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A Preliminary Report on the Effects of Mild Traumatic Brain Injury on Spatial Attention

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Abstract

The objective of this investigation was to measure subtle disturbances in information processing after mild traumatic brain injury (TBI) for spatially presented stimuli as compared to a sample of control participants. Participants completed a temporal order judgment task requiring the correct identification of the order of two asynchronously presented stimuli that were precued either by a peripheral or central cue. Point of subjective simultaneity (PSS) scores demonstrated a dissociation in spatial attentional control. Specifically, deficits for the group with mild TBI were observed for peripheral cues, while volitional attentional control during the centrally cued task was spared, when compared with controls. These data suggest that peripheral distraction strongly captures attention, possibly making disengagement from that location difficult, whereas directed and volitional control over attention is largely spared, as indicated by indistinguishable PSS scores when compared with healthy controls after central cues.

Key words: mild traumatic brain injury, spatial attention, endogenous, exogenous, perception

Introduction

A blow to the head can result in a traumatic brain injury (TBI) and lead to a disruption in normal brain functioning. The provoking incident can result from a projectile or object striking and piercing the skull and directly damaging brain matter, or can occur without damage to the skull (i.e., closed head injury). An estimated 1.7 million Americans suffer a traumatic brain injury (TBI) each year (National Center for Injury Prevention and Control). Of this, three quarters are concussions or other forms of mild TBI. This creates a huge financial burden for both the medical system and those who have incurred a mild TBI, as quite frequently a myriad of persistent cognitive deficits can be observed after mild TBI (Schretlen & Shapiro, 2003).

Despite extensive research into mild TBI, little is known of the exact disturbances of cognition. This is, in part, due to the utilization of traditional assessments of human cognition (e.g., WAIS-R). While commonly used and theoretically sound, these types of cognitive assessment are generally more global and incapable of measuring *subtle* deficits of information processing (e.g., a modulation in exogenous or endogenous attention on the order of milliseconds).

Hall and Chapman (2005) recently discussed a number of cognitive deficits associated with mild TBI, and more importantly, how these participants perform on a number of paradigms designed to assess cognitive functioning. Specifically, these authors mention deficits in information processing speed, attention, and reaction time, as evidenced by difficulty with the Stroop color naming task (Lee, Lyketsos, & Rao, 2003; Stroop, 1935) and the 2 & 7 Processing Speed Test (see for example Cicerone & Azulay, 2002). While informative in their own right, neither of these tests is able to provide a precise measurement of specific mechanisms of attention or processing speed. For instance, the Stroop task is a classically used task that demonstrates the influence of an ignored stimulus, while the 2 & 7 Processing Speed Test purports to measure sustained attention (i.e., the ability to selectively attend to relevant stimuli and ignore irrelevant stimuli).

Cicerone and Azulay (2002) presented participants with mild TBI with cognitive dysfunction with a variety of traditionally used paradigms designed to measure cognitive functioning. Specifically, patients were given the Digit Span subtest from the Weschler Memory Scale (Wechsler, 1955), the Trail Making Test Parts A and B (see Reitan & Wolfson, 1986), the Paced Auditory Serial Addition Test (PASAT; see Diehr, Heaton, Miller, & Grant, 1998), the Continuous Performance Test of Attention (CPTA; Cicerone, 1997), the Stroop task, and the 2 & 7 selective attention test (Ruff & Allen, 1996). Interestingly, only certain tests resulted in significant differences when comparing mild TBI participants with normal healthy controls. Specifically, the authors claim that tests involving measures of processing speed (PASAT and CPTA) were most effective at exemplifying differences between mild TBI participants and controls.

While results such as those discussed above are indeed informative, upon a closer review of the cited works, the picture remains less clear as to exactly how other cognitive functions are affected. In a meta-analysis of 39 TBI investigations investigating 1716 patients, Schretlen and Shapiro (2003) show that cognitive functioning is interrupted to a greater degree after moderate-severe TBI when compared with mild TBI. While this is hardly surprising, this meta-analysis is important as it represents grouped data across a number of experiments that have assessed cognitive functioning after TBI. The overall conclusion was that cognitive functioning is affected more profoundly after moderate-severe TBI than mild TBI, while also suggesting that information processing and memory are interrupted after mild TBI.

