Chapter 22

Attentional Processing in Traumatic Brain Injury and Posttraumatic Stress Disorder

Tobias Wensing, Jean Levasseur-Moreau,
Alexander T. Sack and Shirley Fecteau

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http://dx.doi.org/10.5772/57185

1. Introduction

The objective of this work is to review studies that examine deficits in sustained and selective attentional processing in adults diagnosed with Traumatic Brain Injury (TBI) or Posttraumatic Stress Disorder (PTSD). Deficits in these two attentional mechanisms are assumed to underlie the most prevalent behavioral consequences of TBI and PTSD and can result in deleterious consequences for an individual's everyday life.

TBI is considered a neurological condition that involves critical physical damage to brain tissue. PTSD is a psychiatric disorder that is accompanied by symptoms including intrusive re-experiencing of the traumatic event, avoidance and hyper-arousal. Individuals diagnosed with PTSD have been exposed to a traumatic event with highly threatening physical or psychological harm [1]. Consequently, the causing events underlying TBI, such as a motor vehicle accident or military assault, might also lead to a trauma that develops into a diagnosis of PTSD. Clinical reports described case studies, in which individuals showed symptoms of PTSD following a traumatic event. Moreover, neuropsychological assessments revealed that these symptoms were also accompanied by specific deficits in sustained and selective attentional processing [2] and related cognitive task performances [3]. A vast amount of literature emphasizes that impairments in cognitive processes may play a key role in several neurological and psychiatric disorders. For instance, cognitive deficits have been reported in both TBI and PTSD with considerable overlap including difficulties to concentrate, mental fatigue and hyper-arousal (see [4] for a review). Specifically, comorbid occurrence of TBI and PTSD in military personnel returning from conflicts in Afghanistan and Iraq approaches a prevalence of 50% [1]. Additionally, recent reviews on TBI and PTSD imply that the presence of TBI in an individual might accelerate subsequent development of PTSD diagnosis [4, 5]. Thus, the relationship between TBI and PTSD is pronounced in a one-way direction with PTSD occurring as a consequence of TBI, but not vice versa. This is mainly attributed to a shared causative event [4]. However, damage to critical brain tissue in TBI that is involved in emotional and cognitive processing after injury might also promote successive development of PTSD. Recent neuroimaging studies identified shared neurobiological deficits that include portions of the prefrontal cortex, as well as subcortical regions, such as the hypothalamus or pituitary gland (for a review, see [4]).

Importantly, despite potential symptomatic overlaps, TBI and PTSD require a detailed picture of cognitive deficits that underlie the most debilitating symptoms. With regards to the complex nature of attention and its prominent implication in symptoms observed in both TBI and PTSD, it appears crucial to identify and discuss similarities and differences in attentional processing, which may help to distinguish between both medical conditions. Thus, a comparison of attentional processing towards stimuli independent of emotional valence, either shared by or exclusive to TBI and PTSD, may promote specialized subsequent treatment and rehabilitation approaches.

Attentional processes have been studied for decades. However, we have yet to entirely grasp to which extent attention affects our behaviour. Attention is a central cognitive process that is considered as a precursor of a large majority of other higher cognitive functions. Although attention underlies a variety of behavioral impairments related to neurological and psychiatric disorders, its nature is rather complex and can be observed throughout numerous distinct subtypes, such as sustained attention, selective attention, and inhibition. Accordingly, these subtypes of attention are governed by the implication of different brain regions including the posterior parietal [6], inferior frontal [7], medial frontal and dorsolateral prefrontal cortex [8]. In this work, we will address processing of sustained and selective attention, since we believe that these subtypes of attention most likely resemble mechanisms, which underlie shared symptoms in TBI and PTSD, such as difficulties to concentrate or mental fatigue. Moreover, we will focus on reviewing studies, which solely implement neutral stimuli within their experimental designs. The ability to adequately process neutral stimuli is a vital cognitive requirement for coping with our environment. Deficits in this basic function may have a critical impact on an individuals' well being and even his survival.

2. Sustained attentional processing in TBI

Sustained attention (vigilance) is the ability to maintain attention for sporadic critical events during long periods of time [9]. Maintaining vigilant while performing everyday routines, such as driving a vehicle, is crucial to react to changes and unforeseen events in the environment. To date, behavioral findings on deficits in sustained attention for TBI are inconclusive. Varying findings have been reported for almost every behavioral aspect related to sustained attention, including response time (RT), accuracy, and intra-individual variability in responses (Table 1). In the studies reviewed here, RT is defined as the latency between the onset of a stimulus and the response given by a subject; accuracy mainly reflects errors in the correct

http://dx.doi.org/10.5772/57185

execution of task instructions; intra-individual variability in responses refers to fluctuations in subjects' accuracy or RT over the course of a cognitive task.

Study	TBI (n)	Post-Trauma	Severity	Trauma Type	Cognitive Test	Main Findings
Bloomfield et al. [15]	44	71,5 Months	Mild - Severe	Combat; RTA; Falls	SART	More commission errors in "poor sleepers" group
Bonnelle et al. [18]	28	28 Months (Range: 3-73)	Mild - Severe	Combat; RTA; Falls; Sports	CRT	Decrement in RT over time; No differences in accuracy; Higher IIV
Dockree et al. [12]	29	34,81 Months	Mild - Severe	Combat; RTA; Falls; Work	SART;DART	No differences in RT; More commission errors; Higher IIV
Kim et al. [19]	18	51,1 Months	Moderate - Severe	-	VSAT	No differences in RT; No differences in accuracy
McAvinue et al. [10]	18	38,83 Months (Range: 2-132)	Mild - Severe	-	SART	No differences in RT; More commission errors
Sinclair et al. [16]	20	133 Days-13,4 Years	Mild - Severe	RTA; Falls	PVT	Slower RT; Lower accuracy; Higher IIV
Slovarp et al. [20]	9	3,6 Years	Severe	-	SAT	Slower RT; Lower hit rate; Higher IIV for TBI subgroup
Willmott et al. [14]	40	68,38 Years (Range: 12-462)	Moderate - Severe	RTA	SART	No differences in accuracy

Table 1. Summary of methodologies and main findings of studies investigating sustained attention in TBI (Note: CRT = Choice Reaction Time Task; DART = Dual-task Attention to Response Task; IIV = Intra-individual Variability; PVT = Psychomotor Vigilance Task; RT = Response Time; RTA = Road Traffic Accident; SAT = Sustained Attention Task; SART = Sustained Attention to Response Task; VSAT = Visual Sustained Attention Task; TBI = Traumatic Brain Injury; "-" indicates missing or not reported information).

