21 Narrowing the Knowledge Gap Between Basic Neuroscience Research and Management of Concussive Injury

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Current Clinical Practice

Diagnosis/Evaluation Procedures

At all levels of collision sports, a concussion evaluation is initiated when an athlete has a direct or indirect forceful impact to the head that is associated with visible signs, athlete reported symptoms, or suspicion of head injury by medical staff (athletic trainer or team physician). Officials from the sport may also report possible concussion to team clinicians, and some sports have implemented education programs aimed at training officials to recognize a possible concussion. If adequately trained medical staff is not present at an event, any suspicion by a coach, official, or observer should result in removal of the athlete from play. There should be no return to sport until an appropriate medical evaluation has taken place by qualified medical staff and the athlete is medically cleared for participation. Concussion may be diagnosed immediately but excluding a diagnosis of concussion may take up to 48 hours following the head contact due to delayed presentation. During this period, serial evaluations should continue with medical staff [1].

The diagnosis of concussion involves assessing the nature of the injury, clinical symptoms, physical signs, behavior, balance, and cognition. This evaluation can take place on the sideline or in the clinic. The initial sideline evaluation involves

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observing the ABC's (airway, breathing, and circulation) and taking cervical spine precautions. Any athlete with midline cervical spinous process tenderness or neurological symptoms (upper or lower extremity numbness/tingling or weakness) should be considered to have a cervical spine injury until proven otherwise and be appropriately immobilized. During a sideline evaluation, the athlete should be observed for their motion and GCS (Glasgow Coma Scale) score, which is comprised of eye response, motor response, and verbal response. The appearance of the athlete should also be taken into consideration, particularly their balance (i.e., gait, motor coordination, labored movements), response to questions (confusion, disorientation), and overall affect (vacant or blank look). For athletes at the age of 13 or older, Maddock's questions should be asked to assess the athlete's memory including their recollection of the injury and specific questions pertaining to the game or participation. For athletes younger than 13, Maddock's questions should not be asked due to questionable reliability and usefulness in young children [2]. The athlete should be assessed for red flag symptoms, including neck pain, double vision, slurred speech, severe or increasing headache, loss of consciousness, seizure or convulsion, focal neurologic deficit, repeated vomiting, deteriorating conscious state, and agitation. The presence of these red flag symptoms warrants emergent neuroimaging.

Based on this initial assessment, if there is concern for concussion, the athlete should be immediately removed from competition and undergo thorough examination in a private area that is distraction free. The 5th edition of the Standardized Concussion Assessment Tool (SCAT-5) has been utilized to evaluate athletes for possible concussion. It is a consensus-based instrument validated for use on the sidelines in athletes of ages 13 and over [3]. The Child SCAT-5 is used for evaluating children of ages 12 and younger, and its format is consistent with the format of the SCAT-5 [2].

Links to the SCAT-5 and Child SCAT-5 are as follows:

- SCAT-5: https://bjsm.bmj.com/content/bjsports/early/2017/04/26/bjsports-2017-097506SCAT5.full.pdf
- Child SCAT-5: https://d2cx26qpfwuhvu.cloudfront.net/wru/wp-content/uploads/2019/03/05114400/SCAT5_Child.pdf

The SCAT-5 lists 22 separate symptoms that each athlete is asked to rate on a scale of 0 (nothing) to 6 (severe). This provides a total number of symptoms (out of 22) as well as symptom severity score (addition of all the scaled numbers throughout the 22 separate symptoms). The athlete is then asked about prior history of concussion(s) including date and the recovery course for the concussion(s). They are also asked about prior history of attention deficit disorder (ADD)/attention deficit hyperactivity disorder (ADHD), learning disability/dyslexia, headache disorder or migraine, depression, anxiety, and other psychiatric disorders. The athlete is then screened for cognitive function via the Standardized Assessment of Concussion (SAC) with tests for orientation, immediate memory, and concentration. To assess concentration in the SCAT-5, each athlete is asked to read the months in reverse order as well as a list of digits backward. There are four different lists of digits that the athlete is asked to repeat. Delayed memory is measured after the physical examination takes place, as the athlete is asked to repeat a list of words that was provided to them as part of the test for immediate memory. The SCAT-5 offers additional 10-word lists for immediate and delayed memory as well as longer digital backward sequencing. This minimizes the ceiling effect that was a previous limitation of the SCAT-3; however, no studies have shown increased sensitivity or specificity for diagnosis of sport-related concussion (SRC) with the SCAT-5 over prior versions [4].

The Child SCAT-5 contains a symptom evaluation section that includes a child report and parent report. It is recommended to be completed with the athlete in a resting state. For the child report, a list of 21 separate symptoms is included and the athlete is asked to rate each symptom on a scale of 0 (nothing) to 3 (severe). This provides a total number of symptoms (out of 21) and symptom severity score (addition of all the scaled numbers throughout the 21 separate symptoms). At the end of the child report, the athlete is then asked to rate how they feel on a scale of 0 (very bad) to 10 (very good). For the parent report, the parent is asked to rate the same symptoms of the athlete on a scale of 0 to 3. The same total number of symptoms and symptom severity score are reported, based on the parent's response. The parent is then asked to rate their child on a scale of 0 to 100%. The child is then screened for cognitive function via Standardized Assessment of Concussion – Child Version (SAC-C) with tests for immediate memory and concentration. Orientation is not included due to its doubtful usefulness in young children. To assess concentration in the Child SCAT-5, each athlete is asked to read the days of the week in reverse order and a list of digits backward. There are five different lists of digits that the athlete is asked to repeat. Delayed memory is measured after the physical examination, as the child is asked to repeat a list of words that was provided to them in the test for immediate memory. Five minutes must pass between the assessments of immediate memory and delayed memory [2].

