JRRD Volume 44, Number 7, 2007
Pages 963–974
Journal of Rehabilitation Research & Development

Review of sports-related concussion: Potential for application in military settings

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Abstract—This article reviews current issues and practices in the assessment and clinical management of sports-related concussion. An estimated 300,000 sports-related concussions occur annually in the United States. Much of what has been learned about concussion in the sports arena can be applied to the diagnosis and management of concussion in military settings. Current military guidelines for assessing and managing concussion in war zones incorporate information and methods developed through sports-concussion research. We discuss the incidence, definition, and diagnosis of concussion; concussion grading scales; sideline evaluation tools; neuropsychological assessment; return-to-action criteria; and complications of concussion.

Key words: cognitive impairment, concussion, concussion assessment, concussion grading scales, concussion management, loss of consciousness, neurological impairment, rehabilitation, sports, traumatic brain injury.

INTRODUCTION

Recognizing and managing the effects of cerebral concussion are vitally important to those involved in the healthcare of athletes. "Cerebral concussion" and "mild traumatic brain injury" (MTBI) are overlapping terms. Given that approximately 80 percent of nonfatal traumatic brain injuries (TBIs) from all causes are classified as "mild" [1], an estimated 1 million or more Americans sustain a concussion each year [2]. The annual number of concussions due to sports in the United States is estimated at 300,000 [3]. The U.S. military maintains an extensive sports program that serves to help maintain and enhance the physical conditioning and quality of life of service men and women [4]. The number of military service members who participate annually in sports programs and sustain sports-related concussions is currently unavailable, but we expect the incidence rate to be similar to that of civilian athletes. Because of the current high use of improvised explosive devices (IEDs) in war, awareness of and concern regarding combat-related concussions sustained in the U.S. military have increased. Much of what has been learned about concussion in the past decade has been acquired through the systematic study of concussions sustained in sports.

Abbreviations: AAN = American Academy of Neurology, ANAM = Automated Neuropsychological Assessment Metrics, IED = improvised explosive device, LOC = loss of consciousness, MACE = Military Acute Concussion Evaluation, MTBI = mild traumatic brain injury, PCS = postconcussion syndrome, PTA = posttraumatic amnesia, SAC = Standardized Assessment of Concussion, TBI = traumatic brain injury.

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DOI: 10.1682/JRRD.2006.12.0169

JRRD, Volume 44, Number 7, 2007

DEFINITION OF CONCUSSION

The word "concussion" originates from the Latin word *concutere*, which means "to shake violently." In 1966, the Committee on Head Injury Nomenclature of the Congress of Neurological Surgeons produced the following consensus definition of cerebral concussion: "A clinical syndrome characterized by the immediate and transient posttraumatic impairment of neural function such as alteration of consciousness, disturbance of vision or equilibrium, etc. due to brain stem involvement" [5].

In 1997, the American Academy of Neurology (AAN) defined concussion as "any trauma-induced alteration in mental status that may or may not include loss of consciousness" [6]. In November 2001, clinicians and researchers gathered in Vienna, Austria, for the First International Symposium on Concussion in Sport [7]. This group of experts met to improve the understanding of concussive injury. The group defined concussion as "a complex pathophysiological process affecting the brain, induced by traumatic biomechanical forces." They described several common features that incorporate clinical, pathological, and biomechanical injury constructs and that can be used to define the nature of a concussive head injury:

1. Concussion may be caused by a direct blow to the head, face, or neck or by a blow elsewhere on the body that transmits an "impulsive" force to the head.
2. Concussion typically causes the rapid onset of short-lived neurological impairment that resolves spontaneously.
3. Concussion may cause neuropathological changes, but its acute clinical symptoms largely reflect functional disturbance rather than structural injury.
4. Concussion causes a graded set of clinical syndromes that may or may not involve loss of consciousness (LOC). The clinical and cognitive symptoms typically resolve sequentially.
5. Concussion is typically associated with grossly normal structural neuroimaging studies.

Current definitions and explanations of cerebral concussion will, no doubt, be modified as research in this field continues. The causes of concussion include the shock waves of explosive blasts, which are currently being studied in the numerous U.S. service personnel with blast-related MTBI [8]. Most fatalities and brain injuries among U.S. soldiers in Afghanistan and Iraq are caused by IEDs (http://www.dvbic.org/pdfs/DVBIC-Facts-2007.pdf). In one review of cases, 59 percent of those exposed to explosive blasts were diagnosed with TBI and 44 percent of these TBI cases were considered mild [9]. The changes responsible for the temporary neurological and cognitive impairments associated with concussion have been attributed to a highly complex neurometabolic cascade [10], which cannot be seen with structural neuroimaging. However, as use of functional neuroimaging methods increases, these neurophysiological abnormalities are being viewed more often [11–12].

Belanger and Vanderploeg's meta-analysis of the initial impact of sports-related concussion on neuropsychological test scores found an overall effect size equivalent to one-half of one standard deviation [13]. The largest specific effects involved global cognitive functioning, memory acquisition, and delayed memory, and cognition typically returned to normal within 1 week [13–14]. In a meta-analysis of MTBI from causes other than sports injuries, Belanger et al. found an overall cognitive effect size similar to that found in sports, with the largest specific effects for delayed memory and fluency [15]. Studies of MTBI from causes unrelated to sports have usually used longer time frames for cognitive assessments and have reported that most cognitive difficulties resolve within about 3 months [16–18].

