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Subconcussive head impacts in sport: A systematic review of the evidence

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ABSTRACT

Purpose: To identify and evaluate the evidence that examines subconcussive impacts in sport-specific settings, and address two objectives: a) to determine how 'subconcussion' is characterized in the current literature, and b) to identify directions for future research.

Research design: Systematic review.

Methods and procedures: CINAHL, EMBASE, MedLine, PsycINFO, SportDiscus, and Web of Science were searched for articles that sought to assess subconcussive impacts or outcomes related to non-concussive head impact exposure. Eligible articles were reviewed and evaluated with three quality assessment tools by rotating pairs of reviewers.

Results: A total of 1966 articles were screened. Fifty-six studies met the inclusion criteria. Studies were classified into three main categories based on primary focus: neurobiological, neuropsychological, and impact exposure metrics. The neurobiological studies suggested that in male athletes, functional and microstructural deterioration was associated with repetitive head impacts. There was insufficient to weak evidence for the relationship between repetitive hits to the head and deterioration in neurocognitive performance. Studies of impact exposure metrics examined various indices, including linear acceleration, rotational acceleration, and location and frequency of hits. Insufficient evidence was presented to determine a minimal injury threshold for repetitive hits to the head. Across all categories of studies there was a lack of consistency and clarity in defining and measuring variables related to the concept of 'subconcussion'.

Conclusions: Evidence reviewed predominantly from studies of male athletes in contact and collision sports identifies that repetitive hits to the head are associated with microstructural and functional changes in the brain. Whether these changes represent injury is unclear. We determined the term 'subconcussion' to be inconsistently used, poorly defined, and misleading. Future research is needed to characterize the phenomenon in question.

1. Introduction

The sport concussion literature has grown rapidly in the past two decades. This literature spans various related domains and disciplines (including neuropsychology, neurophysiology, biomechanics, imaging, education, sport policy, sport psychology, and sport medicine), and covers a wide range of topics. One topic garnering increasing attention is repetitive hits to the head and their relation to an emerging concept called *subconcussion* (Bailes et al., 2013). Research interest and awareness of this phenomenon has risen with the surge of interest in chronic traumatic encephalopathy (CTE), which is a postulated long-term outcome of multiple repeated blows to the head with or without concussion (McKee et al., 2009; Omalu et al., 2005).

The literature indirectly related to the concept of subconcussion emerged with Martland's opinion that, "…in punch drunk there is a very definite brain injury due to single or repeated blows on the head or jaw…" (Martland, 1928, p.1103). Subsequently, Pudenz and Shelden observed the effects of what they called "subconcussive blows" (Pudenz and Shelden, 1946, p.495) in the brains of macaque monkeys surgically fitted with a lucite window in the skull. *Dementia pugilistica* was described 27 years later by Corsellis et al. (1973) in a case series of 15 retired boxers. Later, Mendez (1995) reviewed the neuropsychiatry of boxers and reported that these athletes were prone to CTE with exposure to repeated head blows.

Since then, the concepts of subconcussion and subconcussive blows to the head have been addressed directly in the sport injury community (e.g., Broglio et al., 2011; Dashnaw et al., 2012; Rutherford et al., 2003) and indirectly with the examination of head impacts (e.g., Mihalik et al., 2007; Mihalik et al., 2005; Pellman et al., 2003). Both the research and conceptual understanding of this phenomenon are in their infancy.

Despite a few excellent reviews, there remains a lack of clarity and many unanswered questions about the concept of subconcussion. Bailes

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et al. (2013) provided a comprehensive overview of the biophysical, neurophysiological, and neuroradiological evidence in support of subconcussion. They defined subconcussion as "a cranial impact that does not result in known or diagnosed concussion on clinical grounds" (p. 1236), which may be the result of a "slosh phenomenon" (Smith et al., 2012) in which rapid acceleration-deceleration of the brain occurs. Bailes et al. (2013) noted that cumulative exposure to repetitive head hits is the main contributor to subconcussion, and emphasized the need for further study.

Several reviews contribute to the understanding of what Bailes and colleagues refer to as the "underrecognized phenomenon" (2013, p. 1236) of subconcussion. A systematic review by Tarnutzer et al. (2016) reported on the associations between soccer activities and decline in brain structure and function. That review highlighted that frequency of heading was not strongly associated with neuropsychological impairments, and that studies were plagued with bias (Tarnutzer et al., 2016). In contrast, Rodrigues et al. (2016) reviewed the outcomes of soccer heading and brain function. While inconclusive, their findings suggested a relationship between heading the ball in soccer and abnormal brain structure. Koerte et al. (2015b) provided a review on advanced imaging techniques currently used to investigate changes in the brain in two populations exposed to repetitive head impacts, athletes and military personnel. The authors reported evidence of microstructural alterations from subconcussive head impacts in soccer, hockey and football. Koerte et al. called for capitalizing on advanced imaging techniques for studying repetitive head trauma, referring to it as a "whole new era" of study (2015b, p. 345).

