Balance Assessment in the Management of Sport-Related Concussion

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Over the past decade, there is probably no sports injury more discussed in the lay media than concussion or traumatic brain injury (TBI). There has also been a flood of publications into the peer-reviewed medical literature on the topic in recent years, and the medical community has a better understanding of concussive injury today than it did just 10 years ago. Clinicians, especially those responsible for the medical care of elite athletes, have been placed under the microscope and are being scrutinized for their management of these potentially catastrophic injuries. Concussion often presents with varying symptomatology and most experts think it should be evaluated using a multifactorial approach. Yet many clinicians neglect the use of a comprehensive concussion assessment plan, despite the complexity of this injury. Given that athletes may under-report concussions by nearly 50%, significant attention has been given to the validation of objective measures for managing concussion. Although neuropsychological testing has proven to be a valuable tool in concussion management, it is most useful when administered as part of a comprehensive assessment battery that includes grading of symptoms and clinical balance tests.

A thorough sideline and clinical examination by the certified athletic trainer and team physician is considered an important first step in the management of concussion. It is best if the clinician performing the examination knows the athlete well enough to detect changes in their disposition. The evaluation, whether on the field or in the clinical setting, should be conducted in a systematic manner. The evaluation should include obtaining a history for specific details about the injury (eg, mechanism, symptomatology, concussion history), followed by assessing neurocognitive function and balance, which is the focus of this article. The objective measures from balance testing...
can provide clinicians with an additional piece of the concussion puzzle, remove some of the guesswork in uncovering less obvious symptoms, and assist in determining readiness to return safely to participation.

For many years, neurologic examination in the athletic setting has included Romberg’s tests of balance/postural stability. However, the standard Romberg test lacks objectivity and sensitivity for evaluating concussion, especially in elite athletes who tend to normally excel with activities of coordination and agility. Recent technological developments have provided the sports medicine community with more quantitative and objective assessment tools for evaluating head injuries. A review of the balance literature indicates there are characteristic deficits following traumatic brain injury, even those classified as mild traumatic brain injury (mTBI) or cerebral concussion.

ROLE OF THE CENTRAL NERVOUS SYSTEM IN MAINTAINING POSTURAL EQUILIBRIUM

Understanding the central nervous system’s (CNS) feedback mechanism for maintaining postural equilibrium is the first step in building a case for objective balance testing in the management of sport concussion. Maintaining equilibrium requires the CNS to process and integrate afferent information from the visual, somatosensory (proprioceptive), and vestibular systems to execute appropriate and coordinated musculoskeletal responses. Feedback, obtained from sensors housed within the 3 systems, sends commands to the muscles of the extremities, which then generate an appropriate contraction to maintain postural stability.9–13

The primary purposes of the human vestibular system are to (1) maintain the eyes fixed on a stationary target in the presence of head and body movement and (2) maintain balance in conjunction with additional information from visual and somatosensory inputs. To accomplish the first, the semicircular canals of the vestibular labyrinth sense angular acceleration of the head, converting it to velocity information, and sending it through the vestibuloocular reflex pathways to the ocular muscles. Secondly, balance is maintained by central integration of vestibular, visual, and somatosensory orientation information. The vestibular system provides angular information from the semicircular canals and linear acceleration information (including gravity) from the utricles and saccules of the inner ear and transmits it via the vestibulospinal spinal tract to the spinal and lower extremity muscles. Under normal conditions, visual and somatosensory information is adequate for maintenance of balance. However, in populations with known vestibular deficits, the inner ear senses of balance are essential when visual and somatosensory inputs are disrupted or provide conflicting information.13,14

Balance Control

Balance plays a vital role in the maintenance of fluid, dynamic movement common in sport, and is defined as the process of maintaining the center of gravity (COG) within the body’s base of support. Many factors enter into the task of controlling balance within this designated area. The system involves a complex network of neural connections and centers that are related by peripheral and central feedback mechanisms. A hierarchy integrating the cerebral cortex, cerebellum, basal ganglia, brainstem, and spinal cord is primarily responsible for controlling voluntary movements.14,15

