2017

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ANALYSIS OF SIDELINE CONCUSSION SCREENING TOOLS

IN AN ATHLETIC SETTING

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BS – University Studies, Brigham Young University - Idaho, Rexburg, ID, 2013

Professional Paper

presented in partial fulfillment of the requirements
for the degree of

Master of Athletic Training

The University of Montana
Missoula, MT

May 2017

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In the past decade, significant research into sports-related concussions has expanded understanding of what is as a very complex injury. As the definition of concussion has evolved, the impact they have is put into perspective. As more research into the short- and long-term effects of concussions brings to light the effects of continuing to participate after suffering a concussion, the importance of keeping concussed athletes off the field is now understood as a potential life or death situation. With the dangers of continuing to play after concussion becoming apparent there has been a renewed emphasis on tools and/or techniques that screen for symptoms of concussion. Some of the most widespread include, but are not limited to, the Standardized Assessment for Concussion (SAC), the Balance Error Scoring System (BESS), the Sideline Concussion Assessment Tool 3rd Edition (SCAT3) and King-Devick Test (KDT). This paper will explore the benefits, limitations, and implementation of each of these assessment tools.

A crucial part of improving rates of concussion recognition is to look at what has been developed based on the most current understanding of concussions. As more attention has been drawn to the potential dangers of concussions and repeated sub-concussive blows there has been a surge in funding and studies regarding current and developing technique's and tools. This paper examines tools recently implemented or under development and explores their potential benefits, limitations and availability. These include Vestibular-Ocular Motor Screening (VOMS), force plate balance testing and blood tests for proteins associated with injury to the brain. The paper concludes with a discussion of the benefits, limitations and reliability of each test. Recommendations are made for developing a sideline concussion screening protocol. It serves as a primer to healthcare professionals of the now and future of sideline screening for concussion.

Introduction:

The Center for Disease Control (CDC) referred to an increase of mild traumatic brain injury as an epidemic.[1,2] Data collected from 2001-2009 showed a 62% increase in non-fatal traumatic brain injuries[3]. Estimates of reported and unreported concussions range as high as 3.8 million per year in the United States.[4] There has been considerable discussion of how to classify concussions as an injury. Recently, for various reasons, concussions have been in the news alongside Chronic Traumatic Encephalopathy (CTE). Also worth noting is that the terms concussion and mild traumatic brain injury (mTBI) have begun to be used interchangeably within the context of sports, particularly within the United States.[5]

In the past decade, significant research into sports-related concussions (SRC) has expanded understanding of what is as a very complex injury. As the definition of concussion has evolved, the impact they have has become apparent. Youth in particular are susceptible to multiple concussions.[6–8] As more research into the short- and long-term effects of concussions brings to light the effects of continuing to participate after suffering a concussion[5,9–11], the importance of keeping concussed athletes off the field is now understood as a potential life or death situation.[12,13] Research has shown that upwards of 20% of patients who suffered SRC had prolonged (> 3 week) recovery.[14] In the past decade there has been an increased emphasis on the long-term effects and/or risks of continuing to participate in sports after head injury. Of note are post-concussion syndrome (PCS), second impact syndrome (SIS), and the proposed connection with chronic traumatic encephalopathy (CTE).

Post-concussion syndrome, or PCS, is the continuation of concussion-like symptoms for a period of greater then 90 days after the initial injury.[15] Those who suffer continue to have symptoms for up to a year after the initial injury. The continuation of symptoms has an impact on the patient returning not only to play, but to normal function. It is a condition that has significant impact on the patient, but is not in itself dangerous outside of the impact of symptoms. This is an area of increasing research that will shed further light upon the long-term repercussions of concussions.

In contrast, the pathophysiology of concussion places pressure on the brain and this increases the risk of macrostructural injury. Second impact syndrome (SIS) is a term referring to the rapid escalation of symptoms that can occur when a concussed individual is subjected to additional biomechanical forces before proper and complete healing has taken place after concussion. There is debate about whether this should be considered a syndrome, or if it even exists.[16] What is accepted is that there is potential risk among contact sports for serious head trauma, and that precautions should be put in place to reduce risk to the lives of participating athletes.

Recently there has been significant public and private attention given to a condition commonly referred to as chronic traumatic encephalopathy, or CTE. This has led to increased funding and research directed towards concussions and their potential long-term effects. In times past, a series of symptoms similar to CTE, called dementia pugilistica, was associated with boxers. CTE is described in the literature as an accumulation of phosphorylated tau within the brain, leading to chronic progressive cognitive and neuropsychiatric symptoms.[17] There are challenges as to whether CTE should be classified as a disease itself, as its presentation and positive findings exist previously within the literature.[18] What is accepted is that there appears to be a link between recurring head trauma, including sub-concussive blows, and a potential increase in mental or emotional symptoms.[17,19] This has led to an increased emphasis on reducing blows to the head in contact sports, including rule changes and equipment research.

Statements put forth by the International Consensus Conference on Concussion in Sport(ICCCS)[5], National Athletic Trainers' Association (NATA)[13], and the American Medical Society (AMS)[9] have established expectations for evaluating whether an athlete should be removed from play. All three organizations agree it is critical that the evaluation of an athlete who may have suffered a concussion be quick, effective, and reliable.[5,9,13] For this reason the NATA advises that every program, or athletic trainer (AT), establish protocol that fits within their needs and budget.[13]

With the symptoms of a concussion being as varied as they are it is often difficult to determine if an injury has taken place.[12,20] Proper diagnosis is critical for safety of the athletes participating.[21] The established protocol is to remove any athlete from play who is suspected of a potential concussion.[5,13] Often this is difficult to uphold; as some athletes feel that they are well enough to continue, or pressure is placed on the AT by parents, coaches or administrative staff to allow the athlete to continue. It is important to remember that a proper diagnosis cannot be made without systematic injury evaluation being completed[5,13], and rarely is this option available to the medical staff on-site.

Sadly, it is not uncommon that no health care provider (HCP) is available to make return to play (RTP) decisions, and the decision falls on parties that have a vested interest such as coaches, parents and administrators. Therefore, it is critical to educate officials and involved parties of the signs, symptoms, and consequences of concussion. Officials must serve as the objective party when no HCP is available to make potential RTP decisions. They have the authority to enforce their decisions, and to prevent athletes from participating until given proper medical clearance.

