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Attentional deficits in concussion

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Abstract

Primary objective: The purpose of the present study was to examine deficits in the alerting, orienting and executive components of attention in individuals who have recently suffered a concussion.

Research design: A group design was used in which the performance by individuals with concussion was compared to control subjects matched for age, height, weight and activity level.

Methods and procedures: Participants completed the Attentional Network Test (ANT) that breaks down attention into alerting, orienting and executive components. Reaction time and response accuracy were the dependent variables.

Main outcomes and results: It was found that only the orienting and executive components of attention were affected by concussion, whereas the alerting component was normal. Furthermore, participants with concussion required a significantly longer time than controls to initiate correct responses.

Conclusions: These results suggest that the orienting and executive components of attention are most susceptible to the effects of concussion.

Keywords: *Concussion, attention, ANT, reaction time*

Introduction

Concussion has been defined as any transient neurological dysfunction resulting from a biomechanical force to the head [1]. Even with this mild form of brain injury there is evidence that substantial damage can occur resulting in focal lesions and/or diffuse axonal injury [2–5]. While loss of consciousness and post-traumatic amnesia are considered hallmarks of concussion, the *alteration* of consciousness has been regarded as sufficient for a diagnosis of this condition [6].

People suffering a concussion commonly display attentional deficits. In particular, previous studies have revealed difficulties associated with maintaining and distributing attention within and between tasks in patients with concussion [7–14]. Attention itself can be broken down into several different components that can be mapped onto specific circuits within the brain. Posner [15] originally suggested that the spatial orienting of attention is comprised of disengagement, movement and reengagement processes. Clinical studies in patients with brain damage and functional imaging studies in healthy subjects have demonstrated that these different attentional components engage portions of the parietal, frontal, temporal and cingulate cortices and mid-brain in various combinations [16]. For example, lesions to the parietal lobe, but not to the frontal or temporal lobes or mid-brain, result in deficits in the disengagement of attention from cued locations [17, 18]. By contrast, the movement and re-engagement of attention is thought to be mediated by activity in the superior parietal lobule and intra-parietal sulcus of the posterior parietal cortex, the frontal eye fields and cingulate gyrus [19–22].

In the models of attention put forth by Mesulam [23] and Heilman and Van Den Abell [24] components related to arousal, searching and stimulus value are also included in addition to the

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disengagement, movement and reengagement processes. As with the Posner model, evidence from clinical and brain imaging studies has demonstrated that these different components map onto specific sets of brain areas. Of particular relevance to the current study, the searching component engages several portions of the pre-frontal cortex [25], including the dorsomedial and ventrolateral pre-frontal areas [26].

Given the specificity of certain brain regions to the different aspects of attentional processing, it may be possible to gain insight into the relationship between functional deficits following concussion and the areas of the brain that are most susceptible to the injury process. The present experiment attempted to address this relationship by using the Attentional Network Test (ANT) recently developed by Fan et al. [27] to probe the effects of concussion on the alerting, orienting and executive components of attention. The alerting component of attention is associated with the ability to maintain vigilance or arousal during continuous task performance. The orienting component of attention contributes to the ability to covertly direct visual or other sensory processing resources to a particular region of space so that targets that subsequently are presented there are detected more quickly and/or more accurately. Finally, the executive component of attention allows one to switch between different task demands easily and resolve contextual conflict appropriately. It is typically probed in experimental settings using the Stroop or flanker task or set-switching tasks. By using the ANT, one was able to examine the extent to which the general attentional deficits typically noted in concussion participants were due to dysfunction in one or more of these specific attentional components. Portions of the research have appeared previously in abstract form [28].