McAvinue et al. [10] compared individuals with mild to severe TBI to gender-, age- and education-matched healthy individuals on a Sustained Attention to Response Task (SART; [11]). The SART is a cognitive test measuring sustained attention following the Go/NoGo paradigm. Subjects were visually presented with a series of single digits ranging from 1 to 9. Presentation of the digits is followed by a mask and subjects were subsequently asked to press a response button as accurately and fast as possible at the occurrence of every digit but "3" (for a detailed description on the SART, see [11]). To further assess the role of error awareness and feedback on task performance, McAvinue et al. [10] divided the SART into different conditions. Subjects were presented with randomized digits and asked to withhold their response as soon as the digit "3" appeared. Also, three altered versions of the original SART were implemented in this study: an "awareness" condition, requiring subjects to give a verbal report as soon as they made a commission error (i.e., pressing the response button although no target is present); a "feedback" condition in which subjects were given auditory feedback when making an error; and a "fixed" condition, in which digits were not presented randomly but in a fixed order. Overall, individuals with TBI made more commission errors than healthy controls. However, both groups showed similar RT. Moreover, results of the "awareness" condition suggest that individuals with TBI were less aware of the errors they made during the task. Also, error awareness, that is, the number of errors a subject was unaware of, was positively correlated with the number of commission errors made by individuals with TBI. Behavioral results of the "feedback" condition indicated that both groups benefited from the provided error feedback and that both groups were able to decrease their amount of commission errors to the same extent. Another study [12] combined the SART with a continuous performance task (CPT; [13]) resulting in the Dual-task Attention to Response Task (DART). In the original CPT, subjects were asked to respond via button press to random occurrences of any letter of the alphabet, except for "x" ("x"-condition). Additionally, a more demanding task required subjects to withhold response to the letter "x" only if preceded by the letter "a" ("ax"-condition). In the classical CPT, outcome measures are levels of accuracy, assessed in terms of commission and omission errors (i.e., not pressing the response button although a target is present). According to the authors, a combination of the SART and CPT would result in a cognitively more demanding task that challenges sustained attention. In the DART, subjects are required to indicate the random occurrence of grey colored digits additionally to the classical design of the SART described previously. Dockree et al. [12] compared individuals with TBI, who had mild to severe injuries, to gender-, age- and education-matched healthy subjects on both the classical SART and the newly developed DART. Compared to the SART, the cognitively more demanding DART led to an increase in commission errors for both study groups. Individuals with TBI and healthy individuals did not differ in terms of RT on both tasks. However, individuals with TBI made more commission errors and showed higher intra-individual variability in responses during both the SART and the DART. Within a series of attentional tasks, Willmott et al. [14] also used a classical SART paradigm to test sustained attention in moderate to severe TBI. This study revealed no difference between individuals TBI and healthy individuals regarding commission errors. However, individuals with TBI tended, though not statistically significant, to make more omission errors than healthy controls (i.e., missing responses to any digit but "3").

Bloomfield et al. [15] incorporated the SART in a study that compared individuals with mild to severe TBI with respect to absent or present sleeping difficulties. The authors emphasized that individuals with TBI and those with sleep disorders constantly report concentration and attentional impairments. Thus, a deficit in sustained attention might be even more pronounced in individuals with TBI suffering from sleep disorders [15]. Based on a battery of sleep measurement indices, subjects were assigned to either the "poor sleepers" or "good sleepers" group. In accordance with the authors' hypotheses, poor sleepers made more commission errors than good sleepers at the SART. Sinclair et al. [16] compared individuals with mild to severe TBI to age- and gender-matched healthy individuals on the Psychomotor Vigilance Task (PVT; [17]). The PVT is a cognitive test that requires subjects to respond as fast as possible to a randomly presented auditory target stimulus. This task was originally developed to assess sustained attention in individuals with sleep disturbances. Similar to Bloomfield et al. [15], the authors hypothesized that TBI might be accompanied by an increase in mental fatigue and sleeping difficulties. This study examined individuals with TBI that reported fatigue and sleep difficulties and compared them to a healthy control sample. Compared to controls, individuals with TBI showed increased RT, reduced accuracy and larger intra-individual response variability. However, effects were diminished or vanished completely when controlling for reported sleep disturbances and fatigue, respectively. Nonetheless, Sinclair et al. [16] accentuated the close relation between sustained attention and fatigue and sleep disturbances that could at least in part account for the observed results in this study.

A study by Bonnelle et al. [18] assessed sustained attention with a simple Choice Reaction Time task (CRT). In the CRT, subjects were asked to respond as accurately and as fast as possible to a target arrow that pointed either in the right or left direction with respective button presses. An increase in RT over the course of the task would be indicative of possible deficits in sustained attention. The examined TBI group suffered from mild to severe brain injuries. Although individuals with TBI displayed intact accuracy, they had increased RT and larger intra-individual variability compared to healthy controls. Additionally, the same group showed an increase in response speed over time with RT being significantly slower in the last third of the task assessment than in the first one. The authors proposed that this decrease in performance speed might reflect a deficit in maintaining vigilance over time and, thus, sustained attention [18].

Kim et al. [19] assessed individuals with moderate to severe TBI and healthy individuals using a Visual Sustained-Attention Task (VSAT). In the VSAT, subjects were asked to discriminate pairs of vertical lines as either of same or different size, and press a response button only if lines were equal. However, individuals with TBI and healthy controls did not statistically differ in terms of accuracy or RT, although there was a trend towards longer RT and poorer accuracy in individuals with TBI.

Another recent study by Slovarp et al. [20] focused on sustained attention processing in individuals with severe TBI. These individuals and an age-matched control group were tested on a Sustained Attention Task (SAT). Here, subjects were presented with a display of four letters with one letter appearing in the upper half and three letters arranged in a row in the lower half of the screen. The subjects' task was to indicate by button press, if the upper letter matched one of the lower letters on the same display. Outcome measures included levels of accuracy (false alarms/hit rates) and RT. Findings revealed that individuals with TBI made more errors in terms of lower hit rates and were comparably slower in giving responses. Although there was no evidence for an increase in RT variability over time on a group level, Slovarp et al. [20] observed substantial intra-individual response variability over the course of the task in a subgroup of TBI subjects.

