit Span was administered as a general measure of working memory capacity and not as a measure of impulsivity per se. In this sense, the Digit Span was used as a control measure of general cognitive impairment. The score obtained in each condition (forward and backward) was used in this study.

Questionnaire.

Hospital Anxiety and Depression Scale. The Hospital Anxiety and Depression Scale (HADS; Zigmond & Snaith, 1983) is a 14-item self-report scale used to assess states of anxiety and depression among a medical population which has been validated among TBI survivors (Whelan-Goodinson, Ponsford, & Schönberger, 2009). In the present study, we included this questionnaire in order to ensure that the results obtained are not solely attributable to emotional distress.

Observation Scale.

Impulsive Behavior Rating Scale. In the current study, we used Gagnon and Henry's (2013) French adaptation of the rating scale used by Votruba et al. (2008). The scale, composed of extensive definitions followed by examples for each category of impulsive behaviors, was submitted to several validation studies among clinicians working with TBI participants (Gauthier-Mongeon & Gagnon, 2012; Gauthier-Mongeon & Gagnon, 2011; Gagnon, 2011). A professional, usually a nurse, working closely with the patient was asked to determine retrospectively the frequency (i.e., *never*, *monthly*, *weekly,* or *daily*) of ten types of impulsive acts (e.g., *dangerous, aggressive against self, aggressive against other, immediate gratification*) and seven types of impulsive comments (e.g., *aggressive, sexually inappropriate, socially inappropriate, interruptions*). A total score was obtained for each mode of expression (i.e., motor and verbal) by attributing one point to every monthly behavior, two points to every weekly behavior, and three points to everyday behavior.

Procedure

Every patient qualifying for this study was first approached by an independent clinician in order to ensure an unbiased selection of participants and a fully voluntary consent. If the patient accepted to be contacted for the present project, a member of the research team set up a meeting in which he/she explained the aims and the project. If the patient accepted to participate, a written consent in accordance with the institutional review board's guidelines was completed and a socio-demographic questionnaire was administered.

The experiment was done in a standard evaluation room with minimal visual and auditory distractions and the participant was seated in a comfortable arm chair. Each assessment was divided in an average of 2.36 sessions (range from 2 to 4) in order to ensure an optimal level of collaboration and alertness from each participant. The tasks and questionnaires were administered in a balanced order and in between each of these, the evaluator asked the participant if he/she felt alert enough to pursue with the next task.

The computer tasks were administered on a 15" personal computer and the participants were instructed to sit in a way that was comfortable for them and that ensured a good view on the computer screen. They were also instructed to use their dominant hand for each task throughout the evaluation. For one subject, an injury resulting from the accident made it difficult or impossible to use his/her dominant hand and was advised to use the other hand.

It should be noted that, for the SST specifically, participants were provided clear instructions and feedback in between each block as to their RTs in order to minimize the use of excessive strategic slowing as recommended by Verbruggen et al. (2013).

Data analysis

The distribution of each variable was examined to ensure normality. Both independent sample *t*-tests and Mann-Whitney *U* analyses were used to compare patients and controls on sociodemographic variables and on their performances on the GNG, the MSET, the Hayling Test, and the Digit Span. To alleviate the text, when the parametric and non-parametric analyses yield the same results, only the priors were reported. Repeated measures ANOVAs were also used to compare patients and controls on their performances on the SST, the Nelson Task, the IGT, and the DKEFS TMT. Finally, correlation analyses were used, both parametric and non-parametric, to examine the relationships between performances on the inhibition tasks and impulsive behaviors observed in everyday life. We also used partial correlations to explore the relationships between various measures of impulsivity while controlling for the influence of states of anxiety and depression as reported in the HADS.

Results

Preliminary analyses

Student's *t*-test for independent samples have shown that there are no significant differences on age

Table 2

Mean, Standard Deviations, Minimum, and Maximum on Performance Tasks for TBI and Control Participants

