PEDIATRICS
OFFICIAL JOURNAL OF THE AMERICAN ACADEMY OF PEDIATRICS

Sport-Related Concussion

William P. Meehan III and Richard G. Bachur

Pediatrics 2009;123;114
DOI: 10.1542/peds.2008-0309

REVIEW ARTICLE

Sport-Related Concussion

William P. Meehan III, MD, Richard G. Bachur, MD

Division of Emergency Medicine, Children's Hospital Boston, Boston, Massachusetts

The authors have indicated they have no financial relationships relevant to this article to disclose.

ABSTRACT

Sport-related concussion is a common injury in children and adolescents. Athletes seldom report concussive symptoms, which makes the diagnosis a challenge. The management of sport-related concussion has changed significantly over the last several years. The previously used grading systems and return-to-play guidelines have been abandoned in favor of more individualized assessment and management. Neuropsychological testing is being used more frequently to assist in management. After recovery, it is recommended that an athlete's return-to-play progress in a gradual, stepwise fashion while being monitored by a health care provider. Proper assessment and management of a sport-related concussion is crucial, because repeat concussions can result in decreased neurocognitive functioning, increased symptomatology, and, at times, catastrophic outcomes. *Pediatrics* 2009;123:114–123

www.pediatrics.org/cgi/doi/10.1542/peds.2008-0309

doi:10.1542/peds.2008-0309

Key Words
concussion, sport-related concussion, mild traumatic brain injury, closed head injury, athletic injuries, second-impact syndrome

Abbreviations
SRC—sport-related concussion
LOC—loss of consciousness

Accepted for publication Mar 31, 2008

Address correspondence to William P. Meehan III, MD, Children's Hospital Boston, Division of Emergency Medicine, 300 Longwood Ave, Boston, MA 02115. E-mail: william.meehan@childrens.harvard.edu

PEDIATRICS (ISSN Numbers: Print, 0031-4005; Online, 1098-4275).

SINCE THE YEAR 776 BC, athletes have participated in organized sports, such as wrestling and fist-fighting, that place them at risk of concussion.[1] Symptoms of concussion have been observed at least since the time of Hippocrates.[1,2] Despite such a history, the management of sport-related concussion (SRC) is one of the most discussed and controversial topics in sports medicine[2–9] and has become an increasingly popular topic in the lay press.[10–15] SRCs differ from concussions sustained outside athletics because they typically result from low-velocity impact, causing disorientation and confusion more often than loss of consciousness (LOC), which is seen frequently with other mechanisms.[16] SRCs are a major issue in pediatrics, because the majority of at-risk athletes are children.[17,18] Moreover, children are particularly susceptible to SRCs.[9,19] Much of the research on SRC has been conducted in high school and college athletes.[9,20–46] In this article, we will review the literature on SRC.

DEFINITION

Although the terms "concussion" and "mild traumatic brain injury" are used synonymously in the literature, SRC can be a serious injury. The word "mild" is inaccurate in this context. Therefore, the term "concussion" will be used throughout this article.

A concussion results from a rotational acceleration or deceleration injury to the head that causes an alteration of mental status or various other symptoms such as headache or dizziness.[47–49] The precise definition of concussion has changed over time.[1] Universal agreement on a definition has been difficult to reach.[18,50,51] The following definition was developed by consensus among experts in SRC[49] and has subsequently been endorsed.[48]

Concussion is defined as a complex pathophysiological process affecting the brain, induced by traumatic biomechanical forces. Several common features . . . include:

1. Concussion may be caused 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 syndromes that may or may not involve loss of consciousness. Resolution of the clinical symptoms typically follows a sequential course.
5. Concussion is typically associated with grossly normal structural neuroimaging studies.[48,49]

For the practicing clinician, perhaps a more useful working definition is a trauma-induced alteration in mental status that may or may not involve LOC.[18,42,50,52–56]

BIOMECHANICS AND PATHOPHYSIOLOGY

Several theories exist regarding the biomechanics of concussion,[57] but none have been universally accepted. However, several characteristics have been well established. Concussion occurs when rotational or angular acceleration forces are applied to the brain, resulting in shear strain of the underlying neural elements.[58–62] This may be associated with a blow to the skull; however, direct impact to the head is not required.[60] In fact, in the laboratory setting, concussion can be achieved more effectively by nonimpact rotation of the head than by a blow to the head.[59,60] Linear acceleration-deceleration will usually produce focal effects, as opposed to concussion.[58,60,61]

On a molecular level, there seems to be an immediate disruption of neuronal membranes, resulting in a massive efflux of potassium into the extracellular space.[63,64] This results in the calcium-dependent release of excitatory amino acids, particularly glutamate, which stimulates further potassium efflux. As the concentration of extracellular potassium increases, it triggers neuronal depolarization, which is followed by neuronal suppression.[63–67] Sodium-potassium pumps work to restore homeostasis. Given the degree of the induced ion fluxes, a large amount of energy is expended, which increases glycolysis.[64,66,67] This results in local lactic acid accumulation.

To meet these increased metabolic demands and remove accumulated lactate, an increase in cerebral blood flow might be expected. However a decrease in cerebral blood flow has been observed.[64] After the initial increase in glycolysis, mitochondrial dysfunction with decreased oxidative metabolism and decreased cerebral glucose metabolism can be seen within 24 hours, persisting as long as 10 days in experimental models.[64,66]

EPIDEMIOLOGY

Twenty percent of traumatic brain injury resulting in an LOC occurs during sports activity.[68] Eighteen percent of head injuries reported to the National Head Injury Association are sustained during athletic competition.[53] Approximately 300 000 sport-related traumatic brain injuries resulting in an LOC occur each year.[68,69] The majority of these injuries are concussions. Because it has been well established that the vast majority of SRCs do not involve an LOC,[30,33,70] the actual number of SRCs occurring annually is much higher. Studies of children and adolescents have suggested that 26% of closed head injuries in children occur during athletics,[24] and this is likely to be an underestimate, because many children with SRCs do not seek medical attention.[34,40,71]

Concussion incidence has been studied most widely in American football, a sport in which 1.5 million Americans participate.[21,72] Several studies have estimated the incidence of SRC in high school and college football players to be between 4% and 5%.[33,41,70] In each of these studies, however, injuries were documented by athletic trainers. In most circumstances, for an athletic trainer to be aware that a concussion has occurred, it must be reported by the athlete. It has been well documented that athletes do not regularly report concussions to athletic trainers, coaches, parents, or others.[34,40,73,74] Therefore, studies conducted in this manner are likely to underestimate the true incidence of concussion. It is interesting to note that studies in which players have directly and confidentially reported their symptoms after a blow to the head have revealed much higher rates of concussion, ranging from 15% to 45%.[30,34,40,73]

Concussion accounts for ~8% to 11% of all injuries in American football.[39,44] Concussions are more likely to occur during games than practices[32,41,44,73] and are more common in high school athletes than college players.[19,33,44]

Although SRC has been studied most extensively in American football, it has been reported in all sports.[28,34,41,43,46,69,75–79] The incidence rates in ice hockey are even higher than in American football,[76,77] accounting for ~12% of total injuries.[39] In a survey of competitive college athletes engaged in all sports at a university in Ohio, 32% reported concussive symptoms after a blow to the head.[34] As with football, concussion in other sports occurs more commonly during games than practice.[22,29,41,43,78] Concussions are 6 times more likely to occur in organized sports than in leisure physical activity.[24]