3. Sustained attentional processing in PTSD

Deficits in sustained attention have also been reported in studies assessing individuals diagnosed with PTSD (Table 2). Vasterling et al. [21, 22] conducted different studies examining groups of Gulf and Vietnam War veterans, respectively. The researchers compared individuals, which had developed PTSD after combat with a group of PTSD-free veterans. Within a series of cognitive tasks, subjects also performed a computerized version of the CPT [13], which is assumed to measure sustained attention. The authors reported both more commission [21] and omission errors [22] on the "ax"-condition in veterans with PTSD when compared to combat-exposed individuals without PTSD. Sustained attention has also been assessed as part of a larger study on cognitive functioning in veterans of the Bosnian War [23]. Veterans diagnosed with PTSD were compared to a similarly combat-exposed but PTSD-free control group. Both groups were assessed on the SART, which has been widely used in the study of attentional deficits in individuals with TBI. Compared to controls, veterans with PTSD made more commission as well as omission errors in the SART. However, the authors did not find any differences in RT. Another study that measured sustained attention in combat-exposed individuals used the CPT in Vietnam War veterans with PTSD and trauma-free controls [24]. In this study, the CPT was presented visually as well as auditory. In addition to the visual "x"- and "ax"-conditions, subjects performed the same task while listening to letter strings presented via headphones. Task performance was measured in terms of accuracy and RT. While there were no differences between groups in the visual CPT condition, PTSD subjects made less correct responses in the auditory condition. Moreover, subjects did not differ in RT in the auditory and visual CPT. However, the authors did not report any differences in commission errors for both modalities.

Study	PTSD (n)	Control Group	Trauma Type	Cognitive Test	Main Findings
Jenkins et al. [25]	15	Trauma Survivors	Sexual Violence	CPT; PASAT	More omission errors
Koso et al. [23]	20	PTSD-free Veterans	Combat	SART	More commission and omission errors
Shucard et al. [24]	23	Healthy Controls	Combat	CPT	No differences in RT for both modalities; Auditory: lower accuracy
Stein et al. [27]	17	Healthy Controls; Trauma Survivors	Sexual Violence	PASAT	Lower scores in PTSD compared to healthy, but not trauma controls
Vasterling et al. [21]	19	PTSD-free Veterans	Combat	CPT	More commission errors
Vasterling et al. [22]	26	PTSD-free Veterans	Combat	CPT	More omission errors

Table 2. Summary of methodologies and main findings of studies investigating sustained attention in PTSD (Note: CPT = Continuous Performance Task; PASAT = Paced Auditory Serial Attention Task; PTSD = Posttraumatic Stress Disorder; SART = Sustained Attention to Response Task).

Jenkins et al. [25] assessed survivors of sexual violence with and without subsequent development of PTSD, as well as a healthy control group on several tests of cognitive functioning. In order to examine sustained attention in PTSD for both the visual and auditory modality,

http://dx.doi.org/10.5772/57185

the authors used two different kinds of tasks. Besides the CPT for visual attention, they presented their subjects with a Paced Serial Auditory Addition Test (PASAT; [26]). Subjects were presented with auditory single digits and instructed to add each new digit to that of a directly preceding trial. Cognitive performance was measured with respect to time needed reporting a sum of digits, as well as the amount of correctly produced sums of digits. Results showed that individuals with PTSD made more omission errors at the CPT and the PASAT compared to trauma and healthy controls. Another study utilized the PASAT for measurement of auditory sustained attention in PTSD [27]. Survivors of sexual violence showed decreased PASAT overall scores compared to healthy individuals, who matched individuals with PTSD in terms of age, education and socioeconomic status. However, there was no apparent difference in accurate task performance between individuals with PTSD and a respective trauma control group.

In sum, we identified shared processing deficits in sustained attention in TBI and PTSD. Specifically, these deficits are pronounced in terms of reduced accurate task performance, while decrements in RT and variability in task performance over time seem to be associated with processing deficits in TBI only.

4. Selective attentional processing in TBI

Selective attention is the ability to focus attentional resources oriented towards a given stimulus despite the presence of distracting or competing stimuli. Difficulties in maintaining concentration and experiences of fatigue are among the most prevalent symptoms in individuals suffering from TBI. In order to cope with general tasks that involve more than one source of stimuli, it is important that individuals are able to separate task- or content-relevant from irrelevant input. Thus, selective attention is usually assessed by tasks requiring subjects to focus on relevant stimuli while ignoring irrelevant and distracting information (Table 3).

In a study by Goethals et al. [28], individuals with severe TBI completed a Stroop Colored Word Test (abbreviated as "Stroop" subsequently; [29]). In the Stroop task, subjects were presented with three different sorts of cards: the first card contained black-printed words of highly distinguishable colors ("blue", "green", "red", "yellow"); the second card depicted rectangles printed in blue, green, red or yellow color ("color-naming" condition); the last card of the Stroop task showed the same words as card one. However, words were not printed in black, but in a color that did not resemble its actual content ("incongruent" condition; i.e., the word "blue" printed in green). Performance on the first card served as a measure of reading abilities. For assessment of selective attention, subjects were compared on a Stroop interference index calculated by subtracting RT of the incongruent condition from those in the color-naming condition. Thus, deficits in selective attention would be reflected by Stroop interference indices, which largely differ from the value 0. In this study by Goethals et al. [28], impairment in Stroop performance was classified as 1 standard deviation (SD) above mean RT of a matched normative sample. Results showed that individuals with TBI showed deficits in the incongruent, but not the color-naming Stroop condition, which might indicate difficulties in selectively

Study	TBI (n)	Post-Trauma	Severity	Trauma Type	Cognitive Test	Main Findings
Belmont et al. [35]	27	3-26 Months	Severe	-	Go/NoGo-Task	Slower RT; More omission errors
Goethals et al. [28]	9	-	Severe	-	Classical Stroop-Task	Impairment on Stroop-Task
Mayer et al. [32]	22	3-20 Days	Mild	Combat; RTA; Falls	Modified Stroop-Task	No differences in RT
Ries et al. [36]	20	12-360 Months	Severe	-	Negative Priming Paradigm	Slower RT and lower accuracy; Negative priming effect on RT for degraded words
Smits et al. [31]	21	30,6 Days	Moderate - Severe	-	Modified Stroop-Task	Moderate: no differences to controls; Severe: lower accuracy on Stroop-Task
Soeda et al. [30]	5	12-84 Months	Severe	RTA	Modified Stroop-Task	No differences in accuracy
Willmott et al. [14]	40	68,38 Days (Range: 12-462)	Moderate - Severe	RTA	SAT; 2&7	Both tests: slower RT; 2&7: lower accuracy; Larger RT differences between SAT tests
Ziino et al. [33]	46	21-1153 Days	Mild - Severe	-	C-SAT	Slower RT; Lower accuracy; no differences in IIV

Table 3. Summary of methodologies and main findings of studies investigating selective attention in TBI (Note: 2&7 = Ruff 2&7 Selective Attention Task; C-SAT = Complex Selective Attention Task; IIV = intra-individual variability; RT = Response time; RTA = Road Traffic Accident; SAT = Sustained Attention Task; TBI = Traumatic Brain Injury; "-" indicates missing or not reported information).

attending towards task-relevant information and to ignore simultaneously occurring and distracting input.

