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Clinical Evaluation of the Concussed Athlete: A View From the Sideline

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Context: The sideline assessment of concussion is challenging, given its variable presentations, the limited sensitivity and specificity of sideline assessment tools, and how the presentation of the injury evolves over time. In addition, the diagnostic process, as well as the tools used to assess and manage concussion, continue to progress as research and what we know about concussion advance. This paper focuses on the initial assessment on the sideline by reviewing the concussion-evaluation literature, drawing from clinical experience to emphasize a standardized approach, and underscoring the importance of both familiarity with the athlete and clinical judgment.

Objective: To review the evidence regarding the clinical assessment of sport-related concussion on the sideline. Additional considerations included making same-day return-to-play decisions, the sensitivity and specificity of sideline testing, and the importance of ongoing assessment and follow-up of injured athletes.

Data Sources: I conducted a systematic literature review of the assessment of concussion on the sideline. The PubMed and MEDLINE databases were searched using the key term *athletic injuries* with *concussion* and *mild traumatic brain injury*. The search was refined by adding the key terms *sideline assessment* and *on-field assessment*. In addition, select additional position statements and guidelines on concussion were included in the review.

Results: The PubMed search using *athletic injuries* and *concussion* as key terms produced 1492 results. Refining the search by *sideline assessment* and *on-field assessment* produced 29 and 35 results, respectively. When *athletic injuries* and *traumatic brain injury* were combined, 1912 results were identified. Refining the search by *sideline assessment* and *on-field assessment* led to 28 and 35 results, respectively. Only papers that were English-language titles, original work, and limited to human participants and included sideline assessments of sport-related concussion in athletes older than 13 years were considered for this discussion. A total of 96 papers were reviewed, including systematic reviews, consensus guidelines, and position statements.

Conclusions: The sideline assessment of sport-related concussion is challenging given the elusiveness and variability of presentation, reliance on athlete-reported symptoms, and the varying specificity and sensitivity values of sideline assessment tools. In addition, the recognition of injury and assessment often occur in a time-pressured environment, requiring rapid disposition and decision making. Clinicians should begin the evaluation by assessing for cervical spine injury, intracranial bleeding, and other injuries that can present in a similar fashion or in addition to concussion. The sideline concussion evaluation should consist of a symptom assessment and a neurologic examination that addresses cognition (briefly), cranial nerve function, and balance. Emerging tools that assess visual tracking may provide additional information. The sensitivity and specificity of commonly implemented sideline assessment tools are generally good to very good, especially for symptom scores and cognitive evaluations performed within 48 hours of injury, and they are improved when a baseline evaluation is available for comparison. Serial assessments are often necessary as objective signs and symptoms may be delayed. A standardized assessment is paramount in evaluating the athlete with a suspected concussion, but there is no replacement for being familiar with the athlete and using clinical judgment when the athlete seems "not right" despite a "normal" sideline assessment. Ultimately, the clinician should err on the side of caution when making a return-to-play decision.

Key Words: traumatic brain injuries, assessment, return to play

Recognizing and assessing a player with a sport-related concussion (SRC) on the sideline of an athletic event is a challenging responsibility for the athletic trainer and sideline team physician. This often requires a rapid assessment in the midst of competition; the athlete is focused on returning to play and the clinician has a limited time to complete an evaluation and make disposition decisions. Given the importance of early recognition and removal of the concussed athlete from play, a standardized assessment should be practiced and perfected by the sideline health care clinician. As with much of the science of concussive injury, sideline assessment tools and techniques continue to evolve. Questions about the athlete's orientation and short-term and remote memory are important parts of the initial sideline screen. The existing standardized sideline assessment tools, such as the Standardized Assessment of Concussion (SAC)[1,2] and Sideline Concussion Assessment Tool (SCAT2, SCAT3, and child SCAT3),[3–5] have been shown to be useful.[6–9] The SCAT5,[10] modified from SCAT3, was developed at the Fifth International Concussion in Sport Consensus Meeting[11] and will likely prove to be useful. Emerging tools incorporating visual tracking[12,13] and reaction time[14] may provide additional beneficial information. Familiarity with the athlete can be instrumental in making a decision about return to or removal from play, as none of these tools, either alone or in combination, should take the place of clinical judgment. Rather, these tools should be combined with clinical judgment to make the diagnosis.

