An Alternative to the Balance Error Scoring System: Using a Low-Cost Balance Board to Improve the Validity/Reliability of Sports-Related Concussion Balance Testing

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Objective: Recent guidelines advocate sports medicine professionals to use balance tests to assess sensorimotor status in the management of concussions. The present study sought to determine whether a low-cost balance board could provide a valid, reliable, and objective means of performing this balance testing.

Design: Criterion validity testing relative to a gold standard and 7 day test-retest reliability.

Setting: University biomechanics laboratory.

Participants: Thirty healthy young adults.

Assessment of Risk Factors: Balance ability was assessed on 2 days separated by 1 week using (1) a gold standard measure (ie, scientific grade force plate), (2) a low-cost Nintendo Wii Balance Board (WBB), and (3) the Balance Error Scoring System (BESS).

Main Outcome Measures: Validity of the WBB center of pressure path length and BESS scores were determined relative to the force plate data. Test-retest reliability was established based on intraclass correlation coefficients.

Results: Composite scores for the WBB had excellent validity (r = 0.99) and test-retest reliability (R = 0.88). Both the validity (r = 0.10–0.52) and test-retest reliability (r = 0.61–0.78) were lower for the BESS.

Conclusions: These findings demonstrate that a low-cost balance board can provide improved balance testing accuracy/reliability compared with the BESS.

Clinical Relevance: This approach provides a potentially more valid/reliable, yet affordable, means of assessing sports-related concussion compared with current methods.

Key Words: concussion, mild traumatic brain injury, postural control, assessment, force plate

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INTRODUCTION

Sports-related concussions are traumatic brain injuries caused by biomechanical forces transmitted directly or indirectly to the brain during sports activity.[1] Due to a complex underlying pathophysiological process, concussions are transient and include a wide range of symptoms consisting of somatic, cognitive, and sensorimotor indicators.[2] Approximately 3.8 million sports-related concussions are reported annually in the United States, which accounts for 5% to 9% of all sports-related injuries.[3–5]

The American Medical Society recently published guidelines in this journal for the diagnosis of sports-related concussions.[2] These guidelines advocate a multicomponent assessment approach encompassing the establishment of (1) signs and symptoms, (2) cognitive function, and (3) sensorimotor status. For the latter component, balance tests have been used extensively because balance provides an ideal model for determining sensorimotor deficits following sports-related concussion (for review see Guskiewicz[6]). Specifically, balance control requires the complex integration of several sensory feedback sources (ie, vision, proprioception, and vestibular function) and regulation of motor responses to ensure that the center of mass of the body remains over its base of support.[7,8]

Two primary approaches have been used to assess balance in potentially concussed athletes. The first quantifies balance ability based on measured changes in body sway during standing on a scientific-grade force plate, which is the criterion measure or "gold standard" for balance assessment.[9,10] Force plates can track changes in the vertical projection of the center of mass of the body [ie, center of pressure (COP)], which is akin to body sway. Increased body sway is a well-accepted indicator of balance instability and, as such, concussed athletes show increased COP relative to baseline performance.[11]

Unfortunately, force plate balance testing is not feasible for most youth/amateur sports teams. This is due to equipment costs (approximately \$5000–\$15 000) and the lack of force plate portability to perform sideline assessments. Therefore, an alternative to force plate–based balance quantification, the Balance Error Scoring System (BESS), has been implemented in most sport-related concussion assessment batteries. The BESS relies on the observational skills of trained sports medicine professionals to determine the total number of balance errors during standing trials of varying difficulty.[6] Errors are determined by negative balance events

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such as stepping out of place or removing one's hands from his/her hips.

