Journal of Physical Education and Sports Management
June 2015, Vol. 2, No. 1, pp. 109-138
ISSN 2373-2156 (Print) 2373-2164 (Online)

Published by American Research Institute for Policy Development
DOI: 10.15640/jpesm.v2n1a7
URL: http://dx.doi.org/10.15640/jpesm.v2n1a7

Trending Issues and Long-Term Effects of Recurrent Concussion in Sport

Matthew R. Mulholland[1]

Abstract

The purpose of this literature review was to comprehensively assemble prevalent and current publications on the trending issues and long-term effects of recurrent concussion in contact sports to strengthen the understanding, awareness, and appreciation for sport personnel that might not be regularly exposed to this information. With a rising popularity in contact sports and estimated annual sports-related concussions topping 3.8 million, increasing knowledge in these professionals is imperative for collaboration throughout sport to improve concussion management and, correspondingly, improve sport management. The literature reviewed was collaborated based on long-term scope, significance of results, and contribution effect. All reviewed studies centralized on athletic populations in contact sports. This review identifies the causal relationships of recurrent concussion and suggests that evolving research in a more diversified manner will further the discipline's knowledge by revealing extensions of research needs and producing phenomenological explanations by potentially discovering sport or nature of impact trends with otherwise neglected populations.

Keywords: contact sports, concussion management, concussion severity, return-to-play, sports injury, traumatic brain injury

Contact sports are popular leisure activities participated in by many individuals throughout the globe, often gaining early interest at the interscholastic and recreational levels of play. With such popularity, there seems to be an associated concussion factor. Cancelliere and colleagues' (2014) review noted that 1.6 to 3.8 million individuals are affected by sport-related concussions each year in the Unites States alone.

[1] Department of Exercise Science and Sport Studies, California University of Pennsylvania, California, PA 15419. Email: matthew.mulholland@hotmail.com

Although such a range of concussive episodes is still unclear, especially when the unveiling popularity of athletes continuing to play through possible mild to severe concussions is considered (e.g., Cantu & Gean, 2010; Caron, Bloom, Johnston, & Sabiston, 2013; Weinstein, Turner, Kuzma, Feuer, 2013), the prevalence of concussion in sport continues to rise alongside public, legal, and medical scrutiny (Kain, 2009). This appears to occur largely alongside the difficultly in assessment, diagnosis, and management of sports-related concussion (e.g., Carroll, 2012; McCrory et al., 2013). Corresponding with the prevalence of recurrent concussion, though, researchers have found that athletes' concussion histories are associated with cognitive impairment (Bleiberg et al., 2004; Cancelliere et al., 2014; Thornton, Cox, Whitfield, & Fouladi, 2008), depression, anxiety, and suicidal thoughts (Caron et al., 2013; Omalu et al., 2006), and signs of lower mental health scores later in life (Guskiewicz et al., 2005).

Concussion in sport as a popular subject swelled through mainstream media's recent exposure and continuing coverage on the matter within the National Football League (NFL), although the sports medicine discipline has been vehemently investigating the topic for over a decade (e.g., McCrory et al., 2013). Moreover, the culminating power of popular debate arguably evolved through the groundbreaking research published by Omalu et al. (2005; 2006). After sufficiently connecting the preventable, progressively degenerative cognitive disease termed *chronic traumatic encephalopathy* (CTE) to the recurrent concussion nature of American football, Dr. Bennet Omalu and his colleagues have since largely influenced the creation and direction of concussion-regulating sport agencies (Kain, 2009). So much attention has been placed on these revolutionary works that, at the time of publication, at least three cinematic enterprises were reported to be drafting movies centered on the topic (McDonald, 2014).

The purpose of this literature review is to strengthen the understanding, awareness, and appreciation on the issues and long-term effects of recurrent concussion for practitioners and other personnel in sport that might not otherwise be exposed to this information (e.g., coaches, trainers, administrators, managers, students, etc.). McCrory and colleagues noted that increasing concussion knowledge in this population "is a mainstay of progress in this field" (2013, p. 560). As was also noted by Guskiewicz et al. (2007), much of the work on the long-term effects of concussion has overlooked the effects of recurrent concussion.

Thus, the author seeks to orchestrate many of the prevalent, current publications on recurrent concussion into the first comprehensive assembly that addresses trending issues and the long-term concussive effects unveiling themselves throughout contact sports. It is important, however, for the reader to hold an appreciation for the concussion potential and commonality that presents itself in other "noncontact" sports, to include extreme sports (skiing, snowboarding, etc.) and motor sports, for example.

1. Understanding Concussion and Mild Traumatic Brain Injury

The terms *concussion* and *mild traumatic brain injury* (mTBI) have long been used interchangeably throughout many contexts. However, some authors suggested that *concussion* has not been fully understood or effectively interpreted (Kelly & Rosenberg, 1997), especially by the parents of young athletes (DeMatteo et al., 2010). DeMatteo and colleagues indicated that concussion is often classified and adopted separately from brain injury (i.e., TBI) in clinical settings and, therefore, is not elucidating for the patient/family (2010). The authors specifically found that *concussion* was often used to refer to head injury with no significant or perceived long-term consequences in youth, which seems to be influenced by the literature submitting that most young concussed athletes make a full recovery (e.g., Terry et al., 2012). It is important to note, however, that although full recoveries are evident, age has been repeatedly found to be a predictor of post-concussion cognitive impairment, where interscholastic athletes (i.e., athletic competitors between the ages of 8 and 18, generally) have demonstrated slower recoveries than collegiate and professional athletes (Cancelliere et al., 2014; Pellman, Lovell, Viano, & Casson, 2006). That is, despite "full recoveries" having been proposed in concussed youth patients, pathology and severity of concussion should be of greater objective concern. Due to these and other general misinterpretations equating to an increased risk of premature return-to-play, school, or other activity, DeMatteo and colleagues theoretically questioned if *concussion* and *mTBI* should then be referred to as a result of differing scenarios that "are the same but may produce different reactions to the injury" (2010, p. 333).

Inspired by research-practice debate and enduring legal disputes, Kain (2009) investigated the popular denial of recurrent concussion's effects leading to long-term cognitive impairment in the NFL.

Specific claims and other legal actions taken by the NFL were compared with evidence-based research to examine the liability exposure that was encountered. Kain's method to this investigation began with comparing published literature in sport to the legal and medical definitions, symptoms, diagnosis, and treatment of concussion. Although there was greater disagreement and misinformation about the terminology of *concussion* and *mTBI* in the past (e.g., Kelly & Rosenberg, 1997), the American Association of Neurological Surgeons defined *concussion* as trauma resulting in "an immediate and transient alteration in brain function, including an alteration of mental status and level of consciousness" (as cited in Kain, 2009, p. 703). Kain then found that the NFL, in particular, deemed *mTBI* as the synonym to post-concussion symptoms (i.e., *postconcussion syndrome*), which can include prolonged headaches, unsteadiness, memory disturbance, fatigue, blurred vision, and other dysfunction (Omalu et al., 2005).

As a part of the consensus statement inspired by the 4th International Conference on Concussion in Sport to further the conceptual understanding on sporting concussion, McCrory and colleagues (2013) acknowledged the synonymous use of *mTBI* and *concussion* that popularized throughout the disciplines. However, they conversely recommended *concussion* as the preferred term to be utilized in sporting contexts, holding that "concussion is a subset of TBI" (p. 555) and that mTBI may refer to differing injury designs by others not involved in sport (cf. DeMatteo et al., 2010). McCrory et al. then defined *concussion* as a brain injury classified by "a complex pathophysiological process affecting the brain, induced by biomechanical forces" (p. 555). Specifically, the nature and features of concussive head injury in sport include: (a) being caused by blunt force trauma to the head, "or elsewhere on the body with an 'impulsive' force transmitted to the head"; (b) typically resulting in the rapid onset of neurologic impairment, which may resolve spontaneously or up to a number of hours later; (c) may result in neuropathology that clinically reflects functional deficiencies over structural injury; and (d) results in a graded set of symptoms, with or without loss of consciousness (LOC), which may also be prolonged (McCrory et al., 2013, p. 555).

In this review, *concussion* and *mTBI* will be referred to synonymously, as practiced throughout the literature; however, *concussion* is the preferred term for its collective scope in sport, as suggested by McCrory and colleagues.

