International Journal of Psychophysiology 112 (2017) 22–30

Contents lists available at ScienceDirect

International Journal of Psychophysiology

journal homepage: www.elsevier.com/locate/ijpsycho

The independent influence of concussive and sub-concussive impacts on soccer players' neurophysiological and neuropsychological function

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ARTICLE INFO

Article history:
Received 16 July 2016
Received in revised form 27 October 2016
Accepted 11 November 2016
Available online 17 November 2016

Keywords:
Sub-concussion
Concussion
Neurophysiology
ERPs
Neuropsychology

ABSTRACT

Accumulating research demonstrates that repetitive sub-concussive impacts can alter the structure, function and connectivity of the brain. However, the functional significance of these alterations as well as the independent contribution of concussive and sub-concussive impacts to neurophysiological and neuropsychological health are unclear. Accordingly, we compared the neurophysiological and neuropsychological function of contact athletes with (concussion group) and without (sub-concussion group) a history of concussion, to non-contact athletes. We evaluated event-related brain potentials (ERPs) elicited during an oddball task and performance on a targeted battery of neuropsychological tasks. Athletes in the sub-concussion and concussion groups exhibited similar amplitude reductions in the ERP indices of attentional resource allocation (P3b) and attentional orienting (P3a) relative to non-contact athletes. However, only athletes in the concussion group exhibited reduced amplitude in the ERP index of perceptual attention (N1). Athletes in the sub-concussion and concussion groups also exhibited deficits in memory recall relative to non-contact athletes, but athletes in the concussion group also exhibited significantly more recall errors than athletes in the sub-concussion group. Additionally, only athletes in the concussion group exhibited response delays during the oddball task. The current findings suggest that sub-concussive impacts are associated with alterations in the neurophysiological and neuropsychological indices of essential cognitive functions, albeit to a lesser degree than the combination of sub-concussive and concussive impacts.

1. Introduction

Although concussions are recognized as the cause of a spectrum of neurological alterations (Marchi et al., 2013), the vast majority of impacts incurred during sport fall into the category of sub-concussive (Greenwald et al., 2008; Crisco et al., 2012). A sub-concussive impact is a force imparted to the brain which does not result in the acute morbidity and symptoms associated with concussion (Broglio et al., 2012). The force of these impacts varies greatly, ranging from 6 − to 100 + gs (Zhang et al., 2004; McAllister et al., 2012; Broglio et al., 2009; Breedlove et al., 2012). On average, however, a sub-concussive blow from heading in soccer or tackling in football imparts 20–40 linear gs or 1350–2350 rotational rads to the head (McAllister et al., 2012; Svaldi et al., 2015; Breedlove et al., 2012). Athletes routinely incur more than a dozen sub-concussive impacts in a single game (Crisco et al., 2010; McAllister et al., 2012), but unlike concussive injuries, athletes are not removed from play or evaluated following repetitive sub-concussive impacts. As athletes may incur hundreds of sub-concussive impacts during a season, these impacts may represent a serious neurological health issue (McKee et al., 2009; Marchi et al., 2013).

Increasing research examines the influence of repetitive sub-concussive impacts on the neurophysiological and neuropsychological health of athletes. Studies relying solely on neuropsychological testing report mixed results, with some indicating that sub-concussive blows lead to alterations in attention and executive functions (Straume-Næsheim et al., 2009; Breedlove et al., 2014), while others report little-to-no effect (Guskiewicz et al., 2002; Kaminski et al., 2007; Putukian et al., 2000). In contrast, research utilizing neuroimaging appears consistent in suggesting that accumulative sub-concussive impacts lead to alterations in neural structure and function (Abbas et al., 2015; Poole et al., 2014; Marchi et al., 2013; Chun et al., 2015; McAllister et al., 2014; Johnson et al., 2014). For example, Poole et al. (2014) observed that following their football season, high school athletes who incurred sub-concussive impacts exhibited multiple neuro-metabolic alterations in the dorsolateral prefrontal (DLPFC) cortex and the primary motor area (M1), brain regions essential to higher cognition and the voluntary control of behavior (Aron et al., 2004; Diamond, 2013). Further, the number of sub-concussive impacts incurred during the season was correlated with the degree of neuro-metabolic alterations. Thus, repetitive sub-concussive

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http://dx.doi.org/10.1016/j.ijpsycho.2016.11.011
0167-8760/

impacts may incrementally influence the metabolism of brain areas essential to neuropsychological processes.

Neuroimaging research also reveals that repetitive sub-concussive impacts are associated with changes in the integrity of white matter tracks. For example, Koerte et al. (2015) compared the white matter integrity of elite-level soccer players without a history of concussion to elite-level swimmers. Relative to swimmers, soccer athletes exhibited widespread alterations in axial and radial diffusivity in the orbitofrontal cortex, inferior frontal gyrus, corona radiata and the internal capsule, amongst others. Further, the degree of neural alterations was correlated with the number of hits incurred during the season. Other studies observed a similar pattern of results in collegiate and professional American football and soccer athletes (Koerte et al., 2012; Marchi et al., 2013; Chun et al., 2015; McAllister et al., 2014; Lipton et al., 2013). Furthermore, a recent study by Marchi et al. (2013), which evaluated American football players, observed that pre-to-post season changes in white matter were correlated with deficits in inhibitory control. Thus, sub-concussive impacts may compromise the integrity of white matter tracks essential to neuropsychological function.