The highest level of the hierarchy involves areas of the brain responsible for attention, concentration, memory and emotion, as well as the association cortex for receiving and correlating input from other brain structures. The middle level involves the sensorimotor cortex, cerebellum, parts of the basal ganglia, and some brainstem nuclei. The cerebellum is likely the most important structure for coordinating and controlling balance, as it receives information from the muscles, joints, skin, eyes,
ears, and even the viscera.\textsuperscript{14,15} The afferent pathways of the reflex arcs come from 3 sources: the eyes, the vestibular apparatus, and the proprioceptors. Their collective actions are referred to as postural reflexes. The efferent pathways are the alpha motor neurons to the skeletal muscles, and the integrating centers are neuron networks in the brainstem and spinal cord.\textsuperscript{11,14} The lowest level of the hierarchy involves the brainstem and the spinal cord from which the motor neurons exit. These structures receive information from the middle level via the descending pathways. Its function is to specify the tension of particular muscles and the angle of joints necessary to carry out the programs transmitted from the middle level.

**Isolation of Sensory Input**

From our knowledge of the central nervous system’s involvement in maintaining upright posture, we can divide the processes into 2 components. The term sensory organization involves those processes that determine timing, direction, and amplitude of corrective postural actions based upon information obtained from the vestibular, visual, and somatosensory inputs. This concept is important for understanding some of the concussion assessment techniques described later, such as the Sensory Organization Test (SOT; NeuroCom International, Inc, Clackamas, OR, USA). Despite the availability of multiple sensory inputs, the central nervous system generally relies on only one sense at a time for orientation information. For healthy adults, the preferred sense for balance control comes from somatosensory information (ie, feet in contact with the support surface).\textsuperscript{13}

The second component, muscle coordination, describes processes that determine the temporal sequencing and distribution of contractile activity among the muscles of the legs and trunk that generate supportive reactions for maintaining balance. Balance deficiencies in people with neurologic problems can result from inappropriate interaction among the 3 sensory inputs that provide orientation information to the postural control system. Patients may be inappropriately dependent on one sense for situations presenting intersensory conflict.\textsuperscript{11,13,16}

Several studies have attempted to isolate and clarify which sensory inputs are most involved with regulating posture and how the interaction among these inputs affects postural control.\textsuperscript{16–22} A technique described by Shumway-Cook and Horak\textsuperscript{11} and Ingersoll and Armstrong\textsuperscript{23} called the Clinical Test of Sensory Interaction and Balance (CTSIB) was originally used to systematically remove or conflict sensory input from 1 or more of the 3 senses. The technique used combinations of 3 visual and 2 support-surface conditions during assessment of postural sway to identify any reliance on 1 or more of the 3 senses for postural control, which was thought to be present for certain pathologic conditions, including TBI.\textsuperscript{23}

