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The association between a history of concussion and variability in behavioral and neuroelectric indices of cognition

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ABSTRACT

Associations between a history of concussion and variability in behavioral and neuroelectric indices of cognition were assessed in college-aged adults with a history of concussion and a healthy control group, in response to a stimulus discrimination task and a more attentionally demanding flanker task. Greater intra-individual variability was observed only for behavioral indices of reaction time in response to the flanker task for those with a history of concussion. An association was also observed between the number of concussions resulting in a loss of consciousness and greater variability of reaction time regardless of the type of task. Relative to neuroelectric measures, a concussive history was associated with smaller P3 amplitude only in response to the flanker task; with no differences between groups observed in response to the oddball task or for intra-individual variability measures. Thus, increased variability associated with a history of concussion appears to be behavior and process specific. The behavioral metrics and functions assessed are important considerations for identifying subtle, yet persistent influences of concussion on cognitive performance. Further, factors such as loss of consciousness associated with a concussive injury may moderate the extent to which these increases in behavioral variability manifest. Thus, the identification of persistent cognitive impairment following concussive injuries necessitates the utilization of appropriate tasks and may be facilitated by going beyond behavioral measures of central tendency.

1. Introduction

Sport-related concussions represent a growing public-health threat with conservative estimates indicating that nearly 4 million concussive injuries occur annually (Langlois et al., 2006) and account for almost 9% of all high school sport-related injuries (Gessel et al., 2007). While concussion related symptoms appear to resolve within 10 to 14 days in acutely injured individuals (McCrea et al., 2009; McCrory et al., 2013), a number of concussion-related patterns of neurocognitive impairment appear to persist well beyond this time frame (Giza and Hovda, 2001; Halterman et al., 2006; Howell et al., 2013; Sozda et al., 2011). Indeed, previous research has observed persistent decrements in neurocognition for years following concussive injuries (de Beaumont et al., 2007; Moore et al., 2014). Despite such findings, the long-term influence of concussion on neurocognition remains unclear as a number of investigations have failed to observe any persistent concussion-related cognitive impairments (Broglio et al., 2006; Collie et al., 2006; Iverson et al., 2006). Such discrepancies are not altogether unexpected, given the heterogeneous nature of concussive injuries, coupled with a wide variety of performance metrics and cognitive functions evaluated within the literature (Bigler et al., 2013; Livingston et al., 2010; McKinlay, 2010). Furthermore, the vast majority of previous investigations on the cognitive ramifications of concussive injury have relied only on central tendency measures (i.e., mean) of performance.

Beyond measures of central tendency, assessment of the transient within-person fluctuation in cognitive processing during the course of a task – known as intra-individual variability (Fjell et al., 2009; Lovden et al., 2007, 2013) – may provide another index of cognitive function for the assessment of persistent concussion-related decrements. Measures of intra-individual variability such as standard deviation (SD) provide a measure of the consistency of underlying cognitive operations and have been widely used as markers of overall neurological health (Fjell et al., 2011; Lovden et al., 2007). As such, intra-individual variability may aid in the identification and prognostication of neurocognitive deficits associated with concussion. Consistent with this premise, an early investigation by Makdissi et al. (2001) observed greater standard deviation of reaction time on a simple reaction time task in a sample of six concussed athletes during the acute phase of recovery 72 h after injury, relative to seven never-concussed athletes. However, utilizing standard deviation as a measure of intra-individual variability is

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problematic when changes in reaction time also occur. That is, as mean reaction time increases there is a natural tendency for variability – as assessed using standard deviation – to also increase as a result of reducing potential bounding related to floor effects of reaction time. Accordingly a more appropriate metric of intra-individual variability is the coefficient of variation (SD of reaction time [RT]/mean RT), which attempts to adjust for such tendencies. Indeed, both Sosnoff et al. (2007) and Halterman et al. (2006) failed to find differences in intra-individual variability between previously concussed and healthy participants using a variety of tasks from the CogState battery and various components of a visuospatial attention task, respectively. Although the results of these investigations would seem to suggest that measures of variability may be ill-suited for use in identifying concussion related decrements in cognition, it is important to note that these investigations all focused on the acute-phase of injury recovery. As intra-individual variability has been found to distinguish groups more efficiently than mean RT based on a variety of clinical variables including neurodegenerative disease and age-related cognitive decline (Gamaldo et al., 2012; Lovden et al., 2007); it may be that increases in variability manifest over the long-term period following a concussive injury rather than being immediately (i.e., acutely) evident.

