ARTICLE IN PRESS

International Journal of Psychophysiology xxx (xxxx) xxx–xxx

Contents lists available at ScienceDirect

International Journal of Psychophysiology

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

Long-term effects of sport concussion on cognitive and motor performance: A review

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ARTICLE INFO

Keywords:
Motor performance
Cognition
Symptoms
Neurophysiological changes

ABSTRACT

Motor and cognitive dysfunction is intractable sequela in the acute stage of concussion. While typical concussion recovery occurs in two weeks, empirical evidence suggests that some sequela persist beyond this period, though there is inconsistency surrounding the duration the sequela persist. In part, confusion around the issue is limited by the volume of literature evaluating those with a concussion history, permitting vast interpretations of significance. The purpose of this paper is to review the concussion history literature, summarizing the long-term effects of concussion history on motor and cognitive performance. Additionally, this review intends to provide direction and options of future investigations addressing the long-term effects of concussion on motor and cognitive performance.

Cognitive and motor performance dysfunction is commonplace in the acute stage of concussion. Over the past decade, the long-term effects of concussion on cognitive and motor performance have been addressed in a multitude of studies using variable methodological approaches among previously concussed adolescent, amateur, and professional athletes at different time points of the lifespan. In large part, the concussion history literature has identified changes in cognitive and/or motor performance in a previously concussed group, indicating that a sport concussion is anything but a transient injury. However, within this same literature, there are questions surrounding the clinical meaning and/or reproducibility of the reported statistical differences. The purpose of this review is to provide an overview of the current state of the literature surrounding the long-term effects of concussion, focusing on cognitive and motor performance, as well as provide direction and suggestion to where future research should focus.

1. Concussion timeline

The acute signs and symptoms of sport concussion typically resolve within two to four weeks (Broglio and Puetz, 2008; Collins et al., 1999; Guskiewicz et al., 2003; Henry et al., 2016). Several research groups have tried to identify predictors to demarcate recovery times without avail, while some individuals could exhibit sustained symptomology, such as headache and dizziness, for months beyond the typical recovery period. This prolonged period of symptomatology could indicate a clinical diagnosis for post-concussion syndrome (PCS), a condition distinct from a clinical concussion diagnosis (Broshek et al., 2015; Ryan and Warden, 2003). In broad terms, PCS is the presentation of symptoms triggered by an initial concussive event, but the ongoing symptom presentation likely has differing biological underpinnings. That is, at the onset of PCS, the pathophysiology of the concussive injury has resolved and a new syndrome has begun. PCS is as difficult as concussion to objectively diagnose and care for (Broshek et al., 2015). Considering the obfuscation of diagnosis between prolonged concussion recovery and PCS, a clearly defined timeline of "long-term" is required (Fig. 1). The Diagnostic and Statistical Manual of Mental Disorders (Fourth Edition) sets the criteria of symptoms persisting for three months or longer for PCS diagnosis (First, 1994). For the purpose of this review and to avoid possible comorbidities of PCS and long-term concussion effects, long-term will be defined as a minimum of one year beyond the concussive event, with no ongoing presentation of concussion-related signs or symptoms. While this is an imperfect definition, the opaque and individual nature of the clinical concussion diagnosis and clinical recovery timeline limits the specificity of a universal definition. Therefore, this review will focus on the scientific literature evaluating concussed individuals at least one year removed from injury and no longer displaying signs and symptoms related to concussion. This may be a conservative cutoff for reviewing the concussion history literature, but if persistent deficits are observed between three months and one year post-concussion and not beyond one year, then that suggests there are intermediate effects of concussion history, not long-term effects.

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http://dx.doi.org/10.1016/j.ijpsycho.2017.09.019
Received 11 December 2016; Received in revised form 14 September 2017; Accepted 25 September 2017
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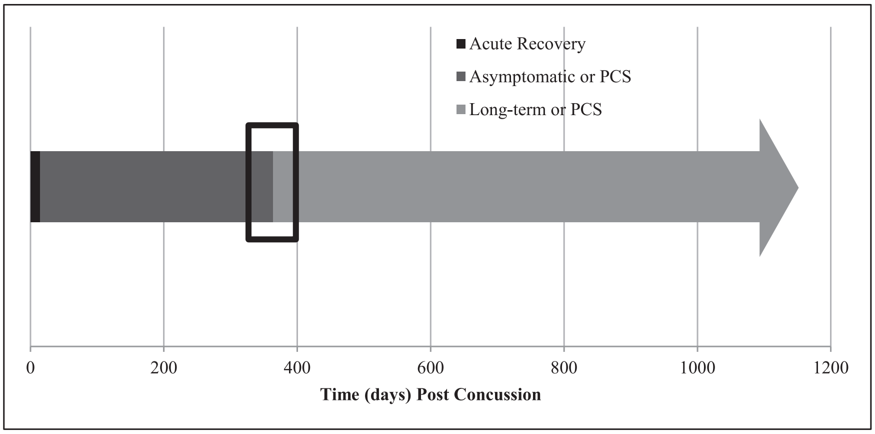

Fig. 1. Timeline demonstrating timing of events following a concussive injury. The black box highlights a gray area of distinction between long-term concussion and PCS.