Soeda et al. [30] used a modified version of the Stroop paradigm to assess selective attention in severe TBI. Unlike in the original version of the Stroop task, subjects were asked to validate congruent word and color combinations via button press. This alteration enabled the authors to directly measure levels of accuracy as well as RT. When compared to age- and education-matched healthy controls, individuals with TBI tended to make more errors, although this difference did not reach statistical significance. Another alteration of the original Stroop task has been used by Smits et al. [31], who examined selective attention in two distinct samples of individuals with moderate and severe TBI. In their "counting" Stroop task, subjects were presented with two task conditions: in the neutral condition, subjects had to respond via button press to the displayed amount of words showing animal names; in the incongruent condition, subjects had to indicate the amount of number words that have been presented on the screen, rather than their value, if the word was presented in normal letters (i.e., at the occurrence of three times the word "five", subjects should press a button for "3"). However, in this condition there were deviant trials in which the word representing a number was given in capital letters.

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In that case, subjects were asked to validate the numeric value this word was representing (i.e., at the occurrence of three times the word “FIVE”, subjects should press a button for “5”). Comparison to a group of healthy controls revealed that individuals with severe but not with moderate TBI made more errors in the incongruent counting Stroop task condition. Mayer et al., [32] varied the Stroop paradigm in a way as to assess selective attention across visual and auditory modalities. The task consisted of congruent and incongruent pairs of simultaneously presented visual and auditory stimuli of written out and pronounced numbers, respectively. Both visual and auditory stimuli occurred at either a high or a low frequency condition in order to induce an increase in cognitive task demands. A preceding multimodal cue instructed subjects to attend to numbers presented in one modality while ignoring the other. Congruent trials referred to identical pairs of simultaneously occurring stimuli, whereas incongruent trials comprised different numbers presented at the same time. When compared to an age- and education-matched healthy control sample, individuals with TBI showed a non-significant trend towards longer RT to incongruent auditory stimuli at high frequency. However, no other effects regarding experimental group, modality or frequency were observed.

Besides the classical or modified versions of the Stroop paradigm, several other cognitive tasks have been used to assess selective attention in TBI. Ziino et al. [33] developed a Complex Selective Attention Task (C-SAT) in order to examine individuals with mild to severe TBI and an age- and education-matched healthy control group on selective attentional processing. The C-SAT required subjects to respond to combinations of red- or green-colored letters and numbers with specific button presses (i.e., right button for green letter/red number; left button for right letter/green number). Subjects were compared on measures of accuracy by means of errors (pressing the wrong button) and misses (not pressing any button during a predefined period of time), as well as RT. The authors argued that this task is especially difficult for subjects suffering from TBI, since it requires a larger working memory load compared to rather simple selective attention tasks [33]. Individuals with TBI showed lower levels of accuracy with significantly more produced errors than healthy individuals, as well as slower RT. Both groups were also compared on variability in RT. However, there was no apparent greater response variability for individuals with TBI as a group.

Alongside a variety of other cognitive functions, Willmott et al. [14] tested selective attention in individuals with moderate to severe TBI using two different behavioral tasks: the Ruff 2 and 7 Selective Attention Test (2&7; [34]) and the Selective Attention Task (SAT; [33]). The 2&7 is a paper-and-pencil task that required subjects to manually cross out the digits “2” and “7”, which were presented within a series of either letters or other digits. The procedure of the SAT was similar to that of the C-SAT reported previously [33] with the alteration that Willmott et al. [14] added a simple version to the SAT (SSAT). The difference between SSAT and C-SAT lay within its rather low cognitive demand; subjects were asked to respond with two distinct button presses if a letter or number was shown in a specific color (i.e., right button for yellow, left button for brown targets). For both tasks, subjects were measured on accuracy and RT. Results of the 2&7 revealed that individuals with TBI were less accurate and slower cancelling out digits embedded within letters, as well as within series of other digits. However, the difference between both task conditions was larger in the healthy control group. In the SAT, individuals with TBI showed slower RT than healthy individuals. Moreover, differences in RT between the SSAT and C-SAT were larger for individuals with TBI indicating that this group had problems with the more cognitively demanding version of the SAT. Belmont et al. [35] implemented a basic Go/NoGo paradigm in their study in order to assess selective attention in a sample of individuals with severe TBI. The task required subjects to respond to target letters via button press and withhold their response at the occurrence of non-targets. Performance of individuals with TBI was compared to that of gender-, age- and education-matched healthy individuals by means of accuracy, that is, the amount of omission errors, as well as RT. The authors found that individuals with TBI made more omission errors and were generally slower in responding than healthy individuals.

Ries et al. [36] used a negative priming paradigm that took into account response inhibition as part of a selective attentional process. Thus, selective attention would be reflected by both facilitation of the selected target as well as suppression of distracting information [37]. In their behavioral task, the authors presented individuals with severe TBI and healthy controls with two subsequent screens per trial, which consisted of a priming display followed by a probe display. Both displays showed two words in two different colors indicating targets and distractors. Additionally to targets or distractors, words were visually degraded in several ways and presented on 50% of the probe displays only. The other 50% of the probe displays consisted of intact word stimuli. Subjects were asked to respond to target words on the prime displays verbally by reading them out loudly. The authors hypothesized that negative priming of intact target words on priming displays would result in inhibitory difficulties on subsequent probe trials in individuals with TBI. Results showed that individuals with TBI generally had slower RT than healthy individuals. Moreover, word degradation slowed RT in both experimental groups, whereas this effect was even significantly more pronounced in individuals with TBI. For intact stimuli, there was a negative priming effect on RT for healthy individuals, but not individuals with TBI. Nonetheless, negative priming affected RT for both groups when stimuli were degraded. Also, individuals with TBI were less accurate than healthy controls. However, neither stimulus degradation nor negative priming had an effect on accuracy of both groups. Ries et al. [36] interpreted their findings as being indicative of inhibitory difficulties in individuals with severe TBI.