Methods

Participants

Twenty participants with concussion (12 males, eight females; mean age: 21 ± 1.74 years (age range: 18–24 years); education: 16 ± 1.65 years) were recruited from the University of Oregon undergraduate student community. All were involved in inter-collegiate, club or intra-mural sports or recreational activities. They were initially identified by Certified Athletic Trainers and/or attending medical doctors in the university inter-collegiate athletic programme or the student health centre and were referred for testing within 2 days (mean elapsed time: 37 ± 11.5 hours; range: 12–50 hours) following the concussion. The cause of the concussion varied from impacts to the head occurring during football games to accidents while participating in recreational sports and falls (see Table I). Each of the participants were categorized as having a Grade 2 concussion according to the standards established by the American Academy of Neurology. For a Grade 1 concussion, participants had to be disoriented as to time and place for less than 15 minutes; whereas for a Grade 2 concussion the disorientation could last longer than 15 minutes. Participants who sustained a Grade 3

Table I. Demographic data in 20 subjects after mild concussion.

Subject	Age (years)	Gender	Height (cm)	Weight (kg)	Time since injury (hours)	Sport activity	Cause of injury
1	23	M	203	121	46	Basketball	Knee to head
2	19	M	194	89	24	Football	Helmet to helmet
3	23	M	180	79	24	N/A	Fall
4	22	M	187	109	42	Football	Helmet to helmet
5	19	F	171	89	46	Rugby	Knee to head
6	21	M	172	72	43	Tennis	Blunt injury
7	20	F	172	69	50	Volleyball	Fall
8	20	M	190	128	43	Football	Helmet to helmet
9	22	M	191	100	48	Football	Knee to helmet
10	18	F	164	70	12	N/A	Fall
11	22	F	169	65	48	N/A	Fall
12	19	F	165	61	36	Soccer	Head to head
13	21	F	153	73	45	N/A	Bicycle accident
14	18	F	174	72	42	N/A	Blunt injury
15	23	M	164	56	38	N/A	Fall
16	22	M	194	145	41	Football	Helmet to helmet
17	21	M	196	140	28	Football	Knee to helmet
18	21	M	186	94	48	Rugby	Head to head
19	20	M	157	64	20	N/A	Fall
20	24	F	172	47	20	N/A	Fall

concussion, defined by a loss of consciousness for any period of time, and participants who had suffered a previous concussion within the last 6 months were excluded from the study. Control participants from the same undergraduate student population matched for age (mean age: 21 ± 1.81 years (age range: 18–24)), gender (12 males, eight females), activity (e.g. football players were matched with teammates who played the same position) and education level (16 ± 1.68 years) to individual participants with concussion were also tested. All of the participants signed an informed consent form prior to partaking in the study and the local university human subjects compliance committee approved the experimental protocol.

Testing procedures

All participants completed the Attentional Network Test (ANT). The ANT was recently developed by Fan et al. [12] as an efficient method for examining the alerting, orienting and executive components of attention. During the ANT, participants sat facing a computer monitor located ~50 cm away on which visual targets subtending ~1° of visual angle were presented. Figure 1(a) displays the general features