Concussion will be further defined as a brain injury which produces: (a) an alteration in cognitive function that illustrates an altered consciousness, including confusion, fogginess, dizziness, or memory deficiency (i.e., an amnesic period); and with (b) signs and symptoms that commonly include headache, loss of balance, blurred vision, personality change, lethargy, LOC, seizure, or other cognitive, emotional, and functional disability, as has been repeatedly reported in sports medicine (e.g., Bleiberg et al., 2004; Cancelliere et al., 2014; Galetta et al., 2011; Guskiewicz et al., 2005; 2013; Omalu et al., 2005; 2006).

1.1 Nature of Concussion Management

As introduced, a range of up to 3.8 million sports-related concussive episodes have been estimated in the U.S. each year. However, some authors have reported much lower figures, around 300,000 annual sports-related concussions (Guskiewicz et al., 2005). Nevertheless, these figures have grown substantially over estimations made nearly two decades ago (e.g., Kelly & Rosenberg, 1997). The significance of these estimated variations may suggest the significance of misinformation and variances encompassing concussion recognition or diagnosis in contact sports. In attempts to bridge this obfuscation, and for the purpose of this review, *contact sports* will be referred to as sports in which athletes participate in altercating physical contact with one another, necessary by nature of the sport. To reiterate, though, it is important for all involved in sport to remain cognizant and appreciative for the significance and potential of concussion in sports that are not considered "contact."

The most common and simplistic sideline concussion evaluation in sport is the orientation question method delivered to the athlete (e.g., "Do you know about what time it is?" "Do you know where you are?" "Who is the President of the United States?"). In McCrory and colleagues' (2013) consensus statement, however, they concurred that this method has shown to be an unreliable informant for concussive symptoms. Instead, these scholars recommended the revised Sport Concussion Assessment Tool (i.e., SCAT3), which is a psychoneurological test battery that assesses cognitive function such as memory and attention span (Guskiewicz et al., 2013), as the preferred method to detecting concussively-risked athletes. This should not, however, deter the coach, trainer, or other practitioner from implementing other evaluation methods that still hold credibility and familiarity.

Withdrawing an athlete from play as any one sign or symptom becomes evident is of the upmost importance ("NCAA," 2011), and it has been unanimously agreed that there should never be a return-to-play (RTP) decision made on the same day of concussive injury (McCrory et al., 2013). This decision is largely based on the delayed onset of neuropsychological symptoms and the difficulty in objectively reporting all such associating evidence or indications.

Corresponding with the uncertainty surrounding diagnosable concussion based on concussive symptoms objectively witnessed from the sidelines, the National Collegiate Athletic Association (NCAA) has adopted a similarly stringent concussion policy expected to be followed throughout all member institutions:

> Institutions shall have a concussion management plan on file such that a student-athlete who exhibits signs, symptoms or behaviors *consistent with* a concussion shall be removed from practice or competition and evaluated by an athletics healthcare provider with experience in the evaluation and management of concussions. ("NCAA," 2011, p. 56, emphasis added)

Thus, a conservative approach toward concussion management is expected throughout NCAA sports, as influenced by the concussion literature, where even a speculative or debatable sign of concussion is expected to remove an athlete from play for further evaluation. Accordingly, the Consensus (i.e., McCrory et al., 2013) illustrated that the importance of sideline evaluations need to be sufficiently understood by all participating in sport, even if "this may require rule change[s] to allow an appropriate off-field medical assessment" (p. 556).

Ongoing off-field evaluations also need to hold priority over expeditious RTP decisions as concussive symptoms may be prolonged or delayed (Bleiberg et al., 2004; Grubenhoff et al., 2014), including functional abnormalities in seemingly asymptomatic athletes (Cao, Tutwiler, & Slobounov, 2008; De Beaumont, Lassonde, Leclerc, & Théoret, 2007; Echlin et al., 2010; Henry, Pardini, McMahon, Nwachuku, & Okonkwo, 2014; Moser, Schatz, & Jordan, 2005). Most notably, "concussion should be seen as an evolving injury in the acute stage" (McCrory et al., 2013, p. 556).

However, clinically speaking, the Consensus noted that off-field medical assessments on concussion need to focus on more thorough neuropsychological testing batteries over the more common computed tomography (CT) and magnetic resonance imaging (MRI) evaluations (see also, De Beaumont, Lassonde, et al., 2007; Simma, Lütschg, & Callahan, 2013; Weinstein et al., 2013). Of course, neuropsychological testing batteries are controvertible (Randolph, McCrea, & Barr, 2005), but the Consensus further noted that CT and MRI tests rarely contribute to concussion evaluations, nor do they identify or diagnose concussion (although neuroimaging should be employed if structural damaged is suspect or evident, as will be illustrated later). Cognitive assessments, therefore, should remain integral in concussion management, especially so regarding RTP decisions. It is also important to note, however, that functional MRI (fMRI) may reveal patters that relate to concussion severity and recovery (Hutchison, Schweizer, Tam, Graham, & Comper, 2014; Johnson et al., 2012; Terry et al., 2012).

Suggesting that an athlete's overall RTP decision should be made via a multidisciplinary approach, the Consensus concluded that practitioners of differing specialties can and should effectively collaborate for more thorough medical decisions (see also Echlin et al., 2010; Heath & Callahan, 2013; Matheson et al., 2011; Shrier, Safai, & Charland, 2014). Not only does this correspond with Doherty's (2013) overture for the direction of sport management, but this will further establish the need to remove sole RTP decisions from a team's medical staff or from individual physicians, which have demonstrated judgments to be financially constricted (Kain, 2009). Thus, the nature of team physicians' RTP guidelines is not only variable in general (Matheson et al., 2011; Shultz et al., 2013), but is victim of conflicting financial and ethical interests (Kain, 2009; Kirschen, Tsou, Nelson, Russell, & Larriviere, 2014), evidently leading to, or at least highly feasible of, poor concussion management.

Kirschen and colleagues (2014), who further examined the legal and ethical issues pertaining to physicians' RTP decisions, suggested that the research and management of concussion in sport would greatly benefit from a wider implementation standard for baseline cognitive testing, and the evolution of a "national concussion registry." The multidisciplinary approach, therefore, supports the outstanding requirement for coaches, trainers, physicians, administrators, and other practitioners in sport to possess comprehensive knowledge in the long-term effects of recurrent concussion.

Where one sport supporter may understand the general athlete's perception of concussion founded by personal experience (e.g., a forwards coach in rugby), a certified athletic trainer may be educated in the doctrine and need for graduated RTP protocol, and a psychoneurologist may produce prolific knowledge in the pathophysiology of each recurrent concussion. Still, it remains clear that concussion management methodology, policy, and philosophy retain a common goal: to reduce, if not prevent, the possibility of recurrent concussion in order to decrease, if not eliminate, the probability of long-term consequences.

1.2 Nature of Recurrent Concussion

Throughout this review, *recurrent concussion* refers to (a) intermittent or repetitive head trauma, each demonstrative of cognitive or other pathophysiological characteristics of concussion, (b) with no specified, yet qualifiedly reasonable, length of time between each injury, whether or not previous signs or symptoms have subsided. That is, recurrent concussion is considered a separated phenomenon from second impact syndrome (SIS), but is embracive of SIS. As a poorly understood and rarely documented anomaly in sport, SIS is generally expected to reflect the loss of cerebral autoregulation (i.e., stable cerebral blood flow) and result in cerebral edema (brain swelling) (e.g., Bey & Ostick, 2009; Cantu & Gean, 2010; McCrory & Berkovic, 1998; Wetjen, Pichelmann, & Atkinson, 2010). Wetjen and colleagues (2010) noted that even a second traumatic impact elsewhere on the body can cause impulsive forces and stress-induced symptoms that lead to similar SIS results (e.g., cerebral edema), which is believed to be specifically caused by the intracranial acceleration/deceleration forces (Cantu & Gean, 2010). The expectation is that such catastrophic effects will occur if one succumbs to the symptoms of a repeat concussion before fully recovering from symptoms of the previous concussion; that is, a form of recurrent concussion (although there remained controversy around this accord [e.g., McCrory, 2001]).

It appears as though a good majority of the SIS literature prevails on the adolescent patient (e.g., Cantu & Gean, 2010; Caskey & Nance, 2014; Grace, 2013; Simma et al., 2013; Veevers, Lawler, & Rutty, 2009; Weinstein et al., 2013), with such evidence possibly relating to the ongoing phenomenon of unnoticed/unrecognized concussive symptoms in these populations (Heath & Callahan, 2013; McCrea, Hammeke, Olsen, Leo, & Guskiewicz, 2004).

