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The Utility of the Balance Error Scoring System for Mild Brain Injury Assessments in Children and Adolescents

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Abstract

The Balance Error Scoring System (BESS) is widely recognized as an acceptable assessment of postural control for adult patients following a mild traumatic brain injury (mTBI) or concussion. However, the measurement properties of the BESS as a post-mTBI assessment test for younger patients are not well understood. The purpose of this study was to evaluate the utility of the BESS as a post-mTBI assessment test for children and adolescents aged 8 to 18 years through 2 investigations: (1) a retrospective medical records review of the relationship among age, BESS scores, and other common post-mTBI assessment tests; and (2) a prospective study comparing BESS scores for a cohort of children with a recent mTBI and BESS scores for a cohort of matched healthy peers. Age was found to be significantly correlated with several of the BESS measures and the total BESS score ($P < 0.05$). Significant differences were observed between the injured and healthy cohorts for 3 of the BESS measures and the total BESS score. However, the observed differences were not likely to be clinically meaningful. Cumulatively, evidence from the literature and the results of these studies indicate that the BESS may be limited for producing accurate

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Conflict of Interest Statement

Catherine Quatman-Yates, DPT, PhD, Jason Hugentobler, PT, DPT, SCS, CSCS, Robin Ammon, EdD, Najima Mwase, BS, Brad Kurowski, MD, MS, and Gregory D. Myer, PhD, FACSM, CSCS, have no conflict of interest to declare.

assessments of younger athletes' post-mTBI postural control abilities. Future research recommendations include testing of modified versions of the BESS or other alternatives for post-mTBI postural control assessments with younger individuals.

Keywords

concussion; balance; postural control; Balance Error Scoring System (BESS); children and adolescents

Introduction

An estimated 1.6 to 3.8 million sports-related concussions, or mild traumatic brain injuries (mTBIs), occur each year in the United States.[1] The severity and effects of mTBIs range from relatively benign cases involving mild symptoms that last a few days to more severe, protracted cases of recovery in which individuals suffer life-disrupting symptoms that last for months to years.[2-8] Evidence indicates that mTBIs in children and adolescents may pose a unique health concern.[9-11] For example, some studies indicate that children and adolescents typically take longer to recover from post-mTBI symptoms than do older athletes, may be more susceptible to catastrophic complications, and may be more likely to suffer increasingly severe effects with each recurrent mTBI.[8,10-14] Although research on sports-related mTBIs in adults has increased significantly in recent years, there remains a paucity of published research on the diagnosis, prognosis, and management of these injuries in children and adolescents,[9] which critically limits evidence-based clinical evaluations and the management of mTBIs in this population.

One key area where our knowledge is lacking for children and adolescents pertains to the effects of mTBIs on postural control. Evidence is available that convincingly supports the inclusion of postural control assessments as a component of multifactorial, comprehensive mTBI evaluations.[15,16] In both research and clinical contexts, the Balance Error Scoring System (BESS) has become one of the most commonly utilized and cited post-mTBI postural control assessment tests.[14,17-19] The BESS was originally designed to serve as a method for evaluating postural stability in collegiate athletes without the use of expensive equipment.[20,21] It has since become widely recognized as an important mild head injury assessment method, and was highlighted in the most recent *Consensus Statement on Concussion in Sport*[8] and the American Medical Society for Sports Medicine Position Statement: Concussion in Sport.[14] Modified versions of the BESS are also recommended as part of the Sport Concussion Assessment Tool, 3rd edition (SCAT3)[22] and the Child SCAT3.[23]

The BESS is an observer-rated test using 6 balance challenge trials of 20 seconds each.[24] The 6 trials are composed of 3 different stances (double-leg stance, single-leg stance, and tandem stance) on 2 different support surfaces (firm and foam); all performed with the subjects' eyes closed (Figure 1).[24] Errors are defined as opening eyes, lifting hands off hips, stepping, stumbling or falling out of the test position, lifting forefoot or heel, abducting the hip by > 30°, or taking > 5 seconds to return to the test position. The number of errors is totaled across the trials to produce a total BESS score, with a minimum and maximum number of possible errors per trial of 0 and 10, respectively, and a total of 60 possible errors across all trials.[24,25] The lower the number of errors, the better the postural control and the lower the risk of post-mTBI postural control impairments.[24]