UNDERREPORTING

Although SRC seems to be quite common, it is still not fully appreciated by athletes. More than one third of athletes do not recognize their symptoms as a result of concussion.[28,30,34,40,73] In a study of professional football players in the Canadian Football League, only 19% of concussed players realized that they had sustained a concussion.[73] Even those who experience LOC often fail to recognize the injury as a concussion or even as a serious injury.[30,73]

In addition, athletes do not regularly report their symptoms to trained personnel.[34,40,71] In American football, only 47% of players sustaining a concussion report their injury.[40] Most commonly, players fail to report a concussion because they feel the injury is not serious enough to warrant reporting.[40,74] Personal desire and outside pressure to continue playing, failure to recognize the symptoms of concussion, and jeopardizing future career or financial benefits are also commonly cited.[40,74]

Twenty-eight percent of athletes report continuing to play after a blow to the head that results in dizziness.[34] Athletes with a headache after a blow to the head continue to play at even higher rates, with 61% of American football players staying in the game.[34] In a study of high school football teams in Minnesota, 69% of the players who experienced an LOC and 81% of the players who sustained a concussion without an LOC returned to play on the same day.[30] Other studies have shown similar results.[73] These results are concerning, given the risks of recurrent concussions[30,32,33,45,73] and the potential for neurologic sequelae.[17,26,80,81]

ASSESSMENT

The recognition, assessment, and classification of an SRC can be challenging. Certainly, concussions that result in

TABLE 1 List of Symptoms Reported in Athletes After Sustaining an SRC

Signs of Concussion	Symptoms of Concussion
LOC	Headache
Amnesia, retrograde or antegrade	Dizziness
Disorientation	Nausea or vomiting
Appearing dazed	Difficulty balancing
Acting confused	Vision changes
Forgetting game rules or play assignments	Photophobia
Inability to recall score or opponent	Phonophobia
Inappropriate emotionality	Feeling "out of it"
Poor physical coordination	Difficulty concentrating
Imbalance	Tinnitus
Seizure	Drowsiness
Slow verbal responses	Sadness
Personality changes	Hallucinations

dramatic findings, such as prolonged LOC, will be readily detected. However, the majority of concussions result in more subtle findings.[33,34,38,39,43,73,82–85] Furthermore, LOC is not a reliable predictor of cerebral dysfunction or length of recovery.[38,39,86] Headache and dizziness are the most commonly reported symptoms of concussion.[32–34,82,83,87] Many other symptoms have been reported and are listed in Table 1.* It should be noted that although all of these various symptoms can be seen with concussion, not every athlete experiencing these symptoms has a concussion. Indeed, many of these symptoms can result from other etiologies such as dehydration, overtraining, and lack of sleep or can be seen with other illnesses such as anorexia nervosa, anemia, learning disabilities, and depression.[92,93] Given the nonspecific symptoms and lack of self-reporting,[34,40,71] the diagnosis can be difficult to make.

The on-field assessment of an acute SRC, similar to all medical assessments, should begin with the airway, breathing, and circulation.[18,56,72,94] Cervical spine injury should be considered[18,56,95]; the unconscious athlete should be treated as having a potential cervical spine injury.[72,90] Those with prolonged LOC should be transported rapidly to an appropriate medical facility.[72] For the conscious athlete suspected of having sustained a concussion, a thorough neurologic examination should be performed, including assessment of the athlete's orientation to person, place, and time.[72] This should be followed by questions to test recent memory (eg, "which quarter is it?" and "which team did we play last week?"), because these are the most sensitive in diagnosing SRC.[16,96] The ability to perform simple tasks should be assessed.[48,72,85] Postural stability should be assessed also.[97] Standardized methods of assessment are available in the literature and can help facilitate sideline examinations.[48,56,70,83,89,98–100]

Previously, >15 concussion-grading systems,[18,51,56] based mostly on the presence and duration of LOC and amnesia, have been used to categorize concussions. However, LOC and amnesia were found to be of minimal utility in predicting the severity or duration of concussion.[19,38,39,86] No grading scale had been universally accepted.[50,51] More recently, grading systems were abandoned.[8,38,39,48,83,101–103]

At the second International Conference on Concussion in Sport, the use of grading systems was abandoned explicitly in favor of classifying concussions as simple or complex. A simple concussion is one in which the injury resolves in 7 to 10 days. A concussion is categorized as complex when the athlete's symptoms persist, the athlete has sustained multiple concussions, or the athlete suffers sequelae such as convulsions, LOC of >1 minute, or prolonged cognitive impairment.[48] It should be noted that under this new classification system a concussion cannot be classified until all the signs and symptoms have resolved. Because the signs and symptoms of concussion can have a delayed onset,[39,88,104] up to several days after the time of injury,[104] this classification cannot be made in the acute setting.

MANAGEMENT

Once the diagnosis of an SRC is established and other significant injuries have been addressed, the clinician must decide when it is safe to return the athlete to play. Again, this is not as straightforward as it may seem.

Although return-to-play guidelines were intended to prevent catastrophic injury and cumulative effects of concussion, little scientific evidence exists to support them.[53,83,104,105] None of the guidelines have been adequately validated.[73] These guidelines, too, have been abandoned by experts in the management of SRC,[36,38,39,83,101,106,107] even by those who developed them.[48,102] In fact, the pursuit of a dependable, practical, universally accepted guideline has been described as "foolish and ill conceived."[103]

Because they were based on the previously mentioned grading scales, which emphasized LOC and amnesia and were found to be of minimal utility in predicting the severity or duration of concussion,[38,39,86] return-to-play decisions should not be based on these guidelines. Rather, each concussion should be managed individually by using multiple means of assessment.[8,48,49]

Generally accepted management principles have been proposed. No player should be returned to play until the symptoms of concussion have resolved completely, both at rest and during exercise.† Because younger athletes require longer recovery times, more conservative return-to-play decisions should be considered for younger athletes.‡ The American Academy of Pediatrics recommends conservative management of concussion.[113]

Studies have shown that concussed athletes score poorly on neuropsychological tests when compared with their own preinjury baseline scores and with uninjured athletes.[26,37,55,70,100,114,115] Such decreases in performance are not seen in uninjured controls who take preseason tests and subsequent tests during the season.[37,116] Experts in the management of SRC have endorsed the use of

*Refs 18, 19, 33, 34, 36, 56, 82, 83, and 88–91.

