Cerebral Concussion in Sport: An Overview

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Sports-related concussions are ubiquitous in contact and collision sports at all levels of play and across a broad age range. Once thought to be a nuisance injury, it is now recognized that these brain injuries may lead to chronic neurocognitive impairment if not managed properly. This paper provides a broad overview of the research and clinical data that have emerged in this rapidly growing area. Included in the review are discussions of injury definition, pathophysiology, signs and symptoms, epidemiology, potential long-term consequences, assessment, and psychological factors. Issues of prevention and education are discussed in light of further increasing awareness of this injury.

Keywords: Concussion, MTBI, cerebral, neurocognitive, sport

There has been a virtual explosion of information on sports-related concussion in the past 10 years. The flow of information has come from traditional academic and scientific research institutions; federal agencies (e.g., Centers for Disease Control, CDC); professional sports organizations (National Hockey League, NHL, National Football League, NFL, Major League Soccer, MLS); nongovernmental sports organizations (e.g., U.S. Soccer Federation, USA Hockey, U.S. Lacrosse); local community groups and leagues; local, state, and federal legislators; and the media. Much of the focus on concussions has come from the realization that concussions are brain injuries that may lead to long-term neurocognitive consequences if not evaluated and managed properly. Yet, it was not long ago that concussions were often found to be “funny” because players would frequently act in unusual ways after being injured. This led to the belief that these players simply had their “bells rung” or got “dinged.” Concussions were often considered nuisance injuries that players were instructed to play through. Today, we know that concussions are not a laughing matter; they are brain injuries characterized by a wide range of cognitive, somatic, and psychological symptoms. Although these injuries are typically time limited and often resolve on their own, if they are not evaluated and managed properly, they can lead to prolonged, and at times, life-altering consequences.
The goal of this article is to provide a broad overview of sports-related concussions that will serve as a foundation for the papers that follow. The discussion will include defining concussion, the pathophysiology of concussion, concussion signs and symptoms, epidemiology, suspected long term effects of concussion, assessment of concussion, and psychological factors related to concussion.

**Concussion Defined**

A cerebral concussion is a brain injury that is often referred to as a mild traumatic brain injury (MTBI). In keeping with much of the literature (e.g., Ruff, Iverson, Barth, Bush, & Broshek, 2009), the term *concussion* will be used interchangeably with *MTBI*. The primary difference between the two terms is that the term *concussion* is typically used in the sports medicine literature, whereas the term *MTBI* is used in the neurosciences and psychological literature.

A concussion occurs as a result of a blow to the head or other part of the body, causing acceleration and deceleration of the brain inside the skull. Several attempts have been made toward defining MTBI in general and sports-related MTBI more specifically.

In 1993, the American Congress of Rehabilitation Medicine (ACRM; Mild Traumatic Brain Injury Committee) defined a MTBI as a traumatic disruption of brain function, manifested by at least one of the following: (a) any loss of consciousness, (b) any loss of memory for events immediately before or after the accident, (c) any alteration of mental state at the time of the accident (e.g., feeling dazed, disoriented, or confused), and (d) focal neurologic deficit(s) that may or may not be transient. Additional markers of the injury included loss of consciousness of approximately 30 min or less; after 30 min, an initial Glasgow Coma Score of 13–15; and posttraumatic amnesia not greater than 24 hr (Mild Traumatic Brain Injury Committee).

In 1997, the American Academy of Neurology published a definition specific to sports-related MTBI: “Concussion is a trauma-induced alteration in mental status that may or may not involve loss of consciousness. Confusion and amnesia are the hallmarks of concussion. The confusional episode and amnesia may occur immediately after the blow to the head or several minutes later” (p. 2). Three grades of severity were assigned based on the presence or absence of specific symptoms and their duration. This and other grading systems will be discussed in detail later in this article.

According to the most recent international consensus statement published by the Concussion in Sport Group (McCrory et al., 2009), a concussion is defined as follows:

Concussion is defined as a complex pathophysiological process affecting the brain, induced by traumatic biomechanical forces. Several common features that incorporate clinical, pathologic, and biomechanical injury constructs that may be utilized in defining the nature of a concussive head injury include the following:

1. Concussion may be caused either by a direct blow to the head, face, neck or elsewhere on the body with an impulsive force transmitted to the head.
2. Concussion typically results in the rapid onset of short-lived impairment of neurologic function that resolves spontaneously.

3. Concussion may result in neuropathological changes, but the acute clinical symptoms largely reflect a functional disturbance rather than a structural injury.

4. Concussion results in a graded set of clinical symptoms that may or may not involve loss of consciousness. Resolution of the clinical and cognitive symptoms typically follows a sequential course; however, it is important to note that, in a small percentage of cases, postconcussive symptoms may be prolonged.

5. No abnormality on standard structural neuroimaging studies is seen in concussion. (p. 176–77)

Several key factors are common across these definitions. Most notably, loss of consciousness (LOC) is not necessary for the diagnosis of concussion. The injury is traumatically induced and tends to be self-limiting (i.e., a single concussion typically resolves without complications within a relatively short period of time); however, persistent symptoms are known to occur in a small percentage of athletes (Iverson, Echemendia, LaMarre, Brooks, & Gaetz 2012). Symptoms are varied and may occur immediately after the injury or may evolve over time (Echemendia & Julian, 2001).