The question is how to best assess the possibility of a mental status change, the hallmark of concussion[12,20,22,23], as part of a sideline evaluation. As symptoms vary on an individual basis[5], and are mimicked by athletic activity[24,25] it is crucial that any method chosen be able to differentiate whether a mental status change has taken place. A critical part of recognizing any change lies in establishing what is normal, or the patients baseline uninjured status. Without a baseline no quantifiable change is determined.[5]

It is critical that the athletic trainer be prepared to recognize potential concussion symptoms and be prepared to remove from competition those that are at risk of further injury. The goal of this paper is to provide sufficient background on the pathophysiology of the injury, potential symptoms, as well as examine common sideline concussion screening tools (SCST) both current and of future consideration. It includes a discussion of these methods and explores what symptoms they target. The complexity of concussions mean that the answers are not simple; rather it is the authors opinion that a thorough understanding of what SCST's are available, or may soon be, is a benefit to every athletic trainer, and those who interact with them to keep athletes healthy and safe. The purpose of this work is to serve as a primer to athletic trainers regarding available, or potential, sideline concussion screening tools. It explores the strengths, limitations and critical facts regarding their implementation and use.

Pathophysiology of Concussion:

An understanding of the pathophysiology of concussion brings to light an understanding of the dangers of unrecognized injury, and inspires a greater understanding of the diversity presented by what is now understood as a complex injury that is often unique to the individual afflicted. Recent research has begun revealing the pathophysiological consequences of concussions. In order to properly recognize the potential of injury, it is important for the clinician to understand that pathophysiological changes occur after the application of biomechanical force.[26] A concussion presents as neurological symptoms without associated macrostructural injury[5], which indicates the possibility of a more severe traumatic brain injury. With a concussion, the damage is often microstructural or functional, and affects the neural tissue as opposed to the macrostructures of the brain itself.[27] It has been proposed that when insufficient time is given for the neural tissue to heal after injury that it becomes stuck within the healing process leading to the potential for long term effects, such as those found in chronic traumatic encephalopathy (CTE).

After the application of biomechanical force creates microstructural damage, a neurometabolic cascade takes place.[26] After the initial impact that increases biomechanical forces on neural tissue, a disruption of the chemical processes of the cellular membranes constructing the tissue results in the aforementioned cascade of glutamate release leading to an ionic flux (See Figure 1).[27] This ionic flux initiates as glutamate triggers receptors that control the flow of sodium and potassium ions through cellular barriers. Potassium is then forced out of the cell leading to depolarization of the neurons. This creates a feedback loop as additional channels open and lead to further depolarization. This results in a diffuse

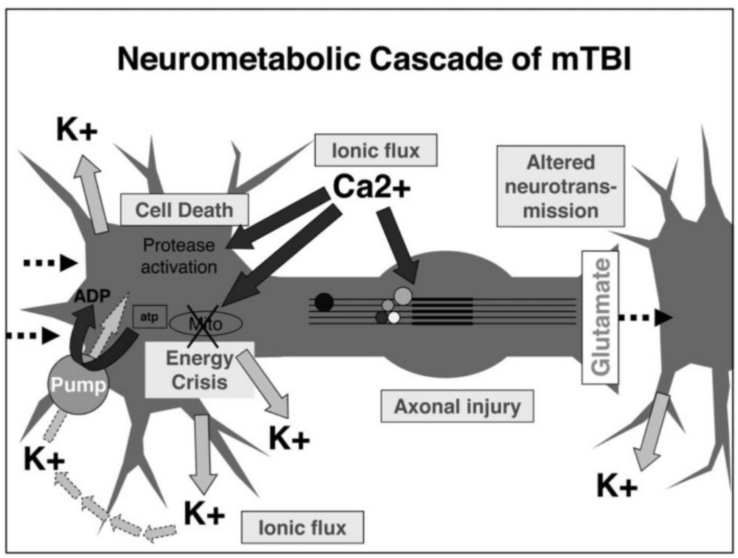

Figure 1: Diagram of acute cellular processes occurring after concussion[27]

"spreading depression-like" state that may explain the acute biological impairments post-injury.[27]

Also affected is cerebral blood flow. When operating under normal conditions the body maintains a constant supply of blood to the brain through cerebral vasoreactivity. When a concussion injury occurs this mechanism is disturbed resulting in reduced autoregulation.[28] This process begins immediately after injury, and is slower to cease at the site of injury.[26] During this time the body is working to restore homeostasis to the environment by increasing ionic pumps to restore the proper ionic balance to the affected cells. This leads to a state of hyperglycolysis and in combination with decreased cerebral flow results in an imbalance of supply and demand.[27]

The cumulative effect of these processes unbalances systems including but not limited to diminished vision, balance and reaction times. These reductions in body systems make it dangerous for an injured athlete to continue activity, as while they are exposed to additional biomechanical forces, the potential for macro-level damage is increased. Further damage increases risk for greater injury, long-term deficits and death; such as with second impact syndrome which occurs when a second impact is sustained before the patient has recovered fully from the previous injury, leading to diffuse cerebral swelling that leads to unconsciousness within minutes. As understanding of the pathophysiology of concussion expands, so does understanding of the potential damage, such as SIS and CTE, when concussions go undiagnosed and/or untreated.

Role of Athletic Trainers:

Athletic trainers are uniquely positioned to recognize potential concussion among athletes. In most situations where an athletic trainer is present, they are the first, if not only, medical personnel to interact with the athlete. Certified athletic trainers have received comprehensive training in the recognition and management of concussion.[13] Athletic training staff also see the patient on a frequent basis, and are more familiar with an individual athlete's behavior. Just as an athletic trainer would recognize a change in gait; changes in behavior, emotions or biomechanics are observed that necessitate the use of a SCST.

Athletic trainers are also critical players in post-injury management. After screening a patient for concussion, and once a concussion diagnosis is confirmed, the athletic trainer acts as a buffer for the athlete in navigating recovery of this complex condition. The responsibilities placed upon an athletic trainer allow them to be able to have frequent interactions with the concussed athlete, and to recognize day-to-day changes in symptoms. Every concussion is different, even within the same patient. The familiarity that athletic trainers develop with their athletes allows them to more accurately cater to the individual needs of the athlete.

