Sport-related Concussion in Adolescents

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KEYWORDS

- Concussion • Neuropsychological testing
- Balance Error Scoring System
- Sport Concussion Assessment Tool

Sport-related concussions are common in adolescents and can have significant acute and long-term adverse effects on the developing brain of the young athlete.[1–8] This review discusses the practical aspects of sport-related concussions that are most relevant in the management of young athletes who present in the office. The Zurich consensus statement on concussion in sport provides a basic framework and a reference point for the evaluation and management of sport-related concussion in adolescents and adults.[7] The Sport Concussion Assessment Tool 2 (SCAT2) (Appendix 1), developed as part of the Zurich guidelines, provides a convenient and standard format for clinical evaluation and serial documentation of symptoms and examination findings of concussion.[7] However, each athlete should be individually assessed, and clinical judgment ultimately supersedes in making management and return-to-play decisions.

DEFINITION

In its practice parameter on concussion management in sports, the American Academy of Neurology defined concussion as a trauma-induced alteration in mental status that may or may not be associated with loss of consciousness.[9] Confusion, loss of memory, and reduced speed of information processing, which may occur immediately or several minutes later, are considered to be the key features of concussion seen in most cases.[3–12]

Concussion is defined by the Zurich consensus statement as a complex pathophysiological process affecting the brain, induced by traumatic biomechanical forces.[7] Certain common clinical, pathologic, and biomechanical features of concussion that form the basis of this definition are listed in **Box 1**.[7]

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Box 1
The Zurich consensus statement common features associated with sport-related concussion

1. Concussion may be caused by a direct blow to the head, face, neck, or elsewhere on the body with 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 structural injury.
4. Concussion may result in a graded set of clinical syndromes that may or may not involve loss of consciousness. Resolution of the clinical and cognitive symptoms typically follows a sequential course; however, in a small percentage of cases, postconcussive symptoms may be prolonged.
5. No abnormality on standard structural neuroimaging studies is seen in concussion.

EPIDEMIOLOGY

The Centers for Disease Control and Prevention, in the United States, reported 300,000 head injuries in a year in high-school sports, 90% of which are concussions.[1,3] Reported incidence of concussions at high-school level is 0.14 to 3.66 concussions per 100 player seasons accounting from 3% to 5% of all sport-related injuries.[12] Gessel and colleagues,[13] using data from the High School Reporting Information Online and National Collegiate Athletic Association Injury Surveillance, reported that concussions represented 8.9% (n = 396) of all high-school athletic injuries and 5.8% (482) of all collegiate athletic injuries. The highest number of concussions has been reported in American football, followed by (in decreasing order of risk) ice hockey, soccer, wrestling, basketball, field hockey, baseball, and softball.[6]

Symptoms and signs of concussion are often not recognized by the athlete or by medical personnel, and the athlete may fail to grasp the significance of head trauma and subsequent symptoms of concussion and not seek timely medical attention.[14–23] Some athletes may not report symptoms or head injury for fear of being excluded from further sport participation. For these reasons it is generally accepted that the reported incidence of concussion is a gross underestimate.[14–24]

MECHANISM AND PATHOPHYSIOLOGY

In addition to direct impact to the head or other parts of the body in contact or collision sports, concussion can also occur in noncontact sports as a result of sudden acceleration, deceleration, or rotational forces imparted to the brain.[1] Thus, absence of a history of direct impact to the head or elsewhere on the body does not rule out the possibility of a concussion.[2]

The biomechanics and pathophysiology of concussion have been elucidated by many investigators in animal models as well as in humans.[6,8,10–27] Pathophysiology of concussion on a cellular level is characterized by disruption and increased permeability of neuronal cell membranes.[6,8] This results in an efflux of potassium into extracellular spaces, resulting in a calcium-dependent release of excitatory amino acids, specifically glutamate.[6] The increase in extracellular potassium triggers neuronal cell-membrane depolarization resulting in neuronal suppression. Sodium-potassium pump is activated to restore homeostasis. The increased cellular metabolic activity increases the need for energy and glucose, and leads to hyperglycolysis. To meet

the increased metabolic demands in the brain, an increase in cerebral blood flow is expected; however, a decrease in cerebral blood flow is observed in concussive injury of the brain.[6,8] A mismatch between metabolic demands and supply results in neuronal dysfunction that can last from 1 to 10 days or more following the concussion, during which time the brain is more vulnerable to further injury.[6,8]

HISTORY

In the primary care setting the athlete with a concussion is seen in the office setting when they present for a follow-up of head injury and need a medical clearance to return to sport.[28–30] On the other hand, some athletes may initially present with symptoms or signs of concussion several days or weeks after the head injury; many may not realize the significance of the initial symptoms and delay seeking medical attention or seek medical attention because of persistence or worsening or onset of new symptoms.[1,2] Parents may first seek a pediatrician's advice when they notice deterioration of academic performance and changes in behavior, mood, or personality in the athlete; in these cases a history of antecedent head trauma should be ascertained.[1,2]

The athlete may give a history of direct blow to the head or other part of the body, a collision with another player, a fall to the ground, or being struck by an object such as a ball, puck, or a bat.[1,2] There may not be any history of direct impact to the head or other part of the body, and concussion can result from indirect shearing or rotational forces imparted to the brain without direct impact.[1] Not uncommonly, a teammate may notice that something is not right with the athlete and communicate that to the trainer on the sideline. The athletic trainer or the coach or, less commonly, a spectator may see a collision and observe that the player is confused, disoriented, and not able to execute tasks or follow commands as expected within the context of the play at the time.[3]