5. Selective attentional processing in PTSD

Interference of emotional or threat-related stimuli on attentional processing has been commonly reported in individuals diagnosed with PTSD [38-43]. A range of studies aimed to investigate if this interference could be translated to a context of stimuli with solely neutral valence as well. Problems in selecting task relevant cues while ignoring distracting information might reflect a general attentional deficit in PTSD, which could not be addressed to emotional saliency per se (Table 4).

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Study	PTSD (n)	Control Group	Trauma Type	Cognitive Test	Main Findings
Bryant et al. [45]	14	Non-traumatized Controls	Interpersonal Violence; RTA	Oddball Paradigm	No differences in RT
Jenkins et al. [25]	15	Trauma Survivors	Sexual Violence	Posner Visual Selective Attention Task	No differences in RT
Vasterling et al. [21]	19	PTSD-free Veterans	Combat	Stroop-Task	No differences in Stroop Interference Scores
Vasterling et al. [22]	26	PTSD-free Veterans	Combat	Stroop-Task	No differences in Stroop Interference Scores

Table 4. Summary of methodologies and main findings of studies investigating selective attention in PTSD (Note: PTSD = Posttraumatic Stress Disorder; RT = Response time; RTA = Road Traffic Accident).

Studies on selective attention deficits in PTSD incorporating neutral stimuli are rather rare. In two consecutive studies, Vasterling et al. [21, 22] assessed selective attention in Vietnam and Gulf War veterans with PTSD and healthy controls on a Stroop task. For both studies, PTSD subjects did not show any differences to healthy individuals on Stroop interference scores. In a series of cognitive tests, Jenkins et al. [25] instructed subjects to perform the Posner Visual Selective Attention Task [44]. In this task, subjects were asked to respond to a target with a button press, which was preceded by two different sorts of cues indicating the position of the target on a computer screen. Valid cues predicted the actual later position of the target, whereas invalid cues appeared at the target's opposite location (i.e., cue on left side of the screen, subsequent target on the right side). Survivors of sexual violence with PTSD were compared to a group of survivors of similar trauma events without PTSD and a group of healthy individuals on RT measures. Results revealed no difference in RT between corresponding groups. Bryant et al. [45] used an oddball paradigm to assess selective attention in individuals with PTSD and trauma-free controls. Auditory stimuli consisted of standard and target tones differing in frequency with target tones occurring at a probability of 15% during the experiment. There was no statistical evidence for differences in RT between both groups.

Put together, TBI appears to be accompanied by deficits in selective attention. These deficits are mainly expressed in terms of reduced accuracy in cognitive tasks, as well as a general slowing in RT. However, no study on selective attention in PTSD revealed corresponding findings, which might be related to a shortage of empirical studies addressing selective attentional processing in PTSD.

6. Discussion

Results of the here reviewed studies suggest a shared processing deficit in sustained attention towards stimuli with neutral valence for TBI and PTSD (Figure 1). This attentional deficit is expressed in terms of reduced accuracy levels when cognitive task performance of individuals with TBI or PTSD is compared to that of healthy controls. In contrast to a shared deficit in accuracy for sustained attention tasks, findings on selective attention in TBI and PTSD point towards a processing deficit of neutral stimuli that is only observed in TBI. Studies assessing individuals with TBI reported reduced accuracy in task performance, as well as a general slowing in RT across different cognitive tasks, levels of severity and trauma types. However, no such corresponding findings were demonstrated in studies that assessed individuals diagnosed with PTSD on selective attention tasks. In order to understand why sustained attention tasks reveal shared attentional deficits in TBI and PTSD, but selective attention tasks do not, we have to consider several aspects that might help explaining our main findings such as the general mechanisms incorporated in execution of cognitive tasks, the subjects' states of arousal, as well as neural correlates underlying attentional processing in TBI and PTSD.

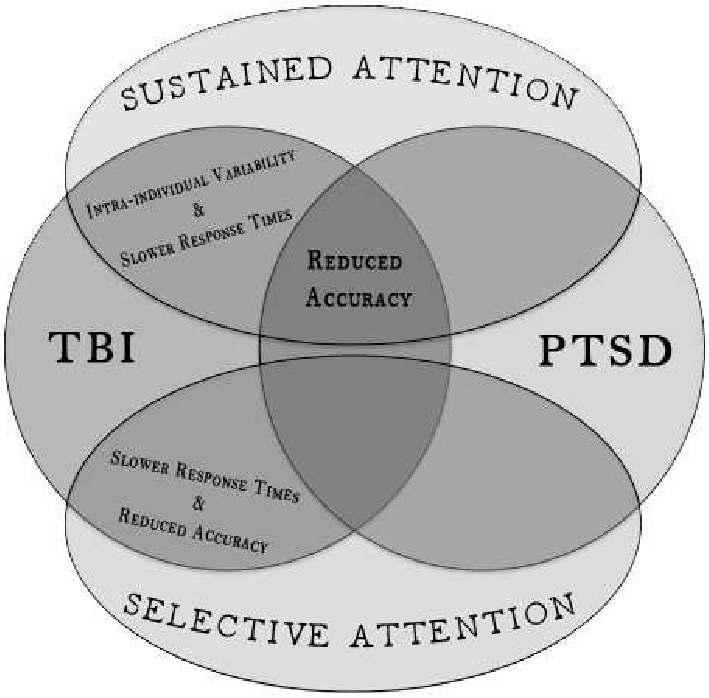

Figure 1. Schematic overview of shared and exclusive attentional processing deficits towards stimuli with neutral valence in Traumatic Brian Injury (TBI) and Posttraumatic Stress Disorder (PTSD).