Although the BESS approach to balance assessment is more cost-effective and portable than that of a force plate, evidence regarding its validity and reliability are mixed (for review see Bell et al[12]). Several reports demonstrate that the BESS has good content validity,[11,13,14] but criterion validity has not been well established relative to a force plate system (compared with Riemann et al[15]). Furthermore, several studies have demonstrated that the BESS has issues regarding intra- and interrater reliability.[16,17] There may also be inherent problems with the specificity/sensitivity of the BESS for concussion diagnosis.[18]

Ideally, the objectivity, validity, and reliability of sophisticated force plate balance assessments could be merged with the portability and cost-effectiveness of the BESS. To this extent, several recent studies have shown convincing evidence that a low-cost (approximately $50) Nintendo Wii Balance Board (WBB) device can be used as a valid and reliable force plate alternative.[19,20] Originally designed as a video game controller, the WBB can be isolated from the Wii gaming system and wirelessly interfaced with a computer as a peripheral device for the development of clinical balance testing applications. Indeed, a variety of WBB-based balance applications now exist in the literature, including the monitoring of weight bearing asymmetry[21,22] and the assessment of balance in various clinical populations.[23,24]

Therefore, the aim of present study was to determine whether a low-cost balance board (ie, WBB) could be used to improve the validity, reliability, and objectivity of sports-related concussion balance testing. Healthy young adults performed balance testing on 2 days separated by 1 week. Body sway data were collected concurrently from a scientific-grade force plate and WBB, and trials were videotaped for later BESS scoring by 3 raters. It was hypothesized that body sway data from the WBB would correlate more strongly with the gold standard force plate than BESS scores, providing evidence of enhanced concurrent validity. Furthermore, it was expected that the objective WBB would have greater test-retest reliability than the BESS by eliminating issues of interrater reliability.

METHODS

Participants

Thirty young adults (15 men and 15 women) aged between 18 and 35 years (mean age, 24.4 ± 3.9 years) participated in this study. The average participant had a height of 171.9 ± 8.3 cm and weight of 68.8 ± 11.3 kg. Subjects were not active in organized sports but were healthy according to the Physical Activity Readiness Questionnaire.[25] Participants also did not show evidence of a current concussion based on a score of >25 on the Standard Assessment of Concussions[26] and a total score of <5 on the Concussions Symptoms checklist.[27] For this study, knowledge of the participant's dominant leg was required. Footedness was determined by asking participants which leg they preferred for kicking a ball. The majority of subjects (27 of 30) were right footed (ie, preferred to kick with the right foot). All procedures were approved by the local institutional review board, and written informed consent was provided by all participants.

Experimental Setup

A schematic of the experimental setup is shown in Figure 1. For each balance trial conducted (see Experimental Procedures), participants stood on an inverted WBB (Nintendo, Kyoto, Japan) affixed to a scientific-grade force plate (model: OR6-7-2000; Advanced Mechanical Technology, Inc, Watertown, Massachusetts). Mechanically coupled to the WBB was a wood board surface extension. This modification accommodated individuals with larger feet and tandem stance balance conditions. In some trials, a balance pad (Alcan Airex, Aargau, Switzerland) was placed on the wood extension to provide an unstable standing surface.

Body sway data in the side-to-side (COPx) and fore-and-aft (COPy) directions were recorded from the force plate and WBB by a personal computer (Dell Optiplex 990; Dell Inc, Round Rock, Texas) using customized software written in LabVIEW (National Instruments, Austin, Texas). Force plate signals were transmitted to the computer via an analogue data acquisition board (model: USB-2533; Measurement Computing, Norton, Massachusetts), whereas the WBB was connected wirelessly to the computer via Bluetooth. Force plate and WBB calibration were accomplished using manufacturer-specified coefficients, which were verified before testing using calibration weights. All trials were video recorded by a Web camera (model: Quickcam Pro 5000; Logitech, Newark, California) at a viewing angle maximized for the establishment of balance errors according to the BESS.