DIAGNOSIS OF CONCUSSION

Figure 1 summarizes the signs, symptoms, and cognitive features of concussion. These characteristics include nausea, reduced coordination and balance, inappropriate behavior, headache, dizziness, visual and auditory disturbances, impaired concentration, confusion, and memory disturbance [19–20]. LOC is not required for a diagnosis of concussion, but some alteration of consciousness must occur. Subtle changes in consciousness are known to be underreported by athletes [21] and can go unnoticed by coaches and trainers. Alteration of consciousness may be manifested by a vacant stare, slowness in following instructions, or distractibility. Confusion may be suspected when an athlete moves aimlessly, walks in the wrong direction (e.g., goes to the wrong team's huddle), or repeatedly asks questions like, "Is the game over?" Typical orientation questions may inadequately elicit symptoms. Effectively capturing disorientation requires questions about issues immediately surrounding the injury, e.g., "Who tackled you?" "What were the last three plays?" "What is the score now?"

Signs	Symptoms	Cognitive Features
• Alteration of consciousness • Nausea/vomiting • Vacant expression • Inappropriate playing behavior • Reduced coordination • Reduced balance • Slowed reactions • Slurred speech • Inappropriate emotions	• Headache • Dizziness • Visual disturbance – Photophobia – Seeing stars – Double vision • Auditory disturbance – Phonophobia – Tinnitus • Psychological disturbance – Irritability – Anxiety – Depression • Sleep disturbance • Fatigue	• Confusion/disorientation • Poor attention & concentration • Memory dysfunction – Impaired learning – Posttraumatic amnesia – Retrograde amnesia • Reduced planning, mental tracking, & flexibility • Reduced verbal fluency • Reduced visual-motor speed & accuracy

Figure 1.
Common characteristics of concussion.

GRADING SCALES AND RETURN TO PLAY

Many different concussion severity grading scales have been published over the years [7]. LOC, amnesia, and confusion are considered important markers of severity in many of these scales. These grading scales have promoted the use of uniform terminology and increased team physicians' awareness of and caution in dealing with concussion. Three commonly used scales and management guidelines are reviewed in this article and summarized in **Tables 1** and **2**.

The Cantu scale was first proposed in 1986 [22]. This scale was developed through clinical experience and uses LOC and posttraumatic amnesia (PTA) as markers of severity. Same-day return to play is allowed when athletes with grade 1 (mild) concussions are asymptomatic both at rest and with exertion. Athletes with grade 2 (moderate) concussions are allowed to return to play in 2 weeks if asymptomatic for 1 week. Athletes with grade 3 (severe) concussions are allowed to return to play in 1 month if asymptomatic for 1 week.

Cantu later redefined the criteria for his guidelines to stress the importance of the duration of posttraumatic signs and symptoms [23]. Grade 1 was redefined as the presence of posttraumatic signs and symptoms along with PTA lasting <30 minutes and no LOC. In addition, the arbitrary LOC cutoff criteria for grades 2 and 3 were changed to <1 minute and >1 minute, respectively.

The Sports Medicine Committee of the Colorado Medical Society published the Colorado Guidelines in 1991 after a high school athlete died from complications of concussion [24]. In these guidelines, a grade 2 concussion does not require LOC but rather confusion with amnesia, which stresses the importance of a mental status evaluation. Same-day return to play is allowed if the injured athlete is asymptomatic during 20 minutes of observation. Immediate transfer to a hospital is recommended for grade 3 concussions.

The current AAN guidelines are a revision of the Colorado Guidelines [6]. Similar to the Colorado Guidelines, the AAN guidelines regard confusion, amnesia, and LOC as the markers of concussion severity. Same-day return to play is allowed if an athlete with a grade 1 concussion is asymptomatic during 15 minutes of observation. For a single grade 2 or 3 concussion, the minimum time recommended before return to play is 1 week; for multiple concussions, the recommended recovery period is 1 to 4 weeks, depending on grade.

Although these severity guidelines have positively influenced concussion management, none has been scientifically validated, thus allowing ongoing controversy [25]. At the 2001 International Symposium on Concussion in Sport in Vienna, a consensus decision abandoned concussion grading scales in favor of individually guided return-to-play decisions [7]. This group clarified that the athlete with ongoing or existing symptoms will not return

Table 1.
Concussion severity grading scales.

Concussion Grade	Cantu, 1986 [1]	Colorado, 1991 [2]	American Academy of Neurology, 1997 [3]
1, Mild	No LOC, PTA <30 min	No LOC, no confusion, no amnesia	Transient confusion, no LOC, concussion symptoms or mental status abnormalities resolve in <15 min
2, Moderate	LOC <5 min, PTA >30 min	No LOC, confusion, amnesia	Transient confusion, no LOC, concussion symptoms or mental status abnormalities including amnesia resolve in >15 min
3, Severe	LOC >5 min, PTA >24 h	LOC	Any LOC: Brief (seconds) or prolonged (minutes)

1. Cantu RC. Guidelines for return to contact sports after a cerebral concussion. Phys Sports Med. 1986;14:75–83.
2. Kelly JP, Nichols JS, Filley CM, Lillehei KO, Rubinstein D, Kleinschmidt-DeMasters BK. Concussion in sports. Guidelines for the prevention of catastrophic outcome. JAMA. 1991;266(20):2867–69. [PMID: 1942455]
3. Practice parameter: The management of concussion in sports (summary statement). Report of the Quality Standards Subcommittee. Neurology. 1997;48(3):581–85. [PMID: 9065530]

LOC = loss of consciousness, PTA = posttraumatic amnesia.