A systematic review by Bell and colleagues[17,26] reported reliability coefficients for college students and unspecified populations ranging from 0.44 to 0.96 for within-rater reliability[17] and 0.63 to 0.90 for between-rater reliability. Specific to typically developing children, within-rater reliability has ranged from 0.60 to 0.98,[27] whereas between-rater reliability has ranged from 0.73 to 0.94.[25] Finnoff et al[28] reported certain subtests of the BESS were sufficiently reliable but that the reliability of the total BESS score is uncertain, with minimal detectable change estimates of 7.3 and 9.4 points for within-rater and between-rater reliability, respectively.

Studies indicate that the BESS can detect differences between concussed and healthy college athletes for 3 to 5 days postinjury.[17,20,29] However, no studies to date have directly investigated the ability of the BESS to detect differences between concussed and healthy states for children and adolescents. It is known that improved motor control and more adaptable postural control systems correspond with maturational development in children and adolescents.[30,31] Thus, better performances on the BESS might be expected for older children (14–18 years) compared with younger children (8–13 years). In addition, as children go through growth spurts during pubertal maturation, their neuromuscular coordination and control abilities undergo an adjustment period to account for their longer limbs, increased mass and changes in body habitus.[32-34] Therefore, balance abilities may be inconsistent during this period.[35] Accordingly, Covassin et al[36] observed age and sex as potential confounders for BESS performance. They found that interaction effects may be present for age and sex relative to post-mTBI performance, in that high school boys performed worse on the BESS than did college men, whereas high school girls performed better on the BESS than did college women. The researchers recommended, however, that future studies perform a similar investigation with younger children and adolescents.

As this literature review indicates, the measurement properties of the BESS that have been established for adults may not be directly applicable for children and adolescents. For these reasons, further consideration and evaluation of the utility of the BESS for use with children and adolescents as a post-mTBI assessment test is warranted. The purpose of this study was to explore the reliability and validity of the BESS for use with children and adolescents (aged 8–18 years). Specifically, 2 investigations were pursued. First, a retrospective analysis of medical records for children and adolescents treated at an outpatient pediatric medical center for an mTBI was performed to investigate the relationship among age, neurocognitive assessment scores, self-report of symptoms, and performance on the BESS. Second, criterion validity was tested using a prospectively recruited sample of children and adolescents with a recent diagnosis of mTBI and a cohort of age-, sex-, and activity-matched healthy peers. For the first stage of the study, it was hypothesized that age would be significantly correlated with BESS score and with a neurocognitive post-mTBI assessment. For the second stage of the study, it was hypothesized that after controlling for age, injury status would predict a significant and unique amount of the variance for BESS performance.

The results of these investigations are discussed relative to the clinical implications and recommendations for post-mTBI BESS assessments with children and adolescents.

Materials and Methods

This study had 2 stages: (1) a retrospective analysis of patient records, and (2) a prospective cohort comparison of BESS performances.

Stage 1

Institutional review board approval was granted to gather a sample of medical records for children and adolescents aged 8 to 18 years (both athletes and nonathletes) treated for mTBI at a large metropolitan outpatient center between August 2010 and June 2013. Records were included in the analysis if a BESS assessment was performed by 1 of 4 trained raters within 14 days of the injury, and neurocognitive tests (Immediate Postconcussion Assessment and Cognitive Testing [ImPACT]; ImPACT Applications, Inc., Pittsburgh, PA) and the Post-Concussion Symptom Scale (PCSS) were administered the same day as the BESS. Records were excluded from the analysis if the subject had a documented history of developmental delay, a learning disability, a vestibular disorder, an attention deficit disorder, or a documented lower extremity or back injury. Administration of the BESS followed the protocol described in the introduction (Figure 1).