†Refs 18, 26, 48, 50, 51, 56, 72, 83, 93, 105, and 108–110.
‡Refs 9, 18, 19, 48, 56, 83, 111, and 112.

neuropsychological testing,[48,72,106,111] calling it "one of the cornerstones of concussion evaluation."[49,89]

Computerized neuropsychological testing is a recent development that is sensitive in diagnosing concussion.[25,104] In fact, it is more sensitive than traditional forms of neuropsychological testing,[117] likely because of more precise measurements of response time.[48,104,118] It has been shown to diagnose some concussions that would have been missed by symptom reporting alone.[9,35,38,104,115,119] In 1 such study of 834 athletes, Erlanger et al[104] used a computerized neuropsychological assessment instrument (HeadMinder CRI [New York, NY]) to compare postconcussion scores with baseline scores. Of the 26 athletes who sustained a concussion, 3 (12%) were noted to have neurocognitive deficits in the absence of self-reported symptoms. These athletes' conditions would not have been identified by symptoms reporting alone. This is of enormous value, because many athletes are reluctant to report concussion symptoms.[30,40,54,71,72] Computerized neuropsychological testing has been endorsed by experts in the field,[48,49] is mandatory for players in the National Hockey League, and is used by most teams in the National Football League.[35,83]

A lower score than that of a player's baseline signifies incomplete recovery.[120] Until recovery is complete, an athlete's reaction time is longer, ability to concentrate is diminished, and more time is required for thought processing,[92,121–124] thus increasing the risk of subsequent injury.[105,125] Reason suggests that returning to play would be safer for athletes whose symptoms have resolved and whose neuropsychological test results have returned to baseline. It should be stated, however, that the safety of returning an athlete to play on the basis of neuropsychological testing has not been explicitly studied.[105,126,127] However, given the association between returning to play before complete recovery and poor, even catastrophic outcomes,[23,72,128,129] it is recommended that return-to-play decisions be based, in part, on results of neuropsychological testing.§ Among experts in the field of SRC, this practice is recommended.‖

Neuropsychological testing is not meant to be used alone but, rather, as 1 of many aspects of evaluation.¶ Symptom reporting, medical history, concussion history, medication use, type of sport and position played, postural stability,[48,97,131,133] and other factors play a role in the decision to return an athlete to play. In young patients, the neuropsychological baseline may change often, because their cognition matures rapidly, requiring frequent baseline testing or changes in interpretation.[48,111]

Although recovery from an SRC will vary, symptoms, neuropsychological test scores, and postural stability usually will recover within 7 to 10 days.[35,38,39,102] Some patients will have a more prolonged recovery.[35,38,39,104] There is no reliable, predictable order in which recovery occurs.[39,86,104] During recovery, an athlete's academic performance may suffer, and intellectual activity may increase their symptoms. Thus, "cognitive rest" has been recommended for school-aged athletes.[48]

Once the decision is made to return an athlete to play, the return should be gradual, stepwise, and closely monitored, starting with light, aerobic activities that do not place the player at risk for subsequent concussion.[18,48,49,56,110] The steps recommended by the second International Conference on Concussion in Sport for returning to play an athlete who has recovered from a simple concussion are listed in Table 2.[48] Any occurrence of concussion symptoms during exertion should prompt the athlete to drop back to a previous asymptomatic level of activity for at least 24 hours before attempting to progress again.[48,49] For an athlete who has sustained a complex concussion, it is recommended that the injury and the athlete's return to play be managed by personnel with expertise in the management of SRC.[48]

TABLE 2 Return-to-Play Protocol Recommended by the Second International Conference on Concussion in Sport[48]

Step	Level of Activity
1	No activity, complete rest; proceed to level 2 once symptoms resolve
2	Light aerobic exercise (eg, walking, stationary cycling)
3	Sport-specific exercise (eg, skating in hockey, running in soccer); addition of light resistance training
4	Noncontact training drills; progressively increased resistance training
5	Full-contact training after medical clearance
6	Game play

SPECIAL CONSIDERATIONS

Repeat Concussions

After a first concussion, a player is at increased risk for additional concussions.[30,32,33,44,73] Those who experience an LOC are 6 times more likely to sustain another concussion than those who have never lost consciousness.[73] The risk of recurrent concussive injury may be greatest within 7 to 10 days of an acute concussive injury.[32] The reasons for this increased risk have not yet been elucidated, but possible explanations include (1) certain athletes' styles of play predispose them to concussion, (2) certain athletes are more susceptible to concussion, (3) the age and level of play may expose certain athletes to greater forces than those who do not sustain concussions,[43] (4) players who sustain multiple concussions may simply receive more play time,[43,73] and (5) it may be that once an athlete's brain has sustained a single concussion it becomes more susceptible to injury.[43]

Cerebral concussion reduces the ability to process information rapidly. This reduction is greater and lasts for a longer period of time after a second concussion than after a first.[17,27,80] Guskiewicz et al[32] showed that athletes who have a history of previous concussions require longer recovery times after an acute SRC than those with no previous history of concussion.

Although studies have suggested that concussions have long-term effects on an athlete's neurocognitive abilities, the number and severity of SRCs that lead to long-term effects have not been elucidated. Some studies have suggested that there is no detectable neurocog-

§Refs 18, 19, 35, 48, 49, 83, 86, 89, 119, 120, 130, and 131.
‖Refs 18, 19, 48, 49, 83, 86, 89, 119, 130, and 131.
¶Refs 19, 48, 49, 86, 88, 89, 105, 119, 131, and 132.

nitive deficits after 1 concussion[26] or even multiple concussions.[134–136] Others have shown that multiple SRCs result in deficits of neurocognitive abilities.[17,26,80,81] It is likely that SRCs have a cumulative effect on neurocognitive abilities but that 1 mild concussion results in small deficits that are not detectable by current means of analysis.

Recently, postmortem studies of athletes who sustained multiple SRCs during their careers, who had neurocognitive and psychiatric problems later in life, and who died at a young age have revealed findings similar to, but unique from, those seen with Alzheimer disease.[91,137] Although preliminary, these findings suggest that athletes who sustain multiple concussions are at risk for chronic traumatic encephalopathy.[138]

Education

Only 43% of athletes feel that they have some knowledge in the area of SRC.[34] Fewer than 50% of athletes understand the problems that occur as a result of concussion.[34] Most of them do not consider it to be a serious problem.[40] Many athletes who sustain an SRC fail to recognize their symptoms as being a result of concussion.[28,30,34,40,73] The problem of recognition is not limited to athletes. A recent survey of coaches revealed that 42% believed that an SRC only occurs when an athlete loses consciousness.[45] One in 4 of them would allow an athlete to return to play despite showing symptoms of a concussion.[45] This is concerning, because more players who sustain concussion are attended to by their coaches than by physicians.[30] Education of athletes, coaches, and medical personnel may lead to increased reporting and proper management of SRC.

Prevention

Preventing SRCs is difficult. Although helmets are often discussed as a means of preventing concussion, this is not the purpose of their design.[88] Current helmets have, at best, a limited effect.[51,72,139,140] Some evidence suggests that the design of certain football helmets may affect the risk of sustaining a concussion.[141,142] Research in this area is ongoing.

By bracing the neck muscles before impact, an athlete decreases the resulting acceleration that the head experiences.[143–145] Therefore, it has been suggested that strengthening the neck musculature may decrease the risk of concussion. Many concussions, however, occur when the athlete does not anticipate the impact, which makes increased musculature of questionable value.[51,88,89]

As noted earlier, sustaining a concussion increases the risk of subsequent concussions, especially before full recovery. Therefore, proper identification and management of SRCs in an attempt to prevent subsequent concussions may be the best prevention strategy currently available.

Second-Impact Syndrome

In 1984, Saunders and Harbaugh[129] described the case of a 19-year-old college athlete who was medically cleared to play football despite being symptomatic from a previous blow to the head. Although he sustained "no unusual head trauma" on the day he returned to football, he walked off of the field, collapsed, and later died despite the evacuation of a small subdural hematoma. An autopsy revealed widespread anoxic changes and transtentorial cerebral herniation. It was surmised that these effects were caused by an elevated intracranial pressure, secondary to minor sports trauma, before complete recovery from a previous concussion.