The physical examination component starts with a neck examination, which consists of inspection of the neck and scalp. This is done to ensure there are no red flag signs that would be concerning for a skull fracture, which would prompt further imaging. At this point, the athlete should have already received palpation of the cervical spine to rule out midline spinous process tenderness and step off deformities, but a more thorough palpation examination can take place to find areas of tenderness within the cervical paraspinal musculature. Active ranges of motion with cervical rotation, side-bending, and flexion/extension are then assessed. Identifying areas of tenderness and monitoring range of motion can help with the rehabilitation and treatment process as an athlete recovers from concussion. Special tests are performed, which include the Hoffman test (tapping the nail of the third or fourth finger and observing for involuntary flexing of the thumb and index finger) to rule out an upper motor neuron lesion, and the Spurling compression test (passively extending the athlete's head and turning to the affected side while providing downward pressure and observing for recreation of radiating upper extremity pain or numbness/tingling) to rule out cervical radiculopathy.

The neurological examination then takes place to rule out signs of focal neurologic deficits. First is assessment of the cranial nerves (two through 12) followed by cerebellum testing, which consists of pronator drift, finger to nose testing, and tandem gait. Next, strength, sensation, and reflexes of the upper extremities are evaluated. The biceps reflex, brachioradialis reflex, and triceps reflex are assessed, followed by strength with shoulder abduction, elbow flexion/extension, wrist flexion/extension, supination/pronation, thumb extension, thumb abduction, pincer grasp, and finger abduction. Sensation is assessed over the cervical spine and thoracic spine nerve root distributions. This is followed by the assessment of strength, sensation, and reflexes of the lower extremities. Hip flexion/extension, hip adduction/adduction, hip internal/external rotation, knee flexion/extension, plantarflexion/dorsiflexion, ankle internal/external rotation, and ankle inversion/eversion strength are measured, followed by assessment of the dermatomal distribution of L1 to S1. The patellar and Achilles reflexes are also checked, in addition to Babinski reflex (stroking the lateral aspect of the sole of the athlete's foot with thumbnail or another sharp object and observing for the great toe dorsiflexing and the other toes fanning out), which is evaluated to rule out an upper motor neuron lesion.

Up to 30% of concussed athletes report visual impairments during the first week after initial injury. Dizziness may represent an underlying impairment of the oculomotor and/or vestibular systems. It is reported in approximately 50% of concussed athletes during their recovery timeline and is associated with a 6.4 times greater risk of predicting recovery beyond 21 days [5]. Thus, vestibular/oculomotor screening (VOMS) is clinically assessed with a careful monitoring of symptoms and eye movement abnormalities. Provoking two or more total symptoms after any VOMS item has a high rate (96%) of identifying concussion [5]. VOMS has also demonstrated internal consistency (Cronbach's alpha = 0.92) in identifying patients with concussion [5]. Furthermore, components of the VOMS may also serve as a prognostic indicator of recovery time in SRC [6].

Initially, VOMS begins with the assessment of vertical and horizontal eye smooth pursuits. The athlete is asked to follow a slowly moving target horizontally to the left and right of the athlete's midline and vertically above and below the midline. While doing this, the examiner is observing the athlete's eye movement for any signs of saccadic eye movement (quick simultaneous movement of both eyes between two or more phases of fixation) or nystagmus (uncontrolled repetitive movements of the eyes, otherwise known as "dancing eyes") (Fig. 21.1). The examiner also asks if this test reproduces dizziness, headache, nausea, or fogginess, and if so, to rate it on a scale of 0–6. This is compared to the athlete's baseline symptom severity score that was reported earlier in the SCAT-5 [5].

Horizontal and vertical saccades are then assessed to test the ability of the eyes to move quickly between targets. Horizontal saccades' assessment involves the examiner holding their fingertips approximately 1.5 feet to the right and left of the athlete's midline. Vertical saccades' assessment involves the examiner holding their fingertips approximately 1.5 feet above and below the athlete's midline. The athlete is instructed to move their eyes as quickly as possible from point to point (first horizontally and then vertically) without moving their head. Again, the examiner is

Fig. 21.1 Clinical eye examination as a part of VOMS

observing the athlete's eye movement for saccadic eye movement or nystagmus while monitoring for dizziness, headache, nausea, or fogginess [5].

Vestibular-ocular reflex (VOR) testing is then performed as a means of assessing the ability to stabilize vision as the head moves. The athlete is asked to fully extend their elbow and flex their shoulder to 90 degrees, with their thumb extended in a superior position (thumbs up). The shoulder is adducted, so that the thumb fingertip is midline and at eye level. The horizontal VOR is assessed by asking the athlete to maintain focus on their thumb fingertip while rotating their cervical spine approximately 20 degrees to each side. Ten repetitions are performed, with one repetition consisting of the head moving back and forth to the starting position. The vertical VOR is assessed by holding the thumb fingertip in the same position and asking the athlete to flex and extend the cervical spine 20 degrees while maintaining focus on their thumb. Ten repetitions are again performed, with one repetition consisting of the head moving up and down to the starting position. With both the vertical and horizontal VOR, the examiner is again observing the athlete's eye movement for saccades or nystagmus, while monitoring for dizziness, headache, nausea, or fogginess [5].

Visual motion sensitivity (VMS) testing is performed to assess visual motion sensitivity itself and the ability to inhibit vestibular-induced eye movements using vision. The athlete is asked to stand shoulder width apart, with the examiner standing next to and behind the athlete. The athlete places their thumbs together in front of their eyes with each thumb in the same position done in the VOR testing. While maintaining focus on their thumbs, the athlete rotates their eyes, trunk, and thumbs approximately 80 degrees to the left and right. Five repetitions are performed with one repetition consisting of the trunk moving back and forth to the starting position [5].