The athlete with concussion may manifest any 1 or more of several symptoms or signs (**Table 1**)[1–5,7,10]; some develop immediately after the injury to the brain, whereas others may be delayed for days or weeks.[9] Because no single symptom or set of symptoms and signs is pathognomonic of concussion, and many symptoms are nonspecific in nature, a contemporaneous relationship between the time of initial head injury and subsequent development of symptoms and signs should be established based on history and examination.[1] Several symptom checklists or scales are used in the evaluation of concussion; however, none is specifically validated for such use.[31–41] SCAT2 includes one such symptom evaluation scheme.[7] Increasing evidence suggests that concussion rating scales based on athlete self-report of multiple symptoms are a more reliable and practical way of detecting concussion and monitoring progress during the recovery phase.[31–41]

Details of any previous head injury should be ascertained. Detailed history should include the date of injury, symptoms or signs, recovery time, and results of any neuropsychological (NP) testing.[1,2,28,30] If multiple concussions have occurred in the past, obtain similar details for each concussion and document the interval between successive concussions.[1,2]

REVIEW OF SYSTEMS

A relevant review of systems should include any known (preinjury) neurologic condition or learning disability, attention deficit/hyperactivity disorder, depression, academic function before and since the injury, use of drugs or performance-enhancing supplements, and use of therapeutic medications.[1–3] Psychosocial history should assess the athlete's interest in sports and any evidence of parental pressure to return to sport.[1,3,42]

Table 1
Symptoms and signs of concussion

Mental status changes	Amnesia Confusion Disorientation Easily distracted Excessive drowsiness Feeing dinged, stunned, or foggy Impaired level of consciousness Inappropriate play behaviors Poor concentration and attention Seeing stars or flashing lights Slow to answer questions or follow directions
Physical or somatic	Ataxia or loss of balance Blurry vision Decreased performance or playing ability Dizziness Double vision Fatigue Headache Lightheadedness Nausea, vomiting Poor coordination Ringing in the ears Seizures Slurred, incoherent speech Vacant stare/glassy eyed Vertigo
Behavioral or psychosomatic	Emotional lability Irritability Low frustration tolerance Personality changes Nervousness, anxiety Sadness, depressed mood

Data from Refs.[1–5,7,10]

NEUROLOGIC EXAMINATION

A complete neurologic examination is essential in the evaluation of athletes with concussion, with specific attention to speech, visual acuity, visual fields, ocular fundi, pupillary reaction, extraocular movements, muscle strength, deep-tendon reflexes, tandem gait, finger-nose test, pronator drift, and Romberg test.[2,3,10,43,44] Postural stability has been shown to be a sensitive indicator of sensory-motor dysfunction in concussion.[33–36] SCAT2 includes the Balance Error Scoring System to assess balance, and finger-to-nose task to assess coordination.[7] Abnormal or focal findings on neurologic examination should prompt consideration of a focal intracranial pathology and emergent evaluation and management of the athlete. Findings on neurologic examination should be normal in athletes with concussion, other than the mental status or cognitive functions.

COGNITIVE FUNCTION

Assessment of cognitive functions, assessed clinically or by formal NP tests (conventional or computer based), is an essential component of the evaluation

of concussion.[7,45–51] Cognitive function can be affected by many factors other than the effects of concussion, such as baseline (preinjury) intellectual ability, learning disability, attention deficit/hyperactivity disorder, substance abuse, level of education, cultural background, lack of sleep, fatigue, anxiety, age, and developmental stage.[1–3,46,47] Cognitive assessment techniques should be appropriate for the athlete's age, level of education, and developmental stage or maturity. SCAT2 provides a method or format for clinically assessing cognitive function.[7] An athlete with concussion may continue to manifest somatic or behavioral symptoms even after resolution of cognitive deficits.

NP TESTING

Conventional (paper-and-pencil) or computer-based NP testing can be used to formally assess the cognitive functions (**Box 2**) of athletes who have concussion.[41,52–57] Conventional NP testing uses a battery of tests administered in 1 or more sessions (several hours) and interpreted by neuropsychologists.[1,2,46,54,55] Conventional NP tests have not been traditionally designed or validated to assess athletes with sport-related concussion, cannot be easily adapted for mass application, and are expensive and labor intensive.

Computerized NP testing specifically designed to assess athletes with sport-related concussion is now being used at high-school, collegiate, and professional levels to obtain baseline as well as postconcussion NP profiles of athletes to monitor recovery.[1–4,47,53–55] Some of the advantages of computerized testing include ease of administration, cost-effectiveness, and ease of interpretation. Examples of currently available computerized NP tests are listed in **Box 3**. For interested physicians, detailed information on each of the tests is available at their Web sites.

It is possible to use NP testing to monitor an athlete's recovery from a concussion, but data obtained from such tests after a concussion are most useful when compared with an injured athlete's performance on those tests before injury (baseline profile model).[4,58] This requires preparticipation baseline testing for all athletes in sports in which the risk of concussion is high. Computer-based tests make preparticipation testing more feasible by reducing the time involved in testing and by reducing observer bias in test results. These tests can also minimize the effect of repeated practice on an

Box 2
Major cognitive functions assessed by NP testing

- Amnesia after trauma
- Attention span (focused, sustained, and visual)
- Mental flexibility
- Motor coordination
- Motor speed
- Orientation to person, place, and time
- Processing speed
- Reaction time
- Verbal memory, immediate and delayed
- Visual scanning

Box 3
Examples of computerized NP test suites

Automated Neuropsychological Assessment Metrics (ANAM)

CogSport (formerly Concussion Sentinel)

Concussion Resolution Index (CRI)

Immediate Measurement of Performance and Cognitive Testing (ImPACT)

Standardized Assessment of Concussion (SAC) and its electronic version eSAC

athlete's performance on specific tests and detect attempts by an athlete to do poorly on baseline testing so that they will be more easily cleared to return to play after a concussion.