Table 2.
American Academy of Neurology (AAN) management guidelines for sports-related concussion.

Concussion Grade	AAN Management Guidelines
1, Mild	Remove athlete from play. Evaluate athlete immediately for mental status changes or postconcussion symptoms at rest & with exertion. Allow athlete with single concussion to return to play if no mental status changes or postconcussion symptoms for 15 min. If athlete has multiple grade 1 concussions, allow return to play after 1 week.
2, Moderate	Remove athlete from play & disallow return that day. Frequently examine athlete on-site for signs of evolving intracranial pathology. Physician should reexamine athlete next day. If athlete asymptomatic at rest & with exertion, allow return to play after 1 week for single concussion & after 2 weeks for multiple concussions.
3, Severe	Transfer athlete to hospital. Perform thorough neurological examination including neuroimaging procedures. Admit athlete to hospital if any signs of pathology are detected or if mental status remains abnormal. Assess athlete's neurological status daily thereafter until all symptoms have resolved. If asymptomatic at rest & with exertion, allow return to play after 2 weeks for single concussion & after 4 weeks or more for multiple concussions.

to play while symptomatic and that the final management decision following a concussion should be based on the sports physician's best clinical judgment.

The duration of LOC is a relatively good predictor of outcome in severe TBI but a less reliable predictor in MTBI [26–27]. Lovell et al. studied 383 patients with MTBI and found that those with LOC did not necessarily have greater neuropsychological impairment [28]. However, McCrea et al. found that although all the concussed athletes they studied returned to normal within 48 hours, those with LOC had more cognitive symptoms initially than those who did not have LOC [29].

The authors of several concussion grading scales consider PTA an important indicator of concussion severity. PTA is defined as the time between the onset of injury and the point at which the individual is once again encoding new experiences into long-term memory [30]. Retrograde amnesia occurs when the athlete does not remember events that occurred before the injury. Some authors consider postconcussion memory problems to be strongly associated with concussion severity, so memory deficits are often a major consideration in determining fitness to return to play after injury [26,31]. However, some studies consider the nature and duration of other postconcussion symptoms, such as headaches, dizziness, and blurred vision, to be more important predictors of injury severity than memory deficits alone [32–33].

SIDELINE EVALUATION

Sports healthcare personnel are often asked to assess a concussed athlete on the sideline to determine fitness to remain in play. While we use the word "sideline" here, the assessment is typically conducted in the locker room or another nearby, relatively protected environment. These assessments must be comprehensive yet quick because of game requirements. Such an assessment should include a physical evaluation and an evaluation of the athlete's mental status, including concentration and memory. Several formal assessments have been published. Maddocks et al.'s questions were developed initially for use in Australian football to rapidly detect retrograde memory impairment [34]:

- Which ground are we at?
- Which team are we playing today?
- Who is your opponent at present?
- Which half is it?
- How far into the quarter is it?
- Which side scored the last goal?
- Which team did we play last week?
- Did we win last week?

Other sideline assessment tools include the evaluation developed by the Colorado Medical Society [35], the management of sports concussion palm card published by the AAN and the Brain Injury Association [36], and the Standardized Assessment of Concussion (SAC) developed by McCrea [37]. The Sport Concussion Assessment Tool was assembled from various parts of existing sideline assessment tools [38]. The SAC and the Colorado Medical Society evaluation use physical exertion to provoke symptoms. The Military Acute Concussion Evaluation (MACE) (http://www.dvbic.org/pdfs/DVBIC_documentation_sheet.pdf), which is recommended for in-theater assessment of concussion [39], incorporates the SAC.

Ideally, each athlete's baseline scores on these tools will be obtained before the sports season begins to allow comparison with results of a postconcussion examination. These tools are adjuncts to a proper medical evaluation of concussion to rule out emergent complications. Not only do these tools provide standardized, systematic assessment of athletes with suspected concussions, they can also educate athletes about the signs and symptoms they may experience, thus "normalizing" their recovery process and reducing unnecessary anxiety. Symptoms are usually worse initially and gradually improve, but they can worsen several days after a concussion as effects from the cascade of neuropathological changes evolve [10]. Thus, the "sideline evaluation," even when normal, should not be the final examination.

NEUROPSYCHOLOGICAL TESTING

Conventional neuropsychological tests (sometimes termed "paper-and-pencil tests") have successfully identified average differences between groups of athletes with concussions and uninjured individuals (control-based comparisons) [20]. These tests have identified acutely a range of postconcussion cognitive deficits, such as reduced ability to plan and switch mental set [40], deficient memory and learning [31,41], reduced attention, slowed information processing [42], and prolonged and more variable visual-motor speed [43–45]. Impaired visuospatial-constructional ability, language, and sensorimotor function have also been reported [28,32].