Experimental Procedures

The balance-testing portion of this study began by having participants change into appropriate clothing and remove all footwear. A familiarization period was given to allow participants to experience the stance and surface conditions of the BESS.[6] This included the following:

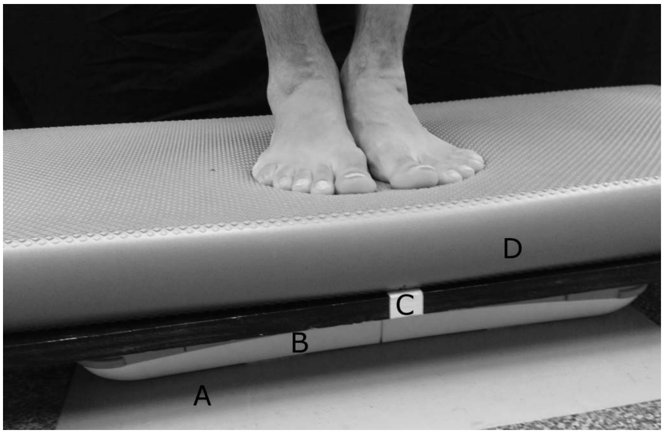

FIGURE 1. Schematic of the experimental setup for this study. Force plate (A), WBB (B), wood surface extension (C), and foam pad (D).

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Condition 1: Double-leg stance on a firm (wood board) surface.
Condition 2: Single-leg stance on a firm (wood board) surface.
Condition 3: Tandem stance on a firm (wood board) surface.
Condition 4: Double-leg stance on an unstable (foam) surface.
Condition 5: Single-leg stance on an unstable (foam) surface.
Condition 6: Tandem stance on an unstable (foam) surface.

In each condition, participants were instructed to keep their hands on their hips and eyes closed. Double-leg stance conditions required that the participant keep both feet on the ground with medial malleoli in contact. Single-leg stances were performed on the nondominant leg while lifting the foot of the dominant leg off the ground to an angle of approximately 45° knee flexion and 30° hip flexion. Finally, tandem stance conditions had participants place their feet heel to toe with nondominant toward the rear.

Once familiar with the various conditions, balance testing began. Test instructions were prompted and read from the data collection computer screen. Each participant performed the balance conditions one at a time in the same order listed above. Participants were told to remain as still as possible while maintaining the test positions and to only open their eyes to reposition themselves following a loss of balance. Each trial lasted 20 seconds and began when the test position was held stable for several seconds. Total testing time was <5 minutes and repeat testing occurred 7 days after the initial data collection at a similar time of day.

Data Processing

Force Plate and WBB COP Determination

Center of pressure for the force plate was calculated using the following formulas:

$$\mathrm{COP}x = \mathrm{M}y/\mathrm{Fz}$$
$$\mathrm{COP}y = \mathrm{M}x/\mathrm{Fz},$$

where My and Mx were the moments of force generated about the y and x axes of the force plate, respectively, and Fz was the total downward (ie, vertical) force.

For the WBB, more simplistic COP calculations were used due to the fact that the WBB does not measure moments of force. These formulas were as follows:

$$\mathrm{COP}x = 21\times((\mathrm{TR}+\mathrm{BR})-(\mathrm{TL}+\mathrm{BL}))/(\mathrm{TL}+\mathrm{TR}+\mathrm{BL}+\mathrm{BR})$$
$$\mathrm{COP}y = 12\times((\mathrm{TL}+\mathrm{TR})-(\mathrm{BL}+\mathrm{BR}))/(\mathrm{TL}+\mathrm{TR}+\mathrm{BL}+\mathrm{BR}),$$

where TR, TL, BR, and BL are the force sensor values from the top right, top left, bottom right, and bottom left corners of the WBB, respectively.

Some participants stepped off of the WBB/force plate during testing, particularly in the more difficult single-leg and tandem stance on foam conditions. In this case, an algorithm was implemented that pushed COPx and COPy 100 cm from the center location of the WBB when concurrently recorded weight for the participant fell below a reading of 20 kg. This penalty was determined based on an approximation of the average amount of COP displacement that would occur during a typical fall. When participants returned to the WBB/force plate, COP measurement returned to normal.

For each BESS condition, and for the sum of all conditions (ie, composite score), COP data were used to calculate total COP path length values. This nondimensional, point-to-point measure of the total COP movement was the main measure describing body sway during balance testing. This variable was calculated according to the following formula:

$$\text{Path length} = \left((\mathrm{COP}x2-\mathrm{COP}x1)^2 + (\mathrm{COP}y2-\mathrm{COP}y1)^2\right)^{0.5},$$

where COPx2 and COPx1 are adjacent time points in the COPx time series and COPy2 and COPy1 are adjacent time points in the COPy time series. The sum of all consecutive points was added together to get total path length.