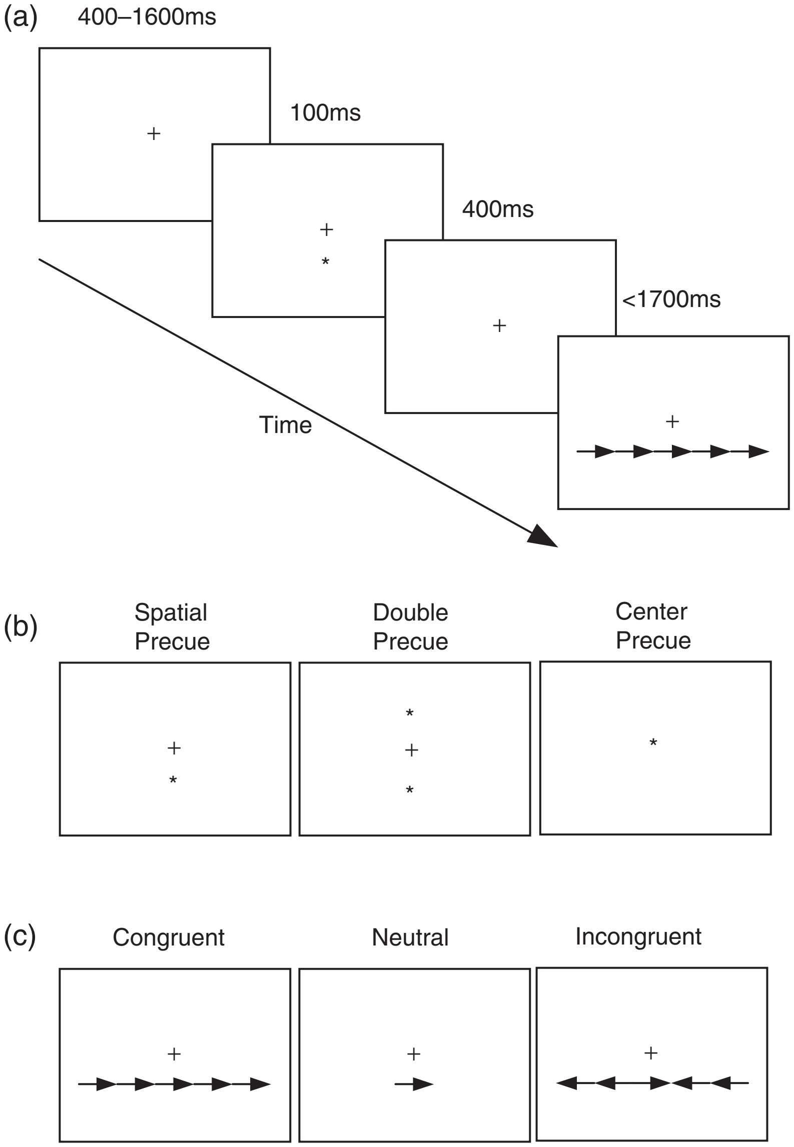

Figure 1. Visual events occurring during the trials. (a) Sequence of events in a typical trial. +, fixation cross; *, pre-cue; arrows, target. Participants responded to the appearance of the central arrow by pressing the corresponding button on the mouse with the appropriate index finger. In this example, the right mouse button would be pressed with the right index finger. (b) Pre-cue configurations. Left, spatially informative pre-cue; middle and right, spatially uninformative pre-cues. On some trials, no pre-cue was given. (c) Target configurations. Left, congruent targets; middle, neutral target; right, incongruent targets.

of a typical trial. Each trial began with the appearance of a central fixation cross. On some trials a pre-cue (an asterisk) would briefly (100 ms) appear after a variable delay (400–1600 ms). On other trials no such pre-cue appeared. After a subsequent constant delay (400 ms), a target arrow pointing either to the left or right would appear either 5° above or below the central fixation cross. The participants were required to respond as quickly and accurately as possible to the appearance of the arrow by pressing the left or right mouse button, respectively, with the left or right index finger. The target arrow remained visible until the subject responded or for 1700 ms, whichever came first.

During trials with a 'spatial pre-cue' the asterisk appeared at the location at which the target arrow subsequently appeared (i.e. it was always valid). During trials with a 'double pre-cue', an asterisk appeared both 5° above and 5° below the central fixation target. Finally, in trials with a 'centre pre-cue', the asterisk appeared on top of the central fixation point. In addition to the manipulation of the pre-cue, the target arrow itself could appear in isolation ('neutral' trials) or surrounded by flanker arrows of the same size (two to the left and two to the right of the target arrow). During 'congruent' trials, these flanker arrows pointed in the same direction as the target arrow, whereas during 'incongruent' trials the flanker arrows pointed in the opposite direction to the target arrow.

Prior to data collection, each subject completed a series of 24 practice trials during which visual feedback was provided concerning reaction time and response accuracy. The practice trials were followed by three blocks of experimental trials each containing 96 trials (4 cue conditions × 2 target locations × 2 target directions × 3 flanker conditions × 2 trials). The experimental trials were presented in a pseudo-randomized order without any visual feedback.

