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ORIGINAL ARTICLE

Instrumenting the Balance Error Scoring System for Use With Patients Reporting Persistent Balance Problems After Mild Traumatic Brain Injury

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Abstract

Objective: To determine whether alterations to the Balance Error Scoring System (BESS), such as modified conditions and/or instrumentation, would improve the ability to correctly classify traumatic brain injury (TBI) status in patients with mild TBI with persistent self-reported balance complaints.

Design: Cross-sectional study.

Setting: Outpatient clinic.

Participants: Subjects (n=13; age, 16.3±2y) with a recent history of concussion (mild TBI group) and demographically matched control subjects (n=13; age, 16.7±2y; control group).

Interventions: Not applicable.

Main Outcome Measures: Outcome measures included the BESS, modified BESS, instrumented BESS, and instrumented modified BESS. All subjects were tested on the noninstrumented BESS and modified BESS and were scored by visual observation of instability in 6 and 3 stance conditions, respectively. Instrumentation of these 2 tests used 1 inertial sensor with an accelerometer and gyroscope to quantify bidirectional body sway.

Results: Scores from the BESS and the modified BESS tests were similar between groups. However, results from the instrumented measures using the inertial sensor were significantly different between groups. The instrumented modified BESS had superior diagnostic classification and the largest area under the curve when compared with the other balance measures.

Conclusions: A concussion may disrupt the sensory processing required for optimal postural control, which was measured by sway during quiet stance. These results suggest that the use of portable inertial sensors may be useful in the move toward more objective and sensitive measures of balance control postconcussion, but more work is needed to increase sensitivity.

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Because mild traumatic brain injury (mTBI) or concussion frequently goes unreported, the estimated annual U.S. incidence of 1.6 to 3.8 million likely reflects an underestimation.[1,2] Additionally, a recent mTBI increases the risk of sustaining a second mTBI,[3-5] and the sequelae of repetitive mTBI may be cumulative.[6] Therefore, premature return to play confers serious risk for further brain injury.[7]

A disturbance in balance is a commonly reported symptom post-traumatic brain injury (TBI). The most frequently used clinical scale for postconcussion balance assessment is the Balance Error Scoring System (BESS). The BESS measures instability by the examiner's subjective count of errors in the maintenance of various stances by the patient, who has his/her eyes closed (feet together, single-leg, and tandem stance) and is standing on different surfaces (firm and foam).[8] Although portable and quick to administer, the BESS suffers from learning,[9,10] practice,[11] and fatigue[12] effects and may be insensitive to mild impairments.[13] These factors represent questions about the validity and reliability of the BESS and the decisions emanating from its use.

A recent shortened version of the BESS, the modified BESS test, includes only 3 stances on firm surface (omitting the 3 stances on the foam surface). The modified BESS was published as a part of the Sport Concussion Assessment Tool 2[14,15] and has published norms[13,16] but may also have problems with sensitivity. A recent study reported no differences in the modified BESS between high school students with and without concussion.[13] The authors suggested that the modified BESS may have a ceiling effect, and the presence of foam in the full BESS may be more helpful at classifying those with and without mTBI. However, the full BESS has known psychometric weaknesses and, similar to the modified BESS, also uses subjective scoring. Objective measures of persisting balance complaints could greatly augment patient safety determinations.

Currently, self-report questionnaires and subjectively scored clinical tests, such as the BESS, represent the most frequently used method of evaluating and monitoring postinjury complaints. Reliance on these measures for return to play and medical management can have grave consequences. A trend toward underreporting mTBI sequelae has been reported in high school and college-aged athletes.[17-19] Many young people experience social pressure to return to their sport before symptoms have fully resolved, which is contrary to their best interests. The widespread use of self-report measures coupled with the tendency to underreport symptoms have prompted the call for more objective forms of measurement.

The instrumentation of clinical motor tests is increasingly used to achieve objective quantification of movement.[20,21] Because balance represents a physically measureable attribute, it lends itself naturally to a technology-based measurement solution. Inertial sensors, the size of a wristwatch, contain accelerometers, gyroscopes, and magnetometers, which can objectively capture subtle anomalies when integrated properly. Various types of inertial sensors have begun to yield evidence of validity and reliability for balance measurement in people with mild or early Parkinson's disease,[22,23] multiple sclerosis,[24] and also in older adults.[25] Software[26] associated with these sensor readings can automatically calculate a myriad of metrics based on the features of human movement, making it feasible for preprogrammed, nonexpert administration. For example, postural sway during quiet stance can be characterized by its amplitude, frequency, and velocity. The National Institutes of Health (NIH) Balance Toolbox[27] recently began promoting the use of inertial sensors to assess general balance (nondisease specific) through postural sway. Specifically, the NIH recommends the Standing Balance Test that measures anterior-posterior (AP) postural sway during different stance conditions (feet together and tandem on firm and foam surfaces). However, what is generally referred to as balance is composed of many more elements than postural sway.[28] Additionally, postural sway can be measured in more basic dimensions than the AP direction (ie, ML). Currently, it is not known which sway features and balance conditions are most frequently impaired after mTBI. A recent study showed that the NIH-recommended Standing Balance Test protocol was inferior to the BESS in separating those with and without mTBI,[29] which, as previously discussed, has demonstrated its own set of weaknesses.[9-11,30,31] The authors suggest that the Standing Balance Test was not developed directly for concussion but rather as a general balance screening; however, the BESS was directly developed to assess balance after mTBI. To our knowledge, no studies have yet attempted to instrument the BESS directly using an inertial sensor to improve objective assessment of balance deficits.

The purpose of this study was to determine whether alterations to the BESS, such as modified conditions and/or instrumentation, would improve the ability to correctly classify participants according to TBI status. We hypothesized that addition of the foam conditions would improve diagnostic accuracy of the BESS over the modified BESS and instrumentation of the BESS would improve diagnostic accuracy over the noninstrumented BESS.

List of abbreviations:

AP	anterior-posterior
AUC	area under the curve
BESS	Balance Error Scoring System
ML	mediolateral
mTBI	mild traumatic brain injury
NIH	National Institutes of Health
OHSU	Oregon Health & Science University
RMS	root-mean-square
ROC	receiver operating characteristic
TBI	traumatic brain injury

Methods

Ethical review

The Oregon Health & Science University (OHSU) Institutional Review Board approved this study. All participants enrolled in the study received and signed informed consent forms approved by the OHSU Institutional Review Board. A legal guardian accompanied participants <18 years old, and subjects ≤16 years signed an additional assent form. All work was conducted in accordance with the Declaration of Helsinki (1964).

Recruitment

The mTBI participants were recruited from the OHSU Sports Medicine Department and the Department of Rehabilitation Services. All mTBI participants, who were diagnosed by a physician in the Department of Sports Medicine, were 2 to 13 months status post-mTBI. All were currently receiving standardized outpatient rehabilitation services for their complaints of continued imbalance and dizziness. Exclusion criteria included recent orthopedic injuries, other neurologic or vestibular disorders unrelated to their