Unfortunately, only a few of the studies reported in Schretlen and Shapiro's (2003) meta-analysis involved rigorous and precise measures of information processing. Moreover, the control groups among studies varied from normal participants, to injured controls, to self-controls. Further, the experimental measures differ greatly, therefore complicating the overall conclusions. For example, Borgaro et al. (2004) tested participants with the Barrow Neurological Institute Screen for higher cerebral functions (BNIS), which has more to do with patients' ability to correctly orient themselves rather than a precise measurement of information processing. Regardless of the potential difficulties in understanding the cognitive deficits associated with mild TBI, the representative research all supports the notion that cognitive functioning is adversely affected. Here, we extend this research to specific measures of information processing related to spatial and temporal attention in order to determine how attention might be adversely affected in the spatial domain.

In a further example, McMillan and Glucksman (1987) investigated cognitive functions with a battery of neuropsychological tests on 24 individuals with moderate TBI. This battery included sections from the WAIS-R. Memory was assessed using sections from the Weschler Memory Scale (Wechsler, 1955) and a reconstruction of the Rey-Osterreith Complex Figure test, while information processing was assessed with the PASAT. Despite this rather large battery of neuropsychological tests, mild TBI participants only differed on one section of the PASAT and on subjective reports of memory disturbances, again highlighting the notion that information processing is adversely effected, but that more precise measures are needed.

The PASAT is often used as a measure of auditory processing speed. However, it should be noted that this test involves simple arithmetic calculations of sequentially presented auditory numbers, and fails to directly measure actual processing speed. Therefore, while this test (and other widely accepted measures of cognition, i.e., the WAIS-R,) are well validated and accepted in the literature, it is possible that they measure only global disturbances of constructs of cognition such as memory, intelligence, and visuo-spatial processing. Subtle disturbances of specific mechanisms of attention, such as reflexive or volitional attention, manifested by a reduction in the ability accurately judge the temporal order of cued targets would not be captured by these types of neuropsychological tests. Therefore, the present research addresses this precise question. Specifically, what are, if any, the effects of mild TBI on the ability to process targets that have been peripherally or centrally cued. The results of McMillan and Glucksman's (1987) investigation further exemplify the need for this research. Indeed, even though their participants were moderately injured, they were still unable to observe consistent deficits in memory and information processing with a traditional battery of neuropsychological tests, suggesting that these tests would not be an adequate measure of information processing for mild TBI (Dikmen, Machamer, & Temkin, 2001; Gentilini et al., 1985; Goldstein, Levin, Goldman, Clark, & Altonen, 2001).

Given the limited capacity of the human attentional system, a subset of incoming stimuli must be selected for goal driven behavior to proceed. Generally speaking, attention is oriented to a spatial position either exogenously (i.e., involuntary, stimulus-driven) or endogenously (i.e., voluntary, goal-driven; see Theeuwes, 2010). We presented participants with mild TBI and healthy normal controls with a classic paradigm; the temporal order judgment task (TOJ), and included either peripheral or central (i.e., exogenous or endogenous) cues. Participants were required to determine the presentation order of two successively presented targets. Accuracy data from this task can be used to measure the amount of time that two events can be separated from each other for the observer to still perceive them as asynchronous events, also referred to as the point of subjective simultaneity (PSS). Importantly, the targets were either non-predicatively cued by either a peripheral flashing box, or central arrow. Therefore, the distracting cue leads to a shift in spatial attention, requiring the non-cued side to be presented before the cued side for the participant to perceive them as being presented simultaneously (i.e., the PSS score; see Spence, Shore, & Klein, 2001; West, Stevens, Pun, & Pratt, 2008). If a disturbance of spatial attention is manifested in participants with mild TBI, then it is likely that the cue will not capture or direct attention as efficiently as it would with uninjured control participants. This could lead to smaller PSS scores when comparing patients with controls. Conversely, it is possible that the group with mild TBI might have trouble disengaging from the cue, thereby leading to higher PSS scores.

Method

Participants

A total of eight mild TBI participants (3 female, average age 35, SD=16, average years of education 17) were recruited via class announcements and posters at the University of Hawaii at Manoa. Participants self-presented as having had a medical professional diagnose them with a mild TBI within the past four months (average time since injury 80.1 days). They were either paid $5 for their time, or were given course credit. An additional 10 control participants (5 female, average age 22, SD=5, average years of education 15.5) were recruited using the same mechanisms.

