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The persistent influence of pediatric concussion on attention and cognitive control during flanker performance

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ABSTRACT

This study investigated the influence of concussion history on children's neurocognitive processing. Thirty-two children ages 8–10 years (16 with a concussion history, 16 controls) completed compatible and incompatible conditions of a flanker task while behavioral and neuroelectric data were collected. Relative to controls, children with a concussion history exhibited alterations in the sequential congruency effect, committed more omission errors, and exhibited decreased post-error accuracy. Children with a concussion history exhibited longer N2 latency across task conditions, increased N2 amplitude during the incompatible condition of the task, and decreased P3b amplitude across task conditions. Children with a history of concussion also exhibited decreased ERN and Pe amplitudes, with group difference increasing for the incompatible condition of the task. The current results indicate that pediatric concussion may lead to subtle, but pervasive deficits in attention and cognitive control. These results serve to inform a poorly understood but significant public health concern.

1. Introduction

Traumatic brain injury is a leading cause of death and disability in developing populations (Langlois, Kegler, & Butler, 2003), with more than a million cases being treated in the United States annually (Yeates et al., 1999). Although the majority of efforts are dedicated towards the diagnosis, tracking, and remediation of moderate-to-severe brain injuries (McKinlay, Grace, Horwood, Fergusson, & MacFarlane, 2010), mild or "concussive" injuries account for approximately 85% of all pediatric brain injuries (Langlois et al., 2003). Furthermore, a growing body of literature indicates that irrespective of severity, the immature brain is uniquely vulnerable to injury, not more resilient (Daneshvar et al., 2011; Giza & Prins, 2006; Prins & Giza, 2012). Specifically, the protracted development of frontal brain areas in terms of myelination, connectivity, and density appears to lead to extensive white and grey matter abnormalities following pediatric brain injury (Giza & Prins, 2006; Prins & Giza, 2012). Accordingly, these injuries warrant increased attention from clinicians and researchers, as concussive injury may disrupt the developmental trajectory of frontally mediated cognitive functions (Baillargeon, Lassonde, Leclerc, & Ellemberg, 2012; Catale, Marique, Closset, & Meulemans, 2009; Moore et al., submitted for publication).

Indeed, although acute evaluations typically reveal global alterations in cognitive function (Carroll, Cassidy, Holm, Kraus, & Coronado, 2004), long-term evaluations appear consummate in revealing selective alterations in frontally-mediated cognitive functions, such as attention and cognitive control (Baillargeon et al., 2012; Catale et al., 2009; Moore et al., submitted for publication). Cognitive control refers to higher-order cognitive functions, which serve to evaluate, regulate, and optimize goal-directed behaviors through the selection, scheduling, coordination, and maintenance of processes underlying aspects of perception, memory, and action (Botvinick, Braver, Barch, Carter, & Cohen, 2001; Norman & Shallice, 1986). Core functions constituting cognitive control are working memory, inhibition and cognitive flexibility (Diamond, 2013). These functions are essential for learning, academic achievement and overall well-being (Diamond, 2013; Holmes, Gathercole, & Dunning, 2009), and deficits in these functions are believed to underlie many individual differences in cognition across the lifespan (Luna, 2009). Therefore, the long-term assessment of the

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functions following pediatric concussion is of particular importance.

One task, which examines multiple aspects of attention and cognitive control, is the Eriksen flanker task (Eriksen & Eriksen, 1974). Flanker tasks require individuals to ignore task-irrelevant information in order to correctly respond to a centrally presented target stimulus amid either congruent or incongruent flanking stimuli. While conceptually simplistic, this task has demonstrated high sensitivity for detecting deficits from years (Moore, Hillman, & Broglio, 2014; Pontifex, O'Connor, Broglio, & Hillman, 2009) to decades (de Beaumont, Brisson, Lassonde, & Jolicoeur, 2007) following injury in adults. This sensitivity is due to the rich variety of cognitive processes/effects, which can be evaluated during flanker performance.

For example, the congruency effect refers to the finding of decreased performance for incongruent relative to congruent trials (Eriksen & Eriksen, 1974; Spencer & Coles, 1999). This effect serves as a metric of interference control, as incongruent relative to the congruent trials require greater amounts of interference control in order to inhibit flanking stimuli, as both the correct (elicited by the target) and incorrect response (elicited by the flanking stimuli) are concurrently activated during stimulus evaluation (Spencer & Coles, 1999). An extension of this phenomenon, the sequential congruency or Gratton effect refers to the finding that lower interference occurs following an incongruent (i) trial relative to a congruent (c) trial (Botvinick et al., 2001; Gratton, Coles, & Donchin, 1992). This sequential modulation in performance is reflective of adjustments in cognitive control immediately following an incongruent trial, whereby participants strategically narrow attention to the central target, thus minimizing the interference of misleading flankers (Botvinick et al., 2001; Gratton et al., 1992). Lastly, the manipulation of stimulus–response compatibility, through which the response mappings to stimuli are reversed (e.g., a target stimulus which previously required a left thumb response, later requires a right thumb response in subsequent conditions), produces a compatibility effect (Friedman, Nessler, Cycowicz, & Horton, 2009). This manipulation allows for the examination of attention and inhibitory processes across multiple gradations, as individuals must inhibit the pre-potent response mapping in addition to regulating interference from flanking stimuli (Friedman et al., 2009; Pontifex et al., 2011; Pontifex, Scudder, Drollette, & Hillman, 2012). This manipulation also produces a sufficient number of errors to examine response evaluation and error correction (i.e., post-error accuracy, and RT).