Since that time, there have been other similar cases described in the literature.[109,128,146] The term "second-impact syndrome" has come to describe such events. Typically, second-impact syndrome occurs after athletes have sustained a concussion from which they are still symptomatic and receive a second injury to the head. This second injury may be minor. Even a blow to the chest or trunk that transmits accelerative forces to the brain can result in second-impact syndrome.[109] After this second insult, the athlete rapidly decompensates, becoming unresponsive with dilated pupils and ultimately succumbs to respiratory failure.[109] It is thought that the autoregulatory control over cerebral blood flow is disrupted, leading to vascular engorgement and marked increase in intracranial pressure. This increase in pressure ultimately leads to uncal herniation or herniation of the cerebellar tonsils.[109,128]

Although its existence has been questioned,[6,16,108,125] most well-recognized authors in the area of SRC recognize this syndrome.# Even authors who question the existence of second-impact syndrome as defined in current literature recommend that athletes not return to play until after their symptoms and neuropsychological deficits have resolved.[108,125]

Concussion and Soccer

Recently, attention has been given to concussion and head injuries in soccer. In particular, some have asked whether heading the ball in soccer leads to concussion or to neurologic effects later in life.[16,148–150]

Concussions occur commonly in soccer,[22,28] accounting for ~2% to 4% of all acute injuries.[41,151] The rates are higher during game play.[22,29,41] In National Collegiate Athletic Association women's soccer, concussions account for 8.6% of all game-time injuries.

Although concussion is a common injury in soccer, it does not seem to occur as a result of purposeful heading of the ball.[22,88,149,151–154] In a 6-year prospective study of 20 Fédération Internationale de Football Association tournaments, none of the recorded concussions resulted from purposeful heading of the ball.[153] Rather, concussion is caused most commonly by collision with another player, a goal post, the ground, or other solid objects or being struck in the head unexpectedly by a ball kicked forcefully from close range.[22,29,41,149,151,153]

Studies have shown no neurocognitive deficits, symptoms, neurochemical changes, or MRI changes, either acute or chronic, from purposeful heading of the ball.[31,155–159] Some studies seem to have suggested such

#Refs 7, 47, 50, 53, 54, 72, 88, 95, 131, 146, and 147.

sequelae.[20,160–162] However, these studies have been criticized for having small numbers, using flawed methodology, and failing to control for potential confounders.[62,154,156,163]

Most experts agree that at this time, no conclusive evidence shows neurologic deficits caused by purposeful heading of the ball.** However, concussions sustained during soccer play may lead to neurologic sequelae.[22,42,154,156,158,162] Any potential effects resulting from frequent heading would be difficult to separate from those resulting from previous concussions, because those athletes who head the ball more frequently are at increased risk for concussion.[154,155]

Helmets have been proposed as a possible way of negating any potential effects of purposeful heading. However, no helmet has been shown to decrease the risk of concussion.[22,31,48,88,140,148,152] Headgear has been developed specifically for use in soccer but has not been shown to have any effect on decreasing head acceleration resulting from purposeful heading of the ball.[62] Headgear may have some efficacy in reducing the risk of concussion from head-to-head impacts.[62] One preliminary study has concluded that headgear decreases the risk of concussion in soccer players.[28] However, only a small number of athletes were included in the study; there were major differences between the headgear-wearing players and the control group; and the study did not properly control for potential confounders. Although the potential value of headgear in soccer should not be overlooked, it is unclear how much benefit headgear provides, what negative impact it will have on ball control, and whether players will accept it.

Some have recommended that players not be allowed to head the ball until they reach a certain age and the brain has reached a certain stage of development and is potentially protected against the possible effects of heading.[88] Others have argued that players should learn the skill of heading the ball properly[144] and develop neck musculature[143] before they are faced with the higher velocities generated during the play of older players.[31,88] At this point, we believe no definitive recommendation can be made.

Perhaps the most effective ways of decreasing the risk of concussion and other head injuries in soccer is to decrease the mass and air pressure of the ball used by smaller, younger players,[154,157,166,167] strictly enforce the rules,[151] and secure and pad goal posts properly.[150,164,165]

Genetic Predisposition

Several studies described in the adult literature have suggested that genetic factors may affect prognosis after brain injury. Specifically, possessing the apolipoprotein Eε4 allele has been associated with worse outcome.[168–170] However, these studies are preliminary, and most of them involved severe traumatic brain injury. Studies of concussion have not found such an association.[171,172] Some studies in athletes suggest that carriers of the apolipoprotein Eε4 allele who are exposed to subconcussive impacts or sustain concussions have more pronounced neurologic effects than controls.[173,174] We are not aware of any study that has made such an association in children. More research is needed in this area before apolipoprotein Eε4 allele status can be used clinically in athletes.

Concussion in Female Athletes

Although most of the publications regarding SRC involve male athletes, it also occurs commonly in female athletes.[29,78,175] In female soccer players, for example, concussion accounts for 3% to 5% of all injuries[29,175] and as much as 11% of all game-time injuries.[78] Some studies have suggested that concussion occurs more commonly in female athletes,[78,153] with women having more significant changes in their neuropsychological testing results than men.[82,176,177] Others studies have suggested that SRC is more common among male athletes.[22,149] Similarly, some evidence suggests that baseline performances on neuropsychological tests are different in the different genders,[177] although other studies have not detected such differences.[82,176] Postconcussion symptom reporting and neuropsychological test results may be different for male and female athletes.[82,149,176]

CONCLUSIONS

SRC is a common problem for children and adolescents. Because athletes are reluctant to report SRCs, proper sideline assessment and diagnosis is essential. SRCs should be classified as either simple or complex, mostly on the basis of the duration of signs and symptoms. This classification cannot be made acutely, because signs and symptoms may not be present initially and often take several days to resolve. Returning an athlete to play should not be considered until all signs and symptoms of concussion have resolved. The return to athletics should be monitored by medical personnel and should proceed in a stepwise fashion.

REFERENCES

1. Echemendia RJ. *Sports Neuropsychology: Assessment and Management of Traumatic Brain Injury*. New York, NY: Guilford Press; 2006
2. McCrory PR, Berkovic SF. Concussion: the history of clinical and pathophysiological concepts and misconceptions. *Neurology*. 2001;57(12):2283–2289
3. Kelly JP. Traumatic brain injury and concussion in sports. *JAMA*. 1999;282(10):989–991
4. Moulton D. Secret locker room game causing concussions. *CMAJ*. 2007;177(1):25
5. McCambridge TM, Small E, Bernhardt DT. Concussion. *N Engl J Med*. 2007;356(17):1788
6. Ropper AH, Gorson KC. Clinical practice: concussion. *N Engl J Med*. 2007;356(2):166–172
7. Cantu RC, Herring SA, Putukian M. Concussion. *N Engl J Med*. 2007;356(17):1787
8. Stricker PR, Moriarity J, O'Connor FG. Concussion. *N Engl J Med*. 2007;356(17):1787–1788
9. Field M, Collins MW, Lovell MR, Maroon J. Does age play a role in recovery from sports-related concussion? A comparison of high school and collegiate athletes. *J Pediatr*. 2003;142(5):546–553