6.1. The role of response inhibition

Sustained attention is mainly assessed by tasks following the Go/NoGo paradigm (i.e., SART and CPT). Here, subjects are instructed to maintain responsive to a set of targets via button press while withholding responses to a predefined and randomly occurring type of stimulus. Thus, accurate performance of a Go/NoGo-task requires subjects' ability of response inhibition. According to this rationale, we might question if a shared deficit resulting from sustained attention tasks is solely pronounced by reduced levels of accuracy, or would also reflect impairments in response inhibition. However, our findings do not support this idea. There is an obvious pattern between the here reviewed studies, which shows that studies assessing TBI and PTSD reported more commission errors only in tasks following the Go/NoGo paradigm. Commission errors are also considered false responses/alarms and occur when subjects fail to inhibit responses to a specific stimulus. However, it does not necessarily follow from these findings that a deficit in sustained attention reflects impairments in response inhibition. To the contrary, studies also reported increases in omission errors while assessing individuals with TBI and PTSD. Omission errors usually reflect missing responses to present targets and, therefore, do not require the ability to withhold responses. Additionally, other studies, which do not utilize a Go/NoGo paradigm within their cognitive tasks, report generally reduced accuracy in terms of lower hit rates towards target detection (which is similar to the concept of omission errors) in TBI and PTSD [16, 20]. Thus, it seems tempting, but unlikely that deficits in sustained attention can be simply addressed to impairments in response inhibition. Instead, there appears to be a deficit in sustained attention in terms of accuracy that is present in both TBI and PTSD.

Studies assessing selective attention point towards a processing deficit of neutral stimuli that is only observed in TBI (Figure 1). Tasks implemented in these studies follow rationales that require selection of content- and task-relevant information while inhibiting simultaneously occurring and competing sensory input (i.e., Stroop task; [28, 30-33, 36]. Thus, selective attention deficits expressed by reduced accuracy and slowing of RT might be related to an underlying impairment to inhibit distracting simultaneous information. Unlike commission errors in Go/NoGo-tasks, there is no equivalent specific accuracy measure, which might indicate an apparent deficit in response inhibition for individuals with TBI while performing selective attention tasks. It might be reasonable to assume that deficits on tasks such as the Stroop display impairments in inhibitory processes [29]. However, given that selective attention deficits have also been reported for TBI in tasks that do not require inhibition of simultaneously occurring input [14], results on these tasks do not necessarily explain selective attention deficits in individuals with TBI.

6.2. The impact of fatigue, arousal and emotion

Since neither sustained nor selective attentional processing deficits are fully explained by impairments of inhibitory mechanisms, we might argue that attentional deficits could possibly result from other phenomena that might be shared by or exclusive to TBI and PTSD. TBI has previously been associated with states of mental fatigue and sleep disturbances [46]. Two of the studies reviewed here extent this view by contrasting performance of sleep-deprived and normal sleeping individuals with TBI on a sustained attention task [15], as well as individuals with TBI and healthy individuals on a cognitive task that has been implemented in sleep studies previously [16]. Both studies propose a sustained attention deficit that is even more pronounced in the presence of sleep disturbances in individuals with TBI. Although Bloomfield et al. [15] reported more commission errors in "poor" sleepers with TBI when compared to "good" sleepers, very recent findings by Sinclair et al. [16] point towards possible floor effects of sleep difficulties in TBI. Since differences between groups in this study diminished as soon as the authors controlled for reported fatigue and sleep disturbances in their statistical analyses, it is hard to argue that these factors might exacerbate already present accuracy deficits in sustained attention for individuals with TBI. The inclusion of a healthy control group with or without sleeping difficulties in a study similar to that by Bloomfield et al. [15] might shed some light on the question in how far sleep disturbances or mental fatigue possibly influence the severity of sustained attention deficits in individuals with TBI. Sleep disturbances are also considered one of the hallmarks in PTSD [1]. However, sleep disturbances in PTSD are mainly pronounced in terms of reoccurring nightmares that resemble aspects of the experienced traumatic event. Therefore, sleep disturbances in PTSD might be rather related to mechanisms that enter the domain of memory and affective states than basic attentional processing (for a review on mechanisms of sleep disturbances in PTSD, see [47]). To our knowledge, there is only one recent study that examined the relation between attentional processing deficits and sleep disturbances in PTSD [48]. In this study, individuals with disaster-related PTSD-symptomatology were assessed on the PASAT. Behavioral outcomes, that is, the number of correct responses in the PASAT, were then related to self-reported symptom severity, including subscales of sleep disturbances. Although results revealed that deficits in sustained attention increased with symptom severity, there was no evidence for an impact of sleep disturbances on attentional processing. The authors argued that the lack of impact of sleep disturbance might be indicative of a solely attentional deficit in PTSD.

Although results from studies reviewed here are somewhat inconsistent with respect to how or if sleep disturbances and fatigue might influence performance on sustained attention tasks, we nonetheless see the urge to consider them in explaining a shared deficit for TBI and PTSD. Cognitive tasks assessing sustained attention are rather simple and modest in terms of duration. The original SART was administered over a period of 4.3 minutes [11]. Other sustained attention tasks, such as the PVT, show high validity when administered over a period of 10 minutes [17]. One might argue that tasks lasting shorter than 15 min might not be able to display the ability to maintain vigilance over time. However, we need to keep in mind that individuals with TBI, as well as those diagnosed with PTSD, might suffer from severe cognitive impairments, which could account for findings on sustained attention presented here. Symptoms of fatigue and difficulties to concentrate have been reported for both TBI and PTSD [4]. Thus, we propose that a shared deficit in sustained attentional processing might reflect a common underlying symptom in both medical conditions.

In selective attention tasks, processing deficits were observed for individuals with TBI, but not for those diagnosed with PTSD. Since deficits in selective attention for individuals with TBI are expressed in terms of decreased accuracy, as well as slower RT, we might again argue that impairments in TBI could be a possible consequence of states of fatigue. Studies reported that errors in selective attention task highly correlated with measures of self-reported fatigue [33, 35]. This effect even remained when results were controlled for mood by depression or general anxiety assessment scales. However, we did not find any apparent selective attentional processing deficits for studies on PTSD. Noteworthy, cognitive tasks assessing selective attention require larger mental effort than sustained attention tasks. Thus, selective attentional processing deficits only observed in TBI might be linked to increases in task difficulty and cognitive demands. Vice versa, an absent selective attention deficit in PTSD might reflect intact arousal, that is, a general reactivity and alertness to stimuli with neutral valence. This would be in line with symptoms of hyper-arousal, which are underlying the diagnosis of PTSD [1]. Nonetheless, the studies reviewed here did not report any facilitating effects towards stimuli for individuals with PTSD either. It seems more reasonable that states of hyper-arousal are closely related to stimuli with emotional valence. A vast amount of studies suggests that in studies on PTSD, individuals' performance on cognitive tasks is highly affected by interference of emotionally related stimuli [38-43]. Consequently, intact selective attentional processing might serve as a marker for subsequent development of hyper-arousal, and thus, would in part explain absent deficits on selective attention in individuals with PTSD reviewed here.