Data analysis

The median reaction time on accurate trials and error rate were the main dependent variables of interest. Reaction time was defined as the period of time from the appearance of the target arrow to when the mouse button was pressed. Error rate was defined as the percentage of trials within a condition that the subject completed incorrectly (i.e. by pressing the inappropriate mouse button). In computing the effects associated with the alerting, orienting and executive components of attention, the logic set out by Fan et al. [12] was followed. In particular, the alerting effect was calculated by subtracting the median reaction time during trials with a double pre-cue from the median reaction time during trials with no pre-cue. It is important to note that the three different target types (i.e. congruent, incongruent, neutral) were equally represented in trials with each of these different pre-cue conditions. This difference provided an index of the savings in reaction time associated with knowing when (400 ms later) the target arrow would appear. Although the spatial pre-cue also provides information about when the target arrow will appear, in addition it cues the subject about where the target will appear and, therefore, does not isolate processing associated with the alerting effect. The orienting effect was calculated by subtracting the median reaction time during trials with a spatial pre-cue from the median reaction time during trials with a centre pre-cue. Again, the three different target types were equally represented in trials with each of these different pre-cue conditions. Because both the centre and spatial pre-cues provided alerting information, the difference in RT in these conditions probed the benefit in reaction time associated with knowing where the target arrow would appear. Finally, the executive component of attention was calculated by comparing the median reaction time during trials with congruent vs incongruent trials. For this component, the different types of pre-cues (i.e. no pre-cue, spatial pre-cue, double pre-cue and centre pre-cue) were equally represented in trials with each of these target types. This difference assesses the influence on reaction time of the ability to make use of or ignore the surrounding arrows. *T*-tests and analyses of variance were used to examine the potential differences within each measure across the different conditions.

Results

Figure 2 displays the main results for median reaction time in each of the conditions. The top bar graph shows the overall median reaction time for all the different combination of conditions in both the control and concussion participants (Figure 2(a)). A *t*-test revealed a significant difference in the median reaction times between the two groups, with concussion participants being slower than controls (*t*-test, $p < 0.05$). The three rows of graphs below this show the results for the alerting, orienting and executive components of attention, respectively. The left hand graphs show the median reaction times in the relevant conditions comprising the effect and the right hand graphs show the size of the effect as a percentage of the overall median reaction time for each group. This latter calculation was performed to provide an assessment of the magnitude of the effect relative to the general speed with which the participants in each group reacted to the appearance of the targets.

The median reaction times in the double pre-cue and no pre-cue conditions comprised the alerting