ANAM

The ANAM (www.armymedicine.army.mil/prr/anam.html) suite was developed primarily by the United States Department of Defense.[59,60] The original purpose of ANAM was to assess how normal physical and cognitive performance might be affected by chemical warfare agents, and many of the component tests were taken from batteries of NP and psychomotor tests developed by different branches of the United States Armed Forces. However, ANAM has been used for evaluation of other types of injuries, including concussion in athletes. Retest reliability needed for baseline measurements has been studied, but ANAM scores do not measure or indicate return to baseline after a concussion.[61,62]

CogSport

CogSport (CogState Limited: www.cogstate.com; known in an earlier version as Concussion Sentinel) is a suite of 4 tests that measure psychomotor function, processing speed, visual attention, vigilance, visual learning, verbal learning, and memory.[57,63] The suite is sensitive to cognitive changes seen in sport-related concussions compared with baseline performance, which is necessary for the evaluation of an athlete after concussion.[64,65]

CRI

CRI[8,10] (HeadMinder, Inc: www.headminder.com) is a Web-based NP test that includes measures of cognitive functions related to postconcussion syndrome, including memory, reaction time, and speed of decision making and of information processing.[58,63] As with several similar test suites, CRI was developed specifically to allow for comparison of an athlete's baseline and postconcussion performance.[57,58,66]

Immediate Postconcussion Assessment and Cognitive Testing (ImPACT)

ImPACT (ImPACT Applications, Inc: www.impacttest.com; the acronym also stands for Immediate Measurement of Performance and Cognitive Testing) was the first test suite designed specifically to evaluate NP function in athletes, at baseline and after concussive injury, and is one of the most widely used test suites for evaluation of concussion in athletes, including professional players.[67,68] ImPACT evaluates multiple neurocognitive skills, and assesses changes in processing speed as a test subject becomes fatigued. It can also vary stimuli randomly, which reduces the effect of practice on the athlete's score, and can detect attempts by an athlete to reduce baseline performance deliberately so that postconcussion changes are masked.

SAC, eSAC

SAC (www.csmisolutions.com) is a brief examination intended for use at the sideline, and is based on the American Academy of Neurology's 1997 Practice Parameter for management of sports-related concussion.[9,69,70] The original SAC, which is still available, was a paper-and-pencil test that measures orientation, immediate and delayed memory, and concentration. Unlike other paper-and-pencil and performance tests, evaluation with SAC does not show a practice effect on repeated administration.[71] An electronic version operating on handheld personal digital assistants is also available.

Validity of Computer-based NP Testing

The validity of computer-based NP testing in the evaluation of sport-related concussions remains a subject of intense debate and remains unsettled.[57] Some investigators have questioned the value of baseline testing because of lack of clear evidence that such testing helps to positively affect the outcome of concussion.[57] The performance of currently available NP tests for the evaluation of athletes after concussion seems to be variable, but better than pencil-and-paper tests. In one study, sensitivity of 2 different neurocognitive tests (CRI and ImPACT) to concussion were 78.6% and 79.2% respectively when used as the sole instrument for detection of concussion, compared with 43.5% for pencil-and-paper tests.[71] When combined in a battery with reports of concussion-related symptoms (which had a stand-alone sensitivity of 68.0%), evaluation of postural control (stand-alone sensitivity 61.9%), and the pencil-and-paper tests, overall sensitivity ranged from 89% to 96%, suggesting that a battery of several tests including NP tests is preferable for detection of concussion effects.

Test-retest reliability has also been shown to be low to moderate over a 5- to 50-day interval between initial and later testing with ImPACT, CRI, and Concussion Sentinel.[72,73] None of these tests reached the correlation coefficient of 0.75 considered acceptable for test-retest reliability. A head-to-head comparison of CogSport, ImPACT, and CRI showed significant but modest correlation in assessment of complex reaction time between ImPACT and CogSport and between ImPACT and CRI, but not between CogSport and CRI, and no significant correlation in assessment of memory indices between any pair of programs.[74] This suggests that the same NP test suite needs to be used for baseline and postinjury evaluation. Self-reported previous histories of concussion do not correlate with performance on pencil-and-paper or computer-based NP tests.[73,75]

One problem frequently encountered in concussion evaluation by comparison of baseline and postconcussion assessment is sandbagging, or performance deliberately reduced by an athlete during baseline testing with the intent of being able to return to play after a concussion without adequate recovery. Manual timing of an athlete during a paper-and-pencil test is difficult and may not have sufficient resolution to detect sandbagging. However, computer-based test suites can be designed to time tasks to high resolution, sometimes on the order of milliseconds, and tests can be designed to detect poor performance (ImPACT, in particular, contains tests that are intended to detect sandbagging); variability in time taken for a task, as well as in responses, is also associated with concussion.[64,67]

Another issue is the effect of repeated practice on an athlete's ability to perform tasks included in a test suite. Because paper-and-pencil tests are limited in their item variability, the practice effect is more pronounced with such tests, although one study showed little such effect with the SAC.[71] Computer-based test suites can and should be designed so as to vary aspects of each individual test in the suite, and many of these tests, including ImPACT, CogState, and ANAM, provide for such variation.[59,64,73]

Applications of Computer-based NP Testing

In the last 10 years NP evaluation of sports-related brain injury has become widespread. The management decisions in concussion should not be guided solely by the results of NP testing, and NP testing should be used as 1 tool in the overall assessment along with clinical evaluation.[2,7,54] Such testing provides at least some objective data on cognitive function in concussion. Computer-based testing reduces interobserver variability in the gathering of test data and makes test results less dependent on the competence of test administrators. Accurate interpretation of the results of these tests requires knowledge of the tests used and of their limitations, in general use and with players in different sports, on different teams, and in different situations.