6.3. Neural correlates of sustained and selective attention in TBI and PTSD

It is rather difficult to draw an overall picture related to the impact of brain damage in TBI on behavioral results in this review. One major drawback in studies assessing attentional processing in TBI concerns missing reports of lesion sites in TBI. It seems quite obvious that damage to different brain regions may affect various cognitive networks and might subsequently result in a variety of behavioral and cognitive impairments. Within the studies reviewed here, only one systematically reported lesion sites for each participating individual [12]. However, given a large heterogeneity in lesion sites within the study's sample of individuals with TBI, the authors did not make any further relations between damaged brain regions and behavioral outcomes.

Regardless of challenges to make inferences of neurobiological deficits based on individual damage to the cortex, a handful of studies made an attempt to relate attentional deficits to alterations or specific states of cortical activity in individuals with TBI. Studies on attention in TBI reported deactivation of cortical areas relevant for accurate task performance [32], as well as changes in cerebral blood flow of the brain in resting state [19], that is, cortical activity and functional connectivity without stimulus-induced processing demands. The brain in resting state comprises a default mode network (DMN), which includes medial portions of the parietal, frontal and temporal cortex [49]. In individuals with TBI, studies indicate that insufficient deactivation of the DMN during cognitive tasks, as well as functional connectivity between areas incorporated in the DMN might be a neurological marker of behavioral deficits observed in sustained attention tasks [18, 32]. Similar to TBI, we identified only few studies that directly linked cortical abnormalities accompanying PTD to deficits in sustained attentional processing. Here, study results indicated that stress induced in combat-related situations might affect sustained attention task performance by a decrease in midbrain activity [50]; an effect, which seemed to diminish after multiple testing sessions, providing evidence for recovery mechanisms related to combat PTSD. However, studies examining the direct relations between attention to neutral stimuli and neural processing in PTSD are still rare. Hence, it seems quite assumptive to derive specific implementations for treatment or cognitive improvements from single study results.

Studies assessing selective attentional processing in TBI reported both decreases [30] or increases [31] in activity of the anterior cingulate cortex (ACC). Since this area is assumed to be involved in conflict monitoring [51], a mechanism essential for specific selective attention tasks such as the Stroop, decreases in task-related activity might reflect underlying impairments in cortical processing that could partially explain selective attentional processing deficits in TBI. However, studies did not distinguish between dorsal or rostral portions of the ACC. The former is assumed to be involved in general cognitive processing, whereas the latter shows responsiveness to stimuli with emotional valence, which might possibly account for these contradictory findings. Accordingly, increased activity in the ACC has been reported in studies on selective attention in PTSD [45, 52], including both dorsal and rostral portions. Thus, processing of stimuli in selective attention tasks appears to be unaffected at least in the ACC for individuals diagnosed with PTSD. Contrasting these results with decreases in ACC activity for TBI might serve as an indicator why selective attentional processing deficits were only observed in individuals with TBI.

6.4. Attentional deficits in comorbid TBI and PTSD

Historically speaking, it was long debated if TBI and PTSD could arise in a comorbid fashion, since TBI is accompanied by at least partial loss of consciousness and posttraumatic amnesia [12, 16, 19, 20, 32, 33]. According to this theory, amnesia or loss of consciousness would circumvent construction of a trauma-related memory, which is considered to facilitate PTSD-related symptoms, such as intrusive thoughts and re-experiencing. However, recent research proposed that TBI and PTSD share certain diagnostic features (for an extensive review, see [53]). As stated previously, it is assumed nowadays that TBI and PTSD occur at a prevalence rate of almost 50% [1]. Moreover, several case studies provided evidence that comorbid TBI and PTSD are not only theoretically related, but require accurate and reliable rehabilitation and treatment plans [2, 3]. Thus, we see a necessity to further explore attentional processing in populations with comorbid TBI and PTSD. To our knowledge, there is only one study that examined attentional processing in individuals with combat-related comorbid TBI and PTSD [54]. Individuals with comorbidity diagnosis were compared to two control groups, a group consisting of individuals with PTSD only and healthy controls on measures of the Attentional Network Task (ANT; [55]). The authors used the ANT to assess attentional processing on three distinct metrics, each reflecting a different aspect of attention: (1) *alerting*; (2) *orienting*; (3) *executive*. Although the ANT's theoretical framework slightly differs from other cognitive tasks reviewed in this work, we might link its alerting and executive networks to mechanisms of sustained and selective attention, respectively [54]. Study results indicated that individuals with comorbid TBI and PTSD were less accurate and slower in responding, and showed higher variability in responses compared to both the PTSD and healthy control group. Respective effects were also observable between individuals with PTSD and healthy controls, although without statistical significance. These findings were in line with several findings of attentional processing deficits described above. While there appeared to be a clear pattern for deficits in sustained and selective attention in TBI, this picture is less consistent in PTSD. Barlow-Odgen et al. [54] pointed out that none of the participating subjects had an exclusive diagnosis of TBI, but was always accompanied by PTSD. More systematic research on comorbid TBI and PTSD and even the inclusion of a group that only consists of individuals with TBI might further progress our understanding about shared and exclusive attentional processes in TBI and PTSD. Besides a considerable prevalence rate of comorbid TBI and PTSD, individuals with PTSD are very likely to meet criteria of at least one other psychiatric disorder [1]. Correspondingly, psychiatric disorders, which also occur at a high comorbidity rate with PTSD, including other anxiety disorders, depression [56] and substance abuse disorder [57], might exacerbate the impact of attentional processing in PTSD.