Lastly, research reveals that sub-concussive impacts are associated with alterations in the default mode network (Abbas et al., 2015; Johnson et al., 2014), which is a network of brain regions active during quiet rest and introspection, and deactivated during performance of neuropsychological tasks (Raichle et al., 2001; Buckner, 2012). In both studies, American football players who incurred repeated sub-concussive blows exhibited decreased functional connectivity in the default mode network relative to their pre-season values. Thus repetitive sub-concussive impacts may compromise network efficiency.

Together, neuroimaging research suggests that sub-concussive impacts can lead to persistent alterations in aspects of brain structure and function essential to neuropsychological health. However, the independent contribution of concussive and sub-concussive impacts on neurophysiological and neuropsychological function is difficult to discern, as prior research did not compare contact athletes with and without a history of concussion to non-contact athletes. Lastly, as no prior study examined brain function during the performance of a cognitive task, the functional significance of these neural alterations is unclear.

One valuable method of linking neural and cognitive processes is event-related brain potentials (ERPs). Buried within the electroencephalogram, ERPs reflect the synchronous activity of large populations of cortical neurons in the service of particular sensory, motor or psychological processes (Luck, 2005; Münte et al., 2000). The benefits of the ERP approach lies in its temporal sensitivity, which allows researchers to parse the stimulus-response relationship into its constituent components (Luck, 2005; Broglio et al., 2011). This allows researchers to determine where and how in the information processing stream individuals differ. Accordingly, ERPs enable a more precise and integrative understanding of concussion outcomes than neuropsychological measures alone (Broglio et al., 2011; Baillargeon et al., 2012). Indeed, long after the abatement of clinical symptoms and deficits on neuropsychological tests, alterations in the ERP indices of sensory, motor and cognitive function are observed (for review see Broglio et al., 2011; Slobounov et al., 2012). These alterations appear to disproportionately modulate attention-related processes (Broglio et al., 2011; Baillargeon et al., 2012; Moore et al., 2014).

One task regularly used to detect concussion-related alterations in attentional processes is the three-stimulus oddball (Baillargeon et al., 2012; Pontifex et al., 2009; Moore et al., 2014). Consisting of a frequently occurring standard stimulus and infrequently occurring target and non-target stimuli, these tasks elicit the N1, P3a, and P3b ERP components. The N1 component is believed to reflect neuronal activity associated with the discrimination, encoding and integration of basic stimulus properties, with amplitude reflecting sensory gains in the service of selective attention (Hillyard and Anllo-Vento, 1998; Hillyard and Munte, 1984). The P3a, evoked in response to the infrequently occurring non-target stimulus, is believed to reflect the reorienting of focal attention to a novel or distracting environmental stimulus (Polich, 2003, 2007). The P3b, evoked in response to the infrequently occurring target stimulus, is believed to reflect the revision of mental events, with amplitude being proportionate to the degree of attentional resources allocated during stimulus engagement (Donchin, 1981; Polich, 2007), Through these ERP components the 3-stimulus oddball task affords the evaluation of the neurophysiology underlying lower and upper-level attention processes.

Accordingly, our aim was to delineate the independent contribution of concussive and sub-concussive impacts on neurophysiology by evaluating the ERPs of collegiate soccer players during a three-stimulus oddball task. As accumulating evidence suggests that mild brain injuries may selectively alter aspects of higher cognition such as attention and executive control (Baillargeon et al., 2012; Ellemberg et al., 2007; Howell et al., 2013; Moore et al., 2014; Koerte et al., 2012; Lipton et al., 2013), we also implemented a battery of neuropsychological tests targeting these functions.

We predict a stepwise pattern of results whereby contact athletes with a history of concussion will exhibit smaller component amplitudes (N1, P3a, P3b) than contact athletes without a history of concussion and non-contact athletes. Further, we also predict that contact athletes without a history of concussion will exhibit smaller component amplitudes than non-contact athletes. We predict a similar pattern for the neuropsychological tasks, whereby both groups of contact athletes with and without a history of concussion will present deficits, with those having a history of concussion presenting greater deficits.

2. Methods

2.1. Participants

2.1.1. Participants

Fifty-six male, university athletes were recruited to participate in this study.

Contact athletes were recruited from the University soccer team to ensure equivalent demographics and contact exposure. Athletes with a history of concussion, who also regularly incurred sub-concussive impacts were recruited from the University soccer team. Athletes who incurred sub-concussive impacts but did not have a history of concussion were also recruited from the University soccer team. Non-contact athletes who did not incur sub-concussive impacts were recruited from the tennis, badminton and volleyball teams. To ensure demographic similarity, non-contact athletes were matched to contact athletes in terms of BMI, age, education, and years of sport participation. For the sake of brevity, these groups will henceforth be referred to as the concussion, sub-concussion and non-contact control groups.

2.1.2. Exclusion & inclusion criteria

Because of their known relation with cognitive function, exclusion criteria for all participants included: substance abuse ($n = 1$), special education ($n = 1$), neuropsychiatric or neurological disorder ($n = 1$), learning disability or attention disorder ($n = 2$). Further, all participants were required to be symptom-free at time of testing according to the SCAT-2 (Sport Concussion Assessment Tool-2; P. McCrory et al., 2009). To control for variability in concussion diagnosis and age at injury, only athletes incurring their concussion(s) during university sports were selected to participate. In accordance with prior research (Ellemberg et al., 2007; Broglio et al., 2009; Larson et al., 2011; Moore et al., 2014), we sought to minimize the likelihood that an athlete with an undocumented concussion was placed into either the sub-concussion or non-contact control group by asking athletes in both groups if they ever experienced a blow to the head, neck or body that led to them experiencing any symptoms listed in the SCAT-3 (P. McCrory et al., 2013). Athletes responding yes to any symptom ($n = 2$) were removed from further participation. Thus, of the original 56 athletes