	TBI Participants (n = 25)				Control Participants (n = 24)				p
	Mean	*SD*	Min	Max	Mean	*SD*	Min	Max	
GNG RT (ms)	456.53	98.03	300	709	373.88	60.40	256	531	**
GNG omission errors (%)	4.00	7.23	0	29	.55	.77	0	3	*
GNG commission errors (%)	31.58	20.69	4	81	34.26	19.69	8	85	
Nelson RT (UF)	1606.69	723.19	744	3234	951.59	278.24	654	1605	***
Nelson RT (F)	1660.91	819.68	903	4416	1060.96	292.22	696	1705	**
Nelson RT (HF)	1660.90	655.93	778	2997	1047.82	276.37	677	1659	***
Nelson RT (RC)	1618.74	616.42	824	3317	1084.70	321.59	690	1691	**
SSRT (ms)	448.66	251.07	237	1072	289.83	102.68	74	484	*
SST omission errors (%)	3.21	7.32	0	30	.06	.22	0	.83	
SST commission errors (%)	40.63	19.26	10	85	46.31	11.94	23	65	
MSET total profile score	1.76	1.39	0	4	3.46	.78	2	4	***
Hayling penalties	9.90	6.96	0	29	7.08	4.67	1	23	*
IGT 1 to 40	-4.00	10.41	-40	14	.42	10.23	-22	40	
IGT 61 to 100	2.61	18.17	-26	40	15.58	16.65	-32	40	**
IGT total score	-4.00	27.41	-48	56	21.08	31.60	-62	100	**
DKEFS TMT Visual Scanning	7.53	4.34	1	13	8.75	2.86	1	12	
DKEFS TMT Number Sequencing	6.13	3.70	1	13	10.00	2.19	5	14	**
DKEFS TMT Letter Sequencing	6.73	4.08	1	12	9.29	3.33	1	13	*
DKEFS TMT Number-Letter Switching	5.93	4.12	1	14	10.54	2.26	6	13	**
DKEFS TMT Motor Speed	9.27	2.71	3	13	10.79	1.50	8	13	*
Forward Digit Span	9.76	3.11	5	16	10.21	1.93	6	13	
Backward Digit Span	7.65	3.74	2	15	7.39	2.33	2	11	

Note. *p < .05, **p < .01, ***p < .001; *SD* = standard deviation; Min = minimum; Max = maximum; GNG = Go/No-Go; RT = reaction time; UF = unfamiliar condition; F = familiar condition; HF = highly familiar condition; RC = response conflict condition; SSRT = Stop-Signal reaction time; SST = Stop-Signal Task; MSET = Modified Six Elements Task; IGT = Iowa Gambling Task.

and years of education between the TBI and control groups (t(47) = .55, p = .585 and t(47) = .86, p = .395, respectively).

Comparison between patients and controls on the performance tasks

Means, standard deviations, minimal and maximal scores of all performance tasks for both TBI and control participants are listed in Table 2.

GNG. For this task two TBI participants and one control were excluded from analyses because of technical difficulties. Independent t-tests were conducted on mean RTs on successful Go trials, on omission, and on commission errors. Results show that TBI participants are significantly slower than the controls, t(36.6) = 3.44, p = .001. Results also reveal that TBI participants made significantly more omission errors (i.e., not pressing the spacebar when they should) than the controls, t(22.5) = 2.28, p = .030. The groups did not differ as to the number of commission errors made (i.e., pressing the space bar when they should not), t(44) = .45, p = .660.

Independent t-tests revealed that the TBI participants' CoVs did not significantly differ from the controls ($t(44) = 1.34$, $p = .187$) and therefore, suggesting that the intergroup differences obtained in the *GNG* task are not attributable to deficits related to sustained attention.

SST. For the analyses of this task, we excluded the participants with a percentage of inhibition errors of 100% (3 TBIs, 0 controls) since it is impossible to accurately estimate stop-signal reaction times (SSRTs) for participants who do not inhibit their responses. Similarly, we excluded participants who obtained negative SSRTs (1 TBI, 0 controls). Also, as mentioned earlier, trials in which participants slowed their response by more than three standard deviations than the mean of the previous trials were eliminated (for the TBI group: min = 41, max = 132, $M = 67.17$, $SD = 19.59$ trials; for the control group: min = 49, max = 80, $M = 63.26$, $SD = 7.11$ trials).

A mixed repeated measure ANOVA between TBI participants and controls in the anger and neutral conditions showed a main group effect, $F(1, 37) = 4.83$, $p = .034$, $\eta^2_p = .12$. This indicates that the TBI participants had significantly slower SSRTs compared to controls. Results also revealed that there was no significant effect of the condition and no interaction effect ($F_s < 1$).

As for the GNG, CoVs were calculated and compared with an independent *t*-test which also revealed that the TBI participants' CoVs did not significantly differ from the controls' (t(43= 1.34, $p = .187$).

Hayling Test. An independent *t*-test conducted on the number of penalties reveals that the TBI survivors obtained significantly more penalties than the control participants ($t(23.84) = 2.49$, $p = .020$), thus indicating a weaker performance (i.e., more interference from the dominant word). Results also reveal a significant difference as to the time awarded to the inhibition condition ($t(26.21) = 2.47$, $p = .020$), indicating that the TBI participants took more time to inhibit the response when compared to the matched controls.

