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Challenging Concussed Athletes: The Future of Balance Assessment in Concussion

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Abstract

The assessment and management of sports related concussion has become a contentious issue in the field of sports medicine. The current consensus in concussion evaluation involves the use of a subjective examination, supported by multifactorial assessment batteries designed to target the various components of cerebral function. Balance assessment forms an important component of this multifactorial assessment, as it can provide an insight into the function of the sensorimotor subsystems post-concussion. In recent times, there has been a call to develop objective clinical assessments that can aid in the assessment and monitoring of concussion. However, traditional static balance assessments are derived from neurologically impaired populations, are subjective in nature, do not adequately challenge high functioning athletes and may not be capable of detecting subtle balance disturbances following a concussive event.

In this review, we provide an overview of the importance of assessing motor function following a concussion, and the challenges facing clinicians in its assessment and monitoring. Additionally, we discuss the limitations of the current clinical methods employed in balance assessment, the role of technology in improving the objectivity of traditional assessments, and the potential role inexpensive portable technology may play in providing objective measures of more challenging dynamic tasks.

Background

Sports related concussion (SRC) has become a significant health concern for those involved in all levels of contact sport such as Rugby Union and American Football. In the USA alone, it is estimated that between 1.6 and 3.8 million concussions occur annually[1,2]. The English Rugby Football Union (RFU) reported that during the 2011-2014 seasons in the English Premiership, concussions had the highest incidence of any injury[3]. Similarly, Lawrence et al[4] reported that concussion was the fifth most common injury between 2012-2014 in the National Football League (NFL) in America. There is a concern that rates of concussion are on the rise with the RFU injury surveillance report demonstrating an increase during the 2013/2014 season outside the expected levels of variation[3], with similar trends being documented in the NFL[4].

By definition, concussion is a functional disturbance rather than a structural injury due to the absence of neurological lesions on traditional neuroimaging[5]. The lack of structural abnormalities has traditionally led to individuals downplaying the severity of the injury[6]. The diagnosis and subsequent management of concussive events has become a contentious issue in recent years. High profile editorials such as that of Helmy and colleagues[7] outlined that published medical advice is often "flouted" in elite sport, and past players have admitted that they often "foxed" baseline cognitive assessments[8]. Additionally, Kemp et al[9] reported that in English professional Rugby Union, 58% of players with confirmed concussions were not removed from the field of play between 2002-2006. Similarly, during the 2010-2011 Irish rugby season, 45% of players reported at least one concussion, with only 46.6% of these presenting to medical staff[10].

Current Consensus in Concussion Monitoring

The traditional model of SRC assessment involves the identification of the signs of concussion, and where required, an on field triage evaluation by the sports clinician to assess the player's symptoms. If suspected or confirmed, the on-field assessment is typically followed-up on the side line or in the medical room with a subjective clinical exam, supported by various assessments to evaluate components of cerebral function including; clinical symptoms, motor function (balance, co-ordination and reaction time) and neurocognitive function[2,5]. Following a concussion diagnosis, World Rugby[11] and NFL guidelines[12] state individuals should be monitored in these main areas of cerebral function at specific time points throughout recovery.

In order to aid clinicians in the evaluation of athletes, assessment batteries such as the Sports Concussion Assessment Tool (SCAT) were developed[13]. In a review paper, Guskiewicz and colleagues[13] concluded that a variety of measures should be utilised to ensure that a complete clinical profile of a concussed individual is obtained. The importance of these assessments has recently been stressed through the consensus statement from the 4th International Conference on Concussion in Sport[5] and the position statement from the American Medical Society for Sports Medicine[2]. However, the accuracy and reliability of these compound side-line assessments is currently undefined, and many of these tests are outdated and are not sufficiently challenging for athletes. Interestingly, despite the paucity of data in this area, these assessments have been modified and included in concussion protocols such as World Rugby's Head Injury Assessment Tool and the NFL Concussion Screening Tool [12,14].

What is the role of balance assessment in concussion?