Importantly, athletes who have not fully recovered from concussive symptoms are incomparably susceptible for recurrent concussion with greater, even fatal, post-concussion symptoms (Caron et al., 2013; Grace, 2013; Wetjen et al., 2010), securely establishing the preeminent need for continued research and awareness on recurrent concussion.

SIS has long been controversial due to the limitedness of obtaining quantifiable data, with increasing questions and uncertainty situating the matter (McCrory, 2001). However, Weinstein and colleagues (2013) were recently presented with the opportunity to publish a case report of SIS that was presentable with CT data between concussive injuries. The patient, a 17-year-old male high school American footballer, encountered what was described as a vigorous helmet-to-helmet collision during competition. The athlete reportedly experienced dizziness, impaired vision, and a persistent headache, yet continued to play the remaining 15 minutes of the game. After continuing sporting activities the following few days, the athlete was examined by his primary care physician, motivated by the athlete's prolonged, persistent headaches. Unenhanced CT scans were performed and interpreted as normal by the primary physician, which received the same judgment by several neurosurgeons and a neuroradiologist (cf. Simma et al., 2013). The athlete was advised to discontinue play until his symptoms subsided; however, he proceeded to practice later, that afternoon.

Approximately 5 days post-concussion, the athlete continued full practice and, during a hitting drill, experienced dizziness and a severe headache. The athlete collapsed several plays later and became unresponsive before sustaining seizure activity. The local emergency room conducted a noncontrast CT, which revealed thin bilateral subdural hematomas. After being flown to a tertiary trauma and neurosurgical center, a repeat noncontrast CT revealed subdural hematomas and cerebral edema (intracranial pressures were reported at 25-30 mm Hg, where 5-15 mm Hg is suggested as normal).

By the patient's third hospital day, the subdural hematomas were reported stable, as revealed by a repeat CT. Unfortunately, though, the athlete experienced many other substantial complications throughout the duration of his stay, to include hypotension, severe metabolic acidosis with renal failure, sepsis, pneumonia with empyema, disseminated intravascular coagulation, and cardiac arrest.

The patient was transferred for rehabilitation approximately 50 days later, and was discharged approximately 3 months post-repeat concussion. It was at this time that the patient was reported as "nonverbal and nonambulatory" (p. 332). After the ensuing 3 years, the patient reported to have recovered only limited verbal, motor, and cognitive abilities (see also, Cantu & Gean, 2010).

Original theories (e.g., Saunders & Harbaugh, 1984) encircling SIS suggested that deformities and other impairment post-initial concussion may be evident by CT, requiring only an initial CT for RTP. However, Weinstein and colleagues disproved this theory in that such derangement did not prove visible on initial routine CT evaluations. Thus, it appears that the need for revised emergency room protocol and standard care treatment of concussed athletes is tenaciously reinforced (Henry et al., 2014; Simma et al., 2013), further supporting that the physician, coach, trainer, administrator, or other sport manager should not solely rely on initial CT or physician reports to determine an athlete's RTP. "Importantly, this case shows that a normal head CT scan does not obviate the need for close clinical follow-up and for the athlete to be cognitively normal and asymptomatic before return to play" (Weinstein et al., 2013, p. 333).

Although this case study positioned one example, possibly unique, the authors clearly presented the exponential uncertainty of recurrent concussion. What is more is that the athlete did not present any initial signs, as perceived from the sidelines, which required withdrawal from play. The athlete complained of cumulative headaches as the primary concern thereafter, yet Weinstein and colleagues found no previous literature specifically accounting for severe headaches with SIS as a resultant; that is, outside of headaches serving as a general, common symptom of concussion.

Accordingly, Kontos et al. (2013) investigated the phenomenon known as *posttraumatic migraine* (PTM) and sought to determine whether PTM, defined as a severe headache that is present with nausea, photosensitivity, and/or phonosensitivity, is an effective predictor of post-concussion cognitive impairment and recovery. The authors examined 138 high school American football players who had a documented, diagnosed sports-related concussion in one of two distinctive institutions in the U.S.

Overall, Kontos and colleagues found that post-concussion PTM was a statistically significant indicator of worsened cognitive impairment (verbal memory, visual memory, and reaction time), elevated symptoms (cognitive, emotional, somatic, and sleep), and prolonged recovery compared to concussed athletes who did not meet PTM criteria, with or without headache.

Kontos et al. did not find a significant association between general headache symptoms and prolonged recovery, although there remained a high presence of headache without migraine symptoms in concussed athletes (n = 119; 86%). This work persisted with what others have found (e.g., Makdissi et al., 2010; Schneider, Meeuwisse, Kang, Schneider, & Emery, 2013; Weinstein et al., 2013), suggesting that headache remains a concerning indicator of concussion, holding that the symptom surfaces shortly thereafter (Stovner, Schrader, Mickevičiene, Surkiene, & Sand, 2009). Moreover, after Weinstein and colleagues' report, the authors searched the concussion literature concerning headaches, concluding that a "profound ongoing headache may be a more specific predictor [of concussion] than other subjective symptoms" (2013, p. 334).

Questions then remain concerning the recovery period required in order to prevent or, at least, reduce recurrent concussion. As it was reviewed, the onset of any one sign or symptom is cause for removal from sport and physical activity in order to best precipitate recovery, and no RTP decision should be made on the same day. Yet, duration of recovery varies throughout the literature. Echlin and colleagues (2010) conducted a study that specifically followed the guidelines suggested from the previous (3rd) Consensus on Concussion in Sport (i.e., McCrory et al., 2009) to examine recovery periods beginning at the onset of possible concussive symptoms. This was the first study to allow independent physicians to follow an athlete's diagnosis, treatment, and RTP protocol initiated by on-site evaluations.

Within this study, 23.8% (n = 5) of the concussed junior ice hockey athletes sustained a recurrent concussion within a mean interval of 78.6 (± 39.8) days (*MED* = 82 days) between injuries. The mean RTP interval between the initial and repeat concussions was 61.8 (± 39.7) days (*MED* = 60 days). Also noteworthy is that Echlin et al.'s mean recovery interval before RTP of all qualifiedly concussed athletes (n = 15) was 12.8 (± 7.02) days (*MED* = 10 days), generated by a range of 7 to 29 days of recovery.

Grouping athletes according to concussion history, the authors found that those with no prior concussion history (n = 8) averaged 11.5 (± 7.60) days before RTP, while athletes with 1 or 2 prior concussions (n = 6) averaged 10.7 (± 2.94) days. Only one player reported a history of more than 3 previous concussions, which subsequently required 29 days of recovery before RTP.

Clearly, there is no universally specified length of recovery for concussive injury to occur when following the guidelines collectively determined by the Consensus (i.e., McCrory et al., 2009; 2013). Although Echlin and colleagues' investigation found that athletes with 1 or 2 prior concussions averaged slightly quicker RTP (M = 10.7 days) compared to that of athletes with no reported concussion history (M = 11.5 days), the larger variance that occurred in recovery after one's first concussion (SD = ± 7.60 days) compared to that of recurrent concussion (SD = ± 2.94 days) is noteworthy and may obligate further work to investigate this phenomenon. Lastly to note is that there remained three athletes who were unrecognizably concussed during supervised game play, despite the liberal approach employed to observation. This paradox furthers the need to investigate, revise, and/or create contemporary methods to recognizing concussion in sport in order to improve concussion management and decrease recurrent concussion possibility.

2. Long-Term Signs and Symptoms

It has been widely established that the superficial (indicative) signs and symptoms of a sports-related concussion generally subside within 7 to 10 days succeeding injury (Cancelliere et al., 2014; McCrory et al., 2013). Moreover, researchers that sought to identify the potentially permanent cognitive effects of a concussion suggested that traits such as recognition memory and reaction speed may not be affected, while visual-spatial processing, mathematical processing, and memory recall may only be susceptible to short-term impairment (i.e., 3 to 14 days; Bleiberg et al., 2004). Literature concentrated on the long-term effects of concussion, however, have authenticated detriments in short-term memory processing (Chuah, Maybery, & Fox, 2004), cognitive reaction and attention span (Howell, Osternig, Van Donkelaar, Mayr, & Chou, 2013), and proprioception and gait inefficiencies (e.g., Cao et al., 2008; Martini et al., 2011; Sosnoff, Broglio, Shin, & Ferrara, 2011). Likewise, recurrent concussion appears demonstrative of possibly cumulating, multimodal long-term deficiencies, which is the scope of this section and fundamental intent of the review.