Nelson Task. One control did not complete this task because of a technical difficulty. A mixed repeated measure ANOVA with the groups (TBI and control) as the between subject factor and the levels of interference (i.e., minimal, intermediate, maximal, and response interference) as the repeated measures indicated a main group effect ($F(1, 43) = 19.70$, $p < .001$, $\eta^2_p = .31$), which showed that the TBI participants' RTs were significantly longer than those of their matched controls. Results also show a significant effect of the condition ($F(3, 129) = 14.69$, $p < .001$, $\eta^2_p = .26$), and a significant interaction effect ($F(3, 129) = 4.62$, $p = .004$, $\eta^2_p = .10$).

In order to determine in which way the condition (level of interference) affected the results, paired sample *t*-tests were conducted for each group. Results revealed that there was no significant difference between the conditions for the TBI sample, which showed that the level of interference did not have an effect on the TBI participants' RTs. Indeed, there were no significant differences between the minimal interference and the intermediate interference conditions ($t(21) = .67$, $p = .511$), between the minimal and maximal interference conditions ($t(21) = .97$, $p = .343$) nor between the minimal and response interference conditions ($t(21) = .20$, $p = .842$). Similarly, no significant differences were found between the intermediate and maximal interference conditions ($t(21) = .00$, $p = 1.00$), between the intermediate and response interference conditions ($t(21) = .36$, $p = .722$) nor between the maximal and the response interference conditions ($t(21) = .67$, $p = .510$).

As for the matched controls, results revealed that the minimal interference condition significantly differed from all three other levels of interference (intermediate: $t(22) = 7.82$, $p < .001$; maximal: $t(22) = 4.32$, $p < .001$; response interference: $t(22) = 5.70$, $p < .001$), which did not significantly differ from each other. Indeed, no significant differences were found between the intermediate and maximal interference conditions ($t(22) = .55$, $p = .590$), between the intermediate and response interference conditions ($t(22) = .93$, $p = .37$) nor between the maximal and the response interference conditions ($t(22) = 1.25$, $p = .222$). Therefore, this task did not allow the discrimination between conditions for the TBI sample.

We also observed the errors committed by each group, but the mean error rate was low for both groups. Indeed, the TBI participants made between 1.2 (minimal interference) and 2.0 (response interference) errors and their matched controls made between 0.2 (minimal interference) and 0.8 (response interference) errors. For this reason, we did not analyse further errors.

Finally, as for the GNG and the SST, a CoV was obtained for each participant and was then compared with an independent *t*-test. Once again, no significant difference was found between the TBI participants and their matched controls ($t(41) = .18$, $p = .855$).

IGT. Two TBI participants and three controls did not complete this task because of a technical difficulty. A mixed repeated measure ANOVA between TBI participants and controls on the block trials (1 to 40 and 61 to 100) indicated a main group effect ($F(1, 40) = 10.14$, $p = .003$, $\eta^2_p = .20$) which showed that the control participants made less disadvantageous choices than the TBI survivors. Results also show a significant effect of the condition ($F(1, 40) = 19.02$, $p < .001$, $\eta^2_p = .32$) and a significant interaction effect ($F(1, 40) = 4.28$, $p = .045$, $\eta^2_p = .10$). Additional analyses reveal a significant difference between the groups on the last experimental block only (trials 61 to 100; $t(40) = 2.92$, $p = .010$). This indicates that the TBI participants made more disadvantageous choices on the last trials than the controls.

MSET. An independent *t*-test conducted on total profile scores reveals a significant difference between the groups ($t(37.98) = 5.30$ $p < .001$). Indeed, the TBI participants had significantly lower profile scores than their control counterparts, which indicates weaker planning abilities from the prior.

DKEFS TMT. A mixed repeated measure ANOVA between TBI participants and controls in visual scanning, number sequencing, letter sequencing, number-letter switching, and motor speed conditions showed a main group effect ($F(1, 36) = 9.53$, $p = .004$, $\eta^2_p = .21$), which indicated that the TBI participants obtained significantly lower scaled scores than their control counterparts. Results also show a significant effect of the condition ($F(4, 33) = 5.66$, $p = .001$, $\eta^2_p = .41$) and a significant interaction effect ($F(4, 33) = 3.68$, $p = .014$, $\eta^2_p = .31$). It should be noted that DKEFS TMT data was not available for eight TBI participants in order not to interfere with their official neuropsychological assessment.