**Pathophysiology of Concussion**

Concussions are often frustrating to players and those who coach and treat them because such injuries are largely invisible. Concussed athletes do not wear casts, slings, orthopedic boots, or use crutches. By all accounts, the players look “normal.” Concussions are not only invisible to the naked eye; they also do not appear on traditional neuroimaging techniques such as CT scans or MRIs, although newer imaging techniques that focus on brain functions hold promise for clinical use in the future (Prabhu, 2011). Sports-related MTBIs are not grossly “structural” injuries, although microscopic structural changes have been noted (Buki & Povlishock, 2006; Povlishock, Buki, Koizumi, Stone, & Okonkwo, 1999; Povlishock & Pettus, 1996). Instead, concussions usually create a neurometabolic cascade that renders cells temporarily dysfunctional.

Typically, within minutes of a concussive injury, there are changes inside and outside of the cell membranes. There is an influx of calcium with a concomitant efflux of potassium that creates depolarization throughout the cells (Katayama, Becker, Tamura, & Hovda, 1990; Okonkwo & Stone, 2003; Pettus, Christman, Giebel, & Povlishock, 1994). The cells attempt to compensate by activating ion pumps, which increases the use of glucose (hyperglycolysis). Increases in lactate occur, which have been associated with increased risk for secondary ischemic injury and possible predisposition for recurrent injury. As the metabolic cascade unfolds, the hyperglycolysis eventually creates a hypermetabolic state in which the brain is using vast amounts of resources to stabilize functioning (Giza & Hovda, 2001; Lee, Wong, Samii, & Hovda, 1999). Unfortunately, this hypermetabolic state is accompanied by disruptions in cerebral blood flow, which creates
a mismatch between the brain’s need for glucose and the glucose available due to restrictions in cerebral blood flow (Lee et al., 1999; Yuan, Prough, Smith, & Dewitt, 1988). A hypometabolic state then ensues that can last for several days after the initial injury (Yoshino, Hovda, Kawamata, Katayama, & Becker, 1991). Decreased cerebral blood flow has been reported to last approximately 10 days following concusive injuries in animal models, which is consistent with the finding of an apparent 7–10 day period of increased susceptibility to recurrent injury (Guskiewicz, Echemendia, & Cantu, 2009). Eventually, cell functioning begins to stabilize and the metabolic crises resolve, returning to the cells to normal levels of activity. This cellular process underscores the evolving and dynamic nature of concussions. In essence, a concussive injury is a process and not a static event.

### Signs and Symptoms of Concussion

*Signs* are behaviors/events that are observable by others, whereas *symptoms* are reported by the player. Typical signs of concussion include loss of consciousness, a dazed or vacant look, motor incoordination/balance problems (stumbles, falls, wobbly legs), and on-field confusion/disorientation (e.g., forgets plays/assignments, does not know which bench or sideline; McCrory et al., 2009).

Symptoms of concussion are varied and may best be grouped into four clusters: somatic, cognitive, psychological/emotional, and sleep disturbances (see Figure 1; Lovell et al., 2006). Athletes who sustain a concussion often experience a state of confusion or disorientation that typically resolves within minutes. This initial state of confusion is what has been historically referred to as being “dinged” or having one’s “bell rung.” Following this initial confusion is a dynamic and evolving course of symptoms that varies player by player. Consistent with the dynamic flux in pathophysiology, symptoms may occur immediately after injury or they may take hours or days to emerge. It is not unusual for a player to initially report that they are feeling fine but then feel sick on the bus or car ride home.

Adding to the complexity of this injury is the observation that symptoms associated with MTBI are not specific to concussion. In fact, they occur frequently within the general population for individuals who have not suffered a concussion (Bailey, Samples, Broshek, Freeman, & Barth, 2010; Benge, Pastorek, & Thornton, 2009; Lannsjo, af Geijerstam, Johansson, Bring, & Borg, 2009; Luis, Vanderploeg, & Curtiss, 2003; Randolph et al., 2009). These symptoms can be seen in individuals who may have a physical illness (e.g., bad cold or flu), a psychological condition (e.g., depression, anxiety, ADHD), or even those who did not sleep well the night before. Consequently, a key task in concussion management is determining which symptoms are due to the acute injury as opposed to those that may be premorbid to or comorbid with other conditions. While a thorough symptom assessment is critical in the evaluation of concussion, it is noteworthy that athletes are strongly motivated to return to play and may therefore minimize symptoms to return to the playing field.
Epidemiology

Concussions in sport are a frequent occurrence accounting for approximately 10% of all athletic injuries (Gessel, Fields, Collins, Dick, & Comstock, 2007). In 1998, the Center for Disease Control estimated that approximately 300,000 sports-related MTBIs occurred each year (Thurman, Branche, & Sniezek, 1998). This estimate was subsequently increased to 1.6–3.8 million sports-related concussions each year because the previous estimate only included MTBIs involving LOC, and the revised estimates also include projections of those sports concussions that are not treated by physicians (Langlois, Rutland-Brown, & Wald, 2006). The marked difference in these two estimates underscores the difficulty in identifying the actual number of sports concussions that occur annually. The inability to arrive at reliable numbers is based on differences in injury definition, players’ ability to recognize
and report postconcussion symptoms, different methodologies used by studies, unwillingness on the part of the player or family to seek medical care, or players’ acceptance of concussion symptoms as being normal rather than an indication that clinical attention is needed. For example, recent studies of Canadian football and soccer players revealed significant discrepancies between the number of players who reported postconcussion symptoms and those who believed that they sustained a concussion. Specifically, approximately 70% of football players and 63% of soccer players studied reported concussion symptoms at the end of a season, but only 23% of the football players and 20% of the soccer players studied realized that they had suffered a concussion (Delaney, Lacroix, Gagne, & Antoniou, 2001; Delaney, Lacroix, Leclerc, & Johnston, 2000, 2002). In addition, McCrea and colleagues reported that only 47.3% high school football players reported their injuries (McCrea, Hammelke, Olsen, Leo, & Guskiewicz, 2004).