The objective of this paper, therefore, is to review the available evidence for the sideline assessment of concussion from the perspective of the health care provider: typically an athletic trainer, either with or without the team physician. It will address current knowledge, recent advances in sideline assessment tools, and the sensitivity and specificity of such tools where available. These findings will be discussed in relation to clinical experience, which ultimately yields a commonsense approach to evaluating an athlete with a concussion, erring on the side of caution, given the serious nature of this injury as well as its potential complications.

METHODS

For the review of literature, a PubMed search between 1968 and 2015 using *athletic injuries* and *concussion* as key words yielded 1492 results; using the same database with the key terms *athletic injuries* and *traumatic brain injury* instead generated 1912 results. Each search was filtered by adding the search terms *sideline assessment* and *on-field assessment*, resulting in 28 and 35 articles, respectively. Only papers that were English-language titles, original work, and limited to humans and included sideline assessments for SRC in athletes older than 13 years were considered. These along with systematic reviews, consensus guidelines, and position statements published since 2004 were reviewed and form the basis of this discussion.[15–22]

RESULTS

Sideline assessment or *on-field assessment* refers to the acute evaluation of an injured athlete shortly after injury under a time limit or with the understanding that a disposition decision needs to be made in a time-constrained environment.[23] For the purposes of this paper, I have divided the sideline assessment into an initial screening, signs and symptoms, cognitive function, balance assessment, combined tests, and additional tests. Where sideline assessments are combined tools (eg, the SCAT2 and SCAT3 are derived in part from the SAC, modified Balance Error Scoring System [m-BESS], and symptoms), information regarding the utility of these as combined or individual components are discussed.

Initial Screening Assessment

At the time of a suspected injury, the provider begins the screening process by evaluating the athlete for cervical spine and more serious brain injury (such as intracranial hemorrhage or skull fracture) and implementing the emergency action plan.[15,16,24] If the athlete is unconscious, he or she should be managed as if a coexisting catastrophic cervical spine or more serious brain injury is present. The player should not be moved, and manual in-line stabilization should be maintained to protect the cervical spine. If the athlete is responsive, the Glasgow Coma Scale (GCS) should be part of the initial screening assessment; although its reliability has been criticized, it can be useful in ruling out moderate to severe brain injury. Observer agreement ranges from low to high, with κ indices ranging from 0.32 to 0.85.[25,26] A recent review concluded that "findings using the scale have shown strong associations with those obtained by use of other early indices of severity and outcome."[27(p844)]

Table 1. When to Refer an Athlete to an Emergency Facility for a Possible Concussion[a]

Worsening or severe headache
Very drowsy or not easily awakened
Unable to recognize people or places
Significant nausea or vomiting
Behaves unusually or is unusually confused or irritable
Develops seizures
Develops weakness or numbness in arms or legs
Slurred speech or unsteady gait

[a] Adapted from the Sport Concussion Assessment Tool3.[15]

In the injured athlete who is not rendered unconscious, performing the initial screening assessment may be challenging, especially in sports that do not include play stoppages for medical assessments. Recently however, World Rugby[28] and National Collegiate Athletic Association soccer[29] guidelines were changed to allow a team to substitute for the injured player while he or she is being evaluated for concussion. The initial screening assessment should include questions that assess the athlete's orientation and both immediate and remote memory. Asking the athlete what he or she remembers about the play before or after the injury can help the provider determine how the athlete is processing information. Inquiring about the day, date, month, and year can also be helpful. Asking for the venue name or location, the score, who scored last, the team's last opponent, and the outcome of the game can easily be done on the sideline.[30] This initial interaction between the health care provider and the athlete on the sideline is an important one and often indicates whether an athlete is concussed. If he is struggling to answer the questions or is clearly confused or having trouble with memory (or both), it may become obvious that he has sustained a concussion, even if subsequent sideline test results are "normal." A complete evaluation should be subsequently performed whenever possible, even when it is clear that the athlete is concussed, as it may provide information regarding the severity of injury and prognosis. Evaluating for other or additional serious brain injury, as outlined by the Advanced Trauma Life Support guidelines,[31] can be done by evaluating cranial nerve function, mental status, and other signs or symptoms (Table 1).[32] The management of other serious brain injuries, such as intracranial hemorrhage, cervical spine injury, or skull fracture, is beyond the scope of this review.