**Refs 31, 88, 148, 150, 151, 154, 160, and 163–165.

10. Fackelmann K. Football players cautioned not to rush back after a concussion. *USA Today*. November 18, 2003
11. MacMullan J. "I don't want anyone to end up like me." *The Boston Globe*. February 2, 2007
12. Meadows B. Concussions: is football too dangerous? *People Magazine*. October 8, 2007:107–110
13. Schwarz A. Silence on concussions raises risks of injury. *New York Times*. September 15, 2007:A1
14. Bowser BA. New research raises questions on how to treat concussion "epidemic" [transcript]. *NewsHour*. PBS television. November 26, 2007
15. Nowinski C. *Head Games: Football's Concussion Crisis*. East Bridgewater, MA: Drummond Publishing Group; 2007
16. 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
17. Iverson GL, Gaetz M, Lovell MR, Collins MW. Cumulative effects of concussion in amateur athletes. *Brain Inj.* 2004; 18(5):433–443
18. Buzzini SR, Guskiewicz KM. Sport-related concussion in the young athlete. *Curr Opin Pediatr.* 2006;18(4):376–382
19. Theye F, Mueller KA. "Heads up": concussions in high school sports. *Clin Med Res.* 2004;2(3):165–171
20. Adams J, Adler CM, Jarvis K, DelBello MP, Strakowski SM. Evidence of anterior temporal atrophy in college-level soccer players. *Clin J Sport Med.* 2007;17(4):304–306
21. Alves WM, Rimel RW, Nelson WE. University of Virginia prospective study of football-induced minor head injury: status report. *Clin Sports Med.* 1987;6(1):211–218
22. Boden BP, Kirkendall DT, Garrett WE Jr. Concussion incidence in elite college soccer players. *Am J Sports Med.* 1998; 26(2):238–241
23. Boden BP, Tacchetti RL, Cantu RC, Knowles SB, Mueller FO. Catastrophic head injuries in high school and college football players. *Am J Sports Med.* 2007;35(7):1075–1081
24. Browne GJ, Lam LT. Concussive head injury in children and adolescents related to sports and other leisure physical activities. *Br J Sports Med.* 2006;40(2):163–168
25. Collins MW, Field M, Lovell MR, et al. Relationship between postconcussion headache and neuropsychological test performance in high school athletes. *Am J Sports Med.* 2003;31(2): 168–173
26. Collins MW, Grindel SH, Lovell MR, et al. Relationship between concussion and neuropsychological performance in college football players. *JAMA.* 1999;282(10):964–970
27. Collins MW, Lovell MR, Iverson GL, et al. Cumulative effects of concussion in high school athletes. *Neurosurgery.* 2002; 51(5):1175–1179; discussion 1180–1181
28. Delaney JS, Al-Kashmiri A, Drummond R, Correa JA. The effect of protective headgear on head injuries and concussions in adolescent football (soccer) players. *Br J Sports Med.* 2008; 42(2):110–115
29. Dick R, Putukian M, Agel J, Evans TA, Marshall SW. Descriptive epidemiology of collegiate women's soccer injuries: National Collegiate Athletic Association Injury Surveillance System, 1988–1989 through 2002–2003. *J Athl Train.* 2007; 42(2):278–285
30. Gerberich SG, Priest JD, Boen JR, Straub CP, Maxwell RE. Concussion incidences and severity in secondary school varsity football players. *Am J Public Health.* 1983;73(12): 1370–1375
31. Guskiewicz KM, Marshall SW, Broglio SP, Cantu RC, Kirkendall DT. No evidence of impaired neurocognitive performance in collegiate soccer players. *Am J Sports Med.* 2002;30(2): 157–162
32. Guskiewicz KM, McCrea M, Marshall SW, et al. Cumulative effects associated with recurrent concussion in collegiate football players: the NCAA Concussion Study. *JAMA.* 2003; 290(19):2549–2555
33. 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):643–650
34. Kaut KP, DePompei R, Kerr J, Congeni J. Reports of head injury and symptom knowledge among college athletes: implications for assessment and educational intervention. *Clin J Sport Med.* 2003;13(4):213–221
35. Lovell MR, Collins MW, Iverson GL, et al. Recovery from mild concussion in high school athletes. *J Neurosurg.* 2003;98(2): 296–301
36. Lovell MR, Collins MW, Iverson GL, Johnston KM, Bradley JP. Grade 1 or "ding" concussions in high school athletes. *Am J Sports Med.* 2004;32(1):47–54
37. Macciocchi SN, Barth JT, Alves W, Rimel RW, Jane JA. Neuropsychological functioning and recovery after mild head injury in collegiate athletes. *Neurosurgery.* 1996;39(3):510–514
38. McClincy MP, Lovell MR, Pardini J, Collins MW, Spore MK. Recovery from sports concussion in high school and collegiate athletes. *Brain Inj.* 2006;20(1):33–39
39. McCrea M, Guskiewicz KM, Marshall SW, et al. Acute effects and recovery time following concussion in collegiate football players: the NCAA Concussion Study. *JAMA.* 2003;290(19): 2556–2563
40. 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
41. Powell JW, Barber-Foss KD. Traumatic brain injury in high school athletes. *JAMA.* 1999;282(10):958–963
42. Rutherford A, Stephens R, Potter D, Fernie G. Neuropsychological impairment as a consequence of football (soccer) play and football heading: preliminary analyses and report on university footballers. *J Clin Exp Neuropsychol.* 2005;27(3): 299–319
43. Schulz MR, Marshall SW, Mueller FO, et al. Incidence and risk factors for concussion in high school athletes, North Carolina, 1996–1999. *Am J Epidemiol.* 2004;160(10):937–944
44. Shankar PR, Fields SK, Collins CL, Dick RW, Comstock RD. Epidemiology of high school and collegiate football injuries in the United States, 2005–2006. *Am J Sports Med.* 2007;35(8): 1295–1303
45. Valovich McLeod TC, Schwartz C, Bay RC. Sport-related concussion misunderstandings among youth coaches. *Clin J Sport Med.* 2007;17(2):140–142
46. Yard EE, Comstock RD. Injuries sustained by pediatric ice hockey, lacrosse, and field hockey athletes presenting to United States emergency departments, 1990–2003. *J Athl Train.* 2006;41(4):441–449
47. Webbe FM. Definition, physiology and severity of concussion. In: Echemendia RJ, ed. *Sports Neuropsychology: Assessment and Management of Traumatic Brain Injury*. New York, NY: Guilford Press; 2006:45–70
48. McCrory P, Johnston K, Meeuwisse W, et al. Summary and agreement statement of the 2nd International Conference on Concussion in Sport, Prague 2004. *Br J Sports Med.* 2005; 39(4):196–204
49. Aubry M, Cantu R, Dvorak J, et al. Summary and agreement statement of the First International Conference on Concussion in Sport, Vienna 2001: recommendations for the improvement of safety and health of athletes who may suffer concussive injuries. *Br J Sports Med.* 2002;36(1):6–10
50. Poirier MP. Concussions: assessment, management, and recommendations for return to activity. *Clin Pediatr Emerg Med.* 2003;4(3):179–185
51. Johnston KM, McCrory P, Mohtadi NG, Meeuwisse W. Evi-