2.1 Consequences to Recurrent Concussion Exposure

It was introduced earlier that Omalu and colleagues' (2005) original research that connected chronic traumatic encephalopathy (CTE) to the recurrent concussion nature of American football largely influenced the current direction of the field. The following year, Omalu and colleagues (2006) published the second autopsy-confirmed case study of CTE in a former NFL athlete. Although the Consensus (i.e., McCrory et al., 2013) agreed that no direct cause-and-effect relationship exists between CTE and concussion exposure due to the limitedness of current research methods (CTE may only be confirmed post-mortem), Omalu and colleagues stated the importance of continuing CTE research where possible being that "chronic neurodegenerative changes have been causally associated with contact sports" (2006, p. 1087). Therefore, Omalu and colleagues' (2005; 2006) infamous works will be introduced here for sport managers to be exposed to predominating literature that inspired others to pursue research efforts on recurrent concussion in sport.

Omalu et al.'s (2005) neuropathological examination presented factual data to the field on the controversial subject of life-long cognitive deficiencies highly attributable to recurrent concussion in contact sports. Their patient, a retired NFL player with a known successful career in American football, competed in 245 games across 17 seasons, 177 of which (10 seasons) were played in consecutively. After the former athlete's passing due to cardiac arrest, evaluation of the patient's medical history revealed noteworthy neuropsychiatric disorders that resembled dysthymic disorder (a depressive mood disorder), memory and judgment deficiencies, and parkinsonian symptoms.

Histomorphology (the study of the morphology of cells) was followed during autopsy, staining all tissue sections of the central nervous system for neural examination. The histological evidence undoubtedly indicated that the former athlete sustained multiple, recurrent concussive trauma. The results were able to dismiss Alzheimer's disease (AD) and fully meet criteria for CTE – the only preventable form of dementia that results in behaviors comparable to AD, yet is caused by repeated brain trauma. Comparing their results to the former CTE literature on professional boxing athletes, Omalu and colleagues' findings firmly suggested that the discovered neurological trauma was resultant from repetitive brain injury sustained in American football.

After taking into consideration the possible genetic predisposition to AD-/CTE-like traits that associate with the apolipoprotein E genotype, Omalu and colleagues were also able to fairly conclude that the patient was not genetically predisposed to such outcomes.

Because this was the first case study to autopsy a former NFL player with specific cognitive declination investigations, this research is commonly compared with new concussion studies in the CTE literature. Still, the prevailing debate against CTE found in historically concussed athletes is genetic predisposition (e.g., Kaplan, 2014). Although Omalu et al.'s 2005 case study showed negative results for such an association, Omalu and colleagues' work in 2006 did exhibit genotype personalities that corresponded with an increased predisposition to CTE. However, this patient also demonstrated unique neuropathological traits that were detailed in the report but that were not evident in the first case.

Their second patient, a 45-year-old African-American male, played a total of 14 years of American football, with the last 8 consecutive years played in the NFL. There were no reported behavioral or psychosocial discrepancies during the athlete's amateur years of athletics. However, by his introductory years in the NFL, the patient was reported as having significant and unpredictable mood, behavioral, and personality fluctuations. These fluctuations continued throughout his NFL career, during which time the patient experienced his first suicide attempt, and continued long into the years thereafter. Many subsequent suicide attempts were reported throughout the duration of the patient's lifetime, which lead to his admittance in psychiatric treatment on three occasions. The patient died from a completed suicide attempt approximately three weeks after being discharged from his third admission.

After extensive neurologic analyses, the abnormalities found were undeniably characteristic components of recurrent concussion sustained from contact sports. The gathered data also collectively corresponded with the commonality of major depression, dementia-related symptoms, and neuropsychological deficits that were reported in other recurrently concussed contact sport athletes. This work promotes the need for continuing research to strive for early detection of CTE, especially considering that both this patient and the former (i.e., Omalu et al., 2005) demonstrated paralleled signs and symptoms of major depressive disorders after retiring from sport (cf., Thornton et al., 2008).

Although the 2006 patient exhibited genetic predisposition to AD-/CTE-like dysfunction, this did not prove absolute predisposition. Likewise, Guskiewicz and colleagues (2005) investigated the association between concussion history and the development of mild cognitive impairment (MCI) and AD in former professional American football players. After establishing a representative sample of members from the National Football League Retired Players' Association (NFLRPA), Guskiewicz and colleagues implemented two questionnaires: (1) the general health questionnaire, to qualitatively attain previous concussion history and calculate physical and mental health scores; and (2) the Mild Cognitive Impairment Instrument, to collect any other cognitive impairments not captured by the first questionnaire. The authors then collected data from 2,552 former professional athletes (that is, 69.3% of the NFLRPA at the time) where the respondents represented a mean age of 53 and a mean of 15 years of experience in competitive American football (mean professional league [NFL] experience was 6.5 years).

Through the responses, Guskiewicz and colleagues were able to identify some relationship between concussion history and lower mental health scores in former athletes older than 50. The Mild Cognitive Impairment Instrument, which received fewer participants and was largely disclosed by close relatives (45.8%), recorded that retirees with three or more concussions have "a fivefold prevalence of being diagnosed with MCI" (p. 722). Limitations may exist by these self-reported and second-person interpretations of cognitive impairment, however. Other limitations are evident in this research as well. The authors failed to specifically correlate the AD statistics with the concussion histories of retired players, resulting in a generalized correlation. That is, concussion history was separately calculated data from players with AD, leaving room for uncertainty for a specific correlation ratio between recurrent concussion exposure and/or severity and AD. Regardless, this work remains largely cited.

Other curious data represented by these former athletes is that only 24% claimed to have sustained three or more lifetime concussions; that is, throughout their mean 15 years of experience. This figure does not seem to conform to current and former legal disputes and other recurrent concussion literature (e.g., 3 out of 5 concussed athletes [i.e., 60%] were found to be recurrently concussed; Echlin et al., 2010).

Notwithstanding the intentions of Guskiewicz and colleagues, who introduced some interesting assertions to sport, such as the later-in-life development of MCI, this work appears to coincide with concerns of other sport concussion academicians in that there has, historically, been a lack in well-designed, controlled, and confirmatory research. Although similar limitations continue to inspire additional controversy on the topic, more recent research has suggested that greater results are obtained from subjective analyses than from neuropsychological evaluations (Thornton et al., 2008). In addition, in regards to Guskiewicz et al.'s seemingly low recurrently concussed figure, others have stated that "the rarity of [recurrent concussion] and the likelihood that a significant number of concussed athletes have played while symptomatic may be indicative of a population subset that is still unidentified" (Weinstein et al., 2013, p. 334). Therefore, contemporary investigations on the causal relationship(s) between dementia-related symptoms and recurrent concussion are necessary for warranted, well-founded conclusions in sport and medicine (McCrory et al., 2013).

2.2 Consequences of Concussion Severity

As introduced earlier, *postconcussion syndrome* includes the initial cognitive, somatic, and behavioral dysfunction after an induced concussion, which may persist from a few days to many months post-injury (Hall, Hall, & Chapman, 2004). Importantly, though, sports medicine's results seem to be trending toward the explanation that concussion severity is the greatest predictor of prolonged post-concussion symptoms and persistent cognitive deficiency as opposed to one's numeric concussion history (e.g., De Beaumont, Lassonde, et al., 2007; Røe, Sveen, Alvsåker, & Bautz-Holter, 2009; Thornton et al., 2008). This phenomenon may be explained by the severe cumulating effects of recurrent concussion (Iverson, Gaetz, Lovell, & Collins, 2004), but not necessarily the incident of concussion itself, since some may be more severe than others (e.g., Cantu, 1998). While athletes' recoveries (or lack thereof) influence their susceptibility for recurrent concussion (Caron et al., 2013; Grace, 2013; Guskiewicz et al., 2003; Wetjen et al., 2010), those with a reported history of one or two severe concussions generally do not demonstrate long-term deficiency, whereas those with three or more severe concussions evidently experience neurologic and behavioral dysfunction (Caron et al., 2013; De Beaumont, Brisson, Lassonde, & Jolicoeur, 2007; Thornton et al., 2008).