Rater-Determined BESS Scores

The videos from each trial were scored by 3 raters according to the BESS.[7] Error counts were established from a single viewing angle with the following errors noted:

1. Moving the hands off of the hips
2. Opening the eyes
3. Step, stumble, or fall
4. Hip abduction/flexion beyond 30 degrees
5. Lifting the forefoot/heel off the testing surface
6. Remaining out of the test position for >5 seconds

The raters in this study had varying levels of BESS experience, with 1 rater having extensive experience (>3 years), 1 intermediate (>2 years), and 1 being a novice (<1 year).

Statistical Analyses

Sample Size

Sample size was rooted in precision[28] and determined based on the calculation of the WBB validity coefficients and intraclass correlation coefficients (ICC) described below. Calculations for the ICC case (2,1) used were derived from

TABLE 1. Validity Measures (r Values) For the WBB and BESS Raters Compared To a Gold Standard Force Plate

Scoring Category	WBB		BESS Scores	
	Test	Retest	Test	Retest
Condition 1	0.99	0.99	—	—
Condition 2	0.99	0.99	0.31–0.60	0.57–0.70
Condition 3	0.99	0.99	0.25–0.55	0.29–0.38
Condition 4	0.99	0.99	0.16–0.40	0.17–0.29
Condition 5	0.99	0.99	0.08–0.21	−0.04–0.13
Condition 6	0.99	0.99	0.23–0.42	−0.01–0.63
Composite	0.99	0.99	0.21–0.52	0.10–0.47

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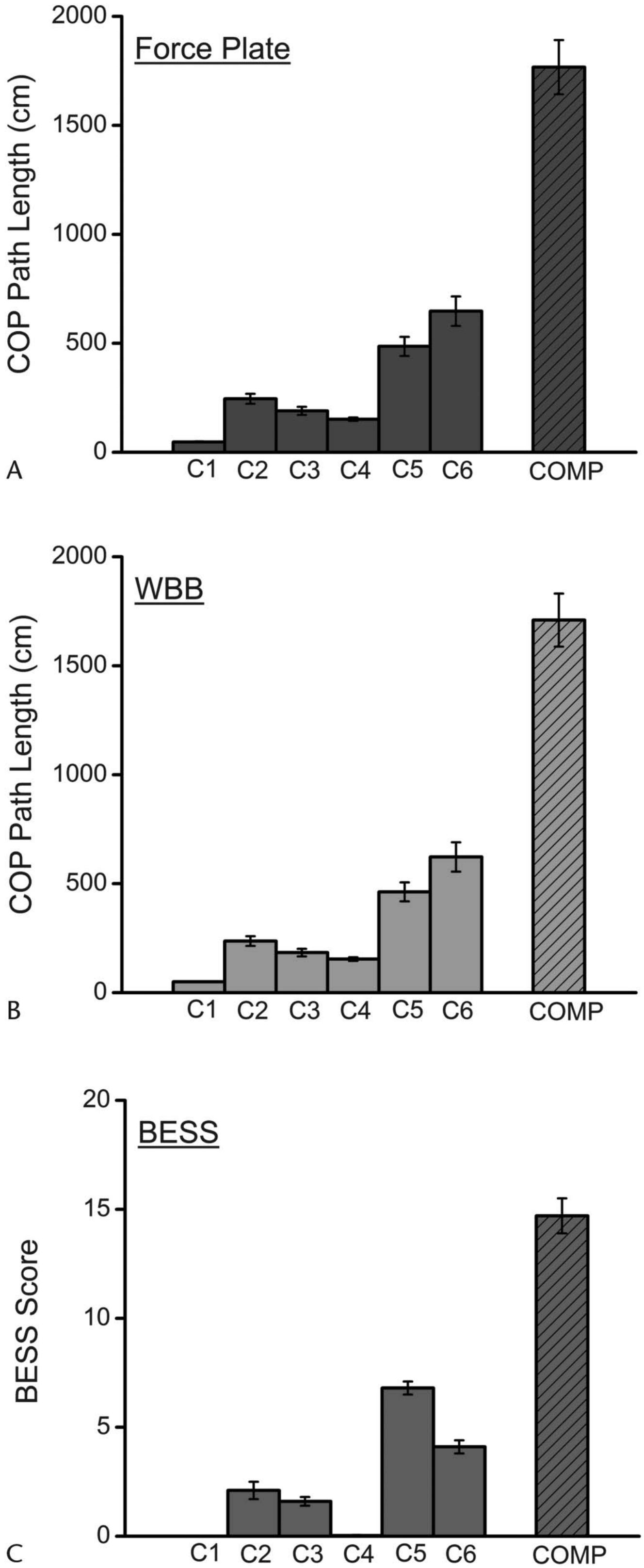