Convergence assesses the ability of the athlete to view a near target without double vision. The athlete is seated and wearing corrective lenses only if needed.

The athlete focuses on the examiner's finger, which begins at an arm's length away from the patient. The examiner's finger is then brought toward the tip of the athlete's nose and, throughout this movement, the athlete maintains focus on the examiner's finger. The athlete is advised to inform the examiner when they begin having double vision or seeing two of the examiner's fingers. The examiner also observes for outward deviation of either eye. When this point is reached, the location of this point is measured to the tip of the athlete's nose. This can be repeated three separate times, so that an average length can be recorded [5]. Normal near point convergence (NPC) is considered less than or equal to 5 cm [7]. Although the sensitivity and specificity of NPC as a single measure is unclear, the NPC measurement of greater than 5 cm has a high rate (84%) of identifying concussions [1].

In a study involving youth and adolescent athletes, symptom provocation and eye movement abnormalities in horizontal/vertical smooth pursuits, horizontal/vertical saccades, and VOR testing were associated with delayed recovery from SRC. The reproduction of symptoms and eye movement abnormalities during NPC testing was not associated with delayed recovery in this study [6]. However, a separate systematic review revealed that concussed athletes display impaired NPC acutely, and there is moderate-level evidence that athletes can display impaired NPC for several months postconcussion [8].

The last portion of the physical examination involves the assessment of balance. The Modified Balance Error Scoring System (mBESS) has been validated as part of the assessment of SRC, and it relies on the clinical judgment and observation of the examiner. There are three separate stances (double leg, single leg, and tandem stance) that the athletes maintain for 20 seconds each while standing on a firm surface with eyes closed and hands on their hips. Throughout the 20 seconds, the examiner observes for negative events, which include foot lifting, stepping, falling, removing hands from hips, eye opening, and failing to return to test position for less than 5 seconds. Each occurrence of a negative event is defined as an error and each error is marked as one point that is subtracted from the final score. For the SCAT-5, each stance has a maximum of 10 points, which makes the total maximum mBESS score 30 [4]. For the Child SCAT-5, athletes of ages 10–12 are graded using the same scoring system, but athletes of ages 5–9 are graded with a maximum score of 20. Only the double leg and tandem stances are assessed for the ages of 5–9 [2]. Clinical judgment serves as the gold standard for diagnosing concussion [9], as definitive data are lacking regarding absolute mBESS scores that reliably rule out or rule in concussion [10]. mBESS can also vary throughout a season independent of the concussion status, as it can be affected by environment, fatigue, and lower extremity injuries [5, 7, 10].

Based on the athlete's response to the SCAT-5/Child SCAT-5 and their physical examination findings, the final determination of SRC is made. If an official diagnosis of concussion is not made but there is ongoing clinical concern, the athlete should be held out of participation and undergo serial evaluations for up to 48 hours, due to the possibility of a delayed symptom onset. If an official diagnosis is made, the athlete should not be left alone after the injury and serial monitoring for deterioration should continue over the initial few hours. Monitoring should continue at regular intervals, until the athlete has reached full return to participation (RTP).

An initial evaluation that takes place in the office or subacute setting involves obtaining a comprehensive history, including the mechanism of injury, symptom trajectory, and sleep/wake disturbance. A detailed neurological examination should involve the assessment of gait, balance, neurocognitive function, and a complete cervical spine evaluation. Vestibular and ocular function should also be assessed by using the VOMS tool, VMS, and NPC. Symptom checklists should be used to track symptom trajectory, as the utility of sideline balance and neurocognitive assessments to identify concussion decreases within 3 days after the injury [11]. If computerized neurocognitive testing was performed after the injury, it should be repeated. Making the diagnosis of SRC involves the presence of a clear mechanism of injury along with signs, symptoms, and time course of concussion. In an athlete who has ongoing symptoms during the first clinical evaluation, there should be a focus on excluding other pathologies such as headache/migraine disorder, mood disorder, cervicogenic pain, and peripheral vestibular conditions. There should also be a screening for psychosocial or mental health disorders. These pathologies may be causing the athletes' current symptoms or indicate previous pathology that has been worsened by the presence of concussion [4]. If an athlete is diagnosed with SRC, anticipatory guidance should be provided. It is not atypical for signs, symptoms, and testing to normalize by the time that an office visit takes place [12]. In this case, the visit should focus on establishing a plan for safe return to school and sport.

Return to Participation (RTP) Protocols

The process of return to participation (RTP) is completed with a stepwise progression. After a brief period of initial rest following the injury (approximately 24–48 hours), athletes can be encouraged to become gradually more active while staying below a symptom-reproducing threshold. Preliminary data suggest that early subthreshold aerobic exercise prescribed to symptomatic adolescent males within 1 week of SRC has the potential to prevent delayed recovery and may also accelerate the overall recovery [13]. There are approximately six stages of the RTP protocol:

- *Stage 1*: goal is for the athlete to undergo symptom limited activity, which includes a gradual reintroduction of school and work-related activities.
- *Stage 2*: light aerobic exercise that is done at submaximal exertion with the goal of increasing heart rate. No resistance exercises should be incorporated at this time. Examples of light aerobic activity include walking or stationary bike for no more than 10 minutes at an intensity of 70–80 revolutions per minute (RPM).
- *Stage 3*: may not begin until the athlete is asymptomatic. Sport-specific activity such as skating in ice hockey and running in soccer or football with the goal of adding movement. There is no head impact activity or resistance training permitted.