Materials

The stimuli were presented on a 2.66 GHz Intel Core 2 Duo Apple/Windows (dual boot) iMac with a 20" screen using DMDX Version 3.2.6.6 software (Forster & Forster, 2003). Observers sat approximately 60 cm from the computer monitor. Participants made a key press response with the "Z" and "/" keys on the computer keyboard to make "horizontal target first" and "vertical target first" responses, respectively. Each trial contained placeholders (2 mm x 2 mm) in the periphery of the screen with a thickness of 1 mm, separated by 10.5 cm. The horizontal stimulus had a width of 1 cm and a height of 1 mm. The vertical stimulus was identical, but rotated 90 degrees.

Procedure

The display for both the peripheral and central cue conditions consisted of two boxes and a fixation cross that remained on the screen throughout the trial. As can be seen in Figure 1, a non-predictive cue for peripheral trials was presented by thickening the placeholder box from 2 to 8 pixels immediately following a pre-cue interval of 1000 ms. After 45 ms the box returned to its original size. Each peripheral location (left and right box) was equally likely to be cued. The first target stimulus (either a horizontal or vertical line) was presented in one of the placeholder boxes, after which the second stimulus was presented in the other box at stimulus onset asynchronies (SOAs) contingent on the previous trial's response (see the description of the step-function design below for SOAs). Participants pressed the "Z" key to indicate that the "horizontal target" appeared first, or the "/" key if they thought the vertical line had appeared first. Both stimuli had an equal chance of being cued, of appearing in either the left or right boxes, and of being presented first. The central cue condition was identical with the exception that an arrow was displayed in the middle of the display instead of a box brightening in the periphery. The peripheral and central conditions were presented separately and counterbalanced.

An adaptation of Stelmach and Herdman's (1991) step-function procedure was used (see also West et al., 2008). Participants began with an SOA of 267 ms that would increase or decrease depending on whether the participant made a correct or incorrect response. On trials where an invalid cue was presented and a correct response was made, the SOA would decrease by one screen refresh rate (16.7 ms). Accordingly, the SOA would increase a screen refresh if an incorrect response was given. The experiment was terminated when a total of fourteen correct/incorrect reversals were recorded.

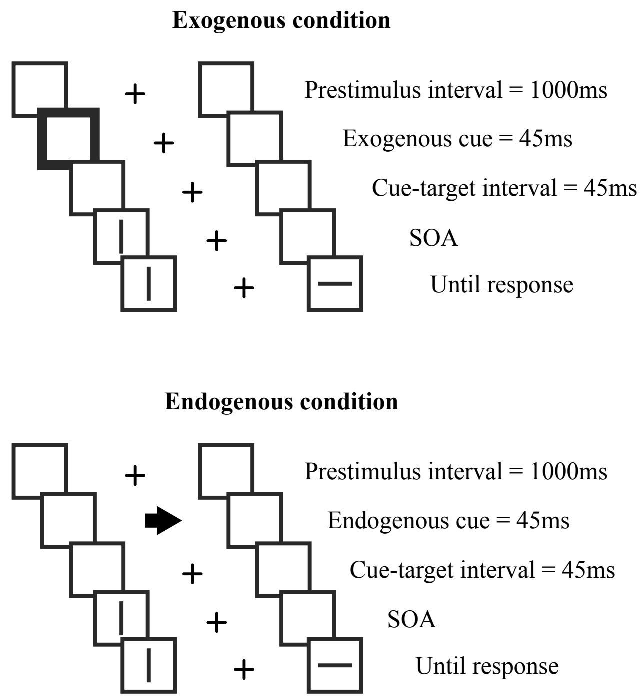

Figure 1. Stimuli and procedure for the TOJ tasks. On each trial participants were presented with two placeholder boxes on either side of fixation. After 1000 ms one randomly chosen placeholder (or a central arrow) was cued for 45 ms. Following a cue-target interval of 45 ms, the onset of either stimuli occurred in one of the placeholders. The onset time of the second stimulus was determined by the step-function procedure.

Results

The PSS was calculated by averaging the SOA of the last six turning points in the staircase design (for review of methodology, see Dixon, 1991) in order to determine the minimum amount of time that the uncued item needed to appear before the cued item in order for both items to be perceived as appearing on the screen simultaneously.