Let us consider Thornton and colleagues (2008), who specifically sought to improve neuropsychology's direction on the neurocognitive functioning and symptomatic effects of recurrent concussion. These researchers obtained and screened (exclusion criteria included non-sport related concussion, neurological disease, and being over 66 years old) a randomized sample of 111 current (n = 95) and former (n = 16) British rugby players. The majority (72%; n = 80) of the sample averaged 26.43 (± 6.53) years of age, composed of 13 female and 67 male athletes, while the remaining 28% (n = 31; all male) were older, with a mean age of 39.3 (± 10.99) years. The 80 younger athletes all continued to play competitively and assumed Thornton et al.'s "Competitive" group. Sixteen athletes in the older population no longer played the sport, while the remaining 15 continued to play recreationally, composing "Retired" and "Recreational" groups, respectively. The Recreational athletes' mean rugby experience was 26.93 (± 15.19) years, while the Competitive and Retired athletes' mean rugby experience was 10.46 (± 6.79) years and 13.13 (± 8.9) years, respectively.

After Thornton and colleagues implemented a self-reported head injury questionnaire to obtain subjective data to index with their established concussion grading criteria (Grade I, II, and III; see Cantu, 1998), all subjects underwent neurocognitive testing which evaluated intellectual abilities, fluid intelligence, processing speed, working memory, long-term memory, and executive skills. Next, Thornton and colleagues evaluated post-concussion symptoms with the Postconcussion Symptom Checklist (PCSC). Then, to measure outcomes during analysis, three groups of Grade II or III concussive episodes were created based on the participants' volume (1-2, 3 or more, or no severe concussions) and, as a quantifiable measure, the extent to which the effects of other variables (e.g., LOC, age, rugby experience) accounted for neurocognitive and symptomatic outcomes were analyzed.

The group analyses revealed that, in regards to current neuropsychological functioning, there were minimal differences notable between Thornton and colleagues' three groups. The only statistical significance evidenced across the groups was in the working memory's listening span, demonstrating that listening span had the largest reduction in athletes with a history of three or more Grade II or III concussions, but not in those who experienced one or two.

Likewise, as uncovered by the PCSC, the Memory, Distress, and Total scales showed declining cognitive wellness later in life that associated with the athletes' concussion histories. That is, the frequency of Grade II and III concussions appeared to positively associate with memory issues, distress, and more overall post-concussion symptoms later in life. This relationship was non-existent in the Competitive sample (*M* age = 26.43 ± 6.53; *M* experience = 10.46 ± 6.79), but was experienced by Retired (*M* age = 39.3 ± 10.99; *M* experience = 13.13 ± 8.9) and Recreational (*M* age = 50.5 ± 9.8; *M* experience = 26.93 ± 15.19) athletes. Therefore, Thornton et al.'s work may: (1) suggest that severe concussion effects do not surface until later in life; (2) represent the resilience to such consequences that younger athletes may possess; and/or (3) support that cognitive impairment from recurrent concussion cumulatively leads to symptoms similar to that of dementia (cf., Guskiewicz et al., 2005; Omalu et al., 2005; 2006).

It is important to note that when Thornton and colleagues grouped their subjects by numeric concussion history, the three or more severe concussion group consisted of athletes who estimated sustaining upwards of 24 severe concussions. The authors discussed this considerable concussion history variance and conceded that their correlations were formed only between concussion severity and cognitive decline as opposed to concussion volume and cognitive decline. Likewise, De Beaumont, Lassonde, and colleagues (2007), who studied 45 asymptomatic athletes with unremarkable MRI results from the University of Montreal's American football team, suggested that recurrent concussion results in long-term subclinical motor cortex dysfunction at least 9 months post-concussion, as evidenced by cortical silent periods (CSP – a period of reduced or absent electromyographic activity following transcranial magnetic brain stimulation). The authors specifically supported this conclusion by three primary sources of evidence: "(1) the duration of the CSP was significantly *prolonged in those athletes with a history of concussions*; (2) sustaining *subsequent concussions exacerbates CSP abnormalities*; and (3) CSP duration is positively correlated with the *severity* of concussions sustained" (p. 334, emphases added). When investigating methods to determine the best predictable variable for CSP abnormalities, they further found that such outcomes attributed to concussion severity significantly greater than other factors in recurrently concussed athletes.

Although these neurophysiological dysfunctions are concurrently experienced from recurrent concussion, others (Caron et al., 2013) subjectively found numerous psychological and behavioral trends that also associated with severe concussion exposure. What is more is that increased exposure was unequivocally and harmfully influenced by improper sport management. Whether psychological or physical disability evolves due to an athlete recurrently sustaining concussion, either disability can be extreme cases of an athlete's decreased quality of life.

Concussion then becomes a large contributor to athletes' careers being replaced by early retirement in contact sports by these concurrent symptoms (Caron et al., 2013; Carroll, 2012). Recognizing this, Caron and colleagues (2013) validated the need to further understand how retired athletes' lives are affected due to recurrent concussion, which strongly supported sport psychology's direction in training and injury management programs. The purpose of the study was to understand professional athletes' psycho-emotional effects of retirement due to recurrent concussion, discovering such effects from the athlete's perspective (i.e., their lived experiences).

The authors implemented an Interpretative Phenomenological Analysis as an inductive method to understand retired athletes' experiences with recurrent concussion and to inspire the development/progression of multimodal interventions for sport practitioners' concussion management protocol. Five retired (for at least four seasons) National Hockey League (NHL) players with no less than ten seasons of professional experience were interviewed to gather what and how these athletes experienced their concussions, inclusive of perceived long-term consequences. All of Caron et al.'s subjects were repeatedly diagnosed with severe concussions and subsequently retired due to the symptoms.

As introduced, the results of this study were numerous, but certain trends surfaced throughout all retirees' interviews. The study revealed: (1) the formidable popularity of athletes continuing to play through possible mild to severe concussions, concealing any signs or symptoms from game personnel (there were unknown numeric concussion histories sustained by the retirees, but each assumed to have experienced at least 10, if not more); (2) the "warrior mentality" culture persists in all levels of hockey and sacrifices proper health and wellness care in order to be praised for playing through injuries;

(3) the commonality of experiencing isolated feelings from sport and society when injured largely precipitated the first two findings; (4) long-term (specifically, 4 to 14 years) concussion symptoms emotionally and behaviorally resulted in anxiety and depressive effects, to include suicidal thoughts (cf., Omalu et al., 2006); and (5) retirees' post-hockey careers were restricted due to the lingering "daily reminders of their lost identities" (p. 176), which were provoked by ongoing headache and migraine symptoms.

The neurologic and behavioral trends that surfaced throughout these works suggest that athletes who are continually (recurrently) exposed to severe concussion experience neurological and behavioral debilitation that severely effects their daily lives. It is also interesting to note that subjective data appear to have been more indicative in associating dysfunction with recurrent concussion. Currently, specialized neuropsychological tests have only been able to discover a portion of such cognitive dysfunction, as has been replicated in research reviewed in previous sections. These trends should be further investigated across multiple contact sport populations in attempts to discover any such ubiquitous effects of severe recurrent concussion, with particular attention on the comparison between subjective and objective data.

3. Other Considerations

It is clear that a word regarding the nature of researching concussive effects in sports medicine is required for all in sport to comprehend. Currently, unveiling the results of the effects of concussion largely requires descriptive/nonexperiemental research (surveys, interviews, correlation research, case studies, observational research, etc). That is, no independent variable is introduced or manipulated and extraneous variables are a struggle to control. Rather, it is taught in descriptive research that "subjects are usually identified by some predetermined criterion [such as concussion history] and are grouped in that fashion" (Berg & Latin, 2008, p. 230).

The rationale for this research method is that experimental research is not always practical or ethical, as is the case for many epidemiological investigations on concussion. For example, no Institutional Review Board, which governs the ethical practices of research conducted at scholarly institutions, will approve of a researcher gathering a sample of healthy, never concussed athletes to impose blunt force trauma on in search of demonstrating the immediate post-concussion effects on previously healthy individuals.

To obtain such information, researchers are currently required to gather a population sample of athletes with established concussion histories, as has been followed in the majority of the sources reviewed in this work. However, the NFL, in opposition, continues to battle against medicine's results on sporting concussion and recently commissioned a professor out of the University of California, San Francisco to include her opinion in the NFL's recent court hearing on the long-term effects of concussion induced by American football (Kaplan, 2014). The scholar argued against the relevant nature of descriptive research, suggesting that the bias nature of population selection and subjectively gathering data is inadequate in determining cause-and-effect. While limitations in these methods do exist, as do limitations in all research, descriptive research "should not be thought of as second-rate research… [It] is based on logical deductions about the connections between variables. This type of association is referred to as a *causal relationship*" (Berg & Latin, 2008, p. 230, emphasis added).