Adolescence is developmentally characterized by continued neurologic maturation associated with increased acquisition of neurocognitive abilities as well as rapid acquisition of new skills and knowledge.[1–3] Therefore, continued improvement in measures of NP tests is expected through adolescence. A return to baseline NP profile may not necessarily indicate full recovery.[3] This confounding factor should be taken into account in interpreting the results of NP tests in adolescents.

Brief mental status evaluations and assessments of cognitive function that can be administered easily on the sideline immediately after a head injury were among the initial applications of computer-based NP testing. Some of these tests, including SAC and ImPACT, were originally developed as pencil-and-paper tests; their adaptation to electronic testing increases precision, repeatability, and objectivity of test results while reducing the practice effect seen with repetitive administration of the same test items. In particular, the high precision of timing, to fractions of a second, possible in computer-based testing allows for better comparison of pre- and postconcussion performance and improved detection of subtle cognitive defects.

Another advantage of computer-based testing for evaluation of concussion is that the ability to test athletes without neuropsychologists having to administer the tests makes NP testing more accessible.[4] Some of the available test suites, in particular ImPACT, can also detect sandbagging or other non–trauma-related changes in test performance, which is especially important during baseline testing.

Computer-based NP testing has been shown to provide valid and repeatable information on the effects of concussion on an athlete, and can be used in conjunction with baseline (before the season) test results to assess changes over time in cognitive functions. Formal NP testing is useful to delineate specific impairments in athletes who fail to recover as expected, or who deteriorate, or those who have had multiple concussions.[3] NP testing can be useful in guiding the management of academic difficulties in children and adolescents. Computerized NP testing can be done on an individual basis in an office or clinic setting; however, in most communities it is done through the school system. Pediatricians are increasingly likely to see athletes who present with such baseline and postinjury test reports (**Fig. 1**).

NEUROIMAGING

Neuroimaging is indicated in athletes with focal neurologic signs, those with progressively worsening symptoms and signs, failure of clinical resolution of symptoms (typically more than 2 weeks), severe acute headache, and loss of consciousness greater than a few seconds.[1–3,52] Static imaging with magnetic resonance imaging (MRI) or computerized tomography does not show any structural abnormalities of the brain in concussion.[1–7] Imaging modalities such as positron emission tomography,

ImPACT ™ Clinical Report

Exam Type	Base line	Post -Injury 1	Post -Injury 2	Post -Injury 3	
Date Tested	12/03/2007	01/17/2008	01/22/2008	01/26/2008	
Last concission			01/12/2008	02/02/2008	
Exam Language	English	English	English	English	
Test Version	2.0	2.0	2.0	2.0	

Composite Score									
Memory composite (verbal)	78	27%	53	<1%	81	37%	96	88%	
Memory composite (visual)	66	22%	39	<1%	72	38%	55	6%	
Vis. motor speed composite	50.97	98%	11.75	<1%	51	96%	51.43	97%	
Reaction time composite	0.57	54%	0.95	1%	0.54	69%	0.58	69%	
Impulse control composite	10		6		8		2		
Total symptom Score	12		12		4		1		

Fig. 1. An ImPACT clinical report showing the composite scores of a 17-year hockey player who sustained 2 concussions in a short period of time. The scores that exceed the Reliable Change Index are highlighted in the report. Percentile scores, if available, are shown as small numbers to the right of the composite score. Percentile scores reflect the percentile rank of the athlete for their gender and age at the time of testing. The full report contains detailed clinical history and detailed analysis of scores for individual modules and subsets.

functional MRI, or single photon emission computed tomography provide information on brain metabolism and regional blood flow; however, their application in clinical evaluation and management of athletes with concussion is limited.[3,7,34,35]

DIFFERENTIAL DIAGNOSIS

In the evaluation of an athlete with symptoms and signs of concussion, the physician should consider other conditions that can present with similar clinical features. In the acute setting, heat-related illness, dehydration, hypoglycemia, and acute exertional migraine can mimic concussion.[1–4] Many of the delayed symptoms of concussion are nonspecific, making it necessary to carefully delineate concomitant conditions such as headache disorders, conduct disorder, depression, attention deficit/hyperactivity disorder, sleep disorder, cerebellar or brain stem lesions, or psychosomatic disorder.[3]

MANAGEMENT

Adolescent Development

Normal psychological and social development has implications for the management of concussion in adolescents.[3] Concrete thinking and concerns about one's physical appearance are characteristics of early adolescence (generally 12–14 years). The adolescent at this stage of development may not fully comprehend the significance of long-term adverse effects of concussion and therefore not report head injury or its symptoms. For the same reason, they may also fail to adhere to the treatment

plan. Questions during history taking and instructions for treatment should be framed in simple, direct, and concrete language.

During middle adolescence (generally 15–16 years), the adolescent is highly susceptible to the influence of peers and media. The adolescent at this stage is also becoming more independent from parents and other adults in their life. Because of a sense of invulnerability, risk taking is common. Despite advice against it, the adolescent may continue to participate in sports for peer acceptance. The adolescent may find it difficult to cope with their inability to continue to play and, in some cases, may become depressed. When treating adolescents at this stage of development, the treating physician should take into account the psychosocial significance of sport participation in the adolescent's life.