As previously noted, concussions occur at all levels of play. In a study of ice hockey, lacrosse, and field hockey players, it was found that children 2–9 years of age sustained twice the proportion of head and face injuries when compared with children aged 10–18. In ice hockey, Bantam (13–14 years) and Pee Wee (11–12 years) age players were found to have a higher risk of concussion when compared with players 9–10 years of age (Emery, Hagel, Declue, & Carly, 2010; Emery & Meeuwisse, 2006).

The National Collegiate Athletic Association (NCAA) Injury Surveillance System published rates of concussion across a variety of collegiate sports (Hootman, Dick, & Angel, 2007). As can be seen in Table 1, concussions ranged from a low of 2.8% of game injuries in women’s gymnastics to a high of 21.6% of game

### Table 1  Epidemiology of Concussion Among Collegiate Sports (NCAA Injury Surveillance System Data)

<table>
<thead>
<tr>
<th>Sport</th>
<th>Percent of Game Injuries</th>
<th>Injury Rate per 1000 Athlete Exposures</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ice Hockey—W</td>
<td>21.6</td>
<td>2.72</td>
</tr>
<tr>
<td>Football—M</td>
<td>6.8</td>
<td>2.34</td>
</tr>
<tr>
<td>Wrestling—W</td>
<td>4.8</td>
<td>1.27</td>
</tr>
<tr>
<td>Ice Hockey—M</td>
<td>9.0</td>
<td>1.47</td>
</tr>
<tr>
<td>Soccer—W</td>
<td>8.6</td>
<td>1.42</td>
</tr>
<tr>
<td>Wrestling—W</td>
<td>4.8</td>
<td>1.27</td>
</tr>
<tr>
<td>Soccer—M</td>
<td>5.8</td>
<td>1.08</td>
</tr>
<tr>
<td>Lacrosse—W</td>
<td>9.8</td>
<td>0.70</td>
</tr>
<tr>
<td>Field Hockey—W</td>
<td>9.4</td>
<td>0.52</td>
</tr>
<tr>
<td>Basketball—W</td>
<td>6.5</td>
<td>0.50</td>
</tr>
<tr>
<td>Basketball—M</td>
<td>3.6</td>
<td>0.32</td>
</tr>
<tr>
<td>Gymnastics—W</td>
<td>2.8</td>
<td>0.40</td>
</tr>
<tr>
<td>Softball—W</td>
<td>6.0</td>
<td>0.25</td>
</tr>
<tr>
<td>Baseball—M</td>
<td>3.3</td>
<td>0.19</td>
</tr>
<tr>
<td>Volleyball—W</td>
<td>4.7</td>
<td>0.15</td>
</tr>
</tbody>
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injuries in women’s ice hockey. Concussions accounted for 6.8% of game injuries in football, 9% in men’s ice hockey, and 4.8% of competition injuries in wrestling.

An interesting and fairly common finding is that women tend to sustain concussions at higher rates than men do. Covassin and colleagues (Covassin, Swanik, & Sachs, 2003) found that women’s soccer and basketball players had higher rates of concussion than the equivalent men’s teams. A review of the data in Table 1 from 1998 to 2004 indicates that concussions accounted for 5.8% of game injuries in men’s soccer, while accounting for 8.6% in women’s soccer. Male basketball players sustained concussions at a rate of 3.6% during games, while concussions accounted for 6.5% of all game injuries in women’s basketball. More alarmingly, male ice hockey players sustained concussions at the relatively high rate of 9% of game injuries, yet women ice hockey players sustained concussions at the rate of 21.6% of all game injuries. The estimate of injuries in women’s hockey may not be reliable since the data were not collected across all years. Yet, these differences are certainly interesting and warrant additional study.

The difference between the rates of concussions in men and women is poorly understood. However, several factors have been implicated as possibilities, including hormonal differences (Broshek et al., 2005; Hall, Pazara, & Linseman, 1991), differences in neck strength (Tierney, Sitler, Swanik, et al., 2005), differences in technique (Barth, Freeman, Broshek, & Varney, 2001), and differences in willingness to report concussion symptoms (Broshek et al., 2005), with the presumption that women are more willing to report symptoms than are men. For a detailed discussion of gender differences in sport concussion, see Covassin and Elbin (2011).

Once an athlete has suffered a concussion, he or she is at risk for subsequent concussions. Studies have found that collegiate athletes are three times more likely to suffer a concussion if they had sustained three or more previous concussions in a 7-year period, and playing with two or more previous concussions required a longer time for total symptom resolution after subsequent injuries (Guskiewicz et al., 2003). Players also were at a three times greater risk for a subsequent concussion in the same season. Repeat concussive injuries within the same season occurred within 10 days of the initial injury 92% of the time. Similarly, a study of high school athletes found that athletes with three or more prior concussions were at increased risk of experiencing loss of consciousness, anterograde amnesia, and confusion after subsequent concussion (Collins, Lovell, Iverson, Cantu, Maroon, & Field, 2002).

Cumulative Effects of Concussion

One of the most important questions in the area of concussions is the extent to which there may be long-term neurocognitive effects of multiple concussions (Solomon, Ott, & Lovell, 2011). Unfortunately, although not surprisingly, the literature may best be described as having inconsistent findings. Some studies have found that previously concussed athletes may have longer recovery times when compared with athletes with no history of concussion (Iverson, Gaetz, Lovell, & Collins, 2004), while others have suggested that athletes with a self-reported history of concussions may have persistent cognitive deficits when compared with those with no history of prior concussions (Collins et al., 1999; Iverson et al., 2004; Moser et al., 2007; Moser, Schatz, & Jordan, 2005; Wall et al., 2006). Yet, other studies have found no
significant neurocognitive effects in athletes with a history of multiple concussions (Broglio, Ferrara, Piland, Anderson, & Collie, 2006; Collie, McCrory, & Makdissi, 2006; Iverson, Brooks, Lovell, & Collins, 2006; McCrory et al., 2005).