Patients completed the ImPACT and PCSS at the start of their visit while alone in a treatment room prior to being seen by a physician. The ImPACT assessment consists of a series of neurocognitive tests designed to test verbal memory, visual memory, reaction time, visual motor processing speed, and impulse control.[37] The PCSS consists of a questionnaire that asks patients to rate from 0 to 6 the severity of each of 22 symptoms (a complete list of symptoms and the assessment technique are available as part of the SCAT3).[22] Metrics for the PCSS include a severity ranking for each symptom, the number of symptoms reported (the number of symptoms rated > 0), and a total symptom score calculated by summing the severity rankings for all of the possible symptoms combined.[22,38] Pearson product moment correlations with a preset $\alpha = 0.05$ were used to evaluate the relationships among age, BESS performances, ImPACT scores, and symptom reports (total number of symptoms and the composite severity of symptoms).

Stage 2

To explore the criterion-related validity of the BESS, 20 children and adolescents were prospectively recruited among the patients referred to physical therapy for a post-mTBI postural control assessment at an outpatient pediatric clinic affiliated with a large metropolitan hospital. Twenty age-, sex-, and activity-matched healthy control participants were recruited from local schools. Participants from the injured cohort were included if they were assessed within 14 days of sustaining a mild head injury. Participants from both cohorts were included only if they reported no history of developmental delay, a learning disability, a vestibular disorder, an attention deficit disorder, or had been diagnosed with a lower extremity or back injury. Healthy participants also had to report no history of head injuries.

Prior to data collection, institutional review board approval was obtained. All participants and their legal guardians provided consent to participate in the study. The BESS was administered to all participants as previously described by 1 of 4 trained raters. Independent-sample *t* tests for each BESS trial and the total BESS score were used to determine if BESS was able to detect differences between the healthy and impaired groups with a preset $\alpha = 0.05$. Hierarchical multiple regression was used to determine if group status predicted a significant amount of the variance on the BESS measures identified through the *t* tests after controlling for the effects of age.

Results

Stage 1

The medical records of 42 patients satisfied these criteria. The mean age of these patients was 14.33 ± 2.07 years, with a range of 9.0 to 17.89 years. The sample consisted of 27 boys (64.3%) and 15 girls (35.7%). For 29 patients (69.0%), the data represented the patient's first documented mTBI; 10 patients (23.8%) reported that this was their second mTBI, and 3 patients (7.1%) reported that this was their third mTBI. The mean and standard deviation for the number of days since injury was 7.42 ± 3.28 days.

The means and standard deviations for each measure are reported in Table 1. Age was found to be significantly correlated with the single-leg firm stance ($r = -0.45$, $P = 0.00$), the tandem firm stance ($r = -0.36$, $P = 0.02$), single-leg foam stance ($r = -0.41$, $P = 0.01$) and total BESS score ($r = -0.39$, $P = 0.01$). Age was also significantly correlated with visual motor speed ($r = 0.62$, $P = 0.00$), reaction time ($r = -0.48$, $P = 0.00$), and impulse control ($r = -0.46$, $P = 0.038$). Significant correlations were also observed between the single-leg floor stance and visual motor speed ($r = -0.33$, $P = 0.03$), single-leg floor stance and reaction time ($r = 0.32$, $P = 0.04$), tandem foam stance and visual motor speed ($r = -0.37$, $P = 0.02$), and total BESS score and visual motor speed ($r = 0.39$, $P = 0.01$).

Stage 2

Participants included 13 boys and 7 girls in each group, with a mean age of 13.24 years and a standard deviation of 1.27 years (range, 10.68–16.45 years). Seven participants from the injured group also reported a prior history of mTBI. The mean number of days from injury to the performance of the BESS assessment, for the injured group, was 7.45 days with a standard deviation of 3.22 days. All of the participants for both cohorts were active in sports and physical activities.

Very few errors were made by either group for the double leg-firm stance and the double-leg foam stance conditions (Table 2). Of the remaining conditions, significant differences between the injured and control participants were found for the single-leg firm stance ($P = 0.01$), tandem firm stance ($P = 0.04$), single-leg foam stance ($P = 0.01$), and total BESS score ($P = 0.01$).