Neuropsychological functioning generally normalizes by the time the neurological signs and symptoms are resolved after an uncomplicated sports-related concussion, which is usually within 1 week of injury [17]. Therefore, neuropsychological testing after that point may simply confirm a decision about readiness to return to play based on other findings [46]. Formal neuropsychological testing is probably most useful for assessing the severity of injury during the first few days after a concussion and monitoring recovery when cognitive difficulties persist longer than usual.

If an athlete was not tested before injury, the neuropsychologist must use demographic information, prior school grades, or current reading level to estimate the athlete's premorbid baseline [47–48]. Then, the athlete's postinjury neuropsychological test performance can be compared with scores from individuals whose abilities are at this expected level (norm-based comparisons). Although this method works fairly well with moderate and severe TBI, it may inadequately identify the subtle changes associated with concussion in a single individual.

To save time and money, abbreviated neuropsychological batteries have been increasingly used in sports-concussion assessment. Brief batteries may include tests that are sensitive to attention and memory deficits, such as the Trail Making Test, the Paced Auditory Serial Addition Test, the Digit Symbol Test, digit span backwards, and tests of word-list memory [20,49]. Computerized neuropsychological batteries are viewed as a further advancement over short conventional test batteries because they are economical, easy to administer and score, and enable finely tuned measurements of mental speed. TBI almost always slows down cognitive processing [50–51], and this slowing may increase with accumulated concussions [50]. The intensity and duration of cognitive slowing correlate with the severity of brain injury as indexed by duration of coma [52].

Several well-known computer-based sports concussion assessment platforms are shown in **Table 3**. These tests have similar administration times but differ from one another with regard to (1) the specific cognitive tasks administered, (2) the cognitive domains purported to be assessed, and (3) the type of metrics provided as testing results. No consensus has been reached on which cognitive tasks and metrics are most sensitive and specific in concussion assessment, so computerized test developers typically include a variety of tasks and scores [53]. ImPACT uses five to seven subtests that were designed to measure attention span, sustained and selective attention, working memory, nonverbal problem solving, and processing speed, with results provided as 17 scores and several graphs. However, when this battery was factor analyzed, just two cognitive factors emerged: reaction time and memory [54]. The Automated Neuropsychological Assessment Metrics (ANAM) Sports Medicine Battery (known as the ASMB) [55], like its predecessor the ANAM [56], provides a useful measure of cognitive processing efficiency called "throughput," which is the number of correct answers obtained per minute.

The reliability, sensitivity, and specificity of computerized reaction-time batteries are still under investigation. More needs to be known about the day-to-day stability of mental performance and the extent of any practice effects that may accumulate during multiple administrations of these tests. Bleiberg et al. found some instances in which the only computerized test measure that differentiated the injured from the uninjured subjects was the absence of practice effect [55]. When interpreting computerized test results after a concussion, one must be aware of the many factors influencing an athlete's cognitive performance at any given time (**Figure 2**).

Because cognitive impairment and incoordination are frequent sequelae of concussion, the athlete's potential for reinjury is heightened if return to play occurs before full mental recovery [57]. Likewise, a soldier who sustains a cerebral concussion as part of a blast injury may be vulnerable if returned to action too quickly. Hence, computerized cognitive assessment tools have potential application in military settings where concussed soldiers' readiness to return to action must be decided. Toward this end, the ANAM has been field-tested in a pilot study with the U.S. military in Iraq.*

*Dennis Reeves, personal communication, 2005.

Table 3.
Common computer-based neuropsychological tests for use in sports.

Product	Source	Administration Time	Metrics
ANAM Sports Medicine Battery (ASMB)	U.S. Department of Defense	20 min	Reaction time, variability, accuracy, throughput
CogSport (Concussion Sentinel)	CogState, Ltd Melbourne, Australia http://www.cogsport.com/	<18 min	Reaction time, variability, accuracy
HeadMinder	HeadMinder, Inc New York, New York http://www.headminder.com/	<25 min	Reaction time
ImPACT	ImPACT, Inc Pittsburgh, Pennsylvania http://www.impacttest.com/	<22 min	Reaction time, variability, accuracy

ANAM = Automated Neuropsychological Assessment Metrics.

Medication and Toxics

- Current medications—Opiates, anxiolytics, hypnotics, antiseizure, etc.
- Present and prior use of alcohol, drugs, performance enhancers
- High quantities of or withdrawal from caffeine, nicotine
- Exposure to neurotoxins

Medical Conditions and Physical Characteristics

- Previous concussions or more serious head injury
- Pain, headache
- Neurological conditions—Epilepsy, cerebrovascular accident, multiple sclerosis, movement disorder, predementia
- Major medical conditions—Diabetes mellitus, ischemic heart disease, cancer
- Physical or mental fatigue
- Sleep deprivation
- Impaired visual or auditory acuity
- Age
- Sex

Culture

- Native language
- Native culture and life experience

Education

- Level of education, prior academic performance
- Vocational training and experience

Psychological and Psychiatric Issues

- Developmental delay
- Learning disabilities
- Attention-deficit/hyperactivity disorder
- Thought disorder—Schizophrenia, psychotic depression
- Mood—Depression, mania, anxiety, posttraumatic stress disorder
- High levels of emotional stress
- Motivation (mental effort on baseline and postinjury tests)

Testing Parameters

- Previous testing—Practice effect
- Testing situation—Location, distractions, rapport, confidentiality
- Familiarity and comfort with computer use
- Time of day

Figure 2.
Factors that may influence neuropsychological test performance.