Davenport et al. (2016) reviewed studies on subconcussive head impacts in youth and high school-aged male football players. They determined that emerging evidence for relationships between neuroimaging data and impact exposure metrics is cause for more focused studies, especially in young vulnerable athletes. Most recently, Belanger et al. (2016) reviewed short-term clinical outcomes of subconcussive head impacts in their formative review. They concluded that human studies of neurological and neuropsychological consequences of subconcussive blows to the head were limited, but that the evidence, to date, suggested that subconcussive blows do not cause significant clinical effects and that any effect "is likely to be small or nonexistent" (p.159). Belanger and colleagues concluded that the term "subconcussion" referred to an "elusive theoretical construct" (p.160), does not adequately describe the phenomenon, and that caution is warranted in suggesting that "brain injury" is secondary to subconcussive impacts because of the societal implications.

All the reviews related to 'subconcussion' have made important contributions. However, the findings are equivocal regarding the effect of subconcussive impacts on the brain. There remains a need to clarify our knowledge, inform directions for future research, and provide a clear description of the phenomenon known as 'subconcussion'. Therefore, the purpose of this systematic review was to identify and evaluate the evidence that examined 'subconcussion' or subconcussive impacts or outcomes in sport settings, and to address two specific objectives: 1) to determine how 'subconcussion' is characterized in the current literature, and 2) to identify directions for future research.

2. Method

2.1. Data sources and searches

The Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) Guidelines (Moher et al., 2009) were followed. Six databases were searched to November 2016: CINAHL, EMBASE, MEDLINE, PsycINFO, SPORTDiscus, and Web of Science. The term subconcussion does not currently exist as a subject heading (e.g., Medical Subject Headings) for the databases searched; therefore, the search string was developed as follows: [((subconcuss* OR sub-concuss*) AND (sport OR athlete)) OR ((repetitive OR multiple OR reoccurr* OR recur* OR cumulative OR chronic) AND (brain OR head) AND (sport OR athlete))]. These keywords were selected to attempt to capture the breadth of terminology used in research related to 'subconcussion'.

2.2. Inclusion and exclusion criteria

Only human studies focusing on athletes were included. They were limited to those published in English. No delimitations were set for year of publication. Exclusion criteria included (a) not directly examining subconcussion, (b) non-peer reviewed articles, (c) traumatic brain injury, (d) languages other than English, (e) non-sport context (e.g., blast injury), (f) forensic studies, (g) animal models, and (h) review articles.

2.3. Study selection

The authors screened the titles, abstracts, and full-texts that resulted from the literature search. In total, 1966 abstracts were screened by rotating pairs of researchers, and disagreements were resolved by a third rater. Inter-rater reliability was calculated with Cohen's Kappa (Cohen, 1960), which can be categorized by strength of agreement from poor ($\kappa = 0.0$) to almost perfect ($\kappa = 0.81–1.00$; Landis and Koch, 1977). Kappa scores were calculated at two different time points of the selection process. The two κ-values of 0.90 and 0.94 indicate almost perfect agreement between author pairs for title and abstract screening. A second inter-rater reliability was calculated on a sample of 20 full-text articles assessed for inclusion by rotating pairs to ensure consistency and rigour. The three κ-values (0.47, 0.63, 0.74) suggested a moderate to substantial level of agreement among raters. Disagreements were resolved through discussion and with assessment by a third rater when needed.

2.4. Assessment of study quality

The criteria to determine the methodological quality of the included studies were developed by the authors, a priori, and adapted from previous tools. Three quality assessment measures were included. First, each study was assessed using a modified version of the Levels of Evidence from the Oxford Centre for Evidence-Based Medicine[1] (CEBM; Centre for Evidence-Based Medicine, 2009). Second, a modified version of the Quality Assessment Tool for Quantitative Studies (henceforth referred to as EPHPP-modified; Effective Public Health Practice Project, 1998) was used for quality assessment. A third quality assessment tool, the Subconcussion-Specific Tool (SST), was developed, adapted from Comper et al. (2010), to assess subconcussion-specific issues. Studies were classified as Category A or B, based on the following five criteria: 1) Was there an attempt to define the term 'subconcussion'? 2) Was the number and/or magnitude of impacts reported? 3) Were subjects who sustained a concussion during the study controlled for or excluded from analyses? 4) Were subjects with a history of concussion controlled for or excluded from the analyses? 5) Did the study analyze sex/gender differences, or acknowledge limitations associated with sampling only males or females? Category A papers fulfilled three or more of these criteria.

3. Results

3.1. Identification of studies

The systematic literature search of the six databases yielded 1966 articles after removing duplicates; 1943 articles were excluded from the

[1] 1A = Individual RCT with narrow confidence interval; 1B = All or none RCT; 2A = Individual cohort study or low quality RCT; 2B = Outcomes research: ecological studies; 3A = Cross-sectional; 3B = Individual case–control study; 4 = Case series (and poor quality cohort and case–control studies); 5 = Expert opinion without explicit critical appraisal.