2. Behavioral effects

While headache and dizziness are among the most commonly reported symptoms of acute concussion, some athletes experience depressive signs and symptoms following a concussion (Ellemberg et al., 2009). That only some athletes exhibit depression in the acute stage of concussion could be an indication that only a subset of athletes are at greater risk for more complex signs and symptoms following a concussion. These athletes, with a higher risk of complex recovery (i.e. depression), may also be the retired professional athletes with multiple concussion history that have been shown to exhibit increased risk of depression, memory impairment and mild cognitive impairment (Guskiewicz et al., 2005; Guskiewicz et al., 2007). In these studies, a history of more than two previous concussions increased the risk of depression three-fold over those with a single or two concussion history. Additionally, when compared to individuals with no concussion history, those with multiple concussion history exhibited a three-fold increase of depression (Guskiewicz et al., 2007). Retired professional athletes with a multiple concussion history, greater than two pervious concussions, were five times more likely to develop mild cognitive impairment (Guskiewicz et al., 2005). In a similar vein, other investigations have linked concussion history to mild cognitive impairment, memory deficits, executive dysfunction, and possibly dementia (Baugh et al., 2012; Guskiewicz et al., 2005; McKee et al., 2009; Montenigro et al., 2017). Though this evidence is specific to the elite athlete, as well as subject to the standard limitations of survey data (i.e. reporting bias, self-reported health history, etc.), these studies helped lay the foundation for future long-term concussion investigations. Following investigations probed further into the long-term effects of concussion, a majority of these investigations focused on cognitive performance.

3. Cognitive performance

The relationship between concussion history and cognitive performance has been assessed across ages and sport level (e.g. high school, college, professional). The results of these investigations provide insight into neurophysiological mechanisms possibly linked to the aforementioned mild cognitive impairment and executive dysfunction observed in retired professional athletes (Baugh et al., 2012; Guskiewicz et al., 2005; McKee et al., 2009; Montenigro et al., 2017). Electroencephalography (EEG) is a measure of cortical electrical activity, usually measured from locations on the scalp thought to be associated with the cognitive/behavioral task implemented in an investigation. Most of the EEG data from long-term concussion literature assesses the cortical activity associated with the allocation of attentional resources as evaluated using event related potentials (ERPs), a subset of EEG methodology (Broglio et al., 2009; De Beaumont et al., 2007a; De Beaumont et al., 2009; Moore et al., 2014; Parks et al., 2015). An ERP is an electrical brain response to a stimulus that is related to cognitive processes, such as memory and attention (Broglio et al., 2009; De Beaumont et al., 2007a). The electrical activity is registered as EEG waveforms, which are time-dependent to stimulus presentation. The stimuli driven ERP focus of the concussion history literature is the positive 300 ms (P3) component, though both the positive 100 ms (P1) and negative 200 ms (N2) components have been assessed to a lesser degree (Broglio et al., 2009; De Beaumont et al., 2007a; De Beaumont et al., 2009; Moore et al., 2014; Parks et al., 2015; Theriault et al., 2009; Theriault et al., 2011).

The P3 amplitude is related to the degree of attention allocated to a task, with greater P3 amplitude related to better memory performance (Fabiani et al., 1990; Polich, 1996, 2007). The P3 latency is a result of stimulus detection, not of time to detect and provide response, with shorter latency indicating quicker attention allocation (Ilan and Polich, 1999; Polich, 1987). The components prior to the P3, P1, N1 and N2, are related to sensory processing and attention and executive/visual processing, respectively (Broglio et al., 2009; Moore et al., 2016; Moore et al., 2014; Moore et al., 2015). Again, attenuated amplitudes and longer latencies indicate poorer performance.

Neurophysiological investigations of pediatric athletes indicate that concussion history (2 years post-concussion) is associated with significantly smaller P3 amplitude (Moore et al., 2016; Moore et al., 2015), decreased N1 amplitude, increased N2 amplitude (Moore et al., 2015), and prolonged N2 latency (Moore et al., 2016; Moore et al., 2015). However, the decreased P3 amplitude and prolonged N2 latency was behavioral task specific. The cognitive tasks that yielded significant concussion history group neurophysiological differences were the flanker task, a set switching task, and a Go-NoGo task. The flanker task yielded significant concussion history group differences for sequential conflict resolution and ability to correct after error, specific to the incongruent condition (Moore et al., 2015). The set switching task results indicated that the concussion history group was significantly worse when the task difficulty increased, particularly for working memory (Moore et al., 2016). Similarly, as the Go-NoGo task difficulty increased, the concussion history group performance was significantly worse (Moore et al., 2016). Interestingly, cognitive task performance was correlated to age of injury during maturation, indicating poorer performance resulting from concussion at a younger age (Moore et al., 2016; Moore et al., 2015).

The correlation between cognitive performance and age when concussion was sustained poses an exciting observation. This correlation could be part of the explanation of the heterogeneity of sport concussion observed in following sections. Very little is understood about how a concussion affects an athlete, which could be due to gender, sport, position, concussion history, and age at initial injury. The observations from the pediatric neurophysiology and cognitive