dence-based review of sport-related concussion: clinical science. *Clin J Sport Med.* 2001;11(3):150–159
52. Practice parameter: the management of concussion in sports (summary statement). Report of the Quality Standards Subcommittee. *Neurology.* 1997;48(3):581–585
53. Echemendia RJ, Julian LJ. Mild traumatic brain injury in sports: neuropsychology's contribution to a developing field. *Neuropsychol Rev.* 2001;11(2):69–88
54. Bailes JE. Diagnosis and management of head injury. In: Bailes JE, Lovell MR, Maroon JC, eds. *Sports-Related Concussion*. St Louis, MO: Quality Medical Publishing; 1999:115–139
55. Schatz P, Pardini JE, Lovell MR, Collins MW, Podell K. Sensitivity and specificity of the ImPACT Test Battery for concussion in athletes. *Arch Clin Neuropsychol.* 2006;21(1):91–99
56. Kirkwood MW, Yeates KO, Wilson PE. Pediatric sport-related concussion: a review of the clinical management of an oft-neglected population. *Pediatrics.* 2006;117(4):1359–1371
57. Shaw NA. The neurophysiology of concussion. *Prog Neurobiol.* 2002;67(4):281–344
58. Denny-Brown D, Russell R. Experimental cerebral concussion. *Brain.* 1941;64(2–3):93–164
59. Gennarelli TA, Adams JH, Graham DI. Acceleration induced head injury in the monkey. I. The model, its mechanical and physiological correlates. *Acta Neuropathol Suppl.* 1981;7:23–25
60. Ommaya AK, Gennarelli TA. Cerebral concussion and traumatic unconsciousness: correlation of experimental and clinical observations of blunt head injuries. *Brain.* 1974;97(4): 633–654
61. Holbourn A. Mechanics of head Injury. *Lancet.* 1943; 242(6267):438–441
62. Withnall C, Shewchenko N, Wonnacott M, Dvorak J. Effectiveness of headgear in football. *Br J Sports Med.* 2005;39(suppl 1):i40–i48; discussion i48
63. Katayama Y, Becker DP, Tamura T, Hovda DA. Massive increases in extracellular potassium and the indiscriminate release of glutamate following concussive brain injury. *J Neurosurg.* 1990;73(6):889–900
64. Giza CC, Hovda DA. The neurometabolic cascade of concussion. *J Athl Train.* 2001;36(3):228–235
65. Mayevsky A, Chance B. Repetitive patterns of metabolic changes during cortical spreading depression of the awake rat. *Brain Res.* 1974;65(3):529–533
66. Yoshino A, Hovda DA, Kawamata T, Katayama Y, Becker DP. Dynamic changes in local cerebral glucose utilization following cerebral conclusion in rats: evidence of a hyper- and subsequent hypometabolic state. *Brain Res.* 1991;561(1): 106–119
67. Andersen BJ, Marmarou A. Functional compartmentalization of energy production in neural tissue. *Brain Res.* 1992; 585(1–2):190–195
68. 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
69. Thurman DJ, Branche CM, Sniezek JE. The epidemiology of sports-related traumatic brain injuries in the United States: recent developments. *J Head Trauma Rehabil.* 1998;13(2):1–8
70. McCrea M, Kelly JP, Randolph C, Cisler R, Berger L. Immediate neurocognitive effects of concussion. *Neurosurgery.* 2002; 50(5):1032–1040; discussion 1040–1042
71. Williamson IJ, Goodman D. Converging evidence for the under-reporting of concussions in youth ice hockey. *Br J Sports Med.* 2006;40(2):128–132; discussion 128–132
72. Bailes JE, Cantu RC. Head injury in athletes. *Neurosurgery.* 2001;48(1):26–45; discussion 45–46
73. Delaney JS, Lacroix VJ, Leclerc S, Johnston KM. Concussions during the 1997 Canadian Football League season. *Clin J Sport Med.* 2000;10(1):9–14
74. Maroon JC. Concussion from the inside: the athlete's perspective. In: Bailes JE, Lovell MR, Maroon JC, eds. *Sports-Related Concussion*. St Louis, MO: Quality Medical Publishing; 1999: 231–251
75. Yard EE, Comstock RD. Injuries sustained by rugby players presenting to United States emergency departments, 1978 through 2004. *J Athl Train.* 2006;41(3):325–331
76. Tommasone BA, Valovich McLeod TC. Contact sport concussion incidence. *J Athl Train.* 2006;41(4):470–472
77. Koh JO, Cassidy JD, Watkinson EJ. Incidence of concussion in contact sports: a systematic review of the evidence. *Brain Inj.* 2003;17(10):901–917
78. Covassin T, Swanik CB, Sachs ML. Sex differences and the incidence of concussions among collegiate athletes. *J Athl Train.* 2003;38(3):238–244
79. Collins CL, Micheli LJ, Yard EE, Comstock RD. Injuries sustained by high school rugby players in the United States, 2005–2006. *Arch Pediatr Adolesc Med.* 2008;162(1):49–54
80. Gronwall D, Wrightson P. Cumulative effect of concussion. *Lancet.* 1975;2(7943):995–997
81. Moser RS, Schatz P. Enduring effects of concussion in youth athletes. *Arch Clin Neuropsychol.* 2002;17(1):91–100
82. Broshek DK, Kaushik T, Freeman JR, et al. Sex differences in outcome following sports-related concussion. *J Neurosurg.* 2005;102(5):856–863
83. Collins M. New developments in the management of sports concussion. *Curr Opin Orthop.* 2004;15(1):100–107
84. Collins MW, Iverson GL, Lovell MR, et al. On-field predictors of neuropsychological and symptom deficit following sports-related concussion. *Clin J Sport Med.* 2003;13(4):222–229
85. McCrea M. Standardized mental status assessment of sports concussion. *Clin J Sport Med.* 2001;11(3):176–181
86. Erlanger D, Kaushik T, Cantu R, et al. Symptom-based assessment of the severity of a concussion. *J Neurosurg.* 2003;98(3): 477–484
87. Viano DC, Casson IR, Pellman EJ. Concussion in professional football: biomechanics of the struck player—part 14. *Neurosurgery.* 2007;61(2):313–327; discussion 327–328
88. Patlak M, Joy JE. Is soccer bad for children's heads: summary of the IOM workshop on neuropsychological consequences of head impact in youth soccer. In: *The IOM Workshop on Neuropsychological Consequences of Head Impact in Youth Soccer*. Washington DC: National Academy of Sciences; 2002
89. Patel DR, Shivdasani V, Baker RJ. Management of sport-related concussion in young athletes. *Sports Med.* 2005;35(8): 671–684
90. Micheli L. *The Sports Medicine Bible*. New York, NY: HarperCollins; 1995
91. Omalu BI, DeKosky ST, Minster RL, et al. Chronic traumatic encephalopathy in a National Football League player. *Neurosurgery.* 2005;57:128–134; discussion 128–134
92. Iverson GL, Brooks BL, Collins MW, Lovell MR. Tracking neuropsychological recovery following concussion in sport. *Brain Inj.* 2006;20(3):245–252
93. American Academy of Pediatrics, Section on Sports Medicine and Fitness. Guidelines for pediatricians: head injuries. *Sports Shorts.* 2000
94. Concussion (mild traumatic brain injury) and the team physician: a consensus statement. *Med Sci Sports Exerc.* 2006; 38(2):395–399
95. Poirier MP, Wadsworth MR. Sports-related concussions. *Pediatr Emerg Care.* 2000;16(4):278–283 quiz 284–286
96. Maddocks DL, Dicker GD, Saling MM. The assessment of orientation following concussion in athletes. *Clin J Sport Med.* 1995;5(1):32–35
97. Guskiewicz KM, Perrin DH, Gansneder BM. Effect of mild