Recently, we were interested in examining whether the contradictory findings in the literature may be due to the type of neuropsychological tests that were being used (i.e., traditional “paper and pencil” vs. computerized testing; Bruce & Echemendia, 2009). We examined the relationship between concussion history and neuropsychological test performance on three different samples of athletes using traditional neuropsychological measures, a computer based neuropsychological battery (ImPACT; Lovell, 2006), and both ImPACT and traditional testing. We asked multisport collegiate athletes to report their history of concussions during preseason baseline testing and then compared those athletes who had no self-reported history of concussion with those who had one, two, and three or more self-reported concussions. No significant differences were found across concussion history groups, irrespective of the type of neuropsychological test instrument used. We did, however, caution that these findings were based on relatively young athletes and that it is quite possible that differences may emerge over time.

A related, though distinctly different, approach to the examination of long-term neurocognitive deficits that may arise from multiple concussions or subconcussive blows has involved postmortem studies of brain tissue. Initial reports involved three NFL players (Omalu et al., 2005; Omalu et al., 2006; Omalu, Hamilton, Kamboh, DeKosky, & Bailes, 2010) whose brain tissue revealed evidence of pathology that was thought to be the cause of their premature dementia and death. Though relatively new to the scientific literature, chronic traumatic encephalopathy (CTE) syndrome was first identified in boxers and termed “dementia pugilistica.” The disease was described as progressive deterioration in cognitive functioning (attention, concentration, memory), executive functioning (impulsivity, poor insight, poor judgment), physical functioning (dizziness, impaired gait, Parkinsonian-like features), and psychological functioning (depression). McKee and colleagues (2009) have elaborated on characteristic features of CTE, specifically the immunocytochemical abnormalities of phosphorylated tau associated with the disease. In their review of 48 cases of neuropathologically-verified CTE, they found that CTE is “characterized by cerebral and medial temporal lobe atrophy, ventriculomegaly, enlarged cavum septum pellucidum, and extensive tau-immunoreactive pathology throughout the neocortex, medial temporal lobe, diencephalon, brainstem and spinal cord” (p. 732). A common pathogenesis of CTE and Alzheimer’s disease (AD) was suggested due to the presence of tau-immunoreactive neurofibrillary tangles, neuropil neuritis, and β-Amyloid in both conditions. The researchers speculated that traumatic brain injury may interact with AD “to produce a mixed pathology with greater clinical impact or synergistically by promoting pathological cascades that result in either AD or CTE” (p. 732).

Guskiewicz and colleagues (Guskiewicz et al., 2005; Guskiewicz et al., 2007) relied on the use of a self-report survey to ask retired professional football players about their history of concussion, psychological symptoms, and cognitive symptoms. Using these self-report data, it was found that athletes with three or more reported concussions had a fivefold prevalence of mild cognitive impairment. In addition, retired players with three or more concussions had a threefold prevalence of self-reported significant memory problems in comparison with retirees who
did not have a history of concussion. Using the same sample and same methodology, they also found a relationship between self-reported recurrent concussion and self-reported clinical depression among retired professional football players (Guskiewicz et al., 2007).

Taken together, the prospect for long-term neurocognitive impairment in athletes, either due to multiple concussions, repeated subconcussive blows, or some combination of the two, sounds an important alarm for the study of concussions. This is an area that requires significant in-depth study with well-designed, well-controlled prospective methodologies. At present, however, the data are only suggestive. A recent comprehensive review of this literature (Solomon, Ott, & Lovell, 2011) concluded that many of the studies had significant methodological flaws and there was little consistency across studies, which made direct comparisons difficult, if not impossible. The authors of the review concluded that long-term neurocognitive deficits due to concussion have only been empirically demonstrated among professional boxers.

### Assessment of Concussion

The assessment and management of sports-related concussion typically begins with an acute evaluation on the field followed by a sideline or locker room evaluation, a formal postacute neurocognitive assessment, graded progression of physical exertion, and finally unrestricted return to play. Each step is designed to answer a different set of clinical questions for which different instruments and techniques need to be used (Echemendia, 2006; McCrory et al., 2009).

A sideline or on-field clinical examination of players is a critical first step. The primary goal of the acute “on-field” assessment is to identify any life-threatening conditions (e.g., developing intracranial bleed) and to assess for the possibility of spinal cord injury. If an athlete’s symptoms are deteriorating, especially if there is deterioration to a stuporous, semicomatose, or comatose state of consciousness, the situation must be treated as a medical emergency and emergency transport is required (Guskiewicz et al., 2009).

If the athlete is deemed medically stable but a concussion is suspected, a comprehensive sideline assessment should be conducted that includes a thorough history, observation of symptoms (signs), player report of symptoms, a careful assessment of the player’s recall of the events before and following the injury, and an assessment of the cognitive and physical areas that are frequently affected by concussion, including tests of learning and memory, concentration, motor coordination, and cranial nerve functioning. Over the years, there has been momentum toward using standardized, empirically derived brief screening tools to evaluate postconcussion signs and symptoms, cognitive functioning, and postural stability on the sidelines immediately after concussion (Barr & McCrea, 2001; McCrea, Kelly, Randolph, Cisler, & Berger, 2002). The Sport Concussion Assessment Tool 2 (SCAT2) is such a standardized method that can be used with athletes who are 10 years of age and older (McCrory et al., 2009). The SCAT2 contains the Glasgow Coma Scale, Standardized Assessment of Concussion (SAC, Cognitive Assessment), Maddocks Questions, a sideline assessment of balance, and an examination of motor coordination. The SCAT2 has been adopted in various forms by a wide
range of professional sports organizations (e.g., NHL, MLS, NFL, MLB). Brief measures such as the SCAT2 are useful for obtaining an initial assessment of cognitive functioning during the acute phase of the injury, but are not a substitute for formal neuropsychological assessment, which is usually conducted in the subacute phase of recovery (Aubry et al., 2002; McCrea et al., 2009).