Signs and Symptoms

Several symptom scales are available to clinicians, but many have been put together without evaluation of psychometric properties[33,34] or are modifications or derivatives of others, including the Post-Concussion Scale Revised,[35] Head Injury Scale,[36] Concussion Resolution Index,[37] SCAT postconcussive symptom scale[38] (also used in the SCAT2 and SCAT3),[4,5] and Concussion Symptom Inventory.[39] Concussion symptoms vary, and several groups[19,40–44] have evaluated the capacity of symptom

Table 2. Examples of Signs and Symptoms Seen After Concussion (Acute and Delayed) in Athletes[a]

Domain			
Sleep	Affective	Somatic	Cognitive
Trouble falling asleep	Labile mood, increased emotionality	Headache (most common)	Confusion (hallmark of concussion)
Sleeping more than usual	Sadness	Dizziness	Disorientation
Sleeping less than usual	Fatigue	Balance dysfunction	Memory dysfunction (anterograde or retrograde amnesia or both)
	Irritability	Nausea or vomiting or both	Loss of consciousness
	Anxiety	Visual complaints (double vision, blurry vision, photosensitivity)	Feeling "out of it," "foggy," "not right"
		Phonosensitivity	Vacant stare
			Trouble focusing
			Slow verbal or motor response or both
			Incoherent or slurred speech
			Excessive drowsiness

[a] Adapted from Herring et al.[19]

scales to accurately identify SRC. In general, the Graded Symptom Checklist or Post-Concussive Symptom Score accurately identifies SRC with a sensitivity of 64% to 89% and a specificity of 91% to 100%.[35,36,45–51]

However, challenges arise when relying solely on symptoms during the evaluation process. Some athletes may have symptoms at baseline, or the reported symptoms may not be concussion specific. For example, despite not being injured, nearly 60% of collegiate varsity football, wrestling, and ice hockey athletes evaluated at baseline with the SCAT symptom scale reported symptoms, with mean scores of 3.52 for men and 6.39 for women.[52] Sex differences in baseline symptom reports have also been noted for symptoms such as headache and emotional lability.[54] Concussion history has been cited as a modifying factor in baseline symptom reports: those with a history of concussion reported a larger number of symptoms than those without a history of concussion (5.25 versus 3.75, respectively).[52] In that study, the most common baseline symptoms were fatigue and low energy (37%), drowsiness (23%), and neck pain (20%). A significant number of athletes also reported baseline symptoms of difficulty concentrating (18%) and difficulty remembering (18%).[52] The differences in baseline symptoms between sexes as well as between athletes with or without a concussion history have been noted in other studies.[54,55] Lastly, though the hallmark of concussion is confusion, other symptoms that occur frequently with concussion but are less specific include headache, dizziness, and drowsiness,[19] which may also be associated with conditions such as febrile illness, cardiac disease, and heat illness (Table 2).

When a provider evaluates an athlete for concussion on the sideline, interpreting the presence or absence of symptoms can be challenging, especially if no baseline is available, and when taking into account the lack of specificity of symptoms. This can be especially difficult during certain times of the year; for example, during the preseason, many athletes are practicing more than once per day, starting school, and participating in the heat. It is not unusual for athletes to be fatigued and have headaches and other symptoms that may or may not be related to concussion. The challenge is to try and decipher whether the symptoms are new and related to a blow to the head or body versus those that might be related to another process (eg, medical or emotional). In the sideline setting, it is again preferable to err on the side of caution and treat symptoms as concussion related until determined otherwise, removing the athlete from play for a more comprehensive evaluation.