Independent *t*-tests reveal significant differences between the TBI participants and the matched controls on the number sequencing ($t(20.19) = 3.67$, $p = .002$), the letter sequencing ($t(37) = 2.14$, $p = .039$), the number-letter switching ($t(17.67) = 3.86$, $p = .001$), and on the motor speed ($t(37) = 2.27$, $p = .029$). On each condition, controls perform better than the TBI participants. No significant difference was found for the visual scanning condition ($t(10.22) = 1.48$, $p = .168$).

Digit Span. Independent *t*-tests on total scores revealed no significant differences between our groups on both forward and backward digit spans, respectively $t_s(27.74) = 1.15$, $p = .258$ and $t_s(39) = 1.39$, $p = .171$. It should be noted that DKEFS TMT data was not available for six TBI participants in order not to interfere with their official neuropsychological assessment.

Table 3

Frequency of Motor and Verbal Impulsive Behaviors in TBI Sample

	Daily (%)	Weekly (%)	Monthly (%)	Never (%)
Aggressive act against other or object	0	0	4	96
Aggressive act against self	0	0	4	96
Dangerous act	23	14	4	59
Sexual act	0	0	0	100
Act of immediate gratification	13	9	0	78
Inappropriate act	9	4	0	87
Act of lack of persistence	18	0	0	82
Act of agitation	9	4	9	78
Disorganized act	26	9	4	61
Perseverative act	9	5	0	86
Aggressive comment against other	9	4	4	83
Sexually inappropriate comment	4	9	0	87
Socially inappropriate comment	26	0	9	65
Inappropriate interruption with a comment	9	0	17	74
Comment of lack of persistence	9	0	9	82
Disorganized comment	17	9	4	70
Perseverative comment	22	4	9	65

Relationships between performance tasks and observations

It should be noted that for the following analyses, only the TBI participants' scores and results were considered.

Impulsive Behavior Rating Scale. Table 3 shows the frequency of each behavior for 23 participants of the TBI sample. Analyses were made in order to determine the correlations between the motor (i.e., acts) and verbal (i.e., comments) impulsive behaviors. Results show a very strong correlation ($r(21) = .98$, $p < .001$) and do not allow us to conclude that these are distinct dimensions ($t(22) = 1.38$, $p = .182$). Therefore, only the total score obtained for each TBI participant was used for the subsequent analyses.

Performance tasks.

IGT. For the following analyses, only the trials 61 to 100 of the IGT were considered since studies have shown that only the latter trials allow to see if the subject understands that, in the long term, the risky decks have no benefits, which is the conceptual rationale of the task. Indeed, it has been suggested that the trials at the beginning, and the end of the task do not tap into the same psychological mechanisms (Dunn, 2006) and it therefore becomes imprudent to base conclusions on the total score.

DKEFS TMT. As mentioned earlier, the number-letter switching condition is the one that assesses cognitive flexibility. Therefore, it is the only condition that was considered for the following analyses.

Correlation Analyses. Spearman correlations between the performance tasks and the impulsive behaviors observed by the treating clinicians or nurses in the rehabilitation setting are reported in Table 4. It should be noted that multiple analyses were made thus augmenting the risk of type I errors. However, since the following study is composed of a relatively small sample and is exploratory, we find it important to conduct and present the following analyses nonetheless in order to begin observing the links between dimensions of impulsivity and cognitive mechanisms among a TBI sample.

Impulsive Behavior Rating Scale. The total score on the Impulsive Behavior Rating Scale was correlated to the total profile score on the MSET ($r(21) = -.57$, $p = .005$). This indicates that a better

Table 4

Spearman Correlations Between Performance Tasks and Impulsive Behaviors

Variables	IBRS Total Score (*n*)
Age	-.274 (23)
Education	-.392 (23)
TBI severity	.332 (23)
GNG RT	-.063 (21)
GNG omission errors	.263 (21)
SSRT	.111 (18)
Nelson minimal interference	-.153 (20)
Nelson intermediate interference	-.146 (20)
Nelson maximal interference	-.144 (20)
Nelson response interference	-.134 (20)
IGT 61-100	-.298 (21)
MSET profile score	-.567** (23)
Hayling penalties	-.093 (18)
DKEFS Number-Letter Switching	-.186 (13)
HADS Anxiety	-.071 (20)
HADS Depression	.245 (20)

Note. TBI severity as diagnosed by the treating physician; ** $p < .01$; GNG = Go/No-Go; RT = reaction time; SSRT = Stop Signal reaction time; IGT = Iowa Gambling Task; MSET = Modified Six Elements Task; HADS = Hospital Anxiety Depression Scale; IBRS = Impulsive Behavior Rating Scale.

performance on the MSET (i.e., higher profile score) is associated with less observed impulsive acts and impulsive comments. Partial Spearman correlations revealed that this correlation was maintained when controlling for anxiety and depression symptoms (r (17) = -.62, p = .005 and r(17) = -.57, p = .010, respectively). It should be noted that HADS data was unavailable for two TBI participants.