**Neuropsychological Assessment**

Neuropsychological evaluation has become an important component of the post-injury or “post-acute” evaluation of a concussion. The current paradigm involves the use of preinjury “baseline” testing, first introduced by Jeff Barth at the University of Virginia (Barth et al., 1989). Using baseline testing with college football players, Barth et al. identified neurocognitive deficits within 24–48 hr postinjury using a brief battery of traditional neuropsychological tests. Recovery began shortly after injury, with most athletes reporting complete recovery within 5–7 days following injury. A broad range of studies across several disciples have now demonstrated that neuropsychological tests can identify neurocognitive deficits as early as 2 hr post injury (Broglio, Macciocchi, & Ferrara, 2007; Broshek et al., 2005; Bruce & Echemendia, 2003; Collie, Makdissi, Maruff, Bennell, & McCrory, 2006; Collins et al., 1999; Collins et al., 2003; Covassin, Schatz, & Swanik, 2007; Echemendia, Putukian, Mackin, Julian, & Shoss, 2001; Erlanger, Kaushik, et al., 2003; Fazio, Lovell, Pardini, & Collins, 2007; Guskiewicz, Ross, & Marshall, 2001; Iverson, Brooks, Collins, & Lovell, 2006; Iverson, Lovell, & Collins, 2003; Lovell et al., 2003; Lovell, Collins, Iverson, Johnston, & Bradley, 2004; Macciocchi, Barth, Alves, Rimel, & Jane, 1996; Makdissi et al., 2001; Matser, Kessels, Lezak, & Troost, 2001; McClincy, Lovell, Pardini, Collins, & Spore, 2006; McCrea et al., 2003; Sosnoff, Broglio, Hillman, & Ferrara, 2007; Van Kampen, Lovell, Pardini, Collins, & Fu, 2006). Although a detailed discussion of this literature is beyond the scope of the present article, brief details about a few studies may be illustrative.

A retrospective analysis of college football players found that athletes with a history of two or more concussions had poorer baseline performance on measures of information processing speed and executive functioning when compared with athletes with no history of concussion (Collins et al., 1999). Athletes with a history of self-reported learning disability and a history of multiple concussions had even poorer baseline performance than those athletes without learning disabilities.

In another study (Echemendia et al., 2001) using a multisport college population, findings revealed that a limited battery of traditional neuropsychological measures was able to differentiate athletes with concussion from uninjured control group athletes within 2 hr of injury. The concussed group of athletes scored significantly lower than control athletes 2 hr after injury and again 48 hr after injury. Group differences were also evident at 1 week following injury but not at 1 month postinjury. The results of this study are noteworthy because they revealed that athletes with concussions did not show significant practice effects, whereas the control athletes did. In other words, the athletes with concussions were not able to benefit from prior exposure to the test. In a follow-up study, Bruce and Echemendia (2003) showed that concussed athletes were unable to identify and use semantic categorization strategies on a verbal learning task but the control
athletes could do so at a much higher rate. Overall, these studies underscored the dynamic nature of recovery following concussion, since the neuropsychological performance of concussed athletes declined from 2 hr to 48 hr after injury, whereas the control athletes improved during this same time frame. More importantly, the neuropsychological test scores could significantly differentiate between athletes with and without concussion at 48 hr, whereas self-reported concussion symptoms, measured by the standard post concussion symptom scale, could not distinguish between the two groups at 48 hr.

The Standardized Assessment of Concussion (McCrea et al., 2002), a sideline cognitive screening instrument, was used in combination with selected traditional neuropsychological measures in a sample of college students. The SAC scores of athletes following concussion were significantly lower than baseline when compared with a group of uninjured athletes. While SAC scores returned to baseline within 48 hr of injury, studies using more comprehensive neuropsychological measures showed typical recovery by 10 days after injury. These findings highlight the complementary nature of brief screening instruments and the more comprehensive neuropsychological batteries tests. Screening instruments such as the SAC appear to be useful on the sidelines and during the acute phase of recovery (initial 48 hr after injury), while neuropsychological test batteries are more effective in identifying enduring neurocognitive deficits (McCrea et al., 2003).