Beginning the proper rehabilitation process, the athletic trainer works with the athlete's physician to implement protocols based on the patient's individual needs. Through relationships with coaches and school staff, the athletic trainer helps facilitate an environment that encourages the patient's full recovery. They are also positioned to allow the athlete to, appropriately, remain integrated with the team; as well as coordinate RTP protocols as established by the patient's physician and athletic trainer. Supervising steps of established RTP protocols allows the athletic trainer to recognize the return of symptoms that the patients themselves might not be aware of.

Clinical Presentation of Concussion:

To properly discuss the usefulness of SCST's, it is critical to understand the most widely recognized symptoms that are linked to concussion injuries. Recent evidence proposes that concussions are not the homogenous, one-size-fits-all injuries once assumed. In previous generations, a concussion was not even suspected unless there was a period of unconsciousness. It is now known that concussed athletes present with a wide array of symptoms that may or may not be clearly linked to the injury itself. It is now accepted within the healthcare community that concussions are individual injuries needing individualized care. This can put a great burden on medical providers to provide the best care possible, as they are often restricted to subjective information, with little objective data or measurements. It is essential that healthcare providers get a thorough history to maximize understanding of the injuries impact upon that individual.

It has been proposed, to provide for the most efficient care, that patients exhibiting similar symptoms can be classified within clinical 'trajectories' of concussion.[29] This modern, conceptualized approach to sport-related concussion allows for the heterogeneity of individual injuries, while allowing for clinicians to recognize avenues and pathways to improve patient care and recovery on an individual level. These trajectories are: Anxiety/Mood, Cervical, Migraine, Cognitive/Fatigue, Vestibular, and Ocular. Recognition of these trajectories, and the clusters of symptoms associated with each, help guide concussion screening by guiding the athletic trainer. For example, if a patient exhibits aggression that is out of character, yet does not exhibit other signs within the anxiety/mood trajectory, further evaluation should be used to determine if the game state has increased aggression, or if it is a sign of something more. This can be further expanded to allow the clinician to recognize potential symptoms that are most commonly seen within the suspended trajectory and to verify those have been appropriately evaluated. Increased awareness of these pathways can help clinicians determine what evaluation methods are best suited for individual patients.

Anxiety/Mood

Emotion- or mood-based symptoms vary widely and are often different between patients. One patient might exhibit an increase in aggression, while another teammate becomes withdrawn. The neurometabolic cascade that takes place after injury leads to a wide array of emotions, often outside of the control, or even awareness, of the patient.[27] For example, it is not uncommon for an athlete to become more aggressive during competition, but recognizing anger within a normally calm athlete is a sign that there is the potential that an injury occurred and indicates further evaluation and/or screening.

This trajectory is characterized by a marked increase in anxiety, including hyperawareness, depression, feelings of hopelessness, and rumination. There is also the possibility of sleep disturbances; coming from a hypervigilant state or worry. The patient may also confuse the symptoms of anxiety as feeling slow or struggling to focus.[29] An accurate and complete history will help determine whether symptoms are related to an acute injury.

Cervical

These patients do not present with the classic motor or sensory symptoms of concussion. Their symptomology focuses on headaches and neck pain. It is critical that these patients receive a full work-up to verify stability in the cervical region. While this is standard practice for most AT's, it is important that their head and neck pain does not have a musculoskeletal explanation that may need further treatment. It is critical that the clinician gather a full and complete history to understand onset, location, severity, and characterization of the headaches to understand potential triggers and to differentiate from migraines.[29] It is easy for a clinician to readily determine that a football player that took a significant hit during a play is feeling sore from impact, and overlook potential signs of a concussion.

Post-Traumatic Migraine

Patients who would be grouped within this trajectory suffer post-traumatic migraines ranging from intermittently to frequent. Post-traumatic migraines are defined as a unilateral, moderate-to-severe intensity headache following head trauma with a pulsating quality and associated with nausea and photo-/phono-sensitivity by the International Headache Society.[30] Triggers include stress, fatigue, emotional changes, and caffeine. It is important to note that those following this trajectory may not immediately present with the symptoms immediately after injury. This can make it difficult to immediately recognize this pathway during sideline screening.

Cognitive/Fatigue

Commonly associated with concussion, cognitive issues stem from disruption of any number of many different pathways. This has been described as a feeling of general 'fogginess' or apathy, and can be associated with increased feelings of fatigue. Memory issues range from difficulty repeating instructions, short-term memory loss or difficulties, to antero- or retrograde amnesia. Attention issues manifest as an inability to follow directions, difficulty concentrating or as a lack of interest in general.[29] It is important to distinguish between cognitive issues associated with normal fatigue from athletic participation, and the fatigue caused by the increased strain of working against cognitive deficiencies.[5]

Vestibular

This pathway involves many of the symptoms that are widely recognized with concussion such as vertigo, nausea, and becoming overly-stimulated in busy environments.[29] Even simple movements, such as turning the head or standing up, exacerbate symptomology and trigger an increase in symptoms. Disruption of the pathways responsible for control of the vestibular system manifests through balance and hearing difficulties. Disruption of the bodies balance system also leads to feelings of vertigo and nausea. Hearing dysfunctions include tinnitus, sensitivity to sound, as well as difficulty correctly processing auditory input. These are disruptive symptoms that are recognizable and often self-reported. From a screening viewpoint, these patients will have increased symptomology with horizontal or vertical eye movement, or balance disruption.[29,31]

Ocular

With the high percentage of the brain circuitry dedicated to vision it stands that another common symptom of concussion is visual disturbances. Patients presenting along an ocular trajectory often have an increase of symptoms with activities that strain the eye(s).[29,32] These disturbances are caused by dysfunction of either the sensory or motor pathways within the brain. While both may affect vision, they do not share pathways and are categorized separately for evaluating screening tools. Sensory visual disturbances include changes in vision or photophobia. Changes in vision include blurred vision, presbyopia, or diplopia caused by improper processing of images received. These symptoms represent the potential of injury to the pathways shared with the optic nerve. Motor disturbances to vision include nystagmus, pupil dysfunction, difficulty tracking as well as diplopia caused by poor coordination between eyes.

Pupil dysfunction includes aniscoria, as well as unbalanced or absent reaction to a light source. Damage to the pathways controlling several spinal nerves that control eye movement present in this way.

