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Electrophysiological impact of multiple concussions in asymptomatic athletes: A re-analysis based on alpha activity during a visual-spatial attention task

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ABSTRACT

Most EEG studies used event-related potentials to assess long-term and cumulative effects of sport-related concussions on brain activity. Time-frequency methods provide another approach that allows the detection of subtle shifts in types and patterns of brain oscillations. We sought to discover whether event-related alpha activity would be significantly affected in asymptomatic multi-concussed athletes. We measured the amplitude of alpha activity (8–12 Hz) from the EEG recorded during a visual-spatial attention task to compare event-related alpha perturbations in 13 multi-concussed athletes and 14 age-equivalent, non-concussed teammates. Relative to non-concussed athletes, multi-concussed athletes showed significantly less event-related perturbations time-locked to stimulus presentation. Alpha activity alterations were closely related to the number of concussions sustained. Event-related alpha activity differed in asymptomatic multi-concussed athletes when compared to controls. Our study suggests that low-level neurophysiological underpinnings of the deployment of visual-spatial attention are affected in multi-concussed athletes even though their last concussion occurred on average 30 months prior to testing.

1. Introduction

Over the last decade, numerous studies have attempted to characterize the long-term and cumulative effects of sports-related concussions (SRC). While the vast majority of concussed athletes tend to clinically recover within three to four weeks after an SRC (Henry et al., 2016a; McCrory et al., 2017; Nelson et al., 2016; Prichep et al., 2013), electroencephalographic (EEG) measures can detect subclinical neurophysiological abnormalities in concussed athletes that persist long beyond the acute phase (Henry et al., 2016b).

For instance, event-related potential (ERP) studies revealed significant and persistent N1 (Gosselin et al., 2006), N2 (Ledwidge and Molfese, 2016), P2 (Gosselin et al., 2006), P3 (De Beaumont et al., 2007; Gaetz et al., 2000; Gosselin et al., 2006; Ledwidge and Molfese, 2016; Theriault et al., 2009) waveform components alterations when concussed athletes performed cognitive tasks relying on attentional processes in the acute phase as well as several years post-accident relative to controls. ERPs are computed from the averaged EEG signal time-locked to an event of interest, often the presentation of a stimulus. With appropriate stimuli and task conditions, the resulting waveforms can reveal components reflecting specific cognitive processes. Repeated concussions were found to significantly accentuate anomalies of ERP markers of attention and working memory (De Beaumont et al., 2007; Gaetz et al., 2000), supporting the notion that concussions are associated with long-term and cumulative effects on brain functions (Guskiewicz et al., 2003; Henry et al., 2016b; Pearce et al., 2014).

In parallel, other studies investigated resting oscillatory activity using time-frequency methods to closely track the recovery of neurophysiological function after concussion (Arciniegas, 2011; Haneef et al., 2013; Kutcher et al., 2013). Time-frequency analyses characterize EEG

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in terms of power (squared amplitude) and phase of oscillations using a variety of analytic techniques that enable researchers to detect changes in the types and patterns of electrical oscillations as a function of a stimulus, task, psychological state, or neurological condition (Tallon-Baudry and Bertrand, 1999). A growing body of research seeks to relate oscillatory activity (e.g., averaged amplitude or power) with underlying cognitive processes involved in information processing and increasingly with intra and inter-region neuronal communication (Bastos et al., 2015; Frey et al., 2015). The EEG spectrum is often described in terms of frequency bands, such as delta (0.5–4 Hz), theta (4–7 Hz), alpha (8–12 Hz), beta 1 (13–20 Hz), beta 2 (20–30 Hz), and gamma (> 30 Hz), although the precise boundaries between bands and often their names vary from author to author (Babiloni et al., 2010; Pfurtscheller and da Silva, 1999). The impact of brain pathology on the alpha band has received much attention mostly due to the presumed association of alpha oscillations with a number of brain processes (Klimesch, 1999). The most documented changes found in brain activity after mild traumatic brain injury (mTBI) or SRC are a decrease in alpha power coupled with a concomitant increase in theta-alpha frequency ratio (Haneef et al., 2013; Korn et al., 2005; Kutcher et al., 2013; Nuwer et al., 2005). Interestingly, this pattern is also found in the aging population as well as in patients presenting with a variety of neurological disorders (Chiang et al., 2011; Klimesch, 1999; van Albada et al., 2010). In the concussion literature, it was proposed that the suppression of alpha amplitude in posterior cortical regions could potentially be a sensitive tool in order to detect lingering cerebral dysfunctions (Rapp et al., 2015; Slobounov et al., 2012; Thatcher et al., 1989). Follow-up studies on acute SRC showed return-to-baseline of oscillatory activity within 45 days of the injury (Barr et al., 2012; McCrea et al., 2010). In contrast, athletes who had suffered a second SRC exhibited a slower rate of recovery on alpha oscillation amplitudes at 7, 14, and 21 days post-injury (Slobounov et al., 2009). Furthermore, one study observed a persistent reduction of resting alpha power in multi-concussion athletes tested at 12 months post-injury (Gosselin et al., 2009). However, no clear EEG or time-frequency features seem specific to mTBI or SRC, especially beyond the acute post-injury phase (Nuwer et al., 2005; Popescu et al., 2016). Nonetheless, it is important to study alpha activity in concussion because of its implication in visual and spatial attention (Foxe and Snyder, 2011; van Diepen et al., 2016), which are affected in asymptomatic concussed athletes (Theriault et al., 2011).