Types of Neuropsychological Assessment Batteries

As noted earlier, traditional neuropsychological test batteries consist of “paper and pencil” tests that usually require individualized face-to-face administration. The development of computerized test batteries created a paradigm shift for neuropsychological assessment in sports. Four major computer based batteries have emerged in sports concussion management: ImPACT (Lovell, 2006), CogSport (Collie, Maruff et al., 2006), HeadMinder Concussion Resolution Index (Erlanger, Feldman et al., 2003), and the Automated Neuropsychological Assessment Metrics Sports Medicine Battery (ANAM-SMB; see Echemendia, 2006). These batteries allow for groups of athletes to be assessed using standardized, automated administration with immediate access to test results. Although each of these batteries is different in their composition and the number of functional domains that are assessed, all of these batteries allow for thorough assessment of simple and complex information processing speed, which has been shown to be a sensitive indicator of neurocognitive dysfunction postinjury. Computerized batteries are much more cost efficient than their paper and pencil counterparts and have extended the use of neuropsychological measurement pre- and postinjury to a much larger number of athletes when compared with traditional batteries. Numerous studies have validated the use of these computerized test platforms (Bleiberg et al., 2004; Bleiberg, Garmoe, Halpern, Reeves, & Nadler, 1997; Collie, Darby, & Maruff, 2001; Collie, Makdissi et al., 2006; Collie & Maruff, 2003; Collie et al., 2003; Collie, Maruff, et al., 2006; Collins et al., 2002; Covassin, Elbin, Kontos, & Larson, 2010; Covassin, Elbin, & Nakayama, 2010; Darby, Maruff, Collie, & McStephen, 2002; Echemendia, 2006; Erlanger, Feldman et al., 2003; Erlanger et al., 2001; Fazio et al., 2007; Guskiewicz et al., 2003; Iverson, Lovell, & Collins, 2005; Lovell et al., 2004).
However, although computerized test batteries have significant advantages when compared with traditional testing, they are not without their drawbacks, including (a) they currently do not fully assess memory functioning, because they are only capable of examining recognition memory; (b) they minimize the interaction between the athlete and the neuropsychologist, thereby reducing qualitative observations of performance; (c) effort and motivation are less effectively assessed and managed using group administration formats; and (d) they limit the ability to examine the process by which injured athletes solve problems and learn and remember information, which has been shown to be useful in the assessment of athletes with a concussion. These computer programs also introduce complex instrumentation error, as scores may differ due to differences in timing accuracy across computer platforms, whether the test is administered via the internet, the speed of the computer’s processor, the type of mouse being used, etc.

A “hybrid” model has been developed that takes advantage of the strengths of both the paper and pencil tests and the computerized tests while minimizing their weaknesses. This hybrid approach has been adopted by some organizations in the NHL and MLS, as well as the U.S. Soccer Federation and several universities. Typically, a computerized assessment is given at baseline, and a battery consisting of paper and pencil tests and the computerized test is administered postinjury. This hybrid approach uses both intraindividual (baseline to postinjury) comparisons and interindividaul (postinjury to normative data) comparisons. This approach could possibly yield more accurate assessments of postinjury neurocognitive functioning than either method alone.

Although there has been considerable excitement regarding the use of neuropsychological tests in the evaluation of sports-related concussion, it is important to note that there are also those who have been critical of the field (Kirkwood, Randolph, & Yeates, 2009; Randolph, McCrea, & Barr, 2005; Randolph & Kirkwood, 2009). The criticisms set forth areas that are in need of further research and questions that need to be answered more completely. One area of concern is the widespread use of baseline testing. While the field has widely adopted the use (and perhaps need) for baseline testing, there are no studies that have established whether the availability of baseline testing adds any greater precision to the detection of postinjury cognitive deficits when compared with postinjury evaluations alone. Although the use of baseline testing makes sense intuitively, it does not come without costs, because it introduces significant complexity into the interpretation of postinjury test data. Not only is there error surrounding the postinjury tests, there is also error around the baseline tests as well as the error associated with comparing tests at two different method alone.

A second area of concern for critics has involved the temporal stability of tests. Barr et al. (2003) reported test-retest coefficients ranging from 0.39 to 0.78 using traditional tests. Iverson, Lovell, and Collins (2003) reported test-rest correlations ranging from 0.67 to 0.86 on the four major ImPACT indices using a test-retest interval of approximately 6 days. Broglio et al. (2007) reported low to moderate test-retest stability on three computer-based programs, with ICCs ranging from 0.15 to 0.65. More recently, Schatz (2010) reported ICCs with an average 2-year test-retest for ImPACT composite indices as follows: visual memory = 0.65; verbal memory = 0.46; processing speed = 0.64; reaction time = 0.68; and 0.43 for the symptom scale. He concluded that baseline cognitive functioning of collegiate
athletes remains fairly constant over 2 years. Although it is important to address questions of psychometric adequacy and improve the quality of tests, the criticisms that have been put forth against tests used in sports neuropsychology are valid in the field of neuropsychology and psychology more generally, particularly instances where individuals are tested serially.

In addition, the widespread use of computerized testing has created the misperception that little or no formal training is needed to administer and interpret these tests, which leads to the basic question, “Who should administer and interpret neuropsychological tests?” Many programs have adopted a model where tests are administered and interpreted without consultation of a qualified neuropsychologist. The Concussion in Sport Group (McCrory et al., 2009) concluded, “Neuropsychologists are in the best position to interpret neuropsychological tests by virtue of their background and training.” Echemendia, Herring, and Bailes (2009) examined this question at length and concluded the following:

The interpretation of neuropsychological tests requires comprehensive knowledge of the tests, their characteristics given a specific population (for example, team, sport), the athlete’s and his or her specific situation, psychological variables and many others. For these reasons we conclude that neuropsychological tests may be administered under the guidance of a neuropsychologist but that the interpretation of neuropsychological test data is best managed by a clinical neuropsychologist. (p. 35)

**Injury Severity**

Historically, concussion severity had been based on the use of “guidelines” that were developed by leaders in the field with little or no empirical validation. Typically, concussion severity was based on the presence or absence of LOC, the extent of posttraumatic amnesia, and symptom duration. The most widely used grading systems (see Table 2) included three grades of concussion: mild (I), moderate (II) and severe (III).

<table>
<thead>
<tr>
<th>Table 2 Concussion Grading Guidelines</th>
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<tbody>
<tr>
<td><strong>System</strong></td>
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<tr>
<td>Cantu</td>
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<td></td>
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<td>Colorado Med Society</td>
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<td>American Academy of Neurology (AAN)</td>
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</tbody>
</table>

*Note. LOC = loss of consciousness, PTA = posttraumatic amnesia, Sxs = symptoms.*
Each of the concussion severity ratings noted above was accompanied by guidelines for return to play, as depicted in Table 3.