Cognitive Tests

The SAC is a brief evaluation of cognitive function and includes standard questions of orientation (place, time, date, month, year), working memory via the immediate recall of 5 words, concentration by recalling a list of digits and the months backward, and remote memory via delayed recall.[1] The SAC has been useful in detecting SRC immediately after injury.[1,8,46,56–59] In a large study[31] of collegiate football players, the SAC score dropped, on average, 2.94 points below baseline (95% confidence interval = –4.39, –1.50) immediately after concussion and returned to baseline within 5 to 7 days. In another investigation of collegiate athletes,[56] the sensitivity of the SAC was 95%, with a specificity of 76% in accurately diagnosing concussion immediately after injury, and significant improvements in SAC scores 48 hours after injury. Both practice and ceiling effects may occur on the SAC, so although immediate postinjury use is recommended, its ability to differentiate concussed from nonconcussed athletes is limited if used more than 48 hours after injury.[1,46,59] Similar to evaluating symptoms on the sideline, interpreting the SAC in an athlete who lacks a baseline result can be challenging. If available, group-based norms for athletes (eg, other athletes of the same age, sex, or sport at the same school or in the same league) may be useful. The SAC does not take the place of clinical judgment, and the results should be used as supportive information for the clinical assessment, especially when no baseline is available.

Balance Assessment

The utility of balance testing in evaluating concussive injury, with deficits returning to baseline within 3 to 7 days, has been well demonstrated.[6,60–63] Swaying or falling and being unable to maintain balance after injury are common symptoms after concussion and are often worsened with eyes closed, due to the loss of vision as a reference for where one stands in space.[6,60–63] Given the utility of balance in assessing SRC, the m-BESS was included in the SCAT2 assessment.[3] This assessment consists of 3 stances: feet together, 1-legged stance, and tandem stance with the eyes closed. Each stance is to be held for 20 seconds, and the errors for each are counted. The complete BESS consists of these 3 stances plus 3 additional trials using a foam surface and is more sensitive than the modified version,[60–63] which prompted its inclusion in the SCAT3.[4] Even so, balance testing is limited by the effects of fatigue and exercise, practice effects with serial assessments, and concerns regarding reliability.[43,63–65] The sensitivity of balance testing was highest within 24 hours of injury (0.34), and specificity on days 1 through 7 after injury was between 0.91 and 0.96.[45] Completing the BESS on the sideline and interpreting the results can sometimes be a challenge, especially if no baseline evaluation is available. The timing of this complete assessment may need to be modified, such that it is performed at half time or in the locker room after the practice or game. Despite the low sensitivity of balance testing in isolation, the high specificity achieved by combining balance testing with other assessments justifies its use in the sideline evaluation of athletes with concussion.

Combined Tests

The SCAT2 was developed in 2008 by the International Concussion in Sport (CIS) group[3] and included an assessment of signs and symptoms (ie, Graded Symptom Checklist), cognitive function (ie, SAC), the Maddock questions, and balance (ie, m-BESS) as well as the GCS, a signs score (loss of consciousness and balance dysfunction), and a coordination examination (finger to nose). The maximum score is 100, with 22 points for no symptoms, 30 points for a perfect SAC, 30 points for no errors on the m-BESS, 2 points for no loss of consciousness or balance dysfunction, 15 points for a normal GCS, and 1 point for normal coordination. The National Football League later modified the SCAT2 for use in professional American football and incorporated additional "no-go" criteria that highlight when immediate removal from play or screening for cervical spine and more serious brain injury is indicated.[19] The SCAT3 was developed in 2012 by the CIS group.[4] The SCAT3 kept the main subcomponents of the SCAT2 (Graded Symptom Checklist, SAC, Maddocks questions, and GCS) but incorporated subtle differences: allowing a test of tandem gait as an "and/or" option with the full BESS, changing the order of assessments, abandoning the scoring system, moving the signs of loss of consciousness and balance dysfunction to a separate section in order to identify signs that would lead to immediate removal from play, and adding a cervical spine evaluation. Simultaneously, for children ages 5 to 12 years, the CIS group created the child SCAT, despite recognizing that minimal data thus far exist for its components.[5] Even with the integration of objective measures, the National Football League and SCAT2 and SCAT3 assessments emphasize the clinician's judgment; knowing the athlete and often the subtleties of his or her personality may lead to a diagnosis of concussion despite "normal" performance on these standardized assessments. Indeed, the clinician's judgment remains the criterion standard for concussion diagnosis, and as such, if there is evidence for or suspicion of concussive injury, the athlete should be removed from play and followed serially to monitor both deterioration and the development of new signs or symptoms of injury.

A prospective study[46] evaluating concussion in collegiate athletes using baseline measures of symptoms, cognitive function, and postural stability (ie, BESS) immediately after injury and serially up to 90 days postinjury showed increases in symptoms and errors on the BESS and decreased cognitive function immediately after injury, with gradual resolution over 7 days. The utility of a multimodal assessment and comparison of the individual postinjury evaluations with each person's unique baseline were also demonstrated.