- *Stage 4*: athlete is permitted to do progressive resistance training. The athlete may also participate in noncontact training drills such as passing drills in ice hockey or football. The goal of this stage is to promote exercise while increasing coordination and thinking.
- *Stage 5*: athlete is permitted to do supervised full contact training, with the goal of restoring confidence and providing a means for coaching staff to assess functional skills. During this full contact training, the athlete is permitted to do all normal training activities.
- *Stage 6*: Return to full participation and normal game play.

For each stage of the protocol, there should be at least 24 hours between the steps in progression. If at any stage the symptoms worsen during the physical activity, the athlete should return to the previous stage. The athlete may then attempt to progress only if symptom free for a 24-hour period at the lower stage. Using this protocol, it takes an athlete a minimum of 1 week to return to full participation once asymptomatic at rest. Athletes who continue to suffer persistent symptoms and inactivity may take longer than 24 hours with each stage due to limitations in physical conditioning [14].

Return to Learn Protocols

Return to learn (RTL) is an important portion of concussion management and there is no standardized protocol of school accommodations that can be provided to teachers, professors, and school administrators. The 2017 Berlin Concussion in Sport Group Consensus Statement recommends that athletes "should not return to sport until they have successfully returned to school" [14]. Currently, students are provided with a list of school accommodations from their physician that can be given to school administrators and disseminated to all teachers and professors. Part of facilitating communication and transition back to school involves obtaining consent between medical and school teams. Accommodations are given with instructions to incorporate as necessary. These depend on the athlete's course of symptoms, academic demands, and preexisting medical conditions (learning disability, mood disorder, or ADHD). The accommodations include the following:

- Extended time on exams/quizzes
- Permission to record lectures/note-taking assistance
- Exams/quizzes in a quiet location
- Absence from class due to scheduled rest periods
- Limit to one exam per day
- Limit the use of electronic screen or adjust screen settings
- Allow the use of headphones or ear plugs to reduce noise sensitivity
- Allow sunglasses or hats to reduce light sensitivity
- Frequent breaks from class, if symptomatic
- Due dates/assignment extensions

- Late arrival or need to leave, prior to the end of class (to avoid crowded hallways)
- Avoid busy, loud, or crowded environments (hallways, lunchroom, assemblies, music room)
- Use of a reader for exams/quizzes
- Defer exams/quizzes

Many athletes recover quickly enough to return to the classroom with no or brief adjustment of academic activities. Schools should be prepared to provide additional support in case recovery takes longer. Athletes who suffer from persistent symptoms should be given an individualized RTL plan that allows for symptom limited activity.

Referral and Management

Multiple symptoms can result from SRC, particularly related to the cervical spine and vestibular system. Most athletes who suffer SRC recover within 10–14 days. However, persistent symptoms are defined as greater than 4 weeks in children and greater than 10–14 days in adults [14]. Prolonged symptoms may result from a primary persistent change in brain function or represent confounding processes, including headache syndromes, depression, and/or oculomotor or vestibular dysfunctions that do not necessarily reflect an ongoing physiological injury to the brain. Psychiatric comorbidities particularly indicate the risk of persistent concussion symptoms and may increase the magnitude of symptoms reported.

Athletes who experience symptoms that are considered persistent or have impairments on physical examination related to the injury may benefit from specific rehabilitation programs. For athletes who have persistent symptoms associated with physical deconditioning or autonomic instability, an individualized symptom limited aerobic exercise program should be instituted. The Buffalo Concussion Treadmill Test (BCTT) is a standardized graded aerobic exercise test that can reliably detect physiological dysfunction in athletes with persistent postconcussive symptoms and quantify exercise capacity to guide treatment [15].

Tilt table testing can also be used to identify autonomic dysfunction in athletes with persistent lightheadedness or vertigo [16]. However, its utilization in the clinical setting is unclear, as there are other simple measures such as orthostatic intolerance or heart rate variability that can be used [17].

There has been evidence of demonstrated benefit with targeted multifaceted physical therapy programs, particularly in patients with cervical spine and/or vestibular causes of symptoms [18]. Athletes with persistent mood or behavioral symptoms should be referred for cognitive behavioral therapy (CBT). A mixed SRC and non-SRC adolescent cohort provided preliminary support for the role of CBT in the management of persistent postconcussive symptoms [17].

Despite widespread use, there is currently no compelling evidence to support the use of pharmacotherapy such as amantadine or peripheral nerve blocks in the treatment of persistent postconcussion symptoms. However, a retrospective study demonstrated that amitriptyline was an effective treatment and was tolerated well in patients with posttraumatic headaches. In this study, female patients were more likely to report posttraumatic headaches, and amitriptyline was found to reduce headache symptoms in 82% of patients [19].

There is evidence that some nutraceuticals may protect or reduce recovery time from concussion in animal models. Vitamin D, omega 3 fatty acids, certain B vitamins, progesterone, and N-methyl-D-aspartate (NMDA) have been investigated. However, there has been no human evidence to show reduced recovery time or protective effect with these agents [4]. Enzogenol®, an antioxidant extracted from the bark of *Pinus radiata* trees, has shown promise as a nutraceutical in the treatment of postconcussion symptoms. Specifically, those individuals who underwent a 6-week Enzogenol supplementation reported reduced mental and physical fatigue and these reports were supported by reduced mental fatigue measures on electroencephalograph (EEG) [20]. If pharmacotherapy or nutraceuticals are begun during the management of SRC, a decision should be made regarding return to play while an athlete is still taking the medication by the treating physician. This is particularly important because the medication may be masking or modifying certain SRC symptoms [17, 18].