Still, researchers can absolutely control for such controversial topics. Recall De Beaumont, Lassonde, and colleagues' (2007) work:

> [T]o partially address the issue of cause and effect—namely, that abnormalities in motor cortex function were a premorbid characteristic and may have played a causal role in individuals sustaining sports concussions—that cannot be excluded in retrospective studies of this nature, we sought to prospectively investigate whether sustaining another concussion would result in worsened motor system abnormalities, which would thereby provide additional support for the contention that the effects of concussions are cumulative. (p. 330)

Although some have suggested that the NFL's continued denial of the causal relationship between preventative cognitive diseases and recurrent concussion is similar to that of the tobacco industry's former denial of smoking causing cancer (Kain, 2009; Kaplan, 2014), there remain legitimate limitations in descriptive research. However, it is imperative to understand that causal relationships described in the concussion literature simply express the continuality of variables presenting themselves simultaneously, such as cognitive impairment and a history of, or exposure to, recurrent concussion. That is, the presentation of such associations cannot and do not explicitly describe causation in and of itself.

Instead, researchers, practitioners, and other consumers of research may justifiably rationalize cause-and-effect via critical thinking and conservative, sound, and logical interpretations supported by scientific substantiation within descriptive research (Berg & Latin, 2008). As Berg and Latin further explained, it would be entirely foolish for consumers of research to attempt to reject powerful causal relationships simply due to the inability of descriptive research to explicitly state cause-and-effect.

Nevertheless, this review cannot incorporate even a comparatively modest amount of the concussion literature in sport, suggesting that the concentration is far beyond its exploratory stage. Advances in the field, though, are required to continually investigate more effective and efficient methods of exploratory research that can replicate (validate) or disprove the cause-and-effect suspicions evolving from the topic's current state. In addition, the majority of the concussion literature in sport is centered on American football. Although the National Federation of State High School Associations (NFHS) (2008; 2014) reported that fewer than 1.1 million youth participated in American football programs across 14,262 U.S. high schools during the 2013-2014 academic year, participation has dropped 1.3% since the 2007-2008 academic year, despite the growing number of schools offering American football programs. Comparatively, using the same data provided by the NFHS, participation in all other contact sports, as defined earlier in this work (viz., ice hockey, lacrosse, rugby, soccer, basketball, judo, water polo, and wrestling), has collectively grown by 4.2%.

The increasing participation data establishes the need for researchers investigating concussion in sport to continue their pursuit in all contact sports and challenge the status quo by not succumbing to the popularizing attention of concussion centralizing on American football. It is expected that this effort: (a) will further the discipline's knowledge in a much more diversified manner; (b) will surely reveal research extensions needed in otherwise neglected sporting populations; and (c) will categorically produce phenomenological explanations of concussion by potentially discovering sport or nature of impact trends, for example (i.a., the incidence rate of concussion in girls' soccer was found to be higher than that in boys' lacrosse [Lincoln et al., 2011]).

4. Summary

The purpose of this literature review was to comprehensively orchestrate many of the prevalent and current publications on the trending issues and long-term effects of recurrent concussion to strengthen the understanding, awareness, and appreciation for sport personnel that might not be regularly exposed to this information. Increasing knowledge in these professionals is imperative for collaboration between sport supporters and sport producers for improved concussion management and, correspondingly, improved sport management.

Contact sports are growing in popularity and are not constrained by demographic trends. With such a following, there appeared to be an associating concussion factor. Likewise, the prevalence of concussion in sport is continuing to gain public, legal, and medical interest, especially so regarding the recurrent concussion phenomenon in contact sports. Although concussive injury proved difficult to observe and measure, especially on the sidelines of sporting events, it is imperative for personnel in sport to recognize that the neuropsychological symptoms of concussion are commonly delayed post-injury, inclusive of causing athletes to appear asymptomatic. Therefore, no RTP decisions should ever be made on the same day of even a debatable concussive injury.

Throughout this review, *recurrent concussion* was defined to refer to intermittent or repetitive head trauma, each demonstrative of cognitive or other pathophysiological characteristics of concussion, with no specified, yet qualifiedly reasonable, length of time between each injury, whether or not previous signs or symptoms have subsided. As a subset of recurrent concussion, although rare, the phenomenon of second impact syndrome supportably presented intriguing literature to understand the exponential uncertainty of recurrent concussion. Likewise, unique second impact syndrome case studies further supported the need for revised standard care treatment and emergency room protocol, as well as portrayed the unreliability of CT evaluations for sport personnel's RTP decisions.

Although there are no set, universal days of recovery before RTP after a sports-related concussion, the literature suggested that longer recovery periods were required for athletes that were recurrently concussed. This alone demonstrated an element of complexity in recurrent concussion.

The indicative signs and symptoms of a concussion generally subsided within 7 to 10 days post-injury, but cognitive impairment was evident up to 14 days after even a single concussive episode. Moreover, recurrent concussion was demonstrative of cumulating and multimodal long-term deficiencies; namely, cognitive impairment, major depressive disorders (which commonly included suicidal thoughts/attempts), and other dementia-related symptoms.

Throughout the literature, though, there stood one primary symptom experienced by all concussed athletes: headache. Research focusing on headache and migraine symptoms suggested that prolonged headache symptoms may be a greater predictor of severe concussion than other signs or symptoms. Also to principally trend on the symptomatic effects of recurrent concussion was the seemingly growing presence of depressive mood disorders. Interestingly, attempting to associate such symptoms with the long-term effects of recurrent concussion did not appear to parallel with athletes' numeric concussion histories. The literature appeared to be trending toward the explanation that the greatest predictor of post-concussion symptoms and persistent cognitive deficiency is the *severity* of recurrent concussions. Some researchers have explained this phenomenon by the cumulating effects of recurrent concussion. That is, that each subsequent concussion results in more severe injury consequences, which corresponded with the increased susceptibility of concussion by athletes with prior severe concussions. However, the incidence of concussion itself did not support this phenomenological explanation. Instead, the incidence of recurrently sustaining severe concussions (Grade II or III) appeared to cause more severe consequences after sustaining a third concussion and, via prolonged recovery and worsened neurologic damage, increased susceptibility for recurrent concussion.

Although there remains difficulty in the assessment, diagnosis, and management of concussion in sport, researchers who have, thus far, sought to understand the long-term effects of recurrent concussion continually unveiled causal relationships between recurrently concussed athletic populations and cognitive impairment, memory issues, recollection and recognition inhibition, poor executive skills, unstable psychosocial development, and lower mental health scores later in life. The growing attention and research on these long-term effects appear to have been largely influenced by breakthrough research coupled with current and former disputes between research-practice gaps.

Regardless of definition, methodology, policy, or philosophy in concussion management, though, it remains clear that the common goal in sport is to reduce, if not prevent, the possibility of recurrent concussion in order to decrease, if not eliminate, the probability of long-term consequences. However, the majority of the attraction seems to be antagonistically centralized on the trends, issues, and effects of concussion in American football. This, in turn, appears to have caused a comparative lack in research on contact sports overall (hockey, rugby, mixed martial arts, etc.).

Recommendations for future research are then apparent – there is a significant need to continue investigations on the long-term, permanent, and/or diagnosable effects of recurrent concussion across all contact sports. With a 1.2% decrease in interscholastic participation of American football compared to a collective 4.2% increase in all other contact sports (ice hockey, lacrosse, water polo, etc.), there is a need for the field to continue contemporary pursuits across multiple contact sport populations. This review suggests that evolving research with such scope will further the discipline's knowledge in a more diversified manner, reveal extensions of research needs in otherwise neglected populations, and produce phenomenological explanations by potentially discovering sport or nature of impact trends.

References

Berg, K. E., & Latin, R. W. (2008). Essentials of research methods in health, physical education, exercise science, and recreation (3rd ed.). Baltimore, MD: Lippincott Williams & Wilkins.

Bey, T., & Ostick, B. (2009). Second impact syndrome. Western Journal of Emergency Medicine, 10(1), 6-10.