CONCUSSION MANAGEMENT

All concussed individuals require a thorough evaluation followed by close monitoring. Neuropsychological testing, including the new computerized tests designed for this purpose, should not be used in isolation but as an important component of a complete clinical evaluation. Return-to-play/action decisions should be individualized and based on sound clinical judgment. Athletic or other risky activity should not resume until after the physical signs and symptoms of concussion are no longer present at rest or with physical exertion and cognitive deficits are fully resolved.

Headache

Headache is the most common postconcussion complaint [45]. Postconcussion headaches may be focal or generalized and, as with other concussion symptoms, may not be fully manifest until hours or days later. Determining whether or not the headache is a sequela of the injury may be difficult if the individual has a prior history of headaches. Since postconcussion headaches usually worsen with physical exertion, assessment both at rest and during physical activity may help in this differentiation. If a headache worsens or is accompanied by vomiting or deteriorating mentation, immediate transfer to a hospital for investigation and management is warranted.

Vision Disturbance

Complaints of disturbed vision should be carefully assessed. The individual may have impaired visual tracking, loss of acuity, photosensitivity, and changes in peripheral vision. These symptoms should be fully resolved before return to action.

Seizures

Postconcussion seizures usually occur immediately after impact, are often benign, and do not have a prolonged course [58]. Standard epileptic medications are generally unwarranted because the seizure episode is usually short lived and very rarely leads to subsequent spontaneous seizures.

Multiple Concussions

Repeated concussion may cause cumulative cognitive effects [50] and slowed recovery of neurological functioning [59], but no consensus exists as to how many concussions are too many. Multiple concussive episodes can cause chronic traumatic encephalopathy such as dementia pugilistica [60], which may occur in boxers. This condition is characterized by cognitive impairment, ataxia, behavioral changes, parkinsonism, and pyramidal tract dysfunction [61–62].

Second-Impact Syndrome

Second-impact syndrome is a rare complication of concussion that occurs when the athlete sustains a second concussion before resolving symptoms from the previous concussion [63–64]. The course of this syndrome starts with disordered cerebral vascular autoregulation and leads to cerebrovascular congestion, rapid development of cerebral swelling, increased intracranial pressure, and brain stem herniation resulting in death [65]. The pathophysiology is believed to involve diffuse cerebral swelling, similar to "malignant brain edema" syndrome in children.

Postconcussion Syndrome

The great majority of individuals who sustain a single uncomplicated concussion recover fully. A minority of individuals develop postconcussion syndrome (PCS), a persistent constellation of symptoms that may include headache, dizziness, fatigue, sleep disturbance, sensitivity to light and noise, anxiety, depression, and complaints of concentration and memory problems that may or may not be verified by cognitive testing [17,66–67]. The causes of PCS are controversial and may involve an interplay between the neurological injury and psychological factors [68–69]. Weight has summarized the difficulties associated with assessing PCS [70]. Very few studies have examined the effectiveness of treatment interventions for PCS. Brief, early educational intervention has been shown to moderately reduce the incidence of PCS symptoms in accident-related cases [71]. Evans et al. list the typical medical interventions for PCS cited in a survey of doctors [72]. For a thorough review of PCS, we refer readers to Iverson et al. [73].

CONCLUSIONS

In recent years, because of the collective efforts of physicians, neuropsychologists, athletic trainers, and related health professionals, as well as increased attention from the media, awareness of the frequency and dangers of sports-related concussion has increased. Concussion grading scales have been created, standardized assessment tools have been developed, and management guidelines have been promulgated. Much of what has been learned in the sports arena may be applied to the assessment and management of concussions in military settings. The incorporation of the SAC into the MACE is one example. Progress in this field will likely include improved concussion assessment tools and protocols, refined return-to-action decision making, improved medical management, better understanding of the long-term sequelae of multiple concussions, and more effective management of PCS.

ACKNOWLEDGMENTS

We gratefully acknowledge Dr. John H. Poole, Dr. Dennis Reeves, Ms. Kathy Helmick, Dr. Edgar Han, Dr. Cheryl Lee, and Dr. Henry Hsieh for their assistance.

This material was unfunded at the time of manuscript preparation.

The authors have declared that no competing interests exist.