Trajectory Summary

To summarize, it is essential that each potential concussion be evaluated on an individual basis as the injury does not have a clearly defined set of symptoms. Any useful SCST needs to be able to recognize symptomology and presentation within any of the trajectories. There is no guarantee that each patient will exhibit symptoms that fit cleanly into a trajectory and therefore it is essential that the clinician choose a sideline concussion screening process that does not overlook any common possibilities. Any SCST needs to be flexible enough to be able to adapt for specific patients and needs.

Testing:

Each of the potential trajectories and the associated symptoms need to be considered to properly and completely screen for a potential concussion. This is especially important as often the athlete presents with symptoms that are not clear to either the patient or clinician, or are even hid by the patient. Obvious concussion symptoms may not immediately manifest themselves, and therefore it may be necessary to remove an athlete from competition until a proper screening takes place. The CDC has encouraged the use of the phrase “When in doubt, sit them out” in order to reduce the potential for more serious injury.[2]

With the dangers of continuing to play after concussion becoming apparent there is a renewed emphasis on SCST’s. Currently there are many varied options for making a sideline decision. Some of the most widespread include, but are not limited to, the Standardized Assessment of Concussion (SAC), the Balance Error Scoring System (BESS), the Sideline Concussion Assessment Tool 3rd Edition (SCAT-III) & Child SCAT-III, and King-Devick. This paper explores the benefits, limitations, and implementation of each of these assessment tools. They are evaluated regarding the opportunity they present to recognize the categories of symptoms previously established.

A crucial part of improving rates of concussion recognition is to look at what has been developed based on the most current understanding of concussions. As more public attention has been drawn to the potential dangers of concussions and repeated sub-concussive blows there has been a surge in funding and studies regarding current and developing technique's and tools. This paper also looks at tools recently implemented or under development and explore the potential benefits, limitations and availability. Some such tools are Vestibular-Ocular Motor Screening (VOMS), force plate testing and blood tests for proteins associated with injury to the brain.

As previously stated the purpose of this paper is to look at the strengths and limitations of available, and potential, sideline concussion screening tools (SCST). Critical to placing value on these tests is looking at the ability to establish a baseline score or result. This establishes the uninjured athletes scores that are then used to determine what, and potentially how much, change has taken place. As previously mentioned, it is impossible to quantify what changes have taken place without a proper baseline from which to compare current results to. The NATA states that baseline testing should include, at a minimum, neurocognitive performance and motor control.[13]

Taken into consideration is the potential and application of administering each test initially to a large group of athletes to establish a baseline. It is recommended that this baseline testing take place under circumstances that approximate the expected conditions of future tests as closely as possible.[33] For example, a high school athletic trainer that anticipates covering football games should establish the patients baseline in an environment that simulates the circumstances during which the screening test takes place.[13] This reduces the potential false positives created by the athlete being tested in a state of hyperawareness and/or emotion associated with competitive activity. Evidence has also been presented that dehydration and fatigue causes an athlete to present with concussion-like symptoms.[24]

Each test is examined as if it is being administered in the absence of any other examination. Each screening tool is evaluated on its ability to recognize and quantify potential symptoms of concussion. It is critical that athletic trainers have quantifiable data to back up their decisions to either allow an athlete to return to competition or remove them from play. This reduces risk to schools, athletes and the athletic trainer themselves in the case of litigation. A determination is made whether a quantifiable variable is produced that allows for tracking of symptom severity. Each SCST is presented with its benefits, limitations, availability, cost, and available reliability data. This data is used to make recommendations for developing a thorough sideline concussion screening protocol. As previously stated the following trajectories of symptomology are used: Anxiety/Mood, Cervical, Migraine, Cognitive/Fatigue, Vestibular, Ocular Motor. Each screening tool is evaluated to determine whether it tests for symptoms within each of these pathways.

Discussion:

CURRENT

Standardized Assessment of Concussion (SAC)

The Standardized Assessment of Concussion (SAC) includes measures of orientation, immediate memory, concentration, and delayed recall.[34] It is intended to immediately provide objective values for the aforementioned categories for the purpose of determining the possibility of concussion. The test itself consists of six categories intended to be completed in order. The first category is organized to determine the patients level of alertness and orientation by asking the patient to give the month, date, day of the week, year, and time. The responses are recorded and a score is calculated out of five, based on correct answers.

The second category is immediate memory. A series of five words are read aloud to the patient and they are evaluated on their ability to repeat the words back to the clinician. The five words are included on the test form, and prompts are provided with test information to standardize its administration. Three trials are performed, each with the same word list. Prior to the first trial, the initial prompt is "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."[35] Scores are assessed as one point per word recalled, regardless of order. For the second trial, the clinician is instructed to caution the patient to repeat all the words even if they were repeated earlier and re-reads the words. Again, one point is assigned for each word correctly repeated during the trial. A third trial is administered and the score is totaled from all the correct answers and totaled out of fifteen. It is important to note that the patient is tested on their recall of these five words after five minutes.[35] The patient is not instructed that they will be tested on their recall.[34] In the meantime, the clinician continues the examination.

The third category is neurological screening, which involves a brief neurologic screening used to assess strength, sensation, coordination, and the presence of either retro- or anterograde amnesia.[34] This allows the clinician to evaluate the potential for disruption to the nervous system.

These open-ended questions do not lend themselves well to quantitative scoring and are recorded but not calculated into the final score.