**BALANCE DEFICITS FOLLOWING TBI**

Disruption of static and dynamic balance in nonathletic populations has been identified and described following pathologic conditions, such as moderate-severe traumatic brain injury,\textsuperscript{23–31} hemiplegia and craniocerebral injury,\textsuperscript{32} cerebellar atrophy and ataxia,\textsuperscript{33} and whiplash.\textsuperscript{25,34} It is thought that communication between the 3 sensory systems is lost in many of these individuals, causing moderate to severe postural instability in either the anterior-posterior direction, medial-lateral direction, or both. In most cases symptoms with visual, vestibular, or somatosensory orientation, such as dizziness, vertigo, tinnitus, lightheadedness, blurred vision, or photophobia, are reported.\textsuperscript{23–34} These deficits may be either temporary or permanent, depending on the structures involved and the severity of the injury.
Occasionally, we witness the woozily looking football player or hockey player who has just been hit trying to find his way back to the huddle, sideline, or bench. More likely, however, we hear of the subtle and less obvious balance problems a concussed athlete might complain of during the follow-up clinic evaluation. The author’s 2000 study of 1003 sport-related concussions, found that balance problems are present 30% of the time following concussive injury, trailing only headache, dizziness, confusion, disorientation, and blurred vision in frequency of occurrence among a list of 18 symptoms (Fig. 1). So what might explain this disruption in balance following TBI, be it mild, moderate, or severe? In the case of cerebral concussion and mTBI, we know that the injury produces functional rather than structural neurophysiologic changes in the cortex and brainstem’s reticular formation. The latter disturbance in particular is presumed to account for the autonomic, motor, and postural impairments that occur in many individuals following TBI. Subtle vestibular deficits caused by sensory integration disruption identified in the nonathlete mTBI population also occurs in sport-related concussion (see later discussion).

The transient nature of most cerebral concussion symptoms and impairments suggests that like a headache, blurred vision, or memory problems, balance deficits (when they exists) should resolve quickly. Several longitudinal studies involving high school and college athletes have demonstrated a typical pattern of recovery using both high-technology (computerized dynamic posturography) and low-technology (clinical balance) methods. In the sports medicine setting, similar balance deficits have been identified, but fortunately have been shown to resolve within 3 to 10 days after injury. High-technology and low-technology balance assessment tools have been validated for assessing the initial deficits and tracking recovery following concussive injury.

HIGH-TECHNOLOGY BALANCE ASSESSMENT FOLLOWING SPORT-RELATED CONCUSSION

Studies of postural stability and balance following concussion have used a variety of methodologies and metrics. For example, in one of the earliest studies assessing balance deficits in concussed athletes, the author used a modified CTSIB on a force plate to systematically remove or conflict sensory inputs. The author recorded

2 indices of center of pressure displacement about a fixed, central reference point to quantify impairments in postural stability in college and high school athletes with cerebral concussion. Concussed subjects, matched to healthy comparison controls, demonstrated decreased postural stability compared with their own baseline scores and to their matched controls during the initial 3 days after injury. The degree of balance impairment in the concussed subjects increased with increasing task demands, such as altering the visual, vestibular, or somatosensory feedback during the trial. The author attributed the overall balance deficits to a sensory interaction problem (ie, difficulty using various combinations of somatosensory, visual, and vestibular information) for controlling upright posture during the first few days following concussion.

More recently, the SOT has been used to assess balance following concussion. The SOT technical force plate system is designed to systematically disrupt the sensory selection process by altering the orientation information available to the somatosensory or visual inputs while at the same time measuring the patients’ ability to maintain a quiet stance. Sway referencing is used throughout the test because the movement of the platform beneath the patients’ feet and the environmental surround move in response to the athlete’s anterior-posterior (A-P) sway. The SOT uses 6 different conditions; each condition is performed 3 times to assess balance (Fig. 2). The test protocol consists of 3 20-second trials under 3 different visual conditions (eyes open, eyes closed, sway referenced) and 2 different surface conditions (fixed, sway referenced) (see Fig. 2). Patients are asked to stand as motionless as possible for each of the 20-second trials in a normal stance with the feet shoulder width apart. The term sway referencing involves the tilting of the support surface or visual surround

Fig. 2. Six testing conditions (1–6) for the Sensory Organization Test used with the NeuroCom Smart Balance Master.
to directly follow the athlete’s COG sway. During sway reference support surface conditions (4–6), the force plate tilts synchronously with the patients’ A-P COG sway. Similarly, during sway referenced visual surround conditions (3, 6), the visual surround tilts synchronously with A-P COG sway. Sway referencing causes orientation of the support surface or surround to remain constant relative to body position. The SOT can assess patients’ ability to ignore the inaccurate information from the sway referenced senses.