REFERENCES

1. Kraus JF, Nourjah P. The epidemiology of mild, uncomplicated brain injury. J Trauma. 1988;28(12):1637–43. [PMID: 3199464]
2. Sosin DM, Sniezek JE, Thurman DJ. Incidence of mild and moderate brain injury in the United States, 1991. Brain Inj. 1996;10(1):47–54. [PMID: 8680392]
3. Sports-related recurrent brain injuries—United States. Centers for Disease Control and Prevention. Int J Trauma Nurs. 1997;3(3):88–90. [PMID: 9295581]
4. Reflecting on the past, focused on the future & providing support for military, an ongoing mission. Government Recreation and Fitness. 2005;25–29.
5. Johnston KM, McCrory P, Mohtadi NG, Meeuwisse W. Evidence-based review of sport-related concussion: Clinical science. Clin J Sport Med. 2001;11(3):150–59. [PMID: 11495319]
6. Practice parameter: The management of concussion in sports (summary statement). Report of the Quality Standards Subcommittee. Neurology. 1997;48(3):581–85. [PMID: 9065530]
7. Aubry M, Cantu R, Dvorak J, Graf-Baumann T, Johnston KM, Kelly J, Lovell M, McCrory P, Meeuwisse WH, Schamasch P, Concussion in Sport (CIS) Group. Summary and agreement statement of the 1st International Symposium on Concussion in Sport, Vienna 2001. Clin J Sport Med. 2002;12(1):6–11. [PMID: 11854582]
8. Taber KH, Warden DL, Hurley RA. Blast-related traumatic brain injury: What is known? J Neuropsychiatry Clin Neurosci. 2006;18(2):141–45. [PMID: 16720789]

9. Okie S. Traumatic brain injury in the war zone. N Engl J Med. 2005;352(20):2043–47. [PMID: 15901856]
10. Giza CC, Hovda DA. The neurometabolic cascade of concussion. J Athl Train. 2001;36(3):228–35. [PMID: 12937489]
11. Belanger HG, Vanderploeg RD, Curtiss G, Warden DL. Recent neuroimaging techniques in mild traumatic brain injury. J Neuropsychiatry Clin Neurosci. 2007;19(1):5–20. [PMID: 17308222]
12. Mendez CV, Hurley RA, Lassonde M, Zhang L, Taber KH. Mild traumatic brain injury: Neuroimaging of sports-related concussion. J Neuropsychiatry Clin Neurosci. 2005;17(3): 297–303. [PMID: 16179650]
13. Belanger HG, Vanderploeg RD. The neuropsychological impact of sports-related concussion: A meta-analysis. J Int Neuropsychol Soc. 2005;11(4):345–57. [PMID: 16209414]
14. McCrea M. Mild traumatic brain injury and post-concussion syndrome. New York (NY): Oxford University Press; 2007.
15. Belanger HG, Curtiss G, Demery JA, Lebowitz BK, Vanderploeg RD. Factors moderating neuropsychological outcomes following mild traumatic brain injury: A meta-analysis. J Int Neuropsychol Soc. 2005;11(3):215–27. [PMID: 15892898]
16. Binder LM, Rohling ML, Larrabee GJ. A review of mild head trauma. Part I: Meta-analytic review of neuropsychological studies. J Clin Exp Neuropsychol. 1997; 19(3):421–31. [PMID: 9268816]
17. Alexander MP. Mild traumatic brain injury: Pathophysiology, natural history, and clinical management. Neurology. 1995;45(7):1253–60. [PMID: 7617178]
18. Rimel RW, Giordani B, Barth JT, Boll TJ, Jane JA. Disability caused by minor head injury. Neurosurgery. 1981; 9(3):221–28. [PMID: 7301062]
19. Maddocks DL, Dicker GD, Saling MM. The assessment of orientation following concussion in athletes. Clin J Sport Med. 1995;5(1):32–35. [PMID: 7614078]
20. Barth JT, Alves W, Ryan TV, Macciocchi SN, Rimel R, Jane JA, Nelson W. Mild head injury in sports: Neuropsychological sequelae and recovery of function. In: Levin HS, Eisenberg HM, Benton AL, editors. Mild head injury. New York (NY): Oxford University Press; 1989. p. 257–75.