Next to be tested is concentration, the fourth category. The patient is asked to listen to a string of 'random' numbers, increasing in length starting at three digits and increasing to six, given by the clinician and then repeat them back to the clinician backwards. If correct, the clinician continues to the next longest string. If the patient cannot complete the string correctly, the clinician reads a second sequence of equal length. If the patient cannot complete the second string, then the clinician ends the concentration portion of the assessment. If the patient completes the string of six digits, then they are instructed to repeat the months of the year backwards. A total score for the category is tabulated by scoring one point for each completed string, and another for correct recitation of the months backwards for a maximum of five points.[35]

As previously mentioned, the final scoring category is delayed memory recall of the five words used during the immediate memory. Again, it is critical that the patient not be instructed that they are tested on their recall. The clinician should not repeat the words for the patient. The clinician scores the number of words recalled for a maximum of five. The scores for all categories are then totaled together for a total score out of 30. This score is then compared to the patient's baseline to assist the clinician in making a return-to-play decision.[35]

The strengths of SAC are simplicity, ease of use, cost, and accessibility. The SAC is broken down into the categories previously discussed and instructions are provided for test administration. It is recommended that the SAC be compared to a baseline for comparison. When compared to a baseline score and a drop of ≥1 is scored on the sideline, the SAC has a sensitivity of 0.95 and a specificity of 0.76.[36] This provides a positive likelihood ratio of 3.96 and a negative likelihood ratio of 0.066. Test-retest reliability for the SAC is only 0.55, making it only moderately reliable.[37]

While the test is easy, designed for use by non-professional,[35] and somewhat quick to administer (~5 min),[34] this still represents a significant time commitment for the healthcare professional to establish baselines for every potential patient. The SAC is limited in its scope as a screening tool. The SAC assesses memory recall for time/place, word list, and concentration well. The SAC does nothing to tease out disruptions leading to vestibular, ocular, anxiety, cervical symptomology. The test is available for free online and can be found in a variety of different formats, allowing for clinicians to find a format that allows them easy reference.

Balance Error Scoring System (BESS)

The Balance Error Scoring System, or BESS, is an assessment tool that is designed to assess static postural stability.[38] The full test requires two different types of surfaces; one solid and level, the other unstable to challenge the patients balance. A foam pad is often used to create the unstable surface. The clinician also needs a stopwatch, the testing protocols to be read, score card and, if available, a spotter to support the patient and prevent falls.[38] It takes about 10 minutes to complete.

The clinician should instruct the patient to remove any shoes or ankle taping prior to beginning the test.[39] The tests consist of a total of six challenges. The patient is asked to perform a double-leg stance with feet together side-by-side touching, single leg stance on the non-dominant foot with the hip flexed at 30° and the knee flexed to 45°, and a tandem stance with the non-dominant foot in the back with the heel of the dominant foot touching the toes of the non-dominant foot. The positions are tested in that order. The patient is instructed to keep their hands on their iliac crests and not to remove them during testing. The patient's eyes are to remain closed throughout the test. Each position is performed in sequence on the stable surface and then the sequence is repeated on the unstable surface.[38]

During testing the clinician records any errors as termed by the testing protocol. Errors include: moving the hands from the iliac crests, opening the eyes, step stumble or fall, abduction or flexion of the hip beyond 30°, lifting the forefoot or heel from the testing surface, and remaining out of the proper testing position for greater than 5 seconds. The maximum number of errors that can be scored for a single position/surface combination is 10. If the patient commits multiple errors together it is recorded as a single error.[40] The patients scores are totaled for each surface, then totaled for a final score out of 60. This total is compared against the patients baseline to assist in determining whether a deficiency exists. The tested foot (preferably non-dominant) is recorded to maintain consistency between tests.[41]

The strength of the BESS is its ability to detect balance deficiencies.[40] It also requires minimal equipment and can be easily modified to require no equipment for a condensed evaluation.[5] This makes it easy to implement in a sideline concussion screening protocol. As with many other SCST's the BESS is available free of charge online and requires no specialized training. The BESS is limited to identifying gross balance deficiencies. It does not explicitly test for symptomology of the anxiety, cervical, migraine, cognitive, or ocular trajectories.

When balance deficiencies are not identified after comparison to baseline scores, specificity of the BESS is 0.96.[42] The BESS also has poor sensitivity at 0.34.[42] This gives the BESS a positive likelihood ratio of 8.6 and a negative likelihood ratio of 0.688. Another considerable limitation of the BESS that it utilizes a highly subjective scoring system that has only relative intrarater reliability at 0.75, and low interrater reliability at 0.57.[41,42]

SCAT III

The Sport Concussion Assessment Tool (3rd Edition), or SCAT-III [AKA SCAT3] was developed as an update upon the previous edition, known as SCAT-II, as part of the 4th International Conference on Concussion in Sport (ICCS) which took place in Zurich during November 2012. It is intended for use in athletes over the age of thirteen who are suspected to have suffered a potential sport-related concussion.[5,43] Developed in conjunction with the SCAT-III was the Child SCAT-III intended for use for patients between the ages of 5-12.[5] The purpose of the SCAT-III was to take best available evidence and develop a screening test that could be used to identify the potential for concussion in a quantifiable exam.[5] The SCAT-III consists of eight main components: The Glasgow Coma Scale, Maddocks Score, graded symptom checklist, cognitive assessment, neck examination, balance examination, coordination exam, and a delayed recall test.

The first component is the Glasgow Coma Scale (GCS). This scale is used to determine level of consciousness of a patient and grades patients according to best eye response, verbal response and motor response for a total score out of 15.[44] This is valuable for determining the potential for an injury that would require an emergency response.[45] The GCS score should be recorded for all patients in case of subsequent deterioration.[5] The second aspect of the SCAT-III is a modification of the Maddocks questions. The clinician instructs the patient that they will be asking them a few questions. The patient is then asked the following questions to grade patient awareness: What venue are we at today? Which half is it now? Who scored last in this match? What team did you play last? Did your team win the last game? These questions were developed with the intention of quickly scoring recent memory.[46]

The next category is the graded symptom evaluation. There is a total of twenty-two symptoms that are graded on a scale of 0-6. The test administrator instructs the athlete that they should score themselves on each symptom based how they are currently feeling.[5] The test administrator is also instructed to assess, if they are very familiar with the athlete prior to the injury, if the patient is acting no different, very different, or if the administrator is unsure. The section is scored both for total number of symptoms (TNS) and for the total score of all symptoms combined, or symptom severity score (SSS).[47] If symptoms change with mental or physical activity, this is recorded as well.