Thus, flanker tasks afford a comprehensive assessment of attention and cognitive processes during conditions that elicit stimulus–response conflict. However, despite this dynamic utility and known sensitivity to concussive injuries, no one has utilized flanker paradigms in pediatric concussion research. Accordingly, the first aim of the current study was to examine the long-term influence of pediatric concussion on attention and cognitive control by employing a modified flanker task.

In addition to examining behavior, the current study also sought to examine the long-term outcomes of pediatric concussion on the neurophysiological level. Currently, little is known regarding the pathophysiological sequelae of pediatric concussion, or how this pathophysiology relates to functional behavioral outcomes. Thus, examining neurophysiological function is essential to gain a more comprehensive understanding of pediatric concussion outcomes (Baillargeon et al., 2012; Mayer et al., 2012). Indeed, examinations of neurophysiological function have been essential to understanding concussion outcomes in adults (Broglio, Moore, & Hillman, 2011; Slobounov, Johnson, & Zhang, 2012). Few pediatric studies, however, have examined neurophysiological function following concussion, and only two studies examined long-term outcomes (Baillargeon et al., 2012; Moore et al., submitted for publication).

Both studies employed electroencephalography (EEG) to evaluate event-related brain potentials (ERPs) during experimental task performance. Specifically, Baillargeon et al. (2012) recorded ERPs during a visual discrimination task (i.e., an oddball task) to evaluate children, adolescents, and adults 6 months after injury. The authors evaluated the P3b ERP component, which is believed to be a neural index of attentional resource allocation during stimulus engagement (Donchin & Coles, 1988; Polich, 2007). Irrespective of age, participants with a concussion history exhibited smaller P3b amplitude relative to control participants, indicating that a single concussion can lead to persistent alterations in the neurophysiology underlying attentional resource allocation in the service of working memory. Moore et al. (submitted for publication) recorded ERPs during switch and go–nogo tasks to evaluate the neuroelectric underpinnings of attention, and cognitive control in children an average of 2 years following injury. The authors observed subtle behavioral deficits in impulsivity (behavioral inhibition), working memory, and cognitive flexibility, with increasing cognitive load. Furthermore, these deficits were accompanied by alterations in the ERP indices of visual attention (N1; Hillyard & Anllo-Vento, 1998), stimulus–response conflict/inhibition (N2; Nieuwenhuis, Yeung, Van Den Wildenberg, & Ridderinkhof, 2003), and attention (P3b; Polich, 2007), suggesting that alterations in neurocognitive processing may become more pervasive with increasing cognitive load.

Together, these studies provide valuable information regarding the long-term outcomes of pediatric concussion and emphasize the utility of experimental and functional neurophysiological measures in pediatric concussion research. Although these results are valuable, much is still unknown regarding the nature and duration of neurophysiological outcomes of pediatric concussion. Thus, the second aim of the current study was to assess stimulus-locked and response-locked ERPs to examine the neurophysiological underpinnings of stimulus engagement and response evaluation in children with and without a concussion history.

In sum, the available evidence suggests that pediatric concussion may lead to persistent alterations in neurocognitive processing, but the answers to clinically relevant questions remain unknown. Specifically, how long do concussion-related deficits persist? What degree of specificity characterizes concussion-related deficits, and do deficits change with age at injury? Accordingly, the current study sought to answer these questions by comparing behavior and brain function in children with a concussion history relative to demographically matched controls. We predicted that children with a concussion history would exhibit both behavioral deficits and neuroelectric differences relative to matched control children during trials/trial sequences (incongruent/iI), and task conditions (incompatible) requiring the modulation of attention and cognitive control. In accordance with previous research (Hessen, Nestvold, & Anderson, 2007; Moore et al., submitted for publication), we predicted that children injured earlier in life would exhibit the poorest outcomes.

2. Experimental procedures

2.1. Participants

Participants were 32 (16 concussion, 16 control) 8–10 years old residing in East-Central Illinois. Participants were recruited through university recruitment services and Central Illinois youth athletic associations (YMCA, hockey, football, soccer). Guardians confirmed that all participants with a concussion history had experienced a single medically diagnosed injury, while participating in sports and recreation 6+ months prior to testing. No participant incurred a complicated injury requiring surgical intervention or hospital admittance. All participants were physically active on a