An overall composite equilibrium score describing a person’s overall level of performance during all of the trials in the SOT is calculated, with higher scores being indicative of better balance performance. The composite score is the average of the following 14 scores: the condition 1 average score, the condition 2 average score, and the 3 equilibrium scores from each of the trials in conditions 3 to 6. The equilibrium scores from each of the trials represent a nondimensional percentage comparing the patients’ peak amplitude of anterior-posterior sway to the theoretical anterior-posterior limit of stability. Additionally, relative differences between the equilibrium scores of various conditions are calculated using ratios to reveal specific information about each of the sensory systems involved with maintaining balance. For example, a vestibular ratio is computed by using scores attained in condition 5 (eyes closed, sway referenced platform) and condition 1 (eyes open, fixed platform). This ratio indicates the relative reduction in postural stability when visual and somatosensory inputs are simultaneously disrupted. Condition 4:Condition 1 represents the visual ratio, and Condition 2:Condition 1 represents the somatosensory ratio. These ratios are useful in identifying sensory integration problems.

Results of several studies using the SOT in concussed athletes have identified sensory interaction and balance deficits that typically resolve within 3 to 5 days after injury. Cavanaugh and colleagues concluded that when applying approximate entropy techniques to the SOT data, athletes balance deficits can be shown to persist longer than 3 to 4 days, even among athletes with no signs of unsteadiness on the standard SOT analysis. The investigators concluded that approximate entropy provides a theoretically distinct, valuable measurement alternative that appears to provide unique insights and may prove useful for reducing uncertainty in the return-to-play decision.

In general, these studies indicate that the regions of the brain responsible for coordinating the sensory modalities (thalamus and its interconnective pathways to the cerebral cortex) may be initially disrupted following concussive injury. These studies also suggest that the sensory system most often affected following concussion is the vestibular system (Fig. 3). If a person has difficulty balancing under conditions in which sensory systems have been altered, it can be hypothesized that they are unable to ignore altered environmental conditions and therefore select a motor response based on the altered environmental cues, which could potentially predispose them to further injury should they return to participation while experiencing sensory interaction problems.

There are 2 possible mechanisms for vestibular dysfunction following cerebral concussion: (1) the peripheral receptors themselves may be damaged and provide inaccurate senses of motion or (2) the brain centers responsible for central integration of vestibular, visual, and somatosensory information may be impaired. Mallinson and Longridge found evidence of central integration balance deficits and subtle peripheral vestibular deficits when comparing SOT and electronystagmography results in subjects with mild head injury from an associated whiplash injury. These findings suggest that various combinations of peripheral and central deficits may be the cause of balance deficits in athletes with concussion. An additional factor that surfaced from
the author’s research is the possibility that concentration and attention impairments identified on day 1 after injury could be a contributing factor to decreased postural stability. Future research should focus on this potential relationship.

Both the modified CTSIB and SOT require sophisticated force plate systems that provide a way to challenge and alter information sent to the various sensory systems. Although the aforementioned studies suggest that force platform sway measures provide valuable information in making return to play decisions following concussion, there is still a question of practicality and accessibility for the sports medicine clinician.