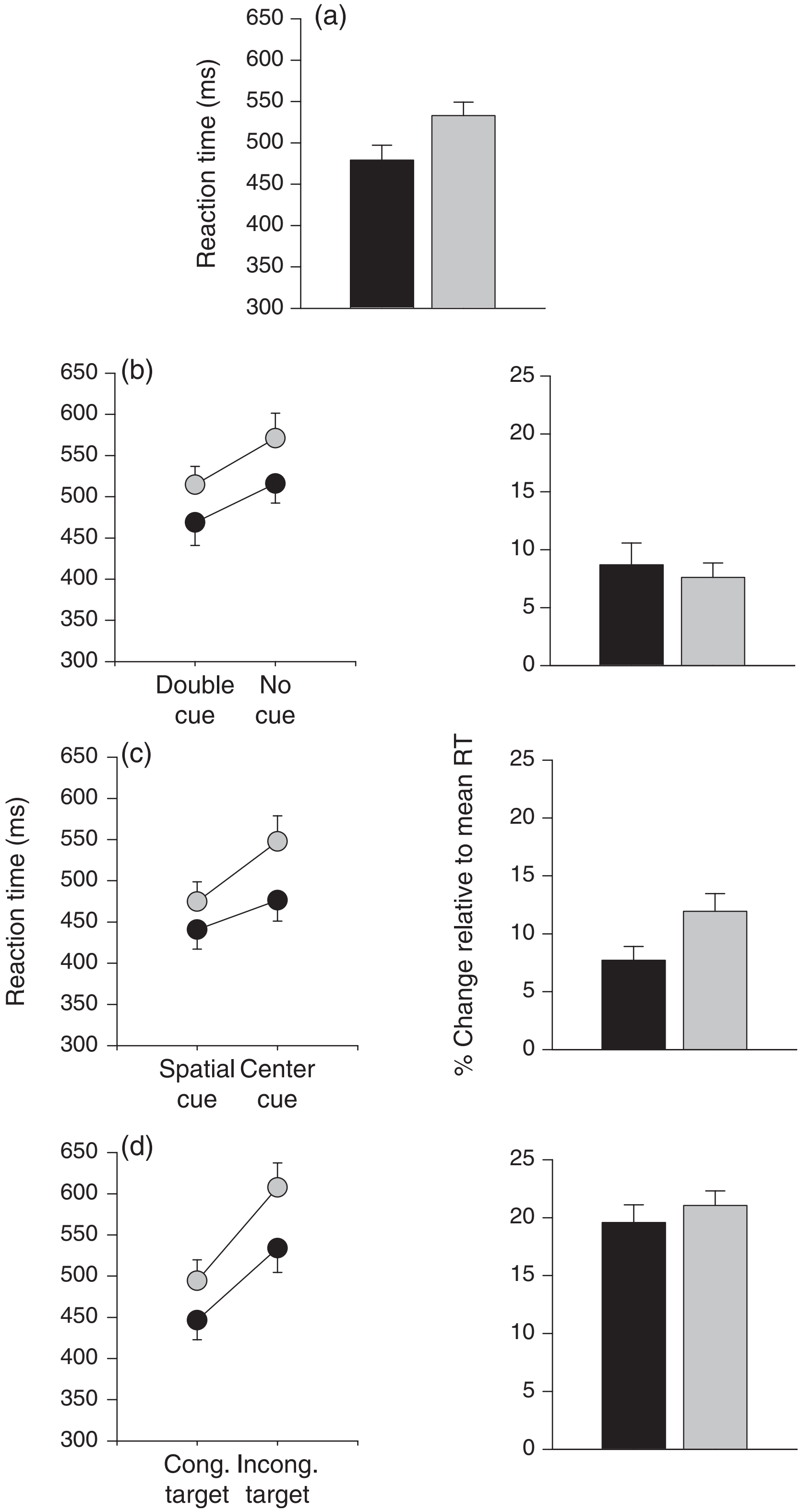

Figure 2. Group means for median reaction time in the various conditions for the control (black symbols/bars) and the concussion participants (grey symbols/bars). (a) Median reaction time across all combinations of conditions. (b) Alerting effect. Left, median reaction time in the double cue and no cue conditions. Right, median reaction time difference in double cue and no cue conditions relative to overall median reaction time. (c) Orienting effect. Left, median reaction time in the spatial cue and centre cue conditions. Right, median reaction time difference in spatial cue and centre cue conditions relative to overall median reaction time. (d) Executive effect. Left, median reaction time in the congruent target and incongruent target conditions. Right, median reaction time difference in congruent target and incongruent target conditions relative to overall median reaction time. Error bars, 1 inter-subject SE.

effect (Figure 2(b), left). Providing a pre-cue appeared to shorten the median reaction time in both the control and concussion participants by alerting them to the time at which the target arrow would appear. A 2 (subject group) × 2 (pre-cue condition) mixed model ANOVA revealed a significant group ($F[1, 60] = 4.9$, $p = 0.031$) and condition effect ($F[1, 60] = 7.63$, $p = 0.008$). However, the interaction between these two variables was not significant. This indicates that the participants with concussion were slower overall in trials with these two pre-cues and that both groups of subjects were slower when no pre-cue was available to alert them to the upcoming appearance of the target arrow. It is possible that this result could be due to either an under, or an over-estimation of the relative effect size due to differences in the overall reaction times across the two groups (Figure 2(a)). To test for this, the alerting effect size was computed relative to the overall median reaction time for both the control and concussion groups (Figure 2(b), right). A *t*-test on this data confirmed that no significant group differences existed (*t*-test, $p > 0.05$). Thus, suffering a concussion does not appear to differentially alter the ability to make use of an alerting pre-cue to reduce reaction time.