Discussion

The goal of this study was to compare post-acute TBI survivors to controls on measures of prepotent response inhibition, resistance to proactive interference, and decision-making and to examine the link between impulsive behaviors and these underlying mechanisms. We expected the TBI sample to show weaker performances on the performance tasks than the controls. We also expected the performances on the measures of prepotent response inhibition, resistance to proactive interference, and decision-making to be associated with impulsive behaviors in everyday life as observed by clinicians.

The TBI survivors showed, as expected, worse performance on measures of prepotent response inhibition (i.e., slower RTs and more omission errors on the GNG task, slower SSRTs and more penalties on the Hayling Task), of proactive interference in working memory (i.e., slower RTs on the Nelson Task), and of decision making (i.e., lower profile scores on the MSET and lower scores on the IGT). Furthermore, the only performance task that was associated with the Impulsive Behavior Rating Scale was the MSET which is a task that calls for planning and decision-making and that is sensitive to global neuropsychological deficits. More precisely, the poorer the performance on the MSET, the higher is the probability that the TBI participant displayed impulsive behaviors.

These findings support previous data indicating that patients with TBI present prepotent response inhibition impairments, proactive interference difficulties, and weakened decision-making.

The findings also show that performance on tasks that are specific to the measure of inhibition (whether it is prepotent response inhibition or resistance to proactive interference) do not allow the prediction of impulsive behaviors in everyday life. This result is coherent with Votruba et al. (2008). Unlike the findings in the current study, theirs demonstrated that the TMT was associated with observed impulsive behaviors. However, both the MSET and the TMT are tasks that are sensitive to global neuropsychological deficits. Therefore, both this study and Votruba et al.'s show that these non-specific tasks are sensitive in identifying patients at risk of committing impulsive behaviors. This may consequently result in a significant number of false-positives and do not allow to accurately predict who is at risk of committing such behaviors.

It should be acknowledged that one limitation in this study is associated with the TBI sample. Indeed, the participants constituted a convenience sample rather than a random one since they were recruited from two specific rehabilitation centers and were not necessarily consecutive admissions. Also, our sample, although it allowed us to detect significant effects, was rather small and only slightly impulsive (i.e., most TBI participants never committed impulsive behaviors as observed by the clinicians; cf. Table 3). Moreover, participants were all undergoing intensive rehabilitation in an acute phase of rehabilitation, this limits the generalizability of the results to other phases of rehabilitation.

Also, we wish to point out that another limitation in this study may relate to the control participants. Indeed, as can be observed in Table 2, some of the controls showed weak performances on certain tasks, namely the Backward Digit Span. However, since they were selected on the basis of matching the TBI group and that the results showed weakened performances from the participants who sustained TBI compared to those controls (results that are consistent with the literature), we believe that this is not a major issue.

Overall, our study shows that TBI participants show impairments on prepotent response inhibition, on proactive response interference, and on decision-making. Finally, our study indicates that only the MSET, which is an ecological task, permits the prediction of impulsive behaviors in an intensive rehabilitation setting. This might indicate that impulsive behaviors in everyday life in an intensive rehabilitation setting are linked to planning and decision-making rather than to inhibition (either prepotent response inhibition or resistance to proactive interference in working memory). These results could also indicate that global ecological tasks are better predictors of impulsivity in everyday life than more specific inhibition related tasks which can hardly be generalized to daily situations.

Moreover, when considering the potential consequences of impulsivity on the patients' and their relatives' well-being, we believe that impulsivity should be assessed systematically in a clinical setting. In that sense, ecological tasks such as the MSET should be used in order to identify patients at risk of committing impulsive behaviors. However, we think that no measure alone can replace adequate clinicians' communication as to their observations of specific impulsive behaviors. In this regard, we believe that the comments and acts listed in the Impulsive Behavior Rating Scale and reported in Table 3 could orient the discussion. We believe that a combination of performance tasks and clinical dialogue is the best way to assess impulsivity in order to ensure the patient's safety without impinging on his/her autonomy.

In this sense, we believe that the fact that this study combines observations of trained professionals as well as objective measures on a multitude of performance tasks based on a theoretical model is an important and valuable strength.

In a clinical perspective, with the results in the current study showing that planning and decision-making might be linked to impulsive behaviors, we wonder if interventions aiming to help post-TBI patients enhance their planning capabilities might also help in decreasing impulsive behaviors in everyday life.

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