LOW-TECHNOLOGY (CLINICAL) BALANCE ASSESSMENT FOLLOWING SPORT-RELATED CONCUSSION

In an attempt to provide a more cost-effective, yet quantifiable method of assessing balance in athletes, the Balance Error Scoring System (BESS) was developed by researchers at the University of North Carolina at Chapel Hill. This clinical balance test can be performed on the sideline, with the use of only a stopwatch and a piece of medium-density foam (Power Systems Airex Balance Pad 81,000, Knoxville, TN, USA). Testing involves 3 different stances (double, single, and tandem) completed twice, once while on a firm surface and once on the foam, for a total of 6 trials (Fig. 4). Athletes are asked to assume the required stance by placing their hands on
the iliac crests and upon eye closure, the 20-second test begins. During the single leg stances, subjects are asked to maintain the contralateral limb in 20° to 30° of hip flexion and 40° to 50° of knee flexion. Additionally, the athlete is asked to stand quietly and as motionless as possible in the stance position, keeping their hands on the iliac crests and eyes closed. The single-limb stance tests are performed on the nondominant foot. This same foot is placed toward the rear on the tandem stances. Patients are told that upon losing their balance, they are to make any necessary adjustments and return to the testing position as quickly as possible. Performance is scored by adding 1 error point for each error committed (Box 1). Trials are considered to be incomplete if the athlete is unable to sustain the stance position for longer than 5 seconds during the entire 20-second testing period. These trials are assigned a standard maximum error score of 10.

Fig. 4. Balance Error Scoring System performed on firm surface (A–C) and foam surface (D–F).
The BESS, which has been described as a rapid, easy-to-administer, and inexpensive clinical balance test, has identified postconcussion deficits in several studies. McCrea and colleagues reported that BESS scores in concussed college football players changed from baseline on average by 5.7 points, when measured immediately following the game or practice in which the injury occurred. Notably, however, at 1 day after injury, their average BESS score was only 2.7 points greater than baseline. For most athletes, BESS performance returned to preseason baseline levels (average 12 errors) by 3 to 7 days after injury. In a large study of American collegiate football players, impairment on the BESS was seen in 36% of injured subjects immediately following concussion, compared with 5% of the control group. A total of 24% of injured subjects remained impaired on the BESS at 2 days after injury, compared with 9% by day 7 after injury. Sensitivity values for the BESS were highest at the time of injury (sensitivity 0.34). Specificity values for this instrument ranged from 0.91 to 0.96 across postinjury days 1 to 7.

Significant correlations between the BESS and force platform sway measures with normal subjects have been established for 4 static balance tests (single-leg stance/firm surface, tandem stance/firm surface, double-leg stance/foam surface, single-leg stance/foam surface, and tandem stance/foam surface), with inter-rater reliability intraclass correlation coefficients ranging from 0.78 to 0.96. Researchers have reported that BESS performance can be influenced by a number of factors, including the type of sport played, a history of ankle injuries and ankle instability, and exertion and fatigue. Healthy athletes typically demonstrate a subtle learning effect on the BESS when it is administered over brief retest intervals, which should be considered when interpreting postinjury results during serial testing, and factoring in a practice effect if the test is being administered multiple times over a short period of time.

In comparison to the SOT scores on 36 concussed athletes previously mentioned (see Fig. 3), the BESS revealed a similar recovery curve (Fig. 5) when administered on the same day as the SOT. Furthermore, the BESS is sensitive to the effects of concussion with and without the use of other brief screening instruments, such as a graded symptom checklist and the Standardized Assessment of Concussion (SAC). However, when used in combination with a graded symptom checklist and the SAC, the BESS is more sensitive and specific for accurately classifying injured and noninjured athletes during the acute postinjury phase.

### Box 1
**Balance error scoring system**

- Hands lifted off iliac crests
- Opening eyes
- Step, stumble, or fall
- Moving hip into more than 30° of flexion or abduction
- Lifting forefoot or heel
- Remaining out of testing position for more than 5 seconds

The BESS score is calculated by adding 1 error point for each error committed during each of the 6 (20 seconds) trials.
More contemporary, and perhaps functional, approaches for identifying postural instability and movement dysfunction following TBI have focused on gait and balance assessment in a virtual environment or during conditions of divided attention (dual task). Researchers have identified alternative approaches to using SOT as the balance portion of a dual task with attention divided between the balance task of the SOT and a cognitive task given either verbally or visually while taking the SOT. This assessment method may have utility in the sports medicine setting, but must first be validated using concussed athletes. It may also have utility as a method of rehabilitation for athletes recovering from postconcussion syndrome.