Screening neuropsychological testing is often used in the acute setting, and a formal neuropsychological assessment is used when an athlete suffers from persistent symptoms. Paper-and-pencil neuropsychological testing has been used with a variety of test batteries that measure multiple aspects of memory (new learning), cognitive processing speed, working memory, attention, and executive functions. Although the validity of the tests has been well documented, most studies have not demonstrated that paper-and-pencil neuropsychological tests can detect concussion once players are asymptomatic [21]. The tests are extensive and thorough but have increased the cost of administration and interpretation. They are also not ideal for serial use, as a great amount of time is required by the athlete and neuropsychologist. Computerized neuropsychological testing is efficient in the sports medicine setting and useful for serial testing. There are five computerized neuropsychological tests that are available for evaluation of sport-related concussions: Immediate Post-Concussion Assessment and Cognitive Testing (ImPACT), Automated Neuropsychological Assessment Metrics (ANAM), CogSport/Axon Sports Computerized Cognitive Assessment (CCAT), and Headminder Concussion Resolution Index (CRI).

ImPACT is a computerized neuropsychological test that was developed to assess symptoms in addition to cognitive domains such as attention span, working memory, response variability, nonverbal problem-solving, reaction time, and sustained and selective attention. Composite scores are calculated for visual memory, verbal memory, reaction time, impulse control, and processing speed. While it is widely used for baseline testing and in the assessment and management phases of concussion, there are limitations. There is varying test-retest reliability, which can be influenced by the athlete's testing environment and level of academic achievement [22]. Other factors that also influence the testing include gender, level of alertness, effort, and prior testing [23]. In general, testing should not be repeated multiple times in a short time span.

ANAM was developed for serial testing and precise management of cognitive function in the US military. However, a sports medicine battery evolved and includes the assessment of concentration (code substitution and continuous performance test), attention (continuous performance test), mental processing (code substitution-delayed), mental processing speed and efficiency (mathematical processing), reaction time (simple reaction time), and visual memory (match to sample). Several studies have shown that ANAM has consistent correlations with traditional neuropsychological tests, which suggest adequate concurrent validity [21, 24, 25].

The CogSport Axon Sports CCAT is designed to keep the athlete motivated by being brief. It focuses on the speed and accuracy to detect changes in cognitive measures. The four included tests are processing speed task, learning task, working memory task, and attention task. The test developer recommends baseline testing be performed once a year or before each contact sport season. The developer also recommends using this test more often if an athlete sustains a concussion or is going through a period of maturation. This test has been shown to have clinical utility and sensitivity, as 70.8% of concussed patients in a cohort study showed a decline from baseline in one or more tests while symptomatic [17, 26].

The Headminder CRI is composed of six subtests to measure visual recognition, speed of information processing, and reaction time. The subtests include the reaction time subtest, cued reaction time subtest, animal decoding subtest, visual recognition 1, visual recognition 2, and symbol scanning. This has been shown to have a sensitivity of 78.6% for detecting concussion at 24 hours, compared to 68% for self-reported symptoms and 43% for paper-and-pencil tests [27].

Computerized neuropsychological test results should be interpreted by the treating clinician and serve as a single component of concussion management in addition to the athlete's entire clinical presentation [11]. Formal neuropsychological testing can identify persistent brain function deficits in athletes following SRC and can impact the determination of limitations and cognitive capacity with schoolwork. However, there are limited data on the utility of formal testing with athletes who suffer from persistent symptoms and further studies are needed [4]. Overall, athletes with persistent symptoms should be managed in a multidisciplinary setting by healthcare providers (primary care sports medicine neurology, neuropsychology, psychiatry, rehabilitation medicine) with experience in SRC [17, 26].

Other measures have evolved as potentially useful tools; however, they are largely still used in research settings. Virtual reality (VR) has also recently gained attention as a possible neurological assessment tool to detect deficits in balance, spatial memory, immediate memory, delayed recall, and reaction time (Fig. 21.2). The conceptual origins of neurological behavior testing arose in response to behavioral and neurocognitive dysfunction seen in war veterans by Luria, and has since been developed with advances in technology as a way to score and monitor deficits [28]. While this modality proves to have potential in diagnosing concussion and identifying specific deficits, it has only been used in research and has not yet been standardized for clinical use.

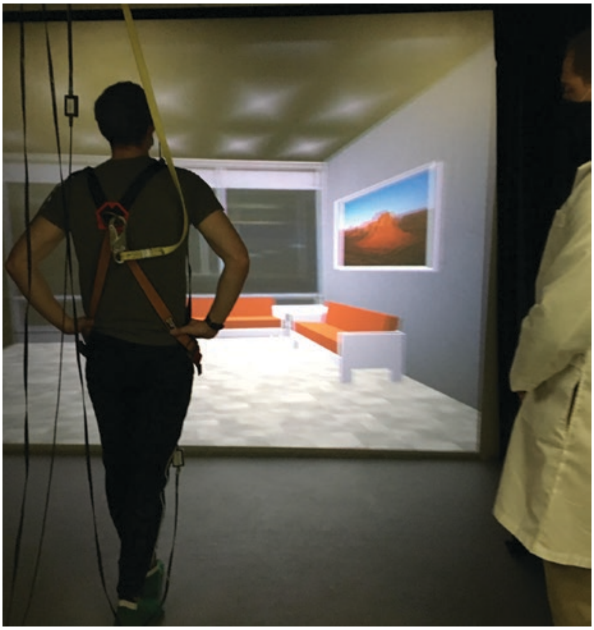

Fig. 21.2 Example of a virtual reality setup

The role of biomarkers (saliva, cerebrospinal fluid, blood) in the diagnosis of concussion is under active investigation, given their potential for predicting the pathophysiology and neurobiological recovery. The overall evidence of using fluid biomarkers for diagnosis of SRC is low, as more research is needed to determine their clinical utility. There is also currently no evidence to support genetic testing as a tool for the evaluation and management of athletes with SRC [29].