Abstract thinking, future perspectives, life career, and interpersonal and social relationships are characteristics of late adolescence (generally 17–19 years). Because the adolescent at this stage is able to comprehend the potential for adverse long-term consequences of concussion, they are more likely to seek timely medical attention and adhere to a treatment plan.

Severity Grading

Concussion grading schemes based on the presence or absence and duration of loss of consciousness, confusion, and posttraumatic amnesia have not been shown to be clinically useful in the management of concussion.[1–10,12,52] Although the duration of certain symptoms and signs, such as the loss of consciousness or amnesia, may suggest the severity of concussion, the severity of concussion in an individual athlete can only be ascertained retrospectively after full clinical recovery has occurred.[1,2,7,10,52] Therefore, severity grading of concussion is not a main consideration in the initial management of most cases.

Return to Play

Each athlete follows a variable time course to recovery from acute cerebral concussion, so an individualized, stepwise plan for return to play is now considered the preferred practice, rather than following the conventional return-to-play guidelines.[1–3,7] Although most athletes recover in a period of between 2 to 3 weeks and 1 to 3 months, each athlete follows a variable trajectory to recovery following a concussion, making any fixed period of time out before return to play (used in the past in conventional concussion severity-based guidelines) a less valid approach.[1–4,7–12]

Following a concussion, complete physical and cognitive rest is recommended.[7] Although there is no agreement on how many days the athlete should be symptom-free before beginning the return-to-play stepwise protocol, most in practice consider at least 7 to 10 days of rest for adolescent athletes before beginning the protocol.[76,77] The Zurich conference consensus statement recommends the following stepwise approach of management[7]:

(1) No activity; complete physical and cognitive rest
(2) Light aerobic exercise (walking, stationary cycling, keeping intensity <70% maximal predicted heart rate, and no resistance training
(3) Sport-specific exercise (skating in hockey, running in soccer)
(4) Noncontact training drills (progression to more complex training drills, eg, passing drills in football; may start resistance training)
(5) Full-contact practice following medical clearance
(6) Return to unrestricted sport participation.

With the stepwise progression, the athlete should continue to proceed to the next level if asymptomatic at the current level. If symptoms recur, the athlete should go back to the previous asymptomatic step and try to progress after 24 hours of rest.[7] Before the athlete is allowed to return to play, they must be asymptomatic at rest as well as on exertion, and the examination must be normal.[3,7,77] The athlete should be monitored for recurrence of any symptoms or signs on physical exertion.

Cognitive Rest

Adolescents should return to increasing levels of school work gradually.[6,7] They need cognitive rest until full cognitive recovery.[7,75,77–79] The school should be informed of the athlete's need for special accommodations (**Box 4**) during the recovery phase.[78] Although most student athletes recover fully from concussion within a few days or weeks, some may need to use special accommodations, which can be accomplished by implementing a Section 504 plan or Individualized Education Plan as necessary.[1,2,78] Cognitive rest also implies limiting such activities as playing video games, texting, and watching television during the recovery period.

Athletes with Multiple Concussions

It is generally believed that the adverse effects of repeated concussions on the brain are cumulative and greater as the interval between successive concussions gets shorter.[3,80–85] However, Bruce and Echemendia[86] reported no significant association between self-reported concussion history and performance on computerized or traditional NP tests, suggesting a need for prospective studies to delineate long-term neurocognitive outcomes of concussion. An athlete may sustain multiple concussions during the same day, during the same season, or during their career.

There is no agreement as to how many concussions in a given period of time (some have suggested 3) should disqualify the athlete from further participation in high-risk sports.[4,5,83,84] Given this lack of clarity, most in practice take a more conservative approach for young athletes. The risks of repeated concussions on the developing brain should be discussed with the young athlete and the parents to allow them to make an informed decision as to whether to return to high-risk sports.

RECOVERY AND OUTCOME

Most young athletes recover fully from concussion. Thirty percent of high-school and collegiate athletes return to play the same day, and 70% after 4 days.[4,7] Same-day return to sports is generally not recommended for adolescents. Based

Box 4
Educational accommodations for athletes recovering from concussion

- Reduce the number of work assignments
- Allow more time to complete class work
- Allow more time for tests
- Outline and break complex tasks into simple steps
- Provide written instructions for student athletes
- Provide distraction-free areas for work
- Provide a note taker
- Incorporate less stressful course work

on NP testing data, correlation between NP testing and clinical findings indicate that most athletes with mild concussion recover cognitive function within 7 to 10 days, and those with severe concussion show recovery in a period of 1 to 3 months.[1–4,7,10,54] Athletes who have recovered in terms of their neurocognitive deficits may still have persistent emotional or behavioral symptoms.