head injury on postural stability in athletes. *J Athl Train.* 1996;31(4):300–306
98. Centers for Disease Control and Prevention, Injury Center. Heads up: brain injury in your practice tool kit. Available at: www.cdc.gov/ncipc/pub-res/tbi_toolkit/toolkit.htm. Accessed September 10, 2008
99. McCrea M, Kelly JP, Kluge J, Ackley B, Randolph C. Standardized assessment of concussion in football players. *Neurology.* 1997;48(3):586–588
100. Barr WB, McCrea M. Sensitivity and specificity of standardized neurocognitive testing immediately following sports concussion. *J Int Neuropsychol Soc.* 2001;7(6):693–702
101. Maroon JC, Lovell MR, Norwig J, et al. Cerebral concussion in athletes: evaluation and neuropsychological testing. *Neurosurgery.* 2000;47(3):659–669; discussion 669–672
102. Bleiberg J, Cernich AN, Cameron K, et al. Duration of cognitive impairment after sports concussion. *Neurosurgery.* 2004; 54(5):1073–1078; discussion 1078–1080
103. McKeag DB. Understanding sports-related concussion: coming into focus but still fuzzy. *JAMA.* 2003;290(19):2604–2605
104. Erlanger D, Saliba E, Barth J, Almquist J, Webright W, Freeman J. Monitoring resolution of postconcussion symptoms in athletes: preliminary results of a Web-based neuropsychological test protocol. *J Athl Train.* 2001;36(3):280–287
105. 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): 134–143
106. Powell JW. Cerebral concussion: causes, effects, and risks in sports. *J Athl Train.* 2001;36(3):307–311
107. Barth J. Sports: a new frontier for neuropsychology. In: Echemendia RJ, ed. *Sports Neuropsychology: Assessment and Management of Traumatic Brain Injury*. New York, NY: Guilford Press; 2006:3–16
108. McCrory P. Does second impact syndrome exist? *Clin J Sport Med.* 2001;11(3):144–149
109. Cantu R. Second impact syndrome: a risk in any contact sport. *Phys Sportsmed.* 1995;23(6):27
110. Schnadower D, Vazquez H, Lee J, Dayan P, Roskind CG. Controversies in the evaluation and management of minor blunt head trauma in children. *Curr Opin Pediatr.* 2007;19(3): 258–264
111. McCrory P, Collie A, Anderson V, Davis G. Can we manage sport related concussion in children the same as in adults? *Br J Sports Med.* 2004;38(5):516–519
112. Bruce DA, Schut L, Sutton LN. Brain and cervical spine injuries occurring during organized sports activities in children and adolescents. *Clin Sports Med.* 1982;1(3):495–514
113. American Academy of Pediatrics, Committee on Sports Medicine and Fitness. Medical conditions affecting sports participation. *Pediatrics.* 2001;107(5):1205–1209
114. 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):293–296
115. Erlanger D, Feldman D, Kutner K, et al. Development and validation of a Web-based neuropsychological test protocol for sports-related return-to-play decision-making. *Arch Clin Neuropsychol.* 2003;18(3):293–316
116. Echemendia RJ, Putukian M, Mackin RS, Julian L, Shoss N. Neuropsychological test performance prior to and following sports-related mild traumatic brain injury. *Clin J Sport Med.* 2001;11(1):23–31
117. Makdissi M, Collie A, Maruff P, et al. Computerised cognitive assessment of concussed Australian Rules footballers. *Br J Sports Med.* 2001;35(5):354–360
118. Collie A, Maruff P, McStephen M, Darby DG. Psychometric issues associated with computerised neuropsychological assessment of concussed athletes. *Br J Sports Med.* 2003;37(6): 556–559
119. Van Kampen DA, Lovell MR, Pardini JE, Collins MW, Fu FH. The "value added" of neurocognitive testing after sports-related concussion. *Am J Sports Med.* 2006;34(10):1630–1635
120. Echemendia RJ, Cantu RC. Return to play following sports-related mild traumatic brain injury: the role for neuropsychology. *Appl Neuropsychol.* 2003;10(1):48–55
121. Cremona-Meteyard SL, Geffen GM. Persistent visuospatial attention deficits following mild head injury in Australian Rules football players. *Neuropsychologia.* 1994;32(6):649–662
122. Sosnoff JJ, Broglio SP, Hillman CH, Ferrara MS. Concussion does not impact intraindividual response time variability. *Neuropsychology.* 2007;21(6):796–802
123. Iverson GL, Lovell MR, Collins MW. Interpreting change on ImPACT following sport concussion. *Clin Neuropsychol.* 2003; 17(4):460–467
124. Hugenholtz H, Stuss DT, Stethem LL, Richard MT. How long does it take to recover from a mild concussion? *Neurosurgery.* 1988;22(5):853–858
125. McCrory PR, Berkovic SF. Second impact syndrome. *Neurology.* 1998;50(3):677–683
126. Randolph C, McCrea M, Barr WB. Is neuropsychological testing useful in the management of sport-related concussion? *J Athl Train.* 2005;40(3):139–152
127. McCrory P. Using a sledgehammer to crack a walnut: the modern management of concussion. *Inj Prev.* 2007;13(6): 364–365
128. Centers for Disease Control and Prevention. Sports-related recurrent brain injuries: United States. *MMWR Morb Mortal Wkly Rep*. 1997;46(10):224–227
129. Saunders RL, Harbaugh RE. The second impact in catastrophic contact-sports head trauma. *JAMA.* 1984;252(4): 538–539
130. Adirim T. Concussions in sports and recreation. *Clin Pediatr Emerg Med.* 2007;8(1):2–6
131. Guskiewicz KM, Bruce SL, Cantu RC, et al. National Athletic Trainers' Association position statement: management of sport-related concussion. *J Athl Train.* 2004;39(3):280–297
132. Putukian M. The team physician's point of view. In: Echemendia RJ, ed. *Sports Neuropsychology: Assessment and Management of Traumatic Brain Injury*. New York, NY: Guilford Press; 2006:305
133. Valovich McLeod TC, Barr WB, McCrea M, Guskiewicz KM. Psychometric and measurement properties of concussion assessment tools in youth sports. *J Athl Train.* 2006;41(4): 399–408
134. Iverson GL, Brooks BL, Lovell MR, Collins MW. No cumulative effects for one or two previous concussions. *Br J Sports Med.* 2006;40(1):72–75
135. Broglio SP, Ferrara MS, Piland SG, Anderson RB, Collie A. Concussion history is not a predictor of computerised neurocognitive performance. *Br J Sports Med.* 2006;40(9):802–805; discussion 802–805
136. Collie A, McCrory P, Makdissi M. Does history of concussion affect current cognitive status? *Br J Sports Med.* 2006;40(6): 550–551
137. Omalu BI, DeKosky ST, Hamilton RL, et al. Chronic traumatic encephalopathy in a national football league player: part II. *Neurosurgery.* 2006;59(5):1086–1092; discussion 1092–1093
138. Cantu RC. Chronic traumatic encephalopathy in the National Football League. *Neurosurgery.* 2007;61(2):223–225
139. Biasca N, Wirth S, Tegner Y. The avoidability of head and neck injuries in ice hockey: an historical review. *Br J Sports Med.* 2002;36(6):410–427
140. McIntosh AS, McCrory P. Impact energy attenuation perfor-