Next the SCAT-III utilizes a cognitive assessment that is a modification of the SAC. The assessment includes the same methods, concepts and scoring used to assess orientation, immediate memory, and concentration for a possible total of 25. The eighth and final component, which is delayed recall is the same question, method and scoring as the SAC tool. In place of the neurological screening utilized in the SAC, the SCAT-III emphasizes an examination of the neck and associated musculature. The clinician is prompted to record any qualitative findings regarding range-of-motion, tenderness or change in upper or lower limb sensation and strength.[43]

The SCAT-III next borrows from the BESS, modifying the test for use on-field to test the non-dominant foot. Footwear, or lack thereof, of the athlete is recorded along with the type of surface used for testing. The athlete is tested in each of the three positions used for the BESS on the recorded surface. Errors are scored the same as in the BESS and recorded for no more than 10 per position, for a total maximum of 30. The SCAT-III also encourages the use of a timed gait test either in addition to, or in place of the modified BESS testing. Referred to in the material as the tandem gait test, the evaluated athlete is instructed to stand with their feet together behind a starting line, preferably with footwear removed. The patient then, as quickly and accurately as possible, walks along a narrow, three-meter line alternating feet in a heel-to-toe gait. After three meters they turn around and return to the starting point with the same gait pattern. Athletes are expected to complete the test in approximately fourteen seconds.[47] A total of four trials should be administered with the best time retained. The athlete is considered to have failed the test if they must touch the examiner or object to regain balance, step off the line, or separate the heel-to-toe approximation.[47]

The last component, other than the previously mentioned delayed recall, is a simple coordination test.[47] The individual to be tested is instructed to flex either shoulder to 90° and extend both the elbow and fingers. When instructed to begin the patient will perform five successive finger-to-nose repetitions; touching their index finger to their nose and returning to the starting position counting as one repetition. The athlete being tested should complete these as quickly and accurately as possible. The patient receives a score of 1 if they complete 5 correct repetitions in less than four seconds, at the discretion of the observer. Testers are instructed to fail the athlete if they do not touch their nose, fail to return to the proper starting position, or do not complete five correct repetitions within the allotted time and assess a score of zero.[47]

The SCAT-III, in a simple sense, is a combination of the GCS, Maddocks Score, SAC, and BESS with a graded symptom checklist included. This gives it the same strengths and limitations as those tests, while attempting to limit the limitations. It is intended to provide a broad view of many signs and/or symptoms of potential sports-related concussion.[5] The greatest benefit of the SCAT-III assessment is its broad scope. The only symptom trajectory that is not evaluated is the ocular trajectory. This also becomes a limitation as well, as it takes considerable time, fifteen to twenty minutes, to administer according to the included protocols. The SCAT-III, and Child SCAT-III, are available free of charge online, but are recommended for use only by healthcare professionals.

Sensitivity, specificity, reliability, positive and negative likelihood ratios should be considered for each of the tests that are included in the SCAT-III in a modified form, such as the SAC and BESS. The graded symptom checklist has had values of 0.96 for sensitivity and 0.77 for specificity reported in clinical evaluations 24 hours post-injury when the SSS is ≥7.[48] Positive and negative likelihood ratios with these values are 4.17 and 0.05 respectively. Test-retest reliability for the graded symptom checklist is reported as 0.62.[49] The SCAT-III has been evaluated for its potential to screen for concussion at 24 hours post-injury[48,49], but sufficient data evaluating its reliability to screen for concussed athletes immediately after injury on the sideline has not been thoroughly evaluated.

King-Devick Test (KDT)

The King-Devick test is a simple sideline screening tool that utilizes multiple cards with printed numbers and records the total time taken for the patient to complete the cards. The number of errors during testing is also recorded as part of the score.[50] A total of four cards are used, the first serving as a demonstration card, and the next three progressing in difficulty (See Figure 2). The difficulty is increased with each card, with the lines between numbers removed between the second and third cards, and the distances between lines being compressed between the third and fourth

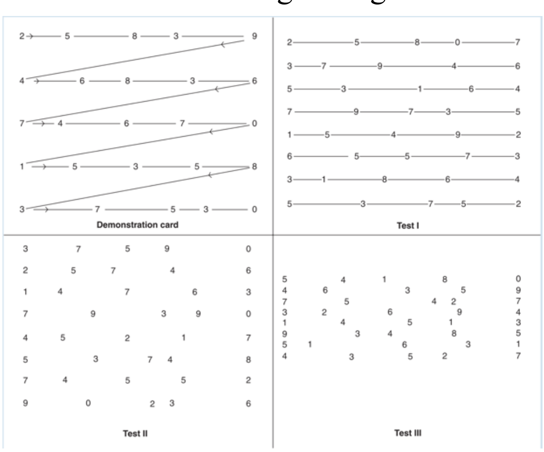

Figure 2: Sample of King-Devick Testing Cards[51]

cards.[50] The KDT can be administered with either physical cards and a stopwatch, or is also available in digital format through a tablet application.

The King-Devick test is quick to administer, taking only 2-3 minutes when administered by a practiced clinician to a patient that has already established a baseline score. The KDT provides quantitative data of disruption of ocular saccades.[32] This is both a strength and limitation of this SCST. The data collected when compared against a baseline score can quantitatively represent deficiencies that warrant further investigation. Sideline sensitivity and specificity values have been reported as 0.86 and 0.90, respectively.[51] Calculation for positive likelihood ratio provides a value of 8.6, with negative likelihood ratio at 0.16. Test-retest reliability has been reported at 0.94.[51]

This also limits the scope and application for administration of the KDT as ocular saccades fall squarely into the vestibular trajectory as it does not require the brain to track movement, interpret motion or binocular vision. Digitally, the KDT is currently administered through the King-Devick Test website and is also available as an application for many popular tablets. The yearly subscription cost for access to test applications and resources is $20/athlete/year.[52] This is another limitation, as there is a cost to build baselines for even a small organization in comparison to previously discussed SCST's. Also of note is that much of the research supporting the values reported was done by those with ties to King-Devick Testing, Inc or parent companies.