As discussed previously, many factors influence symptom reports and performance on cognitive and balance testing. These factors, which include sex, concussion history, acute fatigue, physical illness, and orthopaedic injury, are discussed in detail elsewhere.*

A limited number of studies[8,52,68–70] using the SCAT2 established individual differences in baseline assessments, and only a single study[8] has evaluated the sensitivity and specificity of the SCAT2 for identifying concussion. In this prospective research on collegiate male and female varsity athletes, the SCAT2 was administered at baseline and repeated if a concussive injury occurred. Contact-sport athletes who had not sustained concussions (control group) repeated the SCAT2 to match the experimental group's timeframe postinjury. When a baseline assessment was available, the SCAT2 had a sensitivity of 96% and a specificity of 84%.[8] If no baseline was available, 83% sensitivity and 91% specificity were obtained by using a cutoff value of 74.5 out of a possible maximum score of 100. This study demonstrated the utility of the SCAT2, and therefore the SCAT3, in the assessment of SRC in collegiate athletes. Postinjury, significant changes were noted for the symptom score and m-BESS. Although the SAC score of the concussed athletes did not change after injury from their baseline score, when compared with the control group, who showed an improvement in their repeat test versus their baseline, the difference was significant. This underscores that the lack of improvement in the concussed group suggests concussive injury and the lack of a practice effect, which has been discussed previously.[5] In addition, this prospective study of the SCAT2 in collegiate athletes did not demonstrate a sex difference in baseline performance, nor did it demonstrate a difference in baseline scores for athletes with a history of concussion or other modifiers such as a history of migraines or headaches, depression, anxiety, or learning disability.[8]

In a similar prospective study evaluating the SCAT3 in high school and collegiate athletes at baseline and after concussion (published after the initial PubMed search for this article was conducted), Chin et al[71] identified similar findings related to the utility of a standardized sideline assessment of concussion. Female sex, high school level of competition (versus college), and attention-deficit/hyperactivity disorder were associated with higher baseline symptom ratings. Male sex, attention-deficit/hyperactivity disorder, and learning disability were associated with lower baseline SAC scores. Male sex, high school level of competition, attention-deficit/hyperactivity disorder, and

*References 6, 40, 42, 43, 46, 54, 55, 59, 62–67.

learning disability were associated with poorer baseline BESS performance. After concussive injury, the symptom score showed the largest effect size at the 24-hour assessment. Effect sizes for the SAC and BESS were small to moderate at 24 hours and nonsignificant at days 8 and 15.[71] This study confirms the utility of a standardized assessment that combines several tools, such as the SCAT2 or SCAT3, in evaluating athletes with SRC.

As with each component of the SCAT2 or SCAT3, when no baseline evaluation is available, it is challenging to determine if an athlete's sideline performance represents a decline. Given the findings of the studies referenced earlier, using published normative data can help, but ultimately it is often the clinician's assessment of an athlete's responses and behaviors that determines whether a concussive injury has occurred. As unappealing as it may be for the scientific community to admit, the sideline assessment and diagnosis of concussion are often more art than science, with no clear biomarker currently available for this injury.

Additional Tests

New to the concussion-assessment field are tools that evaluate saccadic eye movements in individuals who may be concussed. The utility of 1 such test has been explored in mixed martial arts athletes, youth and collegiate athletes, and professional hockey players and holds promise in assessing concussive injury.[12,13,72–75] Specifically, the King-Devick (KD) test uses numbers placed in a standardized fashion, spaced at varying intervals on 3 cards. The athlete is timed as he or she reads off the numbers from each card over 1 to 2 minutes. Research[12,13,73–75] on the KD test has demonstrated that visual-scanning ability decreases (ie, takes longer) after concussion. As with other sideline assessment tools, the KD test is also associated with a practice effect in nonconcussed controls, whereby they perform better after having been exposed to it.[13,73] This underscores the importance of having either specific individual baseline scores or group-based norms (or both) available for comparison if using this test on the sideline.