The median reaction times in trials with the spatial pre-cue vs. the centre pre-cue provided the data necessary for computing the orienting effect (Figure 2(c), left). Both groups demonstrated an increase in median reaction times when only the centre pre-cue was provided. This increase appeared to be larger, however, in the participants with concussion. A 2 (subject group) × 2 (pre-cue condition) mixed model ANOVA revealed a significant group ($F[1, 60] = 4.56$, $p = 0.038$) and condition effect ($F[1, 60] = 6.93$, $p = 0.012$) as well as a significant interaction between these two variables ($F[1, 60] = 4.1$, $p = 0.048$). The fact that this was not just due to the slower overall reaction times in the participants with concussion is demonstrated by the significant difference (*t*-test, $p < 0.05$) between concussion and control participants in the orienting effect when it is expressed as a percentage of the overall median reaction time for each group (Figure 2(c), right). Thus, without the information provided by the spatial pre-cue, participants with concussion took a disproportionately longer time to move attention from the central fixation point, search alternative spatial locations and re-engage attention at the appropriate location.

The executive component of attention was computed from the median reaction time in trials with congruent and incongruent target configurations (Figure 2(d), left). In both subject groups, the median reaction times were faster when the target configuration was congruent compared to when it was incongruent. A 2 (subject group) × 2 (pre-cue condition) mixed model ANOVA revealed a significant group ($F[1, 60] = 5.04$, $p = 0.021$) and condition effect ($F[1, 60] = 26.65$, $p < 0.001$). However, the interaction between these two variables was not significant. Indeed, when computed as a percentage of the overall median reaction time for each group (Fgure 2(d), right) there was no significant difference in the effect size between the participants with concussion and controls (*t*-test, $p > 0.05$). Thus, participants with concussion showed a similar congruency effect to the controls.

Although there were not any differences in the executive component between participants with concussion and controls when overall reaction times were taken into account, group differences were apparent when comparing median reaction times during accurate vs inaccurate responses. This was most apparent in trials with the incongruent target configuration where error rates were the highest (error rates were not systematically affected in the conditions probing either the alerting or orienting effects and will not be considered here). Figure 3(a) displays the error rates for each subject group during trials with incongruent target configurations. Although the control participants had a tendency to be more accurate, the difference between the groups was not significant (*t*-test, $p > 0.05$). Figure 3(b) displays the median reaction times for accurate and inaccurate responses during trials with either target configuration for both subject groups. It is apparent that generating accurate responses took disproportionately longer for the participants with concussion than in the controls. A 2 (subject group) × 2 (response accuracy) mixed model ANOVA revealed a significant effect of response accuracy ($F[1, 52] = 21.9$, $p < 0.0001$) and a significant interaction between subject group and response accuracy ($F[1, 52] = 5.31$, $p = 0.026$). The significant interaction confirms that the latency cost for generating accurate responses was substantially larger in the participants with concussion than in the controls. Thus, a closer analysis of the response characteristics in trials probing the executive component of attention suggests that concussion produces a subtle yet systematic effect on this aspect of attention.

Discussion

This report has used the Attentional Network Test (ANT) to examine the extent to which different aspects of attentional processing are influenced by concussion. It has demonstrated that the alerting component is unaffected by concussion; the executive component is partially influenced; and the orienting component is substantially affected.