Similar to ERPs, researchers can compute event-related spectral perturbation (ERSP) analyses that are time-locked to stimulus presentation. These analyses measure the average oscillatory amplitude induced by the presentation of stimuli relative to a prestimulus period (Makeig, 1993), enabling studies of spectral dynamics (i.e., how oscillatory amplitude changes over time). Spectral amplitude variations (increase/decrease) are thought to reflect changes in the activity of large assemblies of neurons in response to a stimulus or to other events of interest. Event-related synchronization (ERS) occurs when the amplitude of a given frequency increases with stimulus presentation, while event-related desynchronization (ERD) reflects a reduction of amplitude in response to a stimulus (Pfurtscheller and da Silva, 1999). According to some researchers, a large increase in alpha amplitude reflects a state of inhibition or cortical deactivation, whereas a decrease in power reflects a state of comparatively high neuronal excitability (Klimesch, 2012; Pfurtscheller, 2003). A decrease in alpha power is characteristically observed in the occipital regions when subjects process visual inputs or when they respond to internal events like mental activation or cognitive effort (Pfurtscheller and da Silva, 1999). Alpha power is also known to decrease as a function of attentional demands and generally spreads over the entire scalp, argued to reflect the gradual release of inhibition associated with the activation of attentional networks during information processing (Klimesch et al., 2007).

Only a few ERSP studies have been conducted with clinical populations. Available results in patients presenting attention-deficit hyperactivity disorder (Gomarus et al., 2009; Missonnier et al., 2013); mild cognitive impairment (Caravaglios et al., 2015; Deiber et al., 2015); Alzheimer's disease (Hogan et al., 2003), Parkinson's disease (Heida et al., 2014), and schizophrenia (Haenschel et al., 2009) show that ERSP analyses can sometimes reveal alterations in brain activity correlated with task performance and various neurological conditions. These clinical populations typically exhibit a pattern of attenuated ERD and larger ERS in alpha amplitude relative to healthy control groups during cognitive tasks. Given the known detrimental effects of concussion on resting alpha band activity, this study sought to determine whether persistent changes of event-related spectral perturbations within the alpha band (ERSP-α) occur while performing an attention task in concussed athletes.

A small number of studies that performed ERSP-α analyses in conjunction with ERP waveform components yielded enlightening results. Among them, a study showed associations between ERSP-α and the P3 component amplitude (Peng et al., 2012). An increase in P3 amplitude, which is thought to reflect attentional resource allocation and memory updating (Polich, 2007), is usually associated with a decrease in alpha amplitude (Ergenoglu et al., 2004; Peng et al., 2012; Sergeant et al., 1987; Yordanova et al., 2001). Interestingly, the P3 component shows chronic amplitude suppression among multi-concussion athletes (Broglio et al., 2009; De Beaumont et al., 2007; Gaetz et al., 2000; Gosselin et al., 2006; Theriault et al., 2009). Thus, studying the long-term effects of SRC on the alpha activity pattern during a cognitive task could reveal an important feature of the underlying neurophysiological underpinnings of persistent, subclinical anomalies after concussion.

The goal of the present study was to investigate the long-term effects of multiple SRC on alpha oscillatory activity modulations. Based on the SRC and oscillatory literature, we hypothesized that alpha desynchronization would be significantly reduced in multi-concussed athletes relative to control athletes when performing a visual-spatial attention task. We also hypothesized that attenuation of event-related alpha desynchronization would be increase with the number of previous concussions.

2. Methods

In the present study, we used electrophysiological recordings from a previous EEG experiment that revealed P3 amplitude alterations in concussed athletes (De Beaumont et al., 2007). This experiment was designed to assess possible differences in brain function between control and multi-concussed athletes in the context of a particular perceptual-cognitive task. The EEG recordings herein were analyzed on different EEG measures, thus not interfering or replicating previously published work. Only electrophysiological recordings from multi-concussed and non-concussed athletes were used for the purpose of this study. Given we are now looking at a different subset of the signal space, we occasionally see artefacts that were not apparent in the original work. Because of EEG signal-quality issues, one subject was removed from the control group and two from the concussion group of the original sample. Refer to the aforementioned published article for a more detailed description of the methods.

2.1. Participants

The sample analyzed in the present study consists of 27 active athletes recruited from a Canadian university football team. Athletes who took part in this study were those who were not rejected after having been screened for the following exclusion criteria: A history of alcohol and/or substance abuse, psychiatric illness, learning disability, neurological history (seizure, central nervous system neoplasm, or brain tumour), a history of TBI unrelated to contact sports or any daily medications. The study was vetted by the local ethics committee and all participants provided written informed consent prior to testing. Subjects received a financial compensation of $30 Canadian for their

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