FUTURE

VOMS

For this analysis, the Vestibular/Ocular Motor Screening tool has been classified as a future tool as it was developed as a clinical tool and not for the sideline. The research that has been done focuses on the link between exacerbation of symptoms during VOMS administration in patients that are suffering from PCS.[31] VOMS is designed to be administered in a controlled-environment with a tape measure, metronome and target with 14pt font letter. [53] The VOMS consists of seven challenges, with a score recorded after each. Before challenging the patient, the clinician asks the patient to ascertain baseline values for headache, dizziness, nausea, and fogginess. The clinician also is afforded space on the test form to record any comments or observations deemed clinically important. Each of the symptoms is independently scored on a scale of 1-10 by the patient when prompted by the evaluator.[29,31]

The first challenge issued is smooth pursuit,[31] which is intended to test the patient's ability to track a moving target. The clinician holds a fingertip 3ft from the patient's midline and instructs them to maintain focus as it is moved. The clinician will then move the fingertip 1.5ft to the right and left of midline at a pace of 2" to complete a pass. One repetition is complete when the target moves back and forth to the starting position with a total of two reps completed. The same criteria are used to assess vertical pursuit as well with the clinician moving the fingertip 1.5ft above and below midline for two repetitions.[31] The patient is then asked to rate the same symptoms with the same scale used on the baseline.[29]

The second and third challenges, or saccades, tests the patient's eyes ability to move quickly between targets.[31] The second tests saccades in the horizontal plane. The examiner hold two fingertips 3ft apart, 1.5ft from midline on either side. The patient is instructed to move their eyes back-and-forth between the two points. One pass back-and-forth between points equals one repetition and a total of ten repetitions are performed.[31] The patient is again asked to quantify symptoms using the same scale.[29] Vertical saccades are tested using the same procedures in the third challenge, with one small modification. During vertical saccade testing the fingertips are located 1.5ft above and below the midline, 3ft apart.[31]

The fourth challenge tests the patient's ability to coordinate eyes and maintain a singular image as a target approaches the nose, or ocular convergence.[31] The examiner should be positioned to observe eye movement during the exam. The patient is asked to focus on a small target, for example a 14pt font letter on a popsicle stick. They are then asked to move the target as close as possible slowly before experiencing two images. The patient should be also instructed to stop if the clinician observes any outward deviation of the either eye. The distance in cm is recorded on the test form, and the test repeated for a total of three trials.[31] The patient is then also asked to assess their symptoms.[29]

Vestibular-Ocular Reflex (VOR) is tested next. VOR assesses the ability for the patient to stabilize vision as the head moves.[31] This will also be tested in both horizontal and vertical planes. For both tests the examiner holds up a target of ~14pt size at 3ft from the patient's midline at eye level. The patient is instructed to horizontally rotate their head 20° at a rate of 180 beats/minute with one direction equaling one beat. A metronome is used to maintain the proper speed. One repetition is the head completing a back-and-forth motion, and a total of ten reps should be completed.1. Center for Disease Control. Report to Congress on Mild Traumatic Brain Injury in the United States. 2003;(September):1-56. http://www.cdc.gov/traumaticbraininjury/pdf/mtbireport-a.pdf%5Cnpapers2://publication/uuid/C2643C39-C5DE-40A2-A290-A3D04BB6F7BC.

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The patient's symptoms are scored again ten seconds after the challenge is completed. Vertical VOR is assessed with the same procedures but again the targets are 1.5ft above and below the midline.[31]

The final challenge is Visual Motion Sensitivity (VMS). This test is designed to challenge the patient's ability to inhibit vestibular-induced eye movements using vision and sensitivity to visual motion.[31] The patient stands with feet shoulder width apart, facing a visually stimulating area such as a grandstand or multicolored wall. The examiner should be positioned close by but behind the patient. The patient outstretches their arm with their thumb extended, the patient focuses on their thumb while rotating their torso, arm and head as single unit at 50bpm (metronome used to maintain rhythm) to 80° from midline both right and left. Repetitions are counted as before and a total of 5 repetitions are performed.[31] Patients scores are recorded as before.

Patients scores can be compared to either the baseline established at the beginning of testing to determine aggravation of symptoms; or against a baseline score previously recorded to gauge the potential for symptomology.[31] The VOMS includes challenges that can identify symptoms in 5 of the 6 trajectories discussed (cervical, migraine, cognitive, vestibular, ocular) and the scoresheet provides space for testers to make comments, allowing for recording of emotional changes during testing. The VOMS is the only SCST that specifically seeks to identify ocular involvement. There is not a cost associated with the VOMS, as it is readily available online. As previously mentioned, the VOMS is established as a clinical tool, but has not been researched as a SCST, and therefore no data is available for determining sensitivity, specificity, or reliability for use as SCST. It is also important to note that some argue that the examiner needs to be proficient in examining various types of eye movement.[54] It is the author's opinion that the test shows potential to be modified for use on the sideline as a screening tool.

Force Plate Balance Testing

It has been theorized that the use of portable force plate technology would increase the healthcare provider's ability to detect postural instabilities with a greater reliability in regards to concussion injuries.[5] Currently the clinical standard for balance assessment after concussion is the BESS.[5,13] Two of the primary limitations of the BESS are the heavy subjectivity of scoring and lack of reliability.[41] Instrumenting this test provides a potential solution for both limitations.[5,55,56] As the cost of portable force plates has become more affordable, there has been increased research seeking to validate the reliability of this as a clinical tool. However the research is split on the efficacy of instrumenting the BESS as a method of reducing the limitations previously noted.[55,56]

Considering instrumented BESS, or other instrumented balance testing, for increasing sideline recognition of potential sideline has many of the same benefits and limitations as previously discussed with the BESS. Further research will shed light on the efficacy of instrumented balance testing in comparison the established standard of the BESS. Currently, there is insufficient evidence to support instrumented balance scoring as an effective, viable SCST individually. The healthcare professional must also take into consideration the availability or cost of equipment involved when deciding about potential inclusion into a sideline concussion screening protocol.

Currently, the research does not provide enough evidence to support a change of position regarding the current standard of expectations regarding sideline postural stability testing. With the current information, it appears that instrumented balance scoring is a clinical tool better served for tracking progress through concussion rehabilitation, and is not necessary for sideline balance or postural evaluation.