These return-to-play (RTP) guidelines differed on several important dimensions. The Cantu system (Cantu, 1992, 1998) required that a player be asymptomatic at rest and upon exertion for 1 week following MTBI, whereas the Colorado Medical Society (CMS) and American Academy of Neurology (AAN) guidelines allowed RTP to the same game if symptoms cleared within 20 min. Cantu required 1 month, and both the CMS and AAN required 2 weeks of no PCSS before RTP for Grade III concussions.

These guidelines served a useful purpose for the management of concussion in the past when there was little widespread understanding of how the injury should be managed; however, there was much disagreement about which guidelines were the best, partly because they all lacked empirical support. There was no standardization of the use of the guidelines. Some teams did not use any guidelines at all, others used the Cantu model, some used the CMS model, and yet others used the AAN model or one of the many other systems in existence (Echemendia & Julian, 2001). Arguments were made that the guidelines were overly restrictive, particularly with collegiate and professional athletes where significant medical resources are available. It was also argued that “one size fits all” guidelines were not appropriate for the management of a broad array of athletes, including children and adolescents.

The Concussion in Sport Group (Aubry et al., 2002) published what has come to be known as the “Vienna Guidelines,” which moved away from the use of standardized group-based RTP guidelines to an individualized approach that emphasized thorough assessment of history, symptoms, cognitive functioning, and physical functioning. Return to play was predicated on a stepwise process with the athlete being symptom free at rest and upon exertion, having completed a graded physical exertion process and returning to his or her cognitive baseline. Also noteworthy was the recommendation that any player who shows signs or symptoms of a concussion should not return to play in the same game or practice. This “Summary and Agreement” was reevaluated in Prague (McCrory et al., 2005) and more

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**Table 3  Return to Play Guidelines**

<table>
<thead>
<tr>
<th>System</th>
<th>Severity</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>Mild (I)</td>
</tr>
<tr>
<td>Cantu</td>
<td>RTP no sx</td>
</tr>
<tr>
<td></td>
<td>1 week</td>
</tr>
<tr>
<td></td>
<td>(2) 2 weeks</td>
</tr>
<tr>
<td>Colorado Med Society</td>
<td>RTP if no sx &amp; no</td>
</tr>
<tr>
<td></td>
<td>amnesia for 20 min</td>
</tr>
<tr>
<td>AAN</td>
<td>RTP if no MSE changes</td>
</tr>
<tr>
<td></td>
<td>or sx at 15 min</td>
</tr>
</tbody>
</table>

*Note.* The Cantu system provides for additional conservatism if the player has had a previous concussion in the same season (2).
recently in Zurich (McCrory et al., 2009). The later consensus statement modified earlier positions regarding “simple” vs. “complex” concussions and reinforced the individualized approach to RTP. The Zurich statement introduced the use of “modifiers,” factors that should be carefully examined when assessing concussions because they may influence the management of concussion. The modifiers include (a) symptoms (number, duration, and severity of symptoms); (b) signs (prolonged LOC or amnesia); (c) sequela (concussive convulsions); (d) temporal (frequency, timing, and recency of concussions); (e) threshold (repeated concussions occurring with lesser forces or slower recovery following each concussion); (f) age; comorbidities, and premorbidities (mental health disorders, learning disabilities, ADHD); (g) medications (psychoactive drugs, anticoagulants); (h) behaviors (e.g., dangerous style of play); and (i) type of sport (high risk activity, contact, collision). Lastly, the Zurich statement introduced the concept of cognitive rest as well as physical rest following concussion. Activities such as reading, playing video games, watching TV, or even attending classes may need to be curtailed following concussion.

A key concept in the Concussion in Sport Group statements has been the use of graded physical exertion as part of the RTP protocol. In general, this refers to a progression of increasing physical exertion following a period of being asymptomatic (usually 24 hr). Once asymptomatic, the athlete progresses through several steps of increasing exertional activity beginning with light nonimpact aerobic exercise, followed by sport-specific training during noncontact training drills. For instance, in ice hockey this may include skating and shooting drills; the football player may participate in running drills, and the soccer player may engage in dribbling or shooting drills (but no heading). Sport-specific drills are followed by controlled full-contact drills and ultimately RTP. Progression from one level of exertion to the next is dependent upon no emergence of postconcussion signs or symptoms. The amount of time spent at each level of activity may vary depending on player history of concussion or the duration of symptoms.

Echemendia and Cantu (2003) proposed a descriptive model of the RTP decision that is highly consistent with the procedures recommended by the Concussion in Sport Group. They described the RTP decision as a dynamic process involving many variables into a complex framework of cost-benefit analyses. The Echemendia and Cantu model contains several major variable groups (factors) that are akin to the modifiers that were described in the Zurich Consensus Statement. Important elements include information related to the concussion itself (concussion factors); medical findings and history (medical factors); player-specific variables (player factors); variables related to the team (team factors); and extraneous but important issues such as field conditions, playing surface, quality and upkeep of equipment, facilities, etc. (extraneous factors). Some factors have a direct and immediate impact on the RTP decision, while others have much less influence. For example, positive radiologic findings, positive findings on physical examination, and the presence of physical symptoms have a direct impact on player participation. Similarly, a decline in neuropsychological test scores relative to baseline will have a direct impact on whether the player is allowed to RTP. The player’s history of concussions, the temporal sequencing of those concussions, as well as the severity of the concussions should impact the RTP decision as well. The player’s career aspirations, personality, style of play, family pressures, and beliefs regarding RTP are also considerations in the RTP decision, but understandably to a lesser degree than other more direct factors.
Age was not included in original model, but research has shown that it should now be included since younger athletes may be more vulnerable to concussion, may have more severe symptoms, and often require a longer period of recovery when compared with older athletes (Field, Collins, Lovell, & Maroon, 2003; Lovell et al., 2003; McCrory et al., 2009; Moser et al., 2005; Pellman, Lovell, Viano, & Casson, 2006; Schatz, Moser, Covassin, & Karpf, 2011).