Recently, Willer and Leddy[15] called for a move away from the traditional symptom based model of assessment towards a more comprehensive structured physical examination, including detailed motor function assessments. Motor function requires the processing of sensorimotor information, and involves the complex hierarchical integration of the cerebral cortex, cerebellum, basal ganglia, brainstem and spinal cord[16]. As a result of this complex integration, motor function can be assessed along an integrative spectrum of sensorimotor function (figure 1). It has been established that concussed individuals often show impairments along this spectrum, demonstrating deficits in proprioceptive performance[17], reaction time[18], balance[19] and changes in focused[20] and duel-task[21] gait strategies. The consequences of these deficits have been highlighted through several studies reporting an increased risk of injury following return to play post-concussion in professional soccer[22], American college sports[23] and professional rugby[24]. A proposed mechanism for these motor function impairments is a disruption of the cortical pathways and/or vestibular function impairment post-concussion[25]. The assessment of balance can provide an important insight into the function and integration of the sensorimotor spectrum, potentially allowing us to detect if an individual has sustained a concussion, or if they are ready to return to play. Balance can be defined as the maintenance of ones centre of gravity within the limits of stability as defined by the base of support[26]. The question is, how can we effectively quantify these balance deficits post-concussion, and monitor changes?

Are existing clinical balance assessments working?

Traditionally, the assessment of the balance aspect of motor function has focused on static balance[11-13]. The maintenance of balance equilibrium involves the central integration of visual, vestibular and somatosensory information[16]. Static balance assessments have attempted to challenge the balance subsystems by utilising simple, subjectively rated tasks, conducted under different visual conditions, and on stable and unstable bases. The removal of visual input results in the increased reliance on the somatosensory and vestibular cortical inputs, while the introduction of an unstable base challenges all three.

The Romberg test provides a gross measure of balance under different visual conditions. If an individual presented with a balance deficit following a concussive event, it would be expected that they would have an increased level of sway during the eyes closed balance task. However, the standard Romberg test is traditionally used in the assessment of patients at risk of falling[27]. It is subjective in nature, lacks in reliability and sensitivity data in concussed populations, and is not challenging enough to elicit deficits in an athletic population[16].

The current standard in clinical balance assessment for concussion is the Balance error scoring system (BESS). It involves three 20 second stances (double, single and tandem) completed on firm and unstable surfaces. Studies have demonstrated that athletes demonstrate a significant increase in errors following a concussive event, and typically return to baseline levels within 3 to 5 days post injury[19]. However, the BESS suffers from learning[28] and fatigue[29] effects. Additionally, a systematic review conducted by Bell et al[30] reported that the BESS was only capable of detecting large changes in balance. In order to provide a more rapid assessment, the modified BESS (only firm surface assessments) was developed and incorporated into the SCAT3[13,31]. However, little research has been conducted in concussed populations, with King and colleagues [32] reporting low sensitivity and specificity. Similarly to the other static balance assessments, the BESS and modified BESS may not be adequately challenging or sufficiently sensitive to detect subtle changes in static balance in higher level athletes, calling into question its wide spread application in athletic populations.

Does the addition of technology help?

In an attempt to increase the sensitivity of balance assessments, expensive laboratory equipment such as force platforms have been incorporated into static balance assessments. Assessments such as the modified Clinical Test of Sensory Organisation and Balance (CTSIB) and the Sensory Organisation Test (SOT) were developed in order to provide researchers with an improved understanding of balance deficits following concussion.

The CTSIB takes advantage of force platform technology in an attempt to provide more objective quantification of postural sway under 3 visual conditions (eyes-open, eyes-closed and looking into visual dome), and on stable and unstable surfaces[33]. Guskiewicz and colleagues [34] utilised the CTSIB and reported that concussed athletes demonstrated decreased postural stability for 3 days post injury. However there is a lack of population specific reliability, sensitivity and specificity data in a concussed population. Similarly to the CTSIB, the SOT attempts to systematically challenge the sensory input through various visual and standing surface conditions while recording postural sway via a force platform [16]. It provides a more challenging task than classic static balance assessments, requiring the individual to maintain their balance while altering the orientation information available to the somatosensory and vestibular systems. Guskiewicz et al and Cavanaugh et al [35,36] demonstrated that the SOT can detect postural control deficits post-concussion, which typically resolve within 3-5 days. The SOT has been shown to demonstrate moderate reliability in a healthy population[37], however no data has currently been presented in a concussed population. Broglio et al[38] concluded that the SOT demonstrated low levels of sensitivity and specificity and should not be used as a standalone assessment in a concussed population.