A few investigators have compared more common sideline assessments with the KD test. One preliminary study[13] demonstrated that the KD test may be more useful than the SAC immediately postinjury. In this prospective study of youth and collegiate ice hockey and lacrosse players, the KD test was used along with the SAC and a timed gait analysis at baseline and after concussion, with nonconcussed athletes as controls. When receiver operating curves from regression models were used to compare changes between the postinjury and baseline assessments, the KD test had a value of 0.92 versus 0.87 for the tandem gait and 0.68 for the SAC.[13]

In another prospective study[76] of emergency room patients, the KD test was used along with the SCAT2 to evaluate patients with mild traumatic brain injury (mTBI) compared with control patients who had acute ankle injuries. The mTBI patients differed from controls on components of the SCAT2, including the symptom score (Cohen d = 1.02–1.15, $P < .001$) and SAC (d = 0.81, $P = .0004$) but not on the KD test (d = 0.40, $P = .148$). In logistic regression analysis, the KD test did not contribute more than these 2 measures in predicting group membership (mTBI versus control, $P = .1991$).[76] This study had limitations in that it was not restricted to patients with SRC; patients with mTBI from other mechanisms were included, as well as a broad age range. More research is necessary to determine how long these deficits persist, how they correlate with other measures of function, and the multitude of factors that may affect how these tests are implemented in the assessment of SRC.[12,13,72–75]

Another novel area of concussion assessment is measurement of reaction time. Although sideline challenges exist, a measuring stick attached to a hockey puck has been used to measure reaction time; performance is based on how quickly and where the athlete grasps the stick when it is dropped.[14] In a study of collegiate athletes, reaction time differentiated concussed from nonconcussed athletes, with a significant decline in postinjury versus baseline time in the concussed group compared with a trend toward improvement in the nonconcussed group.[14] The sensitivity and specificity of the reaction-time test were 75% and 68%, respectively, with a reliable change index of 65%.[14] The reaction-time test has also been shown to remain stable during acute exercise[77] and provide acceptable reliability.[78] Additional investigations of the sideline reaction-time test to evaluate concussion are needed.

Challenges for the Sideline Clinician

The sideline clinician should be confident in erring on the side of safety: that is, pulling an athlete out when no concussion is present is a better scenario than allowing a concussed athlete to continue based on a negative or normal standardized sideline test score. Allowing an athlete with a concussion to return to play if the symptoms were mild or had resolved and were not exacerbated by exertion was accepted clinical practice before 2006.[38,79–81] Since that time, however, the pendulum has swung toward a philosophy of no return to play in the same game or on the same day, given that concussion can be a subtle injury and many athletes who are initially asymptomatic develop signs and symptoms in the first 24 hours.[46,82,83] The National Collegiate Athletic Association[84] instituted a no-return-to-play-on-the-same-day policy in 2010, and many international organizations and professional sports now have similar policies.[85–90] This shift in policy is supported by a study[91] of collegiate football players that identified delayed onset of symptoms in 33% of those with a suspected concussion who returned to the same game compared with only 12.6% of players who did not return.

Similar to policy changes among sporting organizations, legislation affecting youth athletes began in Washington with the Lystedt law, which mandates removal from play and no return to the same game of athletes younger than 18 years old with any signs or symptoms of concussion.[92] Legislation similar to the Lystedt law now exists in each of the 50 United States and Washington, DC, and is under consideration in Canada.

A Common-Sense Approach

If an athlete has sustained a blow to the head and the athletic trainer and team physician (if available) find the athlete does not demonstrate any signs or endorse any symptoms of concussion and the cognitive, balance, and neurologic examinations are normal, then he or she can be returned to play (ie, a concussion is not suspected). In these situations, strong consideration for serial assessments to follow the athlete will enhance player safety. It is also clear that, in some cases, an athlete appears dazed or "out of it," answers questions a bit more slowly than expected, or appears to process information more slowly or displays an unusual affect, and yet completes the sideline assessment without errors. The athletic trainer and team physician should keep the athlete out of play because of the clinical assessment of a suspected concussion. In other words, the clinical assessment and intuition of the sideline clinician remain the criterion standard and should take precedence over how an athlete performs on sideline testing. If signs or symptoms indicate cervical spine injury, intracranial bleeding, or skull fracture, the emergency action plan is initiated and the athlete transported to an emergency facility. Robust public outreach efforts by the Centers for Disease Control and Prevention and the CIS Group (Pocket Concussion Recognition Tool[93]) to non-medically trained individuals, including athletes, parents, and coaches, as well as to health care providers have provided education regarding concussion signs and symptoms that emphasizes the importance of recognition and removal from play.[94] Lastly, if no athletic trainer or other qualified health care provider is available and the athlete presents with signs or symptoms of concussion, he or she should be removed from play and not allowed to return until evaluated by a health care provider, even if symptoms resolve.