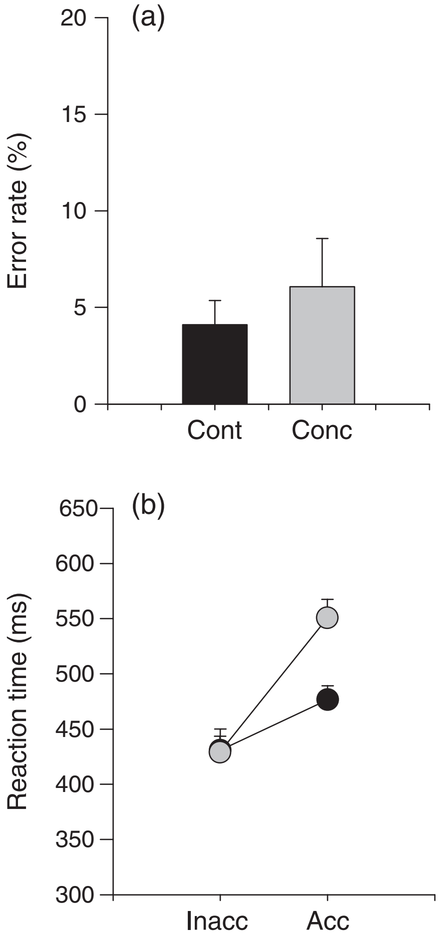

Figure 3. Influence of response accuracy on reaction times in trials testing the executive effect. (a) Mean error rate in trials with the incongruent target configuration. (b) Mean reaction time during accurate and inaccurate trials with both types of target configurations. Black symbols/bars, control participants; grey symbols/bars, concussion participants; error bars, 1 inter-subject SE.

The following will discuss how the results compare to previous studies examining attentional deficits following concussion and attempt to elucidate how these deficits may relate to the function in specific regions of the brain.

The alerting component of the ANT probes the ability to use a pre-cue that provides information about when a response should occur. The benefit associated with the pre-cue provides an index of the state of what has been termed 'phasic alertness' in the subject [29]. Participants with concussion in the present study displayed the same reduction in reaction time associated with the appearance of the pre-cue as control subjects, suggesting that the alerting component of attention is unaffected by this mild form of TBI. This finding is consistent with previous measures of this and similar aspects of attention in participants with concussion [7–11]. This implies that the mechanical forces imparted on the brain in mild concussion do not influence those areas of the brain that function to maintain alertness or arousal during task performance (i.e. the ascending noradrenergic system arising from the locus coeruleus in the brainstem [29]).

The orienting component of attention reflects the ability to use a pre-cue that provides spatial information about the location of a subsequently appearing target. The benefit to reaction time is thought to reflect the fact that attention can be moved to and engaged at the location prior to the appearance of target [15]. It was found that participants with concussion were disproportionately slow in responding when this spatially relevant pre-cue was unavailable. This suggests that concussion affects the ability to move attention from the central fixation point, search alternate locations for the target and re-engage attention at the appropriate location to respond to the target stimulus. This is broadly consistent with the results from previous studies examining attentional deficits in concussion, although these have tended to use tasks that probe the orienting component only indirectly [7–14]. Nevertheless, the evidence suggests that concussion affects those parts of the brain that are involved in the process of orienting attention in space. For the movement and re-engagement components of this aspect of attention, these areas include regions of the superior parietal lobule and intra-parietal sulcus of the posterior parietal cortex, the frontal eye fields and cingulate gyrus [19–22]. By contrast, the searching component appears to engage several portions of the pre-frontal cortex [25], including the dorsomedial and ventrolateral pre-frontal areas [26].

Finally, the executive component of attention probes the ability of participants to make use of relevant stimuli or ignore irrelevant stimuli during task preparation. Participants with concussion in the present study displayed disproportionately longer reaction times when they were exposed to the distracting stimuli during incongruent trials. This finding is consistent with previous studies probing the effects of distractibility in participants with concussion [7, 8, 10]. The ability to ignore distracting and irrelevant stimuli mainly engages the anterior cingulate cortex (ACC) [30–32]. As with the orienting effect, the fact that participants with concussion displayed a deficit in the executive component of attention suggests that the ACC may be particularly susceptible to functional damage as a result of a head impact.

In conclusion, it has been demonstrated that the executive and orienting components of attention are particularly susceptible to the effects of concussion. By contrast, the alerting component appears to be relatively immune to this injury. Because these components of attention engage different areas of the brain, it is speculated that concussion can affect the function in certain brain regions more markedly than in others. Future studies making use of brain imaging techniques in individuals who have recently suffered a concussion will provide further insight into this possibility. Taken together, such studies could be used to better refine the diagnosis and potential treatment of concussion.

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