Studies suggest that children and adolescents tend to have a more prolonged recovery phase than adults following a concussion, and have a higher risk of having a subsequent concussion.[14,79,87–100] Adverse effects of concussion on neurocognitive functions can be cumulative and modified by proximity of successive concussions, their severity, and individual susceptibility.[7] Children and adolescents can have life-long implications as a result of concussion, in terms of poor academic achievement, emotional symptoms, and psychosocial difficulties.[1]

Second impact syndrome (SIS) is characterized by rapidly progressive brain edema, brain stem herniation, and high mortality within minutes of a second concussion in an athlete who still has persistent symptoms (or has not clinically fully recovered) from a previous concussion has been described in adolescent male athletes.[101] Although some reports have debated whether SIS represents a new brain injury or is a complication of the initial injury, its exact etiopathogenesis remains unclear. Given this lack of clarity about the occurrence and significance of SIS, and the increased neuronal vulnerability to injury within few days after a concussion, it is recommended not to allow the symptomatic athlete return to sport.[102–113]

PREVENTION

Increased public awareness of various aspects of sport-related concussion is the most essential element of prevention strategy.[1–7] The Centers for Disease Control and Prevention has developed an excellent program called Heads Up for public education about concussion in sport (http://www.cdc.gov/concussion/headsup). The physician should incorporate education about sport-related concussion in the anticipatory guidance during injury-free visits as well as during the evaluation and management of athletes who present with concussion. Such a discussion with the athlete and the parents should include how to recognize concussion (signs and symptoms), potential complications, importance of seeking timely medical attention, physical and cognitive rest during recovery, and return-to-play criteria.[1]

Enforcement of rules of the sport plays an important role in prevention of head and neck injuries. Use of helmets in American football has reduced the likelihood of severe skull injury; however, helmet use has not been shown to be effective in prevention of brain concussion.[2,7,104,109–111] Research to develop helmets that can prevent or reduce the effects of concussion is actively being pursued. Appropriate use of mouth guards has been shown to reduce the incidence of orofacial injuries; their efficacy in prevention of concussion has not been established.[105–107,112,113] It has been suggested that strong neck muscles may allow the athlete to tense these muscles and maintain the head and neck in a fixed position just before impact and help dissipate the forces, theoretically reducing the impact on the brain; however, research results are equivocal.[3,7,52] Also, in practical terms, there is little time to anticipate the event and fix the head and neck before the impact during a game or practice.

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APPENDIX 1: SPORT CONCUSSION ASSESSMENT TOOL 2 [SCAT2]

SCAT2

Sport Concussion Assessment Tool 2

Name

Sport/team

Date/time of injury

Date/time of assessment

Age Gender M F

Years of education completed

Examiner

What is the SCAT2?[1]

This tool represents a standardized method of evaluating injured athletes for concussion and can be used in athletes aged from 10 years and older. It supersedes the original SCAT published in 2005[2]. This tool also enables the calculation of the Standardized Assessment of Concussion (SAC)[3,4] score and the Maddocks questions[5] for sideline concussion assessment.

Instructions for using the SCAT2

The SCAT2 is designed for the use of medical and health professionals. Preseason baseline testing with the SCAT2 can be helpful for interpreting post-injury test scores. Words in Italics throughout the SCAT2 are the instructions given to the athlete by the tester.

This tool may be freely copied for distribtion to individuals, teams, groups and organizations.

What is a concussion?

A concussion is a disturbance in brain function caused by a direct or indirect force to the head. It results in a variety of non-specific symptoms (like those listed below) and often does not involve loss of consciousness. Concussion should be suspected in the presence of **any one or more** of the following:

- Symptoms (such as headache), or
- Physical signs (such as unsteadiness), or
- Impaired brain function (e.g. confusion) or
- Abnormal behaviour.

Any athlete with a suspected concussion should be REMOVED FROM PLAY, medically assessed, monitored for deterioration (i.e., should not be left alone) and should not drive a motor vehicle.

Symptom Evaluation

How do you feel?

You should score yourself on the following symptoms, based on how you feel now.

	none	mild		moderate			severe
Headache	0	1	2	3	4	5	6
"Pressure in head"	0	1	2	3	4	5	6
Neck Pain	0	1	2	3	4	5	6
Nausea or vomiting	0	1	2	3	4	5	6
Dizziness	0	1	2	3	4	5	6
Blurred vision	0	1	2	3	4	5	6
Balance problems	0	1	2	3	4	5	6
Sensitivity to light	0	1	2	3	4	5	6
Sensitivity to noise	0	1	2	3	4	5	6
Feeling slowed down	0	1	2	3	4	5	6
Feeling like "in a fog"	0	1	2	3	4	5	6
"Don't feel right"	0	1	2	3	4	5	6
Difficulty concentrating	0	1	2	3	4	5	6
Difficulty remembering	0	1	2	3	4	5	6
Fatigue or low energy	0	1	2	3	4	5	6
Confusion	0	1	2	3	4	5	6
Drowsiness	0	1	2	3	4	5	6
Trouble falling asleep (if applicable)	0	1	2	3	4	5	6
More emotional	0	1	2	3	4	5	6
Irritability	0	1	2	3	4	5	6
Sadness	0	1	2	3	4	5	6
Nervous or Anxious	0	1	2	3	4	5	6

Total number of symptoms (Maximum possible 22)

Symptom severity score
(Add all scores in table, maximum possible: 22 x 6 = 132)

Do the symptoms get worse with physical activity? Y N
Do the symptoms get worse with mental activity? Y N

Overall rating

If you know the athlete well prior to the injury, how different is the athlete acting compared to his / her usual self? Please circle one response.

no different	very different	unsure

Cognitive & Physical Evaluation

1 Symptom score (from page 1)

22 **minus** number of symptoms — of 22

2 Physical signs score

Was there loss of consciousness or unresponsiveness? Y N
If yes, how long? _____ minutes
Was there a balance problem/unsteadiness? Y N

Physical signs score (1 point for each negative response) — of 2

3 Glasgow coma scale (GCS)

Best eye response (E)

No eye opening	1
Eye opening in response to pain	2
Eye opening to speech	3
Eyes opening spontaneously	4

Best verbal response (V)

No verbal response	1
Incomprehensible sounds	2
Inappropriate words	3
Confused	4
Oriented	5

Best motor response (M)

No motor response	1
Extension to pain	2
Abnormal flexion to pain	3
Flexion/Withdrawal to pain	4
Localizes to pain	5
Obeys commands	6

Glasgow Coma score (E + V + M) — of 15

GCS should be recorded for all athletes in case of subsequent deterioration.