A mixed-design ANOVA was conducted on the PSS scores with task type (peripheral or central cues) as the within subjects factor and participant type (mild TBI or control) as the between subjects factor. There was a significant main effect of task type F (1,16) = 16.1, p < .01 and participant type F (1,16) = 7.7, p < .01. The interaction was also significant F (1,16) = 8.5, p < .01. Planned t-test comparisons as well as Bonferroni corrected post hoc tests demonstrated that the PSS score for peripheral cues was larger than the PSS for central cues for both mild TBI (156 ms vs. 49 ms, t(7) = 3.24, p < .01) and healthy control groups (65 ms vs. 48 ms, t(9) = 1.96, p < .05; see Figure 4). Lastly, and perhaps most importantly, PSS values for peripheral cues were significantly larger for the group with mild TBI (156 ms) when compared with the controls (65 ms, t(2.83) = 7.2, p < .01) while there was no difference between participants with mild TBI and the healthy controls for central cues (49 and 48 ms respectively, p > .5; see Figure 2).

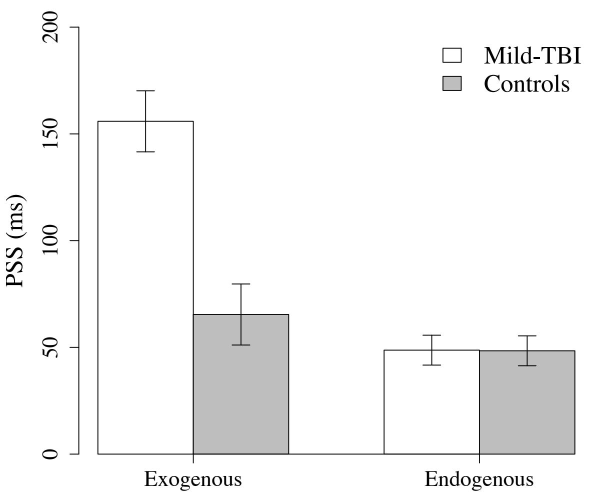

Figure 2. Average PSS scores for the exogenous (peripheral cues) and endogenous (central cues) conditions for both persons with mild TBI and healthy controls.

As highlighted in Figure 3, in the exogenous (peripheral) condition, all but one person with mild TBI fell outside of the 99% confidence intervals, which are based on the performance of the control participants. In this case, confidence intervals varied from 52.5 ms to 78.4 ms. For the central endogenous condition, confidence intervals based on the PSS for the control data was 19.4 ms to 77.5 ms. Opposite of the performance for peripheral cues, all but one person with mild TBI scored within the confidence interval of the controls.

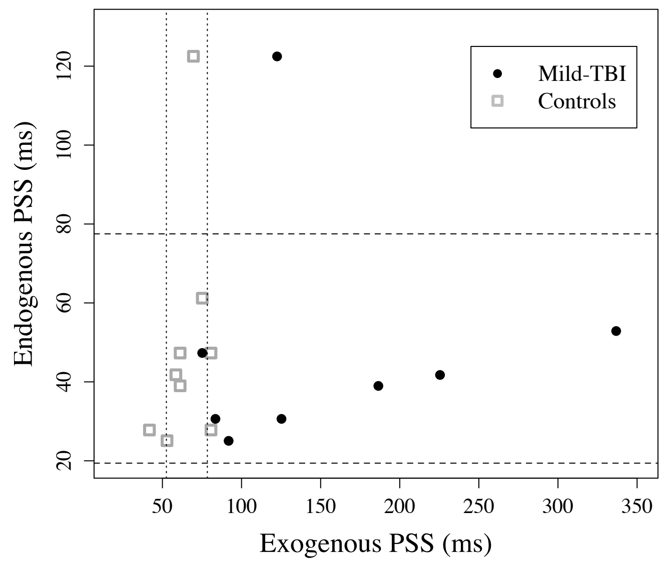

Figure 3. Exogenous (x-axis) and endogenous (y-axis) PSS scores in the TOJ task for each person with mild TBI and control participant. The area defined by the dotted vertical lines represents the 99% confidence interval for normal performance in the exogenous task based on the control data, and the area defined by the dotted horizontal lines similarly represents the 99% confidence intervals for the endogenous task.

Discussion

These results suggest that the participants with mild TBI have an interesting dissociation in performance when compared with healthy controls. This is demonstrated by equivalent performance for non-predictive central cues on the one hand, and clear deficits for the peripheral cues on the other. That is, the group with mild TBI had a greater propensity for attentional capture by peripheral cues indicated by much higher PSS (156 ms) when compared with the control group (48 ms).