Other researchers have experimented with virtual environments for assessing an athlete’s ability to react and respond to environmental stimuli. Slobounov and colleagues tested balance in concussed athletes at days 3, 10, and 30 after injury. Subjects were exposed to a virtual reality image of the room moving. Standard balance testing recovered by day ten, but responses to visual field motion remained abnormal at day thirty despite subjective symptoms and neuropsychological testing having returned to baseline levels. A follow-up study by the same group identified residual postural abnormality in subjects recovering from mTBI while assessing virtual time-to-contact measures, which essentially assesses the dynamic properties of postural control in a 3-dimensional space. The researchers concluded that residual deficits of balance become more prominent when concussed individuals are exposed to more demanding conflicting visual scenes. Other contemporary methods have focused more on gait analysis as a means to identify motor dysfunctions following mTBI. Parker and colleagues examined college athletes who had sustained concussion and performed neuropsychological testing and gait stability testing postinjury days 2, 5, 14, and 28. Gait was assessed as a single-task, and then while completing a simple mental task (dual task). A persistent significant difference was noted in the dual-task gait assessment at day 28, although not in the single-task or isolated neuropsychological assessment. A similar study recently conducted by Catena and colleagues found that level walking with a concurrent verbal cognitive task was able to distinguish between individuals with concussion and those without concussion.
immediately following concussive injury. The concussed individuals walked more slowly and more conservatively (reduced sagittal plan movement of body’s center of mass). By day 6 after injury, attention had recovered to the point at which the divided task was no longer effective in perturbing balance in those with concussion, and it appeared that the concussed subjects had recovered. By day 14 after injury, a more conservative control of mediolateral center of mass was observed in the concussed group during a more challenging task involving obstacle crossing. The authors concluded that although this work was preliminary, the information someday could lead to clinically executable dynamic balance control tests after concussion.

In summary, preliminary findings involving contemporary assessment techniques suggest that in challenging cases, difficult tasks combining divided attention and motor challenges may be more sensitive for identifying deficits in otherwise healthy active athletes. The clinical significance of altered response to virtual reality environments or dual-task gait assessments is intriguing. However, their clinical utility has yet to be established. These dual-task paradigms may also be useful in developing rehabilitation programs for athletes recovering from postconcussion syndrome.

**SUMMARY**

Balance assessment, whether through the use of a force plate or a clinical balance test, such as the BESS, is useful in identifying neurologic impairment in athletes following concussion. In many cases, this impairment lasts only a few days after injury; however, in a small number of cases in which there are lingering vestibular issues, the deficits can last significantly longer. In such cases, balance/vestibular training may be indicated for assuring a full return to activity for the athlete. Clinicians should realize that balance is only one small piece of a large puzzle in the assessment of concussion and may not be affected in every concussed athlete. With repeated testing, there is a subtle practice effect with both the BESS and SOT, so the absence of this improvement in concussed athletes should be considered in the interpretation.

Many of the concussion management consensus statements used by sports medicine clinicians recommend the inclusion of objective balance assessment as part of a comprehensive injury evaluation and follow-up. The new “Zurich Guidelines,” which resulted from the Third International Conference on Concussion in Sport, include, as part of its standardized concussion assessment tool (SCAT2), a systematic balance assessment similar to that of the BESS. The SCAT2 uses the first 3 trials (firm conditions) of the BESS, and errors are recorded in the same way. It is recommended that whenever possible, the BESS, in its entirety (including the foam conditions), be completed for assessing clinical balance of concussed athletes. To ensure best use and interpretation of the BESS or any other metric of postural stability for clinical management of concussion, postinjury scores should be compared with a preseason baseline score. Finally, it is important to recognize that although symptom severity, neurocognitive function, and postural stability are often affected initially following concussion, they are not necessarily related or even affected to the same degree. Thus, a comprehensive concussion assessment plan includes assessment of all these domains.

**REFERENCES**

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