FIGURE 2. Mean (±between-subject standard error) balance performance as measured by the scientific grade force plate (A), WBB (B), and BESS (C) of the most experienced rater. Data from the first (ie, test) session. C1–C6 = Conditions 1–6; COMP = composite score.

confidence intervals, as recommended by Doros and Lew.[29] Overall, a sample size of 30 individuals was deemed adequate to obtain stable and precise estimates. Wii Balance Board validity coefficients were very high, supporting the stability of our correlation approach.[30]

Concurrent Validity

Concurrent validity was examined for both the WBB data and BESS scores compared with the force plate using Pearson product moment correlations. Validity coefficients (r) greater than 0.90 were considered excellent, between 0.80 and 0.89 were good, between 0.70 and 0.79 were fair, and values below 0.70 were considered poor evidence of concurrent validity.[31]

Reliability

Interrater reliability for BESS score was examined using an ICC (2,1) 2-way random effect, single measure model, because the raters were considered a representative sample from a larger population who would normally use the BESS.[32] Seven day test-retest reliability for the force plate, WBB, and BESS was also examined using an ICC (2,1) model. Reliability coefficients (R) greater than 0.75 were deemed excellent, between 0.60 and 0.74 were good, between 0.40 and 0.59 were fair, and below 0.40 were poor.[33]

RESULTS

Validity

Comparisons between the scientific grade force plate, WBB, and rater-determined BESS scores are given in Table 1 and Figure 2. The WBB had a near-perfect (r = 0.99) correlation with the gold standard force plate in each balance test condition and for the composite COP path length. In contrast, the BESS scores varied substantially across balance conditions and raters. In condition 1, validity could not be established, based on the lack of any errors noted by any rater. For the remaining conditions, correlations between the rater-determined BESS scores and the force plate data were low to fair (test: r = 0.08–0.60; retest: r = −0.04–0.70). Composite BESS scores were also low (test: r = 0.21–0.52; retest: r = 0.10–0.47) in all cases. A further demonstration of these results is found in Figure 3, which compares the composite data for the WBB and each rater relative to the force plate.

Contributing to the poor validity of rater-determined BESS scores was less than optimal interrater reliability (Table 2). Intraclass correlation coefficients were only poor to good for the 6 balance conditions and the composite scores at time point 1 (R = 0.24–0.60) and time point 2 (R = 0.00–0.69). Interrater reliability was particularly poor in conditions 4 and 6 and for the composite score (test:

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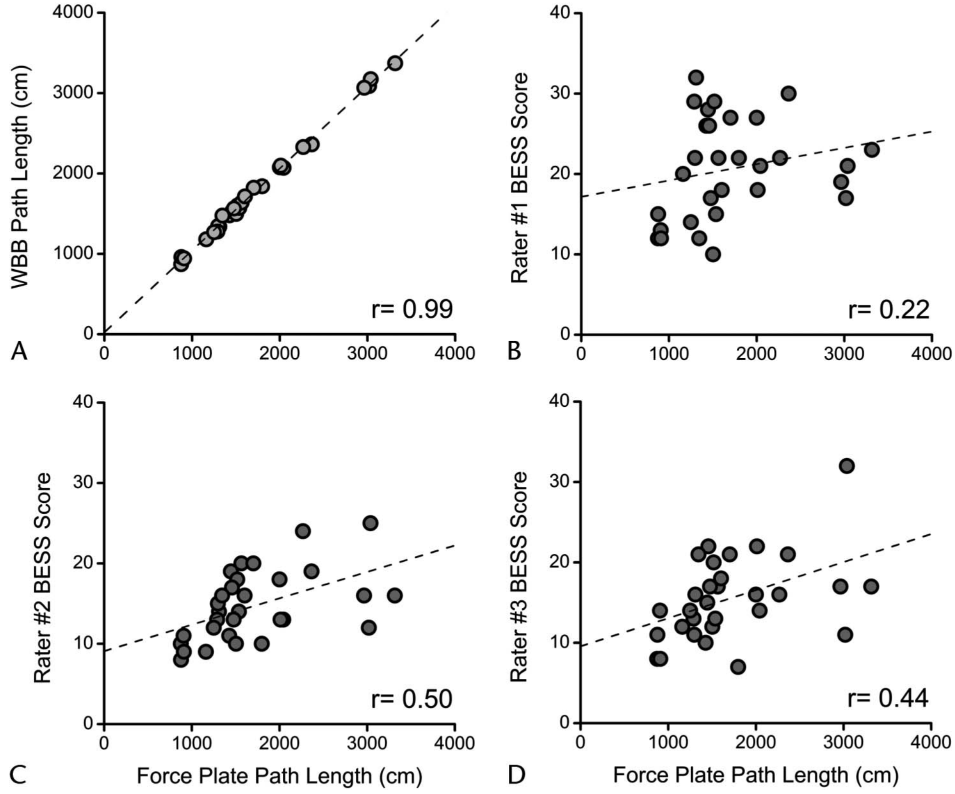

FIGURE 3. Comparison of composite data from the WBB (A) and each of the 3 raters (B–D) versus the gold standard force plate. Data from the first (ie, test) session.

R = 0.35; retest: R = 0.20). Experience level of the raters did not contribute to these findings because each rater was found to be "most" and "least" consistent in at least 1 condition.

Test-Retest Reliability

Test-retest reliability of the force plate, WBB, and BESS scores is summarized in Table 3. Despite poor test-retest reliability in condition 3 (R = 0.27), the force plate and WBB had moderate-to-good test-retest reliability in all other conditions (R = 0.51–0.73). The WBB and force plate had excellent test-retest reliability (WBB: R = 0.88; force plate: R = 0.89) in terms of the composite COP path lengths determined. This value was greater than that seen for composite BESS scores of any individual rater (R = 0.61–0.78). Intraclass correlation coefficients for the rater-determined scores in condition 1 were not possible due to the lack of variability in the data (ie, no errors were perceived across all trials). The lowest reliability for rater-determined BESS scores was in condition 4 (R = 0.00–0.38) and the highest was in condition 2 (R = 0.56–0.73).

DISCUSSION

The present study sought to determine whether a low-cost balance board could be implemented to improve the validity/reliability of sports-related concussion balance assessments. Compared with a gold standard measure of balance (ie, scientific-grade force plate), an inexpensive WBB proved to be superior to the BESS. Specifically, the WBB had an almost perfect agreement with force plate data in terms of COP path length measured. This concurrent validity was seen for all conditions and was notably higher than any rater-determined BESS score, regardless of experience. The test-retest reliability of the WBB, although low for some

TABLE 2. Interrater Reliability (ICCs) Between the 3 Trained BESS Raters

Scoring Category	Test	Retest
Condition 1	—	—
Condition 2	0.60	0.69
Condition 3	0.47	0.33
Condition 4	0.24	0.00
Condition 5	0.46	0.37
Condition 6	0.35	0.20
Composite	0.35	0.20

TABLE 3. Test-Retest Reliabilities (ICCs) for the Force Plate, WBB, and BESS Raters

Scoring Category	Force Plate	WBB	BESS Raters
Condition 1	0.66	0.68	—
Condition 2	0.65	0.59	0.56–0.73
Condition 3	0.28	0.27	0.38–0.57
Condition 4	0.75	0.73	0.00–0.38
Condition 5	0.55	0.51	0.23–0.63
Condition 6	0.71	0.71	0.33–0.51
Composite	0.89	0.88	0.61–0.78

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conditions, was also excellent for composite scores. Composite scores of BESS only ranged from fair to excellent.