The dissociation in PSS scores is of key importance for two reasons. First, it suggests that peripheral and central cues are governed by separate mechanisms (i.e., automatic vs. volitional). This notion is further supported by the findings for the control group, as peripheral cues had a larger effect on the PSS than central cues. These findings are also of particular interest given the short cue-to-target interval (45 ms) used for both the peripheral and central conditions, as typical central cuing effects require a much longer interval (see for example Jonides, 1981). For instance, in Spence et al.'s (2001; see also Shore, Spence, & Klein, 2001) seminal study, the peripheral condition had a 60 ms cue-to-target interval, while the central arrow condition had an interval of 405 ms.

The second important point of discussion arising from this dissociation is that it argues against the possibility that the cue (central or peripheral) is simply found to be more distracting or that the mild TBI participants have trouble disengaging from the cue. This would be similar to a purported mechanism explaining hemispatial neglect relating to these patients' inability to disengage from ipsilesionally presented stimuli (see Posner, Walker, Friedrich, & Rafal, 1984; Posner, Walker, Friedrich, & Rafal, 1987; but see also Pellegrino, Basso, & Frassinetti, 1997). Specifically, Posner et al. (1984; 1987) suggested that patients with brain lesions leading to hemispatial neglect take longer to respond to contralesional stimuli due to attention being directed first, and captured by ipsilesional stimuli. It is possible that in the peripheral cue condition here, mild TBI participants' attention was captured by the cue and subsequently they had difficulty disengaging attention. This could also be explained by a winner takes all attentional account (see Desimone & Duncan, 1995) with attentional resources being utilized in detecting and processing the peripheral cue. However, this does not seem to be the case for the central cue, as participants with mild TBI had *identical* PSS scores, suggesting that the directional information afforded by the cue was used equivalently by both the group with mild TBI and the control participants.

The neurological underpinnings of mild TBI have only recently been explored, but illuminate a potential reason for a slowdown in information processing speed. As normal CT imaging accompanies the cognitive deficits in mild TBI, diffusion tensor imaging (DTI) appears to be better suited for measuring the involved brain damage. In an exploratory study by Bazarian et al. (2007) it was noted that diffuse axonal injury (DAI) seems to play a critical role in the deficits observed after mild TBI. Accordingly, the degree of DAI could be related to the severity of cognitive deficits. Indeed, Niogi et al (2008) recently looked at the amount of white matter damage in a group of participants with mild TBI and correlated this damage to motor response time. Critically, more extensive DAI was correlated with a slowing of response speed. This reduction in processing speed could result in a number of cognitive deficits, including but not limited to deficits in processing spatial (both central and peripheral) cues (see for example Crawford, Knight, & Alsop, 2007; De Monte et al., 2005). A future consideration could correlate the severity of DAI in individuals with mild TBI with the degree to which attention is either captured or directed in this task.

As this pilot study was exploratory in nature, there are a number of things that should be considered. For instance, we allowed a relatively long post-injury period (4 months) for inclusion in the study. It could be argued that any cognitive deficits after mild TBI are transient and unlikely to be observed after such a long time. However, a similar time period was recently used by Levin et al. (2008), who correlated white matter damage in children suffering mild TBI (3 months post-injury) with cognitive functioning using a Flanker task (Eriksen & Eriksen, 1974). A second potential concern is that participants self-reported the mild-TBI. Although a requirement that this diagnosis was first confirmed by a medical doctor, medical records were not accessed in this pilot study to confirm this diagnosis. However, it should be noted that despite this limitation, it is apparent that the group with mild TBI performed significantly differently from the control group, confirming the veracity of the participants' claims. Lastly, the average age of the control group was much younger than that of the group with mild TBI. While future research will include the appropriately age matched group, it is important to note again that performance was equivalent for the endogenous condition, therefore suggesting that the observed dissociation is likely to be attributable to the disturbances in information processing associated with the mild TBI, as opposed to any group difference based on age.

These preliminary findings demonstrate a disruption in attention after mild TBI. It is apparent that reflexive attention appears adversely affected when using peripheral cues, while no differences were seen between groups for central cues. This dissociation would indicate that after mild TBI the attentional system has difficultly disengaging attention after being exogenously captured, while nevertheless maintaining normal levels of volitional control over endogenous orienting. Lastly, and perhaps most importantly, the present findings demonstrate the need for future research involving precise measurements of information processing.

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