The ability to detect persistent, concussion-related deficits may also be dependent upon the type of cognitive tasks used. One such task that has been frequently utilized to detect concussion-related deficits in cognition is the flanker task (de Beaumont et al., 2009; Ellemberg et al., 2007; Moore et al., 2013, 2015; Pontifex et al., 2009), which requires selectively attending to a target stimulus amid an array of flanking stimuli. This task thus engages aspects of inhibitory control to attend to the appropriate stimulus while gating out task irrelevant information, and managing response interference created when the flanking stimulus are mapped to opposing action-schemas as the target stimulus (Eriksen and Eriksen, 1974). Accordingly, the nature of this task has demonstrated the requisite sensitivity to reveal concussion-related deficits persisting for months to years beyond the acute stage of injury (de Beaumont et al., 2009; Ellemberg et al., 2007; Moore et al., 2013; Pontifex et al., 2009). However, to date, the extent to which concussion-related differences in intra-individual variability manifest in response to an inhibitory control task, such as the flanker task, is as of yet unknown. As such, the current study sought to clarify previous research (Halterman et al., 2006; Makdissi et al., 2001; Sosnoff et al., 2007) by evaluating the relationship between a concussive history and response variability using intra-individual variability (i.e., CV of RT) in response to both a simple stimulus discrimination oddball task and a more demanding flanker inhibitory control task.

In addition to the assessment of behavioral variability, the present investigation sought to examine the relation of concussion history to intra-individual variability on the neuroelectric level. Within this body of literature, research has largely focused on an event-related brain potential (ERP) known as the P3 (also known as the P300 or P3b), which provides a neural index of the allocation of attentional resources during stimulus engagement (i.e., P3 amplitude; Polich, 2007) and stimulus classification and processing speed (i.e., P3 latency; Verleger, 1997). This ERP component has considerable utility for revealing persistent concussion-related deficits in brain function (Moore et al., 2014). Indeed, previous ERP research indicates that individuals with a history of concussion exhibit reductions in the allocation of attentional resources as indexed by decreased P3 amplitude (Broglio et al., 2009; Gosselin et al., 2012; Moore et al., 2014; Theriault et al., 2009) and delays in stimulus classification and processing speed as indexed by P3 latency, relative to their healthy counterparts (de Beaumont et al., 2009; Gaetz et al., 2000). Further, similar to behavioral measures, these concussion-related influences on the P3-ERP component appear to be disproportionately larger in response to tasks requiring greater amounts of cognitive engagement. However, despite the growth of research in this area, we have little understanding of how a history of concussive injury may relate to greater trial-by-trial variability in these neural indices of attention. Such information is particularly important given the utilization of signal averaging in the ERP approach, wherein the event-related signal is averaged across multiple trials. As such, greater intra-individual variability in this signal would – as a function of signal averaging – manifest as reductions in the amplitude of the ERP signal, which could also impact latency measures. Thus, it may be that previous findings of concussion-related impairments in the allocation of attentional resources and processing speed may instead simply be reflective of greater variability in these neural processes. Accordingly, the final purpose of the present study was to examine the association between a history of concussion and neuroelectric indices of stimulus engagement in response to two commonly employed tasks (i.e., a simple stimulus-discrimination task and an inhibitory control task) to better understand how a history of concussion may differentially manifest across neuroelectric and behavioral indices of performance as a function of the aspect of cognition assessed.

Based on previous findings, it was hypothesized that in response to a relatively simple oddball task, neither mean nor intra-individual variability of behavioral performance would demonstrate persistent concussion-related impairments in cognition. By contrast, a more demanding flanker task would yield reduced mean level performance and exhibit greater intra-individual variability in concussed relative to non-concussed athletes. Relative to the examination of neuroelectric indices of attention, it was hypothesized that athletes with a previous concussive history would demonstrate reductions in the allocation of attention (as indexed by smaller P3 amplitude) and delays in stimulus classification and processing speed (as indexed by longer P3 latency) regardless of the aspect of cognition assessed. However, the magnitude of the concussion-related deficits was hypothesized to be larger in response to the modified flanker task owing to its more demanding nature of the task characteristics. Given growing interest in this area of research, the investigation of how best to characterize metrics of cognitive performance and the potential interplay of the aspect of cognition assessed may provide insight into accurate detection and tracking of potential concussion-related cognitive impairments that persist well beyond the acute and sub-acute phases of injury.

2. Methods

2.1. Participants

The concussion group was comprised of 48 (10 female) college-aged students recruited from the University of Illinois at Urbana-Champaign based on self-report of previous concussion diagnosis by a medical practitioner (26 with one past self-reported concussion, 22 with two or more past self-reported concussions). Participants in the concussion group were screened to ensure that they were symptom free at the time of testing and that their injury occurred within the context of sport and/or recreation participation. The mean time elapsed since their last concussive injury was reported as approximately 4.2 ± 3.4 years prior. A healthy control group comprised of 50 (25 female) college-aged students with a similar history of athletic participation was also recruited; no significant differences for any demographic variables were observed between groups (t's (96) ≤ 1.9, p's ≥ 0.06, d's ≤ 0.39). To reduce the likelihood that an individual with an undocumented concussion was placed in the control group, individuals in this group were also asked if "following a blow to the head, have you experienced any concussion like symptoms," with a list of clinical diagnostic symptoms provided (McCrory et al., 2009). Only participants free of clinical diagnostic symptoms, a concussive history, and any prior cerebral injury were placed in the control group. All participants provided written informed consent that was approved by the Institutional Review Board of the University of Illinois at Urbana-Champaign and reported being free of any neurological disorder, cardiovascular disease, medication that influence central nervous system function, and had (corrected to)