21. McCrea M, Hammeke T, Olsen G, Leo P, Guskiewicz K. Unreported concussion in high school football players: Implications for prevention. Clin J Sport Med. 2004;14(1): 13–17. [PMID: 14712161]
22. Cantu RC. Guidelines for return to contact sports after a cerebral concussion. Phys Sports Med. 1986;14:75–83.
23. Cantu RC. Posttraumatic retrograde and anterograde amnesia: Pathophysiology and implications in grading and safe return to play. J Athl Train. 2001;36(3):244–48. [PMID: 12937491]
24. Kelly JP, Nichols JS, Filley CM, Lillehei KO, Rubinstein D, Kleinschmidt-DeMasters BK. Concussion in sports. Guidelines for the prevention of catastrophic outcome. JAMA. 1991;266(20):2867–69. [PMID: 1942455]
25. Collins MW, Lovell MR, McKeag DB. Current issues in managing sports-related concussion. JAMA. 1999;282(24): 2283–85. [PMID: 10612307]
26. Erlanger D, Kaushik T, Cantu R, Barth JT, Broshek DK, Freeman JR, Webbe FM. Symptom-based assessment of the severity of a concussion. J Neurosurg. 2003;98(3):477–84. [PMID: 12650417]
27. Collins MW, Iverson GL, Lovell MR, McKeag DB, Norwig J, Maroon J. On-field predictors of neuropsychological and symptom deficit following sports-related concussion. Clin J Sport Med. 2003;13(4):222–29. [PMID: 12855924]
28. Lovell MR, Iverson GL, Collins MW, McKeag DB, Maroon JC. Does loss of consciousness predict neuropsychological decrements after concussion? Clin J Sport Med. 1999;9(4):193–98. [PMID: 10593212]
29. McCrea M, Kelly JP, Randolph C, Kluge J, Bartolic E, Finn G, Baxter B. Standardized Assessment of Concussion (SAC): On-site mental status evaluation of the athlete. J Head Trauma Rehabil. 1998;13(2):27–35. [PMID: 9575254]
30. Russell WR, Smith A. Post-traumatic amnesia in closed head injury. Arch Neurol. 1961;5:4–17. [PMID: 13744864]
31. Lovell MR, Collins MW, Iverson GL, Field M, Maroon JC, Cantu R, Podell K, Powell JW, Belza M, Fu FH. Recovery from mild concussion in high school athletes. J Neurosurg. 2003;98(2):296–301. [PMID: 12593614]
32. Leininger BE, Gramling SE, Farrell AD, Kreutzer JS, Peck EA 3rd. Neuropsychological deficits in symptomatic minor head injury patients after concussion and mild concussion. J Neurol Neurosurg Psychiatry. 1990;53(4):293–96. [PMID: 2341842]
33. McCrory PR, Ariens T, Berkovic SF. The nature and duration of acute concussive symptoms in Australian football. Clin J Sport Med. 2000;10(4):235–38. [PMID: 11086747]
34. Maddocks DL, Dicker GD, Saling MM. The assessment of orientation following concussion in athletes. Clin J Sport Med. 1995;5(1):32–35. [PMID: 7614078]
35. Colorado Medical Society, Sports Medicine Committee. Report of the sports medicine committee: Guidelines for the management of concussions in sport (revised). Denver (CO): Colorado Medical Society 1991.
36. Kelly JP, Rosenberg JH. Diagnosis and management of concussion in sports. Neurology. 1997;48(3):575–80. [PMID: 9065529]
37. McCrea M. Standardized mental status testing on the sideline after sport-related concussion. J Athl Train. 2001;36(3): 274–79. [PMID: 12937496]
38. McCrory P, Johnston K, Meeuwisse W, Aubry M, Cantu R, Dvorak J, Graf-Baumann T, Kelly J, Lovell M, Schamasch P, International Symposium on Concussion in Sport. Summary and agreement statement of the 2nd International