The criterion validity of BESS scores relative to a force plate was previously determined by Riemann et al.[15] In this study, 111 athletes were rated by 3 experienced athletic trainers using BESS criteria, and COP data were concurrently recorded from a force plate. Similar to the present study, correlations between BESS scores and force plate COP data ranged greatly across the various conditions (r = 0.31–0.79), with no comparisons possible for condition 1 due to the lack of errors perceived. In contrast, the low-cost balance board in the present study had excellent concurrent validity in all conditions (r = 0.99) and could provide meaningful data for comparison in condition 1.

The present study also found that the WBB was a better assessment method versus the BESS in terms of composite score test-retest reliability. The BESS has previously been shown to have good test-retest reliability for high school participants (ICC = 0.70)[34] and young adults (generalizability coefficient, 0.64),[35] and the present findings agree with this work for healthy young adults (ICC = 0.61–0.78). Despite these somewhat positive BESS results, the low-cost balance board in the present study had even greater test-retest reliability.

The WBB approach described in this study can provide identical scoring regardless of operator. This contrasts the BESS, which varies between raters.[16] This inconsistency was demonstrated in the present study, where 3 trained raters obtained BESS scores that differed substantively across BESS conditions. This issue of interindividual consistency suggests that all observationally scored BESS tests should be performed by the same rater to ensure reliability.[35] Unfortunately, this is not always feasible in settings with multiple athletic trainers whose patient care may overlap. Balance assessment using an objective device, like the WBB, would allow athletic trainers with multiple levels of experience to score the BESS at different times and achieve comparable data.

Several limitations of the present study should be noted, including the use of a healthy young adult population versus individuals with sports-related concussion. This approach was taken to achieve a large enough sample to fully test the WBB assessment method. Future work is planned with concussed athletes, with the present results indicating that such efforts are likely to be met with success. Indeed, previous studies have shown that force plate balance testing is preferable to the BESS for diagnosing concussion-related postural disturbances.[11] To further extend this work, it will be necessary to determine a threshold criterion for what increase in body sway is associated with sports-related concussion.

A need also exists to address the effects of age and sex on the efficacy of WBB-based balance testing compared with the BESS approach. These questions are beyond the scope of the present study, but evidence suggests that both factors influence balance performance. In particular, younger adults and females have been shown to have less reliable test-retest data compared with adults for the BESS.[36] To what extent a similar decline would exist for the WBB-based balance method remains unclear. However, it is reasonable to expect that a balance board approach would remain superior to the BESS, as comparable declines in efficacy might be expected for the 2 methods.

Several practical issues must still be addressed before the widespread use of the balance board approach described in this study. First, development of a readily available and user-friendly software application is needed to allow sports medicine professionals to easily implement the system. Furthermore, the current system requires a surface extension piece for the WBB to accommodate individuals with larger feet and tandem stance conditions. The height of this addition (plus that of the WBB) may cause safety concerns for an injured athlete, especially during foam surface trials. Interestingly, some of this concern might be mitigated by changes to the BESS in several popular concussion assessment tools, which have made foam conditions optional for balance testing. These tests include the National Football League sideline assessment concussion tool and the more recent versions of the sideline concussion assessment tool (SCAT).[37]

CONCLUSIONS

The present study describes an inexpensive approach to sports-related concussion balance testing using a low-cost balance board. This approach provides a potential solution for the management of sports-related concussion that merges force plate–based and BESS scoring approaches. In the future, this novel method could provide a new standard of care for sports-related concussion testing.

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