6.5. Implications for rehabilitation and treatment

Based on results discussed here, we believe that attentional processing deficits need to be particularly considered when developing and conducting treatment and rehabilitation programs for both TBI and PTSD. To date, cognitive training is highly recommended during TBI in a post-acute phase, including attention training and metacognitive training, but not at an acute stage [58]. Hence, results reviewed here might aid an even further detailed and specialized cognitive training, which takes into account specific deficits in sustained and selective attentional processing for individuals with TBI. Moreover, despite the concrete implementations for cognitive training, the general finding of sustained and selective attention deficits across trauma severity, the time since traumatic event and type of trauma might also affect other types of treatment approaches in TBI, such as physical and ergonomic rehabilitation programs, as well as speech or psychological therapy. Individuals with TBI consistently display difficulties to maintain attention during a cognitive task (e.g., [10, 12]). It seems reasonable that this deficit might also influence performance on other everyday situations that require the ability to stay vigilant over a specific period of time. Findings of studies reviewed here might support that adjustments of rehabilitation or training sessions to apparent impairments on sustained attention tasks could result in improvements of treatment outcome. We also think that findings of this review might especially promote treatment of comorbid TBI and PTSD or PTSD following TBI, respectively. Clinical case studies revealed that sustained and selective attentional difficulties are already tackled in intervention plans for PTSD following a traumatic accident [2]. Providing evidence that impairments in sustained attention are present in both TBI and PTSD populations and selective attention is preserved in the latter might serve as a blueprint for future treatment approaches, especially in terms of session duration and distribution over time. This might, for instance, be achieved by adjustment of intervention plans of cognitive training for shorter, but more frequent training sessions.

7. Limitations

Although we were able to shed some light on shared and rather exclusive attentional processing deficits in TBI and PTSD, there are some limitations to this review and selected studies that need to be taken into account. First of all, there is an extensive amount of literature on attentional processing in TBI using neutral stimuli. However, this is not the case for PTSD, where a vast amount of studies on attentional processing focuses on emotion-related stimuli and research and, thus, tends to neglect corresponding experimental designs that assess similar mechanisms related to stimuli with neutral valence. One might argue that this is not really surprising, since it appears more likely to find considerable differences between individuals with PTSD and control groups when emotion or even trauma-relevant content is involved. However, this tendency could lead to a publication bias that, in turn, might result in lost opportunities to identify basic cognitive mechanisms involved in the onset and development of PTSD. Another point of limitation refers to heterogeneity in study designs, which is mostly pronounced for those studies examining attentional processing in TBI. Given that most studies differ in terms of TBI severity, type of trauma, and time elapsed since traumatic events, it is unlikely to identify a pattern that might point towards possible recovery effects or impact of damage to specific brain regions. Regarding type of trauma, the same inconsistencies in etiology and causalities between studies could be observed in PTSD.

We would also like to point out that there is a rather low verge between continuous vigilant task performance, as reflected by sustained attention, and higher cognitive functions, such as working memory. Some of the studies reviewed here used cognitive tasks or alterations of task designs to recruit higher cognitive demands, which also incorporated working memory capacities [33]. We might question if accurate and fast performance on these kinds of tasks still exclusively reflects attentional processing. Regardless of mechanisms of attention, working memory deficits are a comprehensively investigated cognitive mechanism in TBI. Even within those studies presented here, tasks on working memory were part of larger setups of cognitive tasks [19, 20, 31]. Similar to performance on sustained attention tasks, results on working memory function revealed reduced accuracy levels for TBI, with task performance getting worse with an increase in working memory load [31].

We would like to emphasize that the purpose of this review was to provide improved insight on attentional processing, which might be shared by or be rather exclusive to TBI and PTSD. Thus, one might question the ecological validity of the cognitive tasks that were used throughout the studies reviewed here. Identification of overlap in potential attentional processing deficits should ultimately result in implications on how to provide suitable treatment and rehabilitation approaches. However, experimental settings assessing attention with cognitive tasks are usually highly artificial. Parsons et al. [59] made an interesting attempt towards an increased ecological setting for such tasks. The authors developed a virtual reality Stroop task that exposes individuals to an everyday-life or work-related environment. This approach might serve as one step towards more genuine experimental designs. In turn, these designs may elicit attentional processing mechanisms, which are more closely related to real-life situations for affected individuals in both TBI and PTSD. Consequently, improving the ecological validity of cognitive tasks will not only provide a more accurate picture of the underlying mechanisms in attentional processing in both medical conditions, but might also provide a more seamless translation between cognitive assessment (i.e., characterization of cognitive mechanisms or deficits) and rehabilitation approaches.

8. Conclusion

To this end, in this work we reviewed studies that assessed individuals with TBI, as well as those diagnosed with PTSD, on measures of sustained and selective attention to stimuli with neutral valence. Results of cognitive tasks measuring sustained attention suggest a shared deficit for TBI and PTSD, which is mainly characterized by a reduction in accurate task performance. Additionally, deficits in sustained attention for TBI are characterized by a general slowing in responses, as well as variability in RT and accuracy over time. In contrast to a shared

http://dx.doi.org/10.5772/57185

accuracy deficit in sustained attention for TBI and PTSD, the studies reviewed here point towards impairments in selective attention only observed for TBI as reflected by reduced levels of accuracy and slowing in RT. However, no behavioral deficits for selective attentional processing were found in PTSD. In order to unravel such specific cognitive processing mechanisms in TBI and PTSD, we strongly encourage the conduction of future studies explicitly considering the impact of factors, such as (1) the type of traumatic event, (2) lesion severity and lesion sites in TBI, and (3) comorbid occurring TBI and PTSD on behavioral and rehabilitation outcomes. We also see a need for studies focusing on cognitive processes in PTSD to neutral rather than only emotionally loaded stimuli. Our review proposes that shared and exclusive attentional processing deficits in TBI and PTSD should be considered when developing or improving already existing post-trauma treatment approaches.

Acknowledgements

The authors would like to thank Centre Interdisciplinaire de Recherche en Réadaptation et Intégration Sociale (CIRRIS), Quebec City, Canada, the Canada Research Chair in Cognitive Neuroplasticity, Laval University, and the Faculty of Psychology and Neuroscience, Maastricht University, Maastricht, The Netherlands for supporting this work.

Author details

Tobias Wensing[1,2], Jean Levasseur-Moreau[1,3,4], Alexander T. Sack[2,5] and Shirley Fecteau[1,3,4*]

*Address all correspondence to: shirley.fecteau@fmed.ulaval.ca

1 Centre Interdisciplinaire de Recherche en Réadaptation et Intégration Sociale, Canada

2 Faculty of Psychology and Neuroscience, Maastricht University, Maastricht, The Netherlands

3 Centre de Recherche Universitaire en Santé Mentale de Québec, Quebec, Canada

4 Medical School, Laval University, Quebec, Canada

5 Maastricht Brain Imaging Center, Maastricht University, Maastricht, The Netherlands

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