Conference on Concussion in Sport, Prague 2004. Clin J Sports Med. 2005;15(2):48–55. [PMID: 15782046]

39. Helmick K, Guskiewicz K, Barth J, Cantu R, Kelly JP, McDonald E, Flaherty S, Bazarian J, Bleiberg J, Carter T, Cooper J, Drake A, French L, Grant G, Holland M, Hunt R, Hurtado T, Jenkins D, Johnson T, Kennedy J, Labutta R, Lopez M, McCrea M, Montgomery H, Riechers R, Ritchie E, Ruscio B, Schneider T, Schwab K, Tanner W, Zitnay G, Warden D. Defense and Veterans Brain Injury Center working group on the acute management of mild traumatic brain injury in military operational settings: Clinical practice guideline and recommendations [monograph on the internet]. Washington (DC): Defense and Veterans Brain Injury Center; 2006 [cited 2007 Oct 11]. Available from: http://www.dvbic.org/pdfs/clinical_practice_guideline_recommendations.pdf
40. Matser EJ, Kessels AG, Lezak MD, Jordan BD, Troost J. Neuropsychological impairment in amateur soccer players. JAMA. 1999;282(10):971–73. [PMID: 10485683]
41. Guskiewicz KM, Ross SE, Marshall SW. Postural stability and neuropsychological deficits after concussion in collegiate athletes. J Athl Train. 2001;36(3):263–73. [PMID: 12937495]
42. Iverson GL, Lovell MR, Collins MW. Interpreting change on ImPACT following sport concussion. Clin Neuropsychol. 2003;17(4):460–67. [PMID: 15168911]
43. Warden DL, Bleiberg J, Cameron KL, Ecklund J, Walter J, Sparling MB, Reeves D, Reynolds KY, Arciero R. Persistent prolongation of simple reaction time in sports concussion. Neurology. 2001;57(3):524–26. [PMID: 11502926]
44. Moriarity J, Collie A, Olson D, Buchanan J, Leary P, McStephen M, McCrory P. A prospective controlled study of cognitive function during an amateur boxing tournament. Neurology. 2004;62(9):1497–1502. [PMID: 15136671]
45. Collins MW, Field M, Lovell MR, Iverson G, Johnston KM, Maroon J, Fu FH. Relationship between postconcussion headache and neuropsychological test performance in high school athletes. Am J Sports Med. 2003;31(2):168–73. [PMID: 12642248]
46. Randolph C, McCrea M, Barr WB. Is neuropsychological testing useful in the management of sport-related concussion? J Athl Train. 2005;40(3):139–52. [PMID: 16284633]
47. Franzen MD, Burgess EJ, Smith-Seemiller L. Methods of estimating premorbid functioning. Arch Clin Neuropsychol. 1997;12(8):711–38. [PMID: 14590649]
48. Wechsler Test of Adult Reading. San Antonio (TX): Harcourt Assessment, Inc; 2001.
49. McCrea M, Kelly JP, Kluge J, Ackley B, Randolph C. Standardized assessment of concussion in football players. Neurology. 1997;48(3):586–88. [PMID: 9065531]
50. Gronwall D, Wrightson P. Cumulative effect of concussion. Lancet. 1975;2(7943):995–97. [PMID: 53547]
51. Van Zomeren AH, Deelman BG. Differential effects of simple and choice reaction after closed head injury. Clin Neurol Neurosurg. 1976;79(2):81–90. [PMID: 1029638]
52. Van Zomeren AH, Deelman BG. Long-term recovery of visual reaction time after closed head injury. J Neurol Neurosurg Psychiatry. 1978;41(5):452–57. [PMID: 660209]
53. Grindel SH, Lovell MR, Collins MW. The assessment of sport-related concussion: The evidence behind neuropsychological testing and management. Clin J Sport Med. 2001; 11(3):134–43. [PMID: 11495317]
54. Iverson GL, Lovell MR, Collins MW. Validity of ImPACT for measuring processing speed following sports-related concussion. J Clin Exp Neuropsychol. 2005;27(6):683–89. [PMID: 16019644]
55. Bleiberg J, Cernich A, Reeves D. Sports concussion applications of the Automated Neuropsychological Assessment Metrics Sports Medicine Battery (ASMB). In: Echemendía RJ, editor. Sports Neuropsychology: Assessment and management of traumatic brain injury. New York (NY): Guilford Press; 2006.
56. Kabat MH, Kane RL, Jefferson AL, DiPino RK. Construct validity of selected Automated Neuropsychological Assessment Metrics (ANAM) battery measures. Clin Neuropsychol. 2001;15(4):498–507. [PMID: 11935451]
57. Guskiewicz KM, Weaver NL, Padua DA, Garrett WE Jr. Epidemiology of concussion in collegiate and high school football players. Am J Sports Med. 2000;28(5):643–50. [PMID: 11032218]
58. McCrory PR, Berkovic SF. Concussive convulsions. Incidence in sport and treatment recommendations. Sports Med. 1998;25(2):131–36. [PMID: 9519401]
59. Guskiewicz KM, McCrea M, Marshall SW, Cantu RC, Randolph C, Barr W, Onate JA, Kelly JP. Cumulative effects associated with recurrent concussion in collegiate football players: The NCAA Concussion Study. JAMA. 2003;290(19):2549–55. [PMID: 14625331]
60. Jordan BD. Chronic traumatic brain injury associated with boxing. Semin Neurol. 2000;20(2):179–85. [PMID: 10946737]
61. Jordan BD. Boxing. In: Jordan BD, Tsairis P, Warren RF, editors. Sports neurology. 2nd ed. Philadelphia (PA): Lippincott-Raven Publishers; 1998. p. 351–67.
62. Erlanger DM, Kutner KC, Barth JT, Barnes R. Neuropsychology of sports-related head injury: Dementia pugilistica to post concussion syndrome. Clin Neuropsychol. 1999; 13(2):193–209. [PMID: 10949160]
63. Cantu RC. Second-impact syndrome. Clin Sports Med. 1998; 17(1):37–44. [PMID: 9475969]
64. McCrory P. Does second impact syndrome exist? Clin J Sport Med. 2001;11(3):144–49. [PMID: 11495318]
65. McCrory PR, Berkovic SF. Second impact syndrome. Neurology. 1998;50(3):677–83. [PMID: 9521255]

66. Gouvier WD, Cubic B, Jones G, Brantley P, Cutlip Q. Post-concussion symptoms and daily stress in normal and head-injured college populations. Arch Clin Neuropsychol. 1992; 7(3):193–211. [PMID: 14591254]
67. Savola O, Hillbom M. Early predictors of post-concussion symptoms in patients with mild head injury. Eur J Neurol. 2003;10(2):175–81. [PMID: 12603294]
68. Lishman WA. Physiogenesis and psychogenesis in the 'post-concussional syndrome.' Br J Psychiatry. 1988;153: 460–69. [PMID: 3074853]
69. Jacobson RR. The post-concussional syndrome: Physiogenesis, psychogenesis and malingering. An integrative model. J Psychosom Res. 1995;39(6):675–93. [PMID: 8568727]
70. Weight DG. Minor head trauma. Psychiatr Clin North Am. 1998;21(3):609–24. [PMID: 9774799]
71. Mittenberg W, Canyock EM, Condit D, Patton C. Treatment of post-concussion syndrome following mild head injury. J Clin Exp Neuropsych. 2001;23(6):829–36. [PMID: 11910547]
72. Evans RW, Evans RI, Sharp MJ. The physician survey on the post-concussion and whiplash syndromes. Headache. 1994; 34(5):268–74. [PMID: 8026944]
73. Iverson GL, Zasler ND, Lange RT. Post-concussive disorder. In: Silver JM, McAllister TW, Yudofsky SC, editors. Textbook of traumatic brain injury. Washington (DC): American Psychiatric Publishing; 2005. p. 373–405.

Submitted for publication January 3, 2007. Accepted in revised form August 9, 2007.