Bleiberg, J., Cernich, A. N., Cameron, K., Sun, W., Peck, K., Ecklund, J., … Warden, D. L. (2004). Duration of cognitive impairment after sports concussion. Neurosurgery, 54(5), 1073-1080. doi:10.1227/01.neu.0000118820.33396.6a

Cancelliere, C., Hincapié, C. A., Keightley, M., Godbolt, A. K., Côté, P., Kristman, V. L., … Cassidy, J. D. (2014). Systematic review of prognosis and return to play after sport concussion: Results of the international collaboration on mild traumatic brain injury prognosis. Archives of Physical Medicine & Rehabilitation, 95(3), S210-S229. doi:10.1016/j.apmr.2013.06.035

Cantu, R. C. (1998). Return to play guidelines after a head injury. Clinical Sports Medicine, 17(1), 45-60.

Cantu, R. C., & Gean, A. D. (2010). Second-impact syndrome and a small subdural hematoma: An uncommon catastrophic result of repetitive head injury with a characteristic imaging appearance. Journal of Neurotrauma, 27(9), 1557-1564. doi:10.1089/neu.2010.1334

Cao, C., Tutwiler, R. L., & Slobounov, S. (2008). Automatic classification of athletes with residual functional deficits following concussion by means of EEG signal using support vector machine. IEEE Transactions on Neural Systems & Rehabilitation Engineering, 16(4), 327-335. doi:10.1109/tnsre.2008.918422

Caron, J. G., Bloom, G. A., Johnston, K. M., & Sabiston, C. M. (2013). Effects of multiple concussions on retired National Hockey League players. Journal of Sport & Exercise Psychology, 35(2), 168-179.

Carroll, W. (2012, April 23). Dealing with injury: A look at the process involved in treating injured athletes and getting them back on the field. Street & Smith's SportsBusiness Journal. Retrieved from www.sportsbusinessdaily.com/journal/issues/2012/04/23/in-depth/process-lead.aspx

Caskey, R. C., & Nance, M. L. (2014). Management of pediatric mild traumatic brain injury. Advances in Pediatrics, 61(1), 271-286. doi:10.1016/j.yapd.2014.03.006

Chuah, Y. M. L., Maybery, M. T., & Fox, A. M. (2004). The long-term effects of mild head injury on short-term memory for visual form, spatial location, and their conjunction in well-functioning university students. Brain & Cognition, 56(3), 304-312. doi:10.1016/j.bandc.2004.08.002

De Beaumont, L., Brisson, B., Lassonde, M., Jolicoeur, P. (2007). Long-term electrophysiological changes in athletes with a history of multiple concussions. Brain Injury, 21(6), 631-644. doi: 10.1080/02699050701426931

De Beaumont, L., Lassonde, M., Leclerc, S., & Théoret, H. (2007). Long-term and cumulative effects of sports concussion on motor cortex inhibition. Neurosurgery, 61(2), 329-337. doi:10.1227/01.neu.0000280000.03578.b6

DeMatteo, C. A., Hanna, S. E., Mahoney, W. J., Hollenberg, R. D., Scott, L. A., Law, M. C., … Xu, L. (2010). "My child doesn't have a brain injury, he only has a concussion." Pediatrics, 125(2), 327-334. doi:10.1542/peds.2008-2720

Doherty, A. (2013). "It takes a village:" Interdisciplinary research for sport management. Journal of Sport Management, 27(1), 1-10.

Echlin, P. S., Tator, C. H., Cusimano, M. D., Cantu, R. C., Taunton, J. E., Upshur, R. E. G., … Skopelja, E. N. (2010). Return to play after an initial or recurrent concussion in a prospective study of physician-observed junior ice hockey concussions: Implications for return to play after a concussion. Neurosurgical Focus, 29(5), 1-5. doi:10.3171/2010.9.focus10210

Galetta, K. M., Barrett, J., Allen, M., Madda, F., Delicata, D., Tennant, A. T., … Balcer, L.J. (2011). The King-Devick test as a determinant of head trauma and concussion in boxers and MMA fighters. Neurology, 76(17), 1456-1462. doi:10.1212/wnl.0b013e31821184c9

Grace, M. T. (2013). Concussion in the pediatric patient. Journal of Pediatric Health Care, 27(5), 377-384. doi:10.1016/j.pedhc.2012.10.004

Grubenhoff, J. A., Deakyne, S. J., Brou, L., Bajaj, L., Cornstock, R. D., & Kirkwood. (2014). Acute concussion symptom severity and delayed symptom resolution. Pediatrics, 134(1), 54-62. doi:10.1542/peds.2013-2988

Guskiewicz, K. M., Marshall, S. W., Bailes, J., McCrea, M., Cantu, R. C., Randolph, C., & Jordan, B. D. (2005). Association between recurrent concussion and late-life cognitive impairment in retired professional football players. Neurosurgery, 57(4), 719-726. doi:10.1227/01.neu.0000175725.75780.dd

Guskiewicz, K. M., Marshall, S. W., Bailes, J., McCrea, M., Harding, Jr., H. P., Matthews, A., … Cantu, R. C. (2007). Recurrent concussion and risk of depression in retired professional football players. Medicine & Science in Sports & Exercise, 39(6), 903-909. doi:10.1249/mss.0b013e3180383da5

Guskiewicz, K., M., McCrea, M., Marshall, S. W., Cantu, R. C., Randolph, C., Barr, W., … Kelly, J.P. (2003). Cumulative effects associated with recurrent concussion in collegiate football players: The NCAA concussion study. Journal of the American Medical Association, 290(19), 2549-2555. doi:10.1001/jama.290.19.2549

Guskiewicz, K. M., Register-Mihalik, J., McCrory, P., McCrea, M., Johnston, K., Makdissi, M., … Meeuwisse, W. (2013). Evidence-based approach to revising the SCAT2: Introducing the SCAT3. British Journal of Sports Medicine, 47(5), 1-6.

Hall, R. C. W., Hall, R. C. W., & Chapman, M. J. (2004). Definition, diagnosis, and forensic implications of postconcussional syndrome. Psychosomatics, 46(3), 195-202. doi:10.1176/appi.psy.46.3.195

Heath, C. J., & Callahan, J. L. (2013). Self-reported concussion symptoms and training routines in Mixed Martial Arts athletes. Research in Sports Medicine, 21(3), 195-203.

Henry, L., Pardini, J., McMahon, P., Nwachuku, E., & Okonkwo, D. (2014). C-51 differences in neuropsychological test performance at 3 moths post-injury among CT positive and CT negative mild TBI patients. Archives of Clinical Neuropsychology, 29(6), 592-593. doi:10.1093/arclin/acu038.232

Howell, D., Osternig, L., Van Donkelaar, P., Mayr, U., & Chou, L. (2013). Effects of concussion on attention and executive function in adolescents. Medicine & Science in Sports & Exercise, 45(6), 1030-1037. doi:10.1249/mss.0b013e3182814595

Hutchison, M. G., Schweizer, T. A., Tam, F., Graham, S. J., & Comper, P. (2014). fMRI and brain activation after sport concussion: A tale of two cases. Frontiers in Neurology, 5(46), 1-7. doi:10.3389/fneur.2014.00046

Iverson, G. L., Gaetz, M., Lovell, M. R., & Collins, M. W. (2004). Cumulative effects of concussion in amateur athletes. Brain Injury, 18(5), 433-443. doi:10.1080/02699050310001617352

Johnson, B., Zhang, K., Gay, M., Horovitz, S., Hallett, M., Sebastianelli, W., & Slobounov, S. (2012). Alteration of brain default network in subacute phase of injury in concussed individuals: Resting-state fMRI study. NeuroImage, 59(1), 511-518. doi:10.1016/j.neuroimage.2011.07.081

Kain, D. J. (2009). "It's just a concussion:" The National Football League's denial of a causal link between multiple concussions and later-life cognitive decline. Rutgers Law Journal, 40, 697-736.

Kaplan, D. (2014, November 24). NFL plans to attack medical foundation of concussion claims if cases aren't settled. Street & Smith's SportsBusiness Journal, 17(32), 1-43. Available at www.sportsbusinessdaily.com/journal/issues/2014/11/24/law-and-politics/nfl-concussions.aspx

Kelly, J. P., & Rosenberg, J. H. (1997). Diagnosis and management of concussion in sports. Neurology, 48(3), 575-580.