mance of football headgear. *Br J Sports Med.* 2000;34(5): 337–341
141. Zemper ED. Analysis of cerebral concussion frequency with the most commonly used models of football helmets. *J Athl Train.* 1994;29(1):44–50
142. Viano DC, Pellman EJ, Withnall C, Shewchenko N. Concussion in professional football: performance of newer helmets in reconstructed game impacts—Part 13. *Neurosurgery.* 2006; 59(3):591–606; discussion 591–606
143. Tysvaer AT. Head and neck injuries in soccer: impact of minor trauma. *Sports Med.* 1992;14(3):200–213
144. Shewchenko N, Withnall C, Keown M, Gittens R, Dvorak J. Heading in football. Part 1: development of biomechanical methods to investigate head response. *Br J Sports Med.* 2005; 39(suppl 1):i10–i25
145. Shewchenko N, Withnall C, Keown M, Gittens R, Dvorak J. Heading in football. Part 2: biomechanics of ball heading and head response. *Br J Sports Med.* 2005;39(suppl 1):i26–i32
146. 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):2867–2869
147. Collins M, Pardini J. Concussion. In: McMahon P, ed. *Current Diagnosis and Treatment Sports Medicine*. McGraw-Hill; 2007: 180–193
148. McCrory PR. Brain injury and heading in soccer. *BMJ.* 2003; 327(7411):351–352
149. Barnes BC, Cooper L, Kirkendall DT, McDermott TP, Jordan BD, Garrett WE Jr. Concussion history in elite male and female soccer players. *Am J Sports Med.* 1998;26(3):433–438
150. Green GA, Jordan SE. Are brain injuries a significant problem in soccer? *Clin Sports Med.* 1998;17(4):795–809, viii
151. Andersen TE, Arnason A, Engebretsen L, Bahr R. Mechanisms of head injuries in elite football. *Br J Sports Med.* 2004; 38(6):690–696
152. Al-Kashmiri A, Delaney JS. Head and neck injuries in football (soccer). *Trauma.* 2006;8(3):189–195
153. Fuller CW, Junge A, Dvorak J. A six year prospective study of the incidence and causes of head and neck injuries in international football. *Br J Sports Med.* 2005;39(suppl 1):i3–i9
154. Rutherford A, Stephens R, Potter D. The neuropsychology of heading and head trauma in Association Football (soccer): a review. *Neuropsychol Rev.* 2003;13(3):153–179
155. Straume-Naesheim TM, Andersen TE, Dvorak J, Bahr R. Effects of heading exposure and previous concussions on neuropsychological performance among Norwegian elite footballers. *Br J Sports Med.* 2005;39(suppl 1):i70–i77
156. Putukian M, Echemendia RJ, Mackin S. The acute neuropsychological effects of heading in soccer: a pilot study. *Clin J Sport Med.* 2000;10(2):104–109
157. Janda DH, Bir CA, Cheney AL. An evaluation of the cumulative concussive effect of soccer heading in the youth population. *Inj Control Saf Promot.* 2002;9(1):25–31
158. Jordan SE, Green GA, Galanty HL, Mandelbaum BR, Jabour BA. Acute and chronic brain injury in United States National Team soccer players. *Am J Sports Med.* 1996;24(2):205–210
159. Zetterberg H, Jonsson M, Rasulzada A, et al. No neurochemical evidence for brain injury caused by heading in soccer. *Br J Sports Med.* 2007;41(9):574–577
160. Webbe FM, Ochs SR. Recency and frequency of soccer heading interact to decrease neurocognitive performance. *Appl Neuropsychol.* 2003;10(1):31–41
161. Tysvaer AT, Lochen EA. Soccer injuries to the brain: a neuropsychologic study of former soccer players. *Am J Sports Med.* 1991;19(1):56–60
162. Matser EJ, Kessels AG, Lezak MD, Jordan BD, Troost J. Neuropsychological impairment in amateur soccer players. *JAMA.* 1999;282(10):971–973
163. Kirkendall DT, Garrett WE Jr. Heading in soccer: integral skill or grounds for cognitive dysfunction? *J Athl Train.* 2001; 36(3):328–333
164. American Academy of Pediatrics, Committee on Sports Medicine and Fitness. Injuries in youth soccer: a subject review. *Pediatrics.* 2000;105(3 pt 1):659–661
165. Delaney JS, Frankovich R. Head injuries and concussions in soccer. *Clin J Sport Med.* 2005;15(4):216–219; discussion 212–213
166. Schneider K, Zernicke R. Computer simulation of head impact: estimation of head-injury risk during soccer heading. *Int J Sport Biomech.* 1988;4:358–371
167. Shewchenko N, Withnall C, Keown M, Gittens R, Dvorak J. Heading in football. Part 3: effect of ball properties on head response. *Br J Sports Med.* 2005;39(suppl 1):i33–i39
168. Teasdale GM, Nicoll JA, Murray G, Fiddes M. Association of apolipoprotein E polymorphism with outcome after head injury. *Lancet.* 1997;350(9084):1069–1071
169. Chiang MF, Chang JG, Hu CJ. Association between apolipoprotein E genotype and outcome of traumatic brain injury. *Acta Neurochir (Wien).* 2003;145(8):649–653; discussion 653–654
170. Friedman G, Froom P, Sazbon L, et al. Apolipoprotein E-epsilon4 genotype predicts a poor outcome in survivors of traumatic brain injury. *Neurology.* 1999;52(2):244–248
171. Chamelian L, Reis M, Feinstein A. Six-month recovery from mild to moderate traumatic brain injury: the role of APOE-epsilon4 allele. *Brain.* 2004;127(pt 12):2621–2628
172. Liberman JN, Stewart WF, Wesnes K, Troncoso J. Apolipoprotein E epsilon 4 and short-term recovery from predominantly mild brain injury. *Neurology.* 2002;58(7):1038–1044
173. Kutner KC, Erlanger DM, Tsai J, Jordan B, Relkin NR. Lower cognitive performance of older football players possessing apolipoprotein E epsilon4. *Neurosurgery.* 2000;47(3):651–657; discussion 657–658
174. Jordan BD, Relkin NR, Ravdin LD, et al. Apolipoprotein E epsilon4 associated with chronic traumatic brain injury in boxing. *JAMA.* 1997;278(2):136–140
175. Junge A, Dvorak J. Injuries in female football players in top-level international tournaments. *Br J Sports Med.* 2007; 41(suppl 1):i3–i7
176. Covassin T, Schatz P, Swanik CB. Sex differences in neuropsychological function and post-concussion symptoms of concussed collegiate athletes. *Neurosurgery.* 2007;61(2): 345–350; discussion 350–351
177. Covassin T, Swanik CB, Sachs M, et al. Sex differences in baseline neuropsychological function and concussion symptoms of collegiate athletes. *Br J Sports Med.* 2006;40(11): 923–927; discussion 927

Sport-Related Concussion

William P. Meehan III and Richard G. Bachur

Pediatrics 2009;123;114
DOI: 10.1542/peds.2008-0309