Blood Testing

There has been an increase in research within the last 15 years into the presence of biomarkers of brain injury following sports-related concussion and traumatic brain injury.[57] These studies have discovered an array of biomarkers present in either cerebrospinal fluid (CSF) or blood.[58] Biomarkers are classified by their presence in specific neurological structures of the central nervous system.[59] These biomarkers are linked to specific types of neural injury, and therefore potentially guide diagnostic and rehabilitation progressions. Not all biomarkers are present in both CSF and blood.[59]

As it is not realistic to collect a CSF sample on the sideline, research and funding tied to the recognition of concussion has been tied to those biomarkers present in blood. The ability to detect elevated biomarkers in the blood after concussion currently requires a blood draw and specialized equipment. This is not a realistic expectation on the sideline for most healthcare professionals. In the author's opinion, the ability to detect the presence of biomarkers of concussion needs to progress to a point that it would be administered by the same method as blood sugar testing. Given the circumstances and conditions that most sideline screenings for potential concussion would take place, the healthcare professional would need to be able to quickly and accurately assess the patient's blood for the potential presence of biomarkers with minimally invasive and efficient methods. The biomarker that has shown the most promise for detection in a sideline setting is tau protein.[57–60] Tau protein is the blood-borne biomarker that peaks at the highest level during the first hour post-injury.[57] An elevated presence of tau protein has also been linked to increased return-to-play rates[61] and PCS symptoms.[57]

While the current research is promising regarding it's ability to detect blood-borne biomarkers after concussion, there is a need for further research to validate the findings of current work in comparison to reliable and objective measures of concussion. The promise of the predictive power of a blood test detecting concussion is great; but it is difficult to rate the predictive power of currently known biomarkers as they are currently being compared against subjective and variable clinical measures.[59] Biomarkers are present with many types of neural pathology, including sport-related concussion, TBI, CTE and mental illness. Currently, much of the research has focused on the presence of the biomarkers and has not specified what type of injury is being identified. There is opportunity for further research in this regard. It is the authors opinion that there is potential in screening with this method, but that there is significant research and development still to be done before it becomes viable.

Conclusion:

Evaluating currently used SCST's available it became clear that each have strengths, limitations, and questions regarding specificity, sensitivity, and/or reliability (See Table 1). A critical component of all current SCST's is the cooperation and effort of the individual being tested. If the athlete does not allow for a proper baseline to be established, or if they do not cooperate with the testing, it is difficult to establish relationships or draw accurate conclusions. The most powerful tool to a clinician is their training and intuition. For example, many tests do not explicitly quantify emotional symptoms; but the clinician would be well served to record any unusual emotions. Athletic trainers are well positioned as healthcare providers at the forefront of concussion recognition and management to be able to make decisions with relevant data.

Looking to the future (see Table 3), instrumentation of the BESS with portable force plates represents potential for more accurate BESS scoring, but does not address the other limitations for the BESS. The potential of VOMS as a sideline evaluation tool is promising. Of the SCST's analyzed, both current and future, it shows the greatest promise in identifying symptomology in all six trajectories of concussion. Blood testing for biomarkers present also shows promise as a potentially definitive tool for identifying when an injury has occurred, making it an excellent screening tool if it can be developed to a point where it's use becomes practical in a sideline setting.

Regarding currently established SCST's (See Table 2), the SCAT-III stands above the SAC and BESS as it implements sections that utilize the core principles and evaluation methods of each test in a single exam format. However, it is commonly recommended that no single tool should be relied on to screen for concussion.[5,13] The limitation of SCAT-III lacking any true vision testing can be overcome by supplementing with another tool, such as VOMS or KDT, that will provide crucial visual challenges to the patient. This combination of SCST's provides the clinician with a variety of challenges designed to identify potential for concussion along each of the trajectories considered.

Table 1: Clinical Trajectory Assessment by SCST

	Anxiety/Mood	Cervical	Migraine	Cognitive	Vestibular	Ocular
Current						
SAC	Not Included	Not Included	Not Included	Memory Recall; Concentration	Not Included	Not Included
BESS	Not Included	Not Included	Not Included	Not Included	Assessed for balance deficiencies	Not Included
KDT	Not Included	Not Included	Not Included	Not Included	Coordination of eye movement	Not Included
SCAT III	Patient Reported	Patient Reported; Clinician Exam	Patient Reported	Patient Reported; Memory Recall; Concentration	Modification of BESS	Not Included
Future						
VOMS	Physician Determined[29]	Assessed for headaches	Assessed for dizziness	Assessed for fogginess	Assessed for nausea	Assessed for visual convergence
Blood Testing	N/A	N/A	N/A	N/A	N/A	N/A
Force Plate	Not Included	Not Included	Not Included	Not Included	Instrumented assessment of posture and balance	Not Included

Table 2: Current SCST Trait Analysis

	Available	Baseline	Quantifiable Results	Strengths	Limitations	Sens/Spec	Likelihood Ratio	Reliability	Access	Cost
Current										
SAC	Now	Yes	Yes	Cost; Simple	Limited scope; word list can be memorized	Drop of ≥1[36] SN = 0.95 SP = 0.76	LR+ = 3.96 LR- = 0.066	Test-Retest = 0.55[37]	Online	Free
BESS	Now	Yes	Yes	Cost; Identify Balance Deficiency	Specific to balance; Heavy reliance on rater perception	SN = 0.34 SP = 0.96[42]	LR+ = 8.5 LR- = 0.688	Interrater = 0.57 Intrarater = 0.74[41]	Online	Free
KDT	Now	Yes	Yes	Quick (2-3 min); Evaluate Saccades	Requires access to cards and/or materials	SN = 0.86 SP = 0.90[51]	LR+ = 8.6 LR- = 0.16	Test-Retest = 0.94[62]	Online	$20/yr/athlete
SCAT III	Now	Yes	Yes	Internationally developed and accepted; Pulls from variety of established tests	Length to complete full exam (15-20 min)	SSS ≥ 7 SN = 0.96 SP = 0.77[48]	LR+ = 4.17 LR- = 0.05	Test-Retest for GSC = 0.62[49]	Online	Free

Table 3: Future SCST Trait Analysis

	Available	Baseline	Quanti-fiable Results	Strengths	Limitations	Sens/Spec	Likeli-hood Ratio	Reliability	Access	Cost
Future										
VOMS	Now	Yes	Yes	Ocular Pursuit, convergence, and accommodation; minimal equipment; correlates well with trajectories	Reliance on patient reporting; not intended for sideline use	Not established for sideline	Not established for sideline	Not established for sideline	Online	Free
Blood Testing	Lab	Yes	Yes	Theoretically definitive; objective results	Cost; Access; Blood Draw required	Not established for sideline	Not established for sideline	Not established for sideline	Lab Required	Variable
Force Plate	Now	Yes	Yes	Precision over BESS alone	Equipment requirements; still isolated to posture/balance deficiencies	Not established for sideline	Not established for sideline	Not established for sideline	Equipment Needed	Equipment Dependent

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