Kirschen, M. P., Tsou, A., Nelson, S. B., Russell, J. A., & Larriviere, D. (2014). Legal and ethical implications in the evaluation and management of sports-related concussion. Neurology, 83(4), 352-358. doi:10.1212/wnl.0000000000000613

Kontos, A. P., Elbin, R. J., Lau, B., Simensky, S., Freund, B., French, J., & Collins, M. W. (2013). Posttraumatic migraine as a predictor of recovery and cognitive impairment after sport-related concussion. American Journal of Sports Medicine, 41(7), 1497-1504. doi:10.1177/0363546513488751

Lincoln, A. E., Caswell, S. V., Almquist, J. L., Dunn, R. E., Norris, J. B., & Hinton, R. Y. (2011). Trends in concussion incidence in high school sports: A prospective 11-year study. American Journal of Sports Medicine, 39(5), 958-963. doi:10.1177/0363546510392326

Makdissi, M., Darby, D., Maruff, P., Ugoni, A., Brukner, P., & McCrory, P. R. (2010). Natural history of concussion in sport: Markers of severity and implications for management. American Journal of Sports Medicine, 38(3), 464-471. doi:10.1177/0363546509349491

Martini, D. N., Sabin, M. J., DePesa, S. A., Leal, E. W., Negrete, T. N., Sosnoff, J. J., & Broglio, S. P. (2011). The chronic effects of concussion on gait. Archives of Physical Medicine & Rehabilitation, 92(4), 585-589. doi:10.1016/j.apmr.2010.11.029

Matheson, G. O., Shultz, R., Bido, J., Mitten, M. J., Meeuwisse, W. H., & Shrier, I. (2011). Return-to-play decisions: Are they the team physician's responsibility? Clinical Journal of Sport Medicine, 21(1), 25-30. doi:10.1097/jsm.0b013e3182095f92

McCrea, M., Hammeke, T., Olsen, G., Leo, P., & Guskiewicz, K. (2004). Unreported concussion in high school football players: Implications for prevention. Clinical Journal of Sport Medicine, 14(1), 13-17.

McCrory, P. (2001). Does second impact syndrome exist? Clinical Journal of Sport Medicine, 11(3), 144-149.

McCrory, P. R., & Berkovic, S. F. (1998). Second impact syndrome. Neurology, 50(3), 677-683.

McCrory, P., Meeuwisse, W. H., Aubry, M., Cantu, R. C., Dvořák, J., Echemendia, R. J., … Turner, M. (2013). Consensus statement on concussion in sport: The 4th international conference on concussion in sport, Zurich, November 2012. Journal of Athletic Training, 48(4), 554-567. doi:10.4085/1062-6050-48.4.05

McCrory, P., Meeuwisse, W., Johnston, K., Dvořák, J., Aubry, M., Molloy, M., & Cantu, R. (2009). Consensus statement on concussion in sport: The 3rd international conference on concussion in sport held in Zurich, November 2008. Journal of Athletic Training, 44(4), 434-448.

McDonald, S. N. (2014, June 4). Will Smith in talks to star in NFL concussion movie. The Washington Post. Retrieved from www.washingtonpost.com/news/morning-mix/wp/2014/06/04/will-smith-in-talks-to-star-in-nfl-concussion-movie/

Moser, R. S., Schatz, P., & Jordan, B. D. (2005). Prolonged effects of concussion in high school athletes. Neurosurgery, 57(2), 300-306. doi:10.1227/01.neu.0000166663.98616.e4

National Collegiate Athletic Association. (2011). 2011-12 NCAA sports medicine handbook (22nd ed.). Indianapolis, IN: The National Collegiate Athletic Association. Available at www.ncaapublications.com/productdownloads/MD11.pdf

National Federation of State High School Associations. (2008). 2007-08 high school athlete participation survey [Data file]. Retrieved from www.nfhs.org/participationstatics/pdf/2007-08%20participation%20survey.pdf

National Federation of State High School Associations. (2014). 2013-14 high school athlete participation survey [Data file]. Retrieved from www.nfhs.org/participationstatics/pdf/2013-14_participation_survey_pdf.pdf

Omalu, B. I., DeKosky, S. T., Hamilton, R. L., Minster, R. L., Kamboh, M. I., Shakir, A. M., & Wecht, C. H. (2006). Chronic traumatic encephalopathy in a National Football League player: Part II. Neurosurgery, 59(5), 1086-1093. doi:10.1227/01.neu.0000245601.69451.27

Omalu, B. I., DeKosky, S. T., Minster, R. L., Kamboh, M. I., Hamilton, R. L., & Wecht, C. H. (2005). Chronic traumatic encephalopathy in a National Football League player. Neurosurgery, 57(1), 128-134. doi:10.1227/01.neu.0000163407.92769.ed

Pellman, E. J., Lovell, M. R., Viano, D. C., & Casson, I. R. (2006). Concussion in professional football: Recovery of NFL and high school athletes assessed by computerized neuropsychological testing–part 12. Neurosurgery, 58(2), 263-274. doi:10.1227/01.neu.0000200272.56192.62

Randolph, C., McCrea, M., & Barr, W. B. (2005). Is neuropsychological testing useful in the management of sport-related concussion? Journal of Athletic Training, 40(3), 139-152.

Røe, C., Sveen, U., Alvsåker, K., & Bautz-Holter, E. (2009). Post-concussion symptoms after mild traumatic brain injury: Influence of demographic factors and injury severity in a 1-year cohort study. Disability & Rehabilitation, 31(15), 1235-1243. doi:10.1080/09638280802532720

Saunders, R. L., & Harbaugh, R. E. (1984). The second impact in catastrophic contact-sports head trauma. Journal of the American Medical Association, 252(4), 538-539. doi:10.1001/jama.1984.03350040068030

Schneider, K. J., Meeuwisse, W. H., Kang, J., Schneider, G. M., & Emery, C. A. (2013). Preseason reports of neck pain, dizziness, and headache as risk factors for concussion in male youth ice hockey players. Clinical Journal of Sport Medicine, 23(4), 267-272. doi:10.1097/jsm.0b013e318281f09f

Shrier, I., Safai, P., & Charland, L. (2014). Return to play following injury: Whose decision should it be? British Journal of Sports Medicine, 48(5), 394-401. doi:10.1136/bjsports-2013-092492

Shultz, R., Bido, J., Shrier, I., Meeuwisse, W. H., Garza, D., & Matheson, G. O. (2013). Team clinician variability in return-to-play decisions. Clinical Journal of Sport Medicine, 23(6), 456-461. doi:10.1097/jsm.0b013e318295bb17

Simma, B., Lütschg, J., & Callahan, J. M. (2013). Mild head injury in pediatrics: Algorithms for management in the ED and in young athletes. American Journal of Emergency Medicine, 31(7), 1133-1138. doi:10.1016/j.ajem.2013.04.007

Sosnoff, J., Broglio, S. P., Shin, S., & Ferrara, M. S. (2011). Previous mild traumatic brain injury and postural-control dynamics. Journal of Athletic Training, 46(1), 85-91.

Stovner, L. J., Schrader, H., Mickevičiene, D., Surkiene, D., & Sand, T. (2009). Headache after concussion. European Journal of Neurology, 16(1), 112-120. doi:10.1111/j.1468-1331.2008.02363.x

Terry, D. P., Faraco, C. C., Smith, D. Diddams, M. J., Puente, A. N., & Miller, L. S. (2012). Lack of long-term fMRI differences after multiple sports-related concussions. Brain Injury, 26(13-14), 1684-1696. doi:10.3109/02699052.2012.722259

Thornton, A. E., Cox, D. N., Whitfield, K., & Fouladi, R. T. (2008). Cumulative concussion exposure in rugby players: Neurocognitive and symptomatic outcomes. Journal of Clinical & Experimental Neuropsychology, 30(4), 398-409. doi:10.1080/13803390701443662

Veevers, A. E., Lawler, W., & Rutty, G. N. (2009). Walk and die: An unusual presentation of head injury. Journal of Forensic Sciences, 54(6), 1466-1469. doi:10.1111/j.1556-4029.2009.01201.x

Weinstein, E., Turner, M., Kuzma, B. B., & Feuer, H. (2013). Second impact syndrome in football: New imaging and insights into a rare and devastating condition: Case report. Journal of Neurosurgery: Pediatrics, 11(3), 331-334. doi:10.3171/2012.11.peds12343

Wetjen, N. M., Pichelmann, M. A., & Atkinson, J. L. D. (2010). Second impact syndrome: Concussion and second injury brain complications. Journal of the American College of Surgeons, 211(4), 553-557. doi:10.1016/j.jamcollsurg.2010.05.020