Structural imaging techniques, such as magnetic resonance imaging (MRI) or computed tomography (CT), have limited value in athletes with persistent postconcussive symptoms. However, advanced imaging techniques, such as quantitative EEG, magnetic resonance spectroscopy (MRS), diffusion tensor imaging (DTI), and functional MRI (fMRI), have shown changes in brain activation patterns in athletes with persistent symptoms. These findings are shown, even after the athlete has returned to sport and recovered clinically. However, the clinical significance of these findings is yet to be determined. Thus, the use of advanced neuroimaging in the research setting should continue to be encouraged to provide further understanding about the etiology of persistent symptoms [17, 26].

Long-Term Follow-Up/Assessment

Studies pertaining to the long-term consequences of exposure to recurrent head trauma are inconsistent. There is much to learn about the possible cause and effect relationship between repetitive head trauma and concussions. Subconcussive head impacts, which are defined as transfers of mechanical energy to the brain causing axonal or neuronal damage in the absence of clinical signs or symptoms, have been associated with neurologic disorders including chronic traumatic encephalopathy (CTE). CTE is a distinct tauopathy with an unknown incidence in athletic populations. There has been no concrete relationship demonstrated between CTE and SRC or exposure to contact sports. More research is needed to understand the prevalence, incidence, risk factors, protective factors, and clinical diagnostic criteria as well as the extent of neuropathological progression [14].

The short- and long-term effects of repetitive head impacts cannot be characterized using current technology. Future research will focus on developing technologies that can assess any brain changes after repetitive asymptomatic head trauma [4]. Although current impact sensors indirectly monitor linear and angular acceleration forces to the head, they may not consistently record forces transmitted to the brain. Current impact measures are a poor predictor of SRC, as some athletes experience no symptoms with high forces and others suffer a concussion with lower impact forces [30]. Thus, impact monitors are currently only a research tool and require additional study.

A prior history of SRC, participation in collision sport, and being female are considered risk factors for SRC. History of multiple SRCs is associated with more emotional, cognitive, and physical symptoms, prior to participation in a season. Currently, the most consistent predictors of slower recovery from SRC are the initial severity and number of symptoms within the first few days of the injury. Having a low level of symptoms on the first day after the injury is a positive prognostic indicator [14]. For most injured athletes, symptoms improve rapidly during the first 2 weeks after injury. Recent studies have reported longer recovery times, but this may have been influenced by ascertainment bias as well as increased adoption of graduated RTP protocols [14].

According to the 2017 Concussion in Sport Group (CISG) consensus statement, it is reasonable to say that clinical recovery takes place within the first month of injury for most athletes. Children, adolescents, and young adults with a pre-injury history of migraine headaches or mental health disorders are at risk of suffering from symptoms for more than 1 month, while those with history of ADHD or learning disability are not. However, athletes with history of ADHD may need different planning and intervention strategies when returning to school. One concern is the fact that neurobiological recovery may extend beyond 1 month in some athletes [14]. Recent studies have suggested that physiological recovery could exceed the time of clinical recovery, which could lead to an athlete returning to play while still having ongoing brain dysfunction. This highlights a significant challenge to the clinician, who needs to be mindful of the potential risks of returning athletes to sport too early. It also brings and highlights some limitations with current clinical practice.

Issues and Drawbacks from Current Practice

Rule changes have taken place in the sports of ice hockey and American football with efforts to reduce SRC. The Ice Hockey Summit III recently provided updates regarding SRC in ice hockey and discussion on rule changes. In June 2011, USA Hockey approved a rule that banned body checking in youth hockey until the bantam level (ages 13–14). Subsequently in September 2013, Hockey Canada also announced a body checking ban in the peewee youth hockey (ages 11–12). Implementing these bans in the USA and Canada has reduced the incidence of SRC in peewee hockey by 67% [31]. The American Academy of Pediatrics (AAP) has also recommended restricting body checking in boys' youth ice hockey to the highest competition levels (Tier 1, Tier 2, AA, AAA), starting no earlier than 15 years of age. Furthermore, the AAP has recommended reinforcement of boys' youth ice hockey rules to prevent body contact from behind (especially into or near the boards), strict enforcement of zero-tolerance rules against any contact to the head, and a continued emphasis on coaching education to prevent body contact from behind [32].

In American football, kickoff rule changes at the collegiate and professional level have taken place recently. At the collegiate level before the 2012 season, kickoffs were moved from the 30-yard line to the 35. The starting position of the team receiving a touchback was also moved from the 20-yard line to the 25. In 2016, the Ivy League passed a conference-specific rule change that moved the kickoff line from the 35-yard line to the 40. With this rule, the team who received a touchback would start from the 20-yard line, instead of the 25. The intent of this rule was to have more kickoffs land in the end zone and reduce the likelihood of the receiving player in advancing the ball. However, there was a possibility that the movement of the touchback line would lead receivers to try and advance the ball, even when kicked into the end zone. A before-after study took place that examined the annual concussion rates before and after this rule, change was implemented. The mean annual concussion rate per 1000 kickoff plays was 10.93, prior to the rule change and 2.04 after. Although results of this study may not be generalized beyond the Ivy League, it does provide insight for further consideration of kickoff rule changes in all collegiate conferences [33].