Role of Head-Impact Sensors in Detecting Concussive Injury

Given the challenge of providing athletic trainer coverage for all sport activities at every level of competition, a market has developed for additional methods of injury recognition, including products that evaluate the possibility of concussive injury by measuring head-impact forces, despite the lack of correlation between absolute impact magnitude and likelihood of concussive injury. To date, the threshold for concussive injury is unknown, and it is likely to be different for each person.[95–100] American football players were concussed by impacts to the head that occurred over a wide range of magnitudes (60.51*g* to 168.71*g* linear acceleration), and clinical measures of acute symptom severity, balance, and neuropsychological function all appeared to be largely independent of linear impact magnitude and location.[97] Further, clinical outcomes of symptoms, balance, or neuropsychological performance were not related to impact magnitude or location, and the athletes with concussions sustained as a result of lower magnitudes ($<70g$) tended to present with just as many clinical deficits as those from higher magnitudes ($>110g$). Thus, despite the literature suggesting that large magnitudes of head impact, particularly with high angular acceleration, resulted in more serious clinical outcomes in cases of moderate or severe traumatic brain injury,[84,85] the magnitude and location of impact may not predict clinical outcomes.

In addition, concussion symptoms are commonly not reported after impacts greater than 90*g*,[99] and fewer than 0.35% of all impacts greater than 80*g* resulted in a diagnosed concussion.[101] Because of the low sensitivity and specificity of head-impact sensors, systems that claim to identify concussions are not recommended at the present time; however, they may have utility for illustrating dangerous behaviors and teaching athletes how to reduce the risk of injury.[101] Such devices may also allow for the study of biomechanics with the goal of influencing rule changes to improve safety in contact sports. For example, the aims of such changes would be to prevent open-field and open-ice collisions in which players may be ill prepared for high-level impacts to the head. It is important that athletes, parents, coaches, and other laypeople understand the limitations of head-impact sensor technology and instead rely on educational information[93,94] regarding the recognition of concussion.

SUMMARY

The sideline assessment of the athlete after SRC is complex, and the clinical impression remains the criterion standard in making the concussion diagnosis. Asking questions that discern the athlete's ability to recall the events of the injury, as well as those before and after the injury, and determining if he or she is slow to respond to questions, appears to have trouble processing information, or obviously struggles with simple tasks are important components of the clinical assessment. Standardized sideline concussion-assessment tools are strongly encouraged and should include individual (eg, symptoms, balance, and cognitive functioning) or bundled evaluations (eg, SCAT3) as part of the neurologic examination. The assessment should be done as soon as possible after injury, with the understanding that the optimal timing of the examination is not yet clear. To evaluate a potential concussion, recent research supports the use of sideline visual-tracking tests compared with preinjury baseline tests whenever possible, but more investigation is needed, and these tests are best used as part of a multimodal assessment.

Ultimately, clinicians should feel comfortable and confident when applying clinical suspicion to overrule a "negative" or "normal" result on a standardized sideline assessment tool. Athletes with a suspected or confirmed concussion should be removed from the field of play and not returned to playing or training on the same day. Athletes assessed for concussion should be followed with serial evaluations. If no athletic trainer or other health care professional is present, it is important to err on the side of caution, keeping any athlete suspected of having a concussion out of play until he or she can be evaluated. This process can be aided by providing education to athletes, parents, and coaches regarding the recognition of concussion signs and symptoms with subsequent removal from play. Though more study is needed, the utility of head-impact sensors in detecting potential injury is, at this time, of unclear significance, given the lack of correlation between biomechanical forces and clinical measures.

Lastly, most concussion research has focused on high school and collegiate athletes, primarily males, and American football is overrepresented. Thus, a significant amount of bias is present in the information we know and underscores the need for more work in other sports and including a full spectrum of ages and of both male and female athletes.

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