Although such measures may provide important information surrounding determining an individual's readiness to return to play, the lack of population specific data, impracticalities and limited accessibility for clinicians are major drawbacks[16]. Additionally, such assessments stem from the traditional static assessment, and as a result may still fail to sufficiently challenge the sensorimotor system in athletic populations.

Could we utilise portable technology?

In order to provide a more objective quantification of balance deficits post-concussion, recent research has focused on incorporating inexpensive portable sensing technology into traditional clinical static balance assessments.

The use of the Wii Balance Board (WBB) in the assessment of balance has increased since the seminal work of Clarke and colleagues [39] who demonstrated that it is a reliable measure for assessing centre of pressure during static stance. Research has primarily focused on the use of Wii balance games and custom software in the assessment of centre of pressure excursion. The WBB has been shown to provide valid measures of static postural control in healthy subjects [39] and Parkinson disease patients [40], and can detect changes in balance [41]. However, Wii Fit Balance games have demonstrated poor concurrent validity with current balance assessments [42,43]. Importantly there is currently no reliability and validity data surrounding the use of the WBB in the evaluation of concussed individuals [44]. These findings suggest that the WBB may provide an accessible and low cost means to objectively quantify static balance following concussion, however there is a lack of data in concussed populations, and this quantification may not increase the ability of static balance assessments to detect deficits in athletic populations.

Recently there has been an increase in the number of instrumented clinical tests using inertial sensors[32]. Inertial sensors contain accelerometers, gyroscopes and magnetometers which are capable of capturing subtle changes in movement. Inertial sensor systems are low cost and can be implemented easily in a clinical setting as a result of their unobtrusive nature. Evidence surrounding the validity and reliability of instrumented balance measures in individuals with Parkinson disease [45] and multiple sclerosis [46] has begun to emerge. In a concussed population, there have been conflicting reports surrounding the utility of instrumented static balance assessments[32,47]. Furman et al [47] demonstrated that an instrumented static balance assessment utilising an inertial sensor mounted on the lumber spine is not as effective as the traditional BESS in identifying abnormalities post-concussion. However more recently, King and colleagues [32] reported improved levels of sensitivity and specificity from both the BESS and modified BESS instrumented with an inertial sensor. It is likely that the conflicting conclusions are as a result of the different quantified variables implemented in both studies. King et al[32] utilised root mean squared acceleration which may be more capable of detecting subtle balance deficits than the inertial sensor derived sway path length used by Furman and colleagues[47]. These initial reports demonstrate a positive step forward in the objectification of current methods of assessment, however more research is required in concussed populations to determine if this improves static balance assessments ability to detect concussion deficits.

Future direction

Recently there has been an increased awareness that the standard subjective balance assessments may not be sufficiently challenging to elicit deficits in concussed athletes. Indeed, ahead of the 5th International Conference on Concussion in Sport, Kemp and colleagues called for the development of more challenging assessments and return to play protocols[25]. It is not adequate to rely on traditional subjective measures originating from falls risk and low functioning neurological populations.

As discussed above, research has previously attempted to challenge the balance subsystems though the use of different stance surfaces and visual conditions, with and without instrumentation. However, this has involved the use of subjective measures, or expensive force platform technology, which are not accessible to most clinicians. Early work developing cheap and accessible objective instrumented assessments has shown promising results, however static tasks may still not be sufficiently challenging to elicit subtle deficits in an athletic population, or as an individual progresses past the initial acute phase of the injury. It may be hypothesised that objective quantification of both static and dynamic balance tasks using sensor technology may provide a means to objectively evaluate the function and integration of the motor control subsystems as the individual progresses through the different stages of recovery.

In the future, it is possible that objective instrumented balance assessments will be accessible to clinicians in the management of concussion. Such assessments could be incorporated into a wider multimodal assessment battery, that is not only specific to the particular stage of recovery, but capable of sufficiently challenging the individual as they progress towards eventual recovery.

Implications

- Traditional static balance assessments may not be sufficiently challenging to detect balance deficits in concussed individuals.
- Quantification of static balance assessments in a laboratory setting provides useful information, however it is expensive and not accessible to most clinicians.
- Quantification of static and dynamic balance assessments using accessible technology may provide a greater degree of granularity.
- Quantifiable and challenging balance and motor performance assessments need to be developed and incorporated into clinical practice.
- Objective balance and motor performance assessments should be incorporated into wider multimodal assessment batteries, that are specific to the point in the recovery process.

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