The National Football League (NFL) also moved the kickoff line from the 30-yard line to the 35 in 2011. In 2018, further kickoff rule changes included multiple changes for blocking and line-up locations for the kicking and receiving teams (Fig. 21.3). These current rule changes are still in effect and include the following:

- The kickoff team must have five players on each side of the ball and cannot line up more than one yard from where the ball is kicked.
- On each side of the ball, at least two of the players must be lined up outside the yard line number and at least two players between the yard line number and inbound lines.
- For the receiving team, eight players must be lined up in the 15-yard setup zone (15 yards away from where the ball is kicked) and three players are permitted outside this setup zone.
- Double team blocking can only be performed by members of the receiving team located in the setup zone at the time of kick.
- Wedge blocks (two or more players intentionally aligning shoulder-to-shoulder within two yards of each other, and who move forward together with the purpose of blocking for the runner) are not allowed.

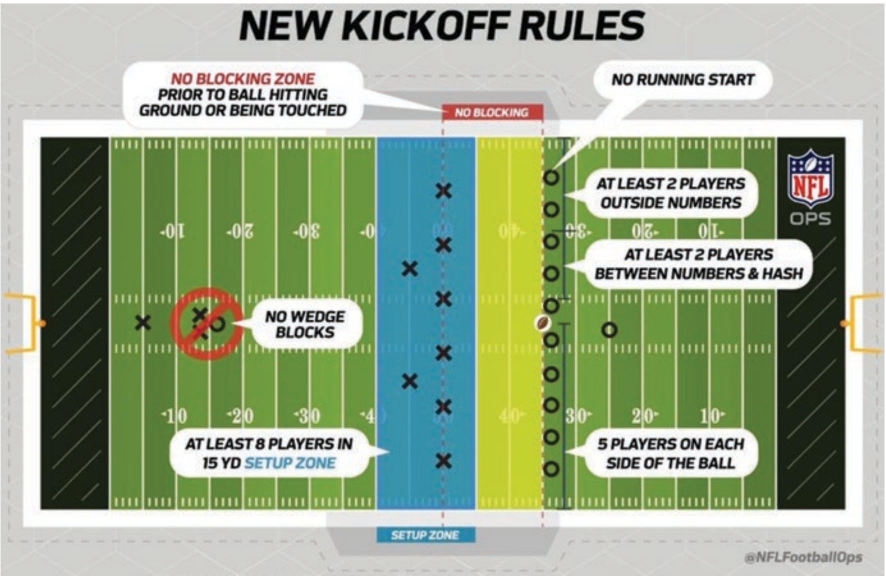

Fig. 21.3 Diagram of NFL kickoff rules

- No player from the kicking or receiving team can block within the 15-yard area from the kicking team's restraining line, until the ball is touched or hits the ground.
- A touchback is called if the ball is not touched by the receiving team but touches the ground in the end zone.

A major limitation with current clinical practice includes inconsistencies with symptom reporting in athletes who suffer SRC. At the high school level, access to athletic trainers can vary, and athletes without access to athletic trainers tend to have lower knowledge of SRC symptoms. Furthermore, these athletes may report their symptoms to a head coach, which is different to reporting to a medical professional. It has also been found that increased knowledge does not necessarily lead to increased reporting behaviors. Many athletes fear that coaches will remove them from a starting position if they report symptoms. Other reasons for not reporting symptoms include not wanting to lose playing time, fear of letting their team down, and feeling that an injury is not serious enough to require medical attention [34].

At the collegiate level, many athletes have a basic understanding of SRC but still fail to identify all the signs and symptoms. Many athletes also continue participating in practices and games after sustaining a possible injury, which suggests a potential lack of understanding of the consequences of SRC. Both female and male athletes have had decreased reporting of symptoms due to not knowing if an injury was a SRC or not believing SRC to be serious [35]. Male athletes have been shown to report less symptoms in comparison to female athletes. Reasons for this discrepancy include not wanting to let their team down in addition to male athlete identity, stigmas, and perceived perceptions of coaches and teammates [35].

Previous experience with concussion (i.e., a greater number of previous concussions) has been shown to negatively impact athlete disclosure of and attitude toward concussion. This may stem from prior experience of being removed from play or from the way that previous concussions were managed. Attitudes may also be driven from perceptions of social, school, or team environment norms. Thus, addressing negative attitudes to concussion may help in improving disclosure in young athletes [36].

Policy changes that have taken place to reduce the health impact of SRC include prevention, education, and rule change programs. The Centers for Disease Control and Prevention (CDC) Heads Up (HU) program was introduced as an educational outreach program, with the goal of improving player safety for youth and high school players (Fig. 21.4) [37]. As part of this program, coaches are trained and certified on safety fundamentals, including proper tackling techniques, ensuring appropriate equipment fitting, and teaching others involved in football (other coaches, players, and parents) on how to recognize and respond to injuries. Additionally, parents, officials, and other athletes have access to the CDC's HU program to protect athletes from concussion or serious brain injury by learning how to spot a concussion and knowing what to do if a concussion takes place. In May 2009, the state of Washington passed the "Zackery Lystedt Law" to address concussion management in athletes, and this was the first state law to require a "removal and clearance to return to play" among youth athletes. According to the Centers for Disease Control and Prevention (CDC), all 50 states now have a return to play law.

A prospective cohort study that took place during the 2015–2016 high school football season evaluated the impact of the HU program on SRC incidence. The SRC incidence of 14 high school teams with one coach who underwent training in the HU program (HU programs) was compared to 10 control teams who did not have training in the HU program (non-HU programs). The HU programs demonstrated a 33% lower concussion rate and 27% faster return to participation in comparison to the non-HU programs. However, limitations of this study were the nonrandomized assignment to each group and the fact that team sizes in the non-HU programs were smaller than the HU programs. Exact game exposures were also not available and specific SRC game incidence rates could not be created [38]. Larger studies with equal sample sizes over longer periods of time are needed to provide more data on the impact of HU programs with SRC incidence.