4 Sideline Assessment – Maddocks Score

"I am going to ask you a few questions, please listen carefully and give your best effort."

Modified Maddocks questions (1 point for each correct answer)

At what venue are we at today?	0 1
Which half is it now?	0 1
Who scored last in this match?	0 1
What team did you play last week/game?	0 1
Did your team win the last game?	0 1

Maddocks score — of 5

Maddocks score is validated for sideline diagnosis of concussion only and is not included in SCAT 2 summary score for serial testing.

5 Cognitive assessment

Standardized Assessment of Concussion (SAC)

Orientation (1 point for each correct answer)

What month is it?	0 1
What is the date today?	0 1
What is the day of the week?	0 1
What year is it?	0 1
What time is it right now? (within 1 hour)	0 1

Orientation score — of 5

Immediate memory

"I am going to test your memory. I will read you a list of words and when I am done, repeat back as many words as you can remember, in any order."

Trials 2 & 3:

"I am going to repeat the same list again. Repeat back as many words as you can remember in any order, even if you said the word before."

Complete all 3 trials regardless of score on trial 1 & 2. Read the words at a rate of one per second. Score 1 pt. for each correct response. Total score equals sum across all 3 trials. Do not inform the athlete that delayed recall will be tested.

List	Trial 1	Trial 2	Trial 3	Alternative word list		
elbow	0 1	0 1	0 1	candle	baby	finger
apple	0 1	0 1	0 1	paper	monkey	penny
carpet	0 1	0 1	0 1	sugar	perfume	blanket
saddle	0 1	0 1	0 1	sandwich	sunset	lemon
bubble	0 1	0 1	0 1	wagon	iron	insect
Total						

Immediate memory score — of 15

Concentration

Digits Backward:

"I am going to read you a string of numbers and when I am done, you repeat them back to me backwards, in reverse order of how I read them to you. For example, if I say 7-1-9, you would say 9-1-7."

If correct, go to next string length. If incorrect, read trial 2. One point possible for each string length. Stop after incorrect on both trials. The digits should be read at the rate of one per second.

		Alternative digit lists		
4-9-3	0 1	6-2-9	5-2-6	4-1-5
3-8-1-4	0 1	3-2-7-9	1-7-9-5	4-9-6-8
6-2-9-7-1	0 1	1-5-2-8-6	3-8-5-2-7	6-1-8-4-3
7-1-8-4-6-2	0 1	5-3-9-1-4-8	8-3-1-9-6-4	7-2-4-8-5-6

Months in Reverse Order:

"Now tell me the months of the year in reverse order. Start with the last month and go backward. So you'll say December, November ... Go ahead"

1 pt. for entire sequence correct

Dec-Nov-Oct-Sept-Aug-Jul-Jun-May-Apr-Mar-Feb-Jan — 0 1

Concentration score — of 5

[1] This tool has been developed by a group of international experts at the 3rd International Consensus meeting on Concussion in Sport held in Zurich, Switzerland in November 2008. The full details of the conference outcomes and the authors of the tool are published in British Journal of Sports Medicine, 2009, volume 43, supplement 1.
The outcome paper will also be simultaneously co-published in the May 2009 issues of Clinical Journal of Sports Medicine, Physical Medicine & Rehabilitation, Journal of Athletic Training, Journal of Clinical Neuroscience, Journal of Science & Medicine in Sport, Neurosurgery, Scandinavian Journal of Science & Medicine in Sport and the Journal of Clinical Sports Medicine.

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6 Balance examination

This balance testing is based on a modified version of the Balance Error Scoring System (BESS)[6]. A stopwatch or watch with a second hand is required for this testing.

Balance testing

"I am now going to test your balance. Please take your shoes off, roll up your pant legs above ankle (if applicable), and remove any ankle taping (if applicable). This test will consist of three twenty second tests with different stances."

(a) Double leg stance:
"The first stance is standing with your feet together with your hands on your hips and with your eyes closed. You should try to maintain stability in that position for 20 seconds. I will be counting the number of times you move out of this position. I will start timing when you are set and have closed your eyes."

(b) Single leg stance:
"If you were to kick a ball, which foot would you use? [This will be the dominant foot] *Now stand on your non-dominant foot. The dominant leg should be held in approximately 30 degrees of hip flexion and 45 degrees of knee flexion. Again, you should try to maintain stability for 20 seconds with your hands on your hips and your eyes closed. I will be counting the number of times you move out of this position. If you stumble out of this position, open your eyes and return to the start position and continue balancing. I will start timing when you are set and have closed your eyes."*

(c) Tandem stance:
"Now stand heel-to-toe with your ***non-dominant foot*** *in back. Your weight should be evenly distributed across both feet. Again, you should try to maintain stability for 20 seconds with your hands on your hips and your eyes closed. I will be counting the number of times you move out of this position. If you stumble out of this position, open your eyes and return to the start position and continue balancing. I will start timing when you are set and have closed your eyes."*

Balance testing – types of errors

1. Hands lifted off iliac crest
2. Opening eyes
3. Step, stumble, or fall
4. Moving hip into > 30 degrees abduction
5. Lifting forefoot or heel
6. Remaining out of test position > 5 sec

Each of the 20-second trials is scored by counting the errors, or deviations from the proper stance, accumulated by the athlete. The examiner will begin counting errors only after the individual has assumed the proper start position. **The modified BESS is calculated by adding one error point for each error during the three 20-second tests. The maximum total number of errors for any single condition is 10.** If a athlete commits multiple errors simultaneously, only one error is recorded but the athlete should quickly return to the testing position, and counting should resume once subject is set. Subjects that are unable to maintain the testing procedure for a minimum of **five seconds** at the start are assigned the highest possible score, ten, for that testing condition.