In sum, there are many complex and dynamic factors that must be evaluated in the course of making a RTP decision. At the very least, a player must be symptom free at rest and upon exertion, and if available, neuropsychological test scores should have returned to the player’s estimated baseline.

An important area of disagreement in concussion management is RTP in the same day a concussion is diagnosed. Studies have found that 30% of all high school and collegiate football players with concussions returned to competition on the same day of injury (Guskiewicz et al., 2003). If symptoms resolve rapidly and the player remains symptom free following exertion, the question becomes whether he or she can return to the same game or practice. Some argue that an athlete should never be returned to the same game or contest following concussion (Aubry et al., 2002). Others, typically elite college/university and professional sports, find this prohibition to be too restrictive. The Zurich Concussion in Sport Group reviewed the clinical and research data and concluded the following:

With adult athletes, in some settings, where there are team physicians experienced in concussion management and sufficient resources (e.g., access to neuropsychologists, consultants, neuroimaging, etc.), as well as access to immediate (i.e., sideline) neurocognitive assessment, RTP management may be more rapid. . . . There is [sic] data, however, demonstrating that, at the collegiate and high school level, athletes allowed to RTP on the same day may demonstrate NP deficits post-injury that may not be evident on the sidelines and are more likely to have delayed onset of symptoms. (p. 188-189)

**Psychological Considerations in Sports**

Although often overlooked, it is important to note that concussions can lead to psychological symptoms such as anxiety, depression, irritability, emotional lability, and changes in personality functioning due to the direct physiological effects of brain trauma and to “indirect” effects related to factors associated with having had a concussion (Putukian & Echemendia, 2003). For example, players who are held out of competition due to injury often become anxious or depressed because they feel the press to compete from their colleagues, coaches, parents, and friends, and because they look “fine.” In some instances, they question whether they may be viewed as “weak” or “soft” for not playing. Similarly, the culture in athletics often encourages athletes to play through pain and downplay symptoms. Complaining of symptoms without apparent physical injury may contribute to the perception that the player is not tough or “doesn’t want it badly enough.”

In addition, concussions can be very frightening and overwhelming to athletes when they first experience the injury (Bruce & Echemendia, 2004). Part of the frustration with concussions is that players do not know how long the symptoms will last. The medical team can provide broad estimates, but significant variability
in recovery occurs among individuals. The current approach to concussion manage-
ment is to have players rest, both physically and cognitively, following a concussion.
At times, athletes can become subclinically or clinically depressed not just from
the direct effects of the concussion, but from the fact that they are no longer as
physically active as they were before, are concerned about losing their spot on the
team and becoming physically deconditioned, and often experience increased social
isolation due to diminished contact with teammates, friends, etc. These athletes also
frequently experience sleep disturbances due to a lack of physical activity, feeling
“stir crazy,” and anxious. If they are students, athletes may have a very difficult
time focusing their concentration during class, feel less capable of learning and
remembering information, fatigue easily, and experience symptom exacerbation
with focused attention (e.g., sitting in class, studying), among others. Taken together,
these experiences further intensify the psychological distress experienced by many
of these athletes. Intervention is necessary early in the postacute phase to provide
reassurance (e.g., time-limited nature of symptoms), education (e.g., symptom
progression), environmental interventions (e.g., academic accommodations), and
psychological interventions (e.g., for symptoms of anxiety, depression) as needed.

Conclusions

Cerebral concussions are common in all collision and contact sports as well as
sports and activities not commonly considered as having contact (e.g., cheerlead-
ing). These injuries occur over a broad age range and at all levels of play. Recent
research has helped raise awareness that what was once commonly considered a
“nuisance” or even comical injury is now considered a serious injury that can have
deleterious chronic neurocognitive and psychological consequences. Scientific
findings with respect to concussions have been emergently rapidly through varied
multidisciplinary research endeavors. It is now understood that concussions (a) can
present with a broad range of signs and symptoms; (b) have complex pathophysiol-
yogy involving both neurochemical and structural disturbances; (c) can be measured
reliably, although imperfectly, with neuropsychological assessment tools; and (d)
may possibly lead to chronic cerebral pathology. Despite the advances in science,
these injuries are still poorly understood and there are several basic questions that
remain to be answered: Why do some players seem more susceptible to multiple
concussions and others not? What forces are necessary to cause a concussion?
Who is most at risk for long-term neurocognitive consequences? Why do women
appear to have higher rates of concussion in some sports? What can be done to
help prevent concussions? How many concussions are too many?

Although there is considerable debate among scientists, clinicians, and admin-
istrators, there are areas of universal agreement: Players should not be allowed to
return to play until they are symptom free at rest and on exertion and they have
returned to their neurocognitive baseline. In addition, players under the age of 18
who are suspected of having a concussion should not return to play in the same
game or practice. As the field moves forward to answer the many questions that
continue to exist, one of psychologists’ key responsibilities remains to educate
athletes, their families, coaches, physicians, athletic trainers, and policy makers to
recognize and appropriately manage this complex injury. In doing so, we will more
effectively enhance player safety and prevent disabling symptoms.
References