Despite access to the CDC's HU program, not all collegiate coaches receive basic training regarding SRC. In a cross-sectional online survey, two-thirds of US collegiate coaches reported receiving instructional material about concussion from their respective institutions. The material typically contained information about symptoms and proper management of concussion. This survey also contained a test that assessed the overall general knowledge regarding SRC of the coaches. Female coaches of noncontact or collision teams more frequently answered correctly in comparison to male coaches of male contact or collision teams [39]. This is concerning but not surprising as qualitative evidence has shown that in Division I football programs (all of which are coached by men), competitive pressures can lead to a conflict of interest in the care of concussed athletes [40].

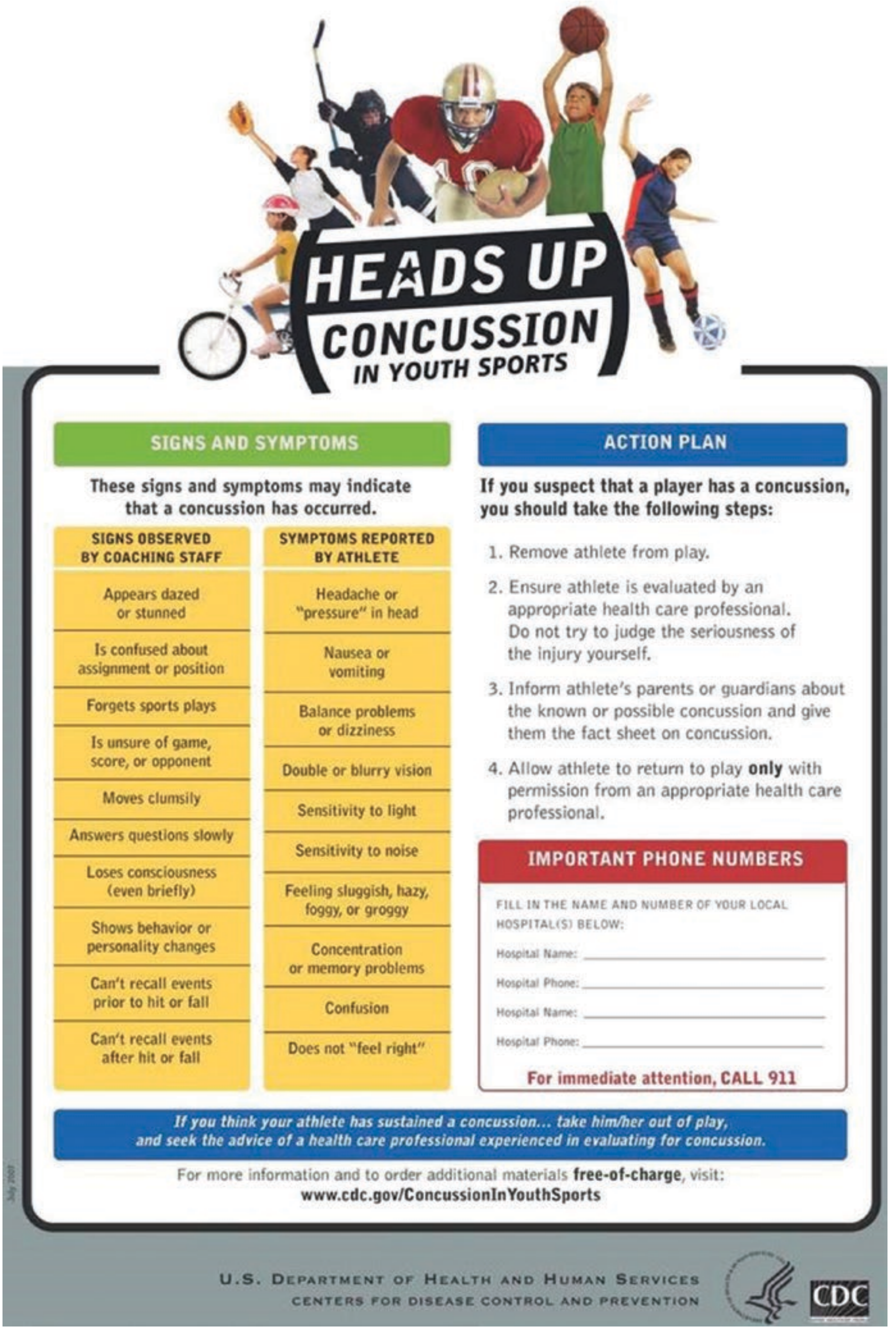

Fig. 21.4 CDC's Heads Up concussion initiative

Clinical testing for concussion also has its limitations, including reliance on the subjective nature of athlete reported symptoms, variability of presentation, and varying sensitivity and specificity of sideline assessment tools. It is also difficult for healthcare providers to establish a timeline of recovery after SRC. Suboptimal neuropsychological testing, as well as the lack of a gold standard diagnostic tool, limits the clinician's ability to make this determination. As mentioned previously, physiological recovery may continue after clinical recovery has taken place. Modalities that provide insight into physiological recovery include fMRI, MRS, DTI, cerebral blood flow (CBF), electrophysiology, fluid biomarkers, heart rate, measures of exercise performance, and transcranial magnetic stimulation (TMS). However, at this time, these modalities are not used clinically but are available for use in the research setting. Going forward, it is recommended that studies are designed longitudinally and follow both clinical and physiological recovery. This may help with correlating neurobiological modalities with clinical measures and allow clinicians to better treat athletes suffering from SRC.

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