Which foot was tested: ☐ Left ☐ Right
(i.e. which is the **non-dominant** foot)

Condition	Total errors
Double Leg Stance (feet together)	of 10
Single leg stance (non-dominant foot)	of 10
Tandem stance (non-dominant foot at back)	of 10
Balance examination score (30 **minus** total errors)	of 30

7 Coordination examination

Upper limb coordination

Finger-to-nose (FTN) task: *"I am going to test your coordination now. Please sit comfortably on the chair with your eyes open and your arm (either right or left) outstretched (shoulder flexed to 90 degrees and elbow and fingers extended). When I give a start signal, I would like you to perform five successive finger to nose repetitions using your index finger to touch the tip of the nose as quickly and as accurately as possible."*

Which arm was tested: ☐ Left ☐ Right

Scoring: 5 correct repetitions in < 4 seconds = 1

Note for testers: Athletes fail the test if they do not touch their nose, do not fully extend their elbow or do not perform five repetitions. Failure should be scored as 0.

Coordination score of 1

8 Cognitive assessment

Standardized Assessment of Concussion (SAC)

Delayed recall

"Do you remember that list of words I read a few times earlier? Tell me as many words from the list as you can remember in any order."

Circle each word correctly recalled. Total score equals number of words recalled.

List	Alternative word list		
elbow	candle	baby	finger
apple	paper	monkey	penny
carpet	sugar	perfume	blanket
saddle	sandwich	sunset	lemon
bubble	wagon	iron	insect

Delayed recall score of 5

Overall score

Test domain	Score
Symptom score	of 22
Physical signs score	of 2
Glasgow Coma score (E + V + M)	of 15
Balance examination score	of 30
Coordination score	of 1
Subtotal	**of 70**
Orientation score	of 5
Immediate memory score	of 5
Concentration score	of 15
Delayed recall score	of 5
SAC subtotal	**of 30**
SCAT2 total	**of 100**
Maddocks Score	**of 5**

Definitive normative data for a SCAT2 "cut-off" score is not available at this time and will be developed in prospective studies. Embedded within the SCAT2 is the SAC score that can be utilized separately in concussion management. The scoring system also takes on particular clinical significance during serial assessment where it can be used to document either a decline or an improvement in neurological functioning.

Scoring data from the SCAT2 or SAC should not be used as a stand alone method to diagnose concussion, measure recovery or make decisions about an athlete's readiness to return to competition after concussion.

Athlete Information

Any athlete suspected of having a concussion should be removed from play, and then seek medical evaluation.

Signs to watch for

Problems could arise over the first 24-48 hours. You should not be left alone and must go to a hospital at once if you:

- Have a headache that gets worse
- Are very drowsy or can't be awakened (woken up)
- Can't recognize people or places
- Have repeated vomiting
- Behave unusually or seem confused; are very irritable
- Have seizures (arms and legs jerk uncontrollably)
- Have weak or numb arms or legs
- Are unsteady on your feet; have slurred speech

Remember, it is better to be safe.
Consult your doctor after a suspected concussion.

Return to play

Athletes should not be returned to play the same day of injury. When returning athletes to play, they should follow a stepwise symptom-limited program, with stages of progression. For example:

1. rest until asymptomatic (physical and mental rest)
2. light aerobic exercise (e.g. stationary cycle)
3. sport-specific exercise
4. non-contact training drills (start light resistance training)
5. full contact training after medical clearance
6. return to competition (game play)

There should be approximately 24 hours (or longer) for each stage and the athlete should return to stage 1 if symptoms recur. Resistance training should only be added in the later stages.
Medical clearance should be given before return to play.

Tool	Test domain	Time	Score			
		Date tested				
		Days post injury				
SCAT2	Symptom score					
	Physical signs score					
	Glasgow Coma score (E + V + M)					
	Balance examination score					
	Coordination score					
SAC	Orientation score					
	Immediate memory score					
	Concentration score					
	Delayed recall score					
	SAC Score					
Total	**SCAT2**					
Symptom severity score (max possible 132)						
Return to play			☐ Y ☐ N	☐ Y ☐ N	☐ Y ☐ N	☐ Y ☐ N

Additional comments

Concussion injury advice (To be given to concussed athlete)

This patient has received an injury to the head. A careful medical examination has been carried out and no sign of any serious complications has been found. It is expected that recovery will be rapid, but the patient will need monitoring for a further period by a responsible adult. Your treating physician will provide guidance as to this timeframe.

If you notice any change in behaviour, vomiting, dizziness, worsening headache, double vision or excessive drowsiness, please telephone the clinic or the nearest hospital emergency department immediately.

Other important points:

- **Rest and avoid strenuous activity for at least 24 hours**
- **No alcohol**
- **No sleeping tablets**
- **Use paracetamol or codeine for headache. Do not use aspirin or anti-inflammatory medication**
- **Do not drive until medically cleared**
- **Do not train or play sport until medically cleared**

Clinic phone number

Patient's name

Date/time of injury

Date/time of medical review

Treating physician

Contact details or stamp