The hierarchical multiple regression models indicated that after controlling for age, injury status explained a significant amount of the variance for the single-leg firm stance, single-leg foam stance, and total BESS score ($P < 0.05$). Injury status uniquely explained 18.9% of the variance for single-leg firm stance, 20.7% of the variance for single-leg foam stance, and 19.5% of the variance for total BESS score. However, the differences between groups for mean BESS performances only ranged from 1.1 to 3.45.

Discussion

By design, the BESS is relatively inexpensive and easy to administer. For these reasons, it is an appealing option for post-mTBI postural control assessments for people of all ages. Nonetheless, the BESS was originally designed and tested with college-level athletes. Therefore, the initial population for which the instrument was intended had relatively advanced, adult-like neuromuscular and postural control abilities. As the BESS has gained acceptance as a valuable test for post-mTBI assessments in college and upper level high school athletes, it has also become popular for use with younger children and adolescents. The results of stage 1 supported the proposed hypothesis that age was significantly correlated with a number of the BESS trials and total BESS score as a whole and several of the subtests on the ImPACT. Likewise, the results of stage 2 supported the second hypothesis, that if the effects of age are controlled for, the BESS may be able to detect differences between healthy and injured children. Nonetheless, the difference in the mean scores between the 2 cohorts was relatively small. Collectively, the findings from studies in the literature and the results presented here raise several interesting issues regarding the utility of the BESS in this capacity.

The concurrent validity of the BESS and other commonly used post-mTBI assessments has been shown to be relatively low, suggesting the need for multiple types of assessments and a multifactorial approach to monitoring recovery from mild head injuries.[14,39,40] Postural control assessments have become recognized as a key aspect of this multifactorial approach.[14,16,19,39]

In general, the results of this study were somewhat consistent with the Covassin et al[36] study that indicated that age may influence BESS performance for children with a recent mild head injury. The results of the study presented here indicate that the younger the patient with a head injury performing the test, the more errors they are likely to make, especially for the single-leg conditions and the tandem firm condition. However, these results conflict with a prior study comparing normative values for healthy children, which found no differences between younger and older children.[41] One potential explanation is that there is a ceiling effect for healthy individuals' performance on the BESS that limits the differences that can be observed between ages. In other words, although there may be a relationship between age and balance abilities for healthy children, the nature of the BESS may mask these differences. Another potential explanation is that the BESS may be most valid in the first few days following injury for younger individuals as well. Therefore, further investigation into the ideal timing of implementation of the BESS with younger individuals could be worthwhile.

From a validity perspective, the results of this study indicate that after controlling for the effects of age, differences between healthy children and children with a recent mTBI may be detectable by the BESS, and specifically by the single-leg firm stance and reflected in the total BESS score. However, the differences were not great enough to fall outside the within- and between-rater minimal detectable change estimates of 7.3 and 9.4 points. Therefore, the significant findings may not be clinically meaningful. One potential limitation of these results is that the number of days since the injury occurred varied with a mean of 7 days from the initial injury. With such a large range of days since injury, some of the children may actually have recovered within that window of time. To explore this concern, a Pearson product-moment correlation was performed to test for a relationship between time from injury and BESS performance. No significant correlations were found between the days since the injury occurred and any of the BESS subtests or the total BESS scores.

Few errors were committed by either group for the double-leg firm, tandem firm, and double-leg foam stances. As such, the clinical value of these subtests may be very limited. Therefore, in order to optimize the use of the BESS with children and adolescents, clinicians may consider dropping the double-leg stance conditions from their BESS assessments in this population. Secondary benefits of dropping these subtests may include helping to minimize symptom exacerbation and fatigue during administration of the BESS with injured children and adolescents. Incidentally, double-leg firm is one of the recommended stances for the modified BESS in the SCAT3[22] and the Child SCAT3.[23] The mean age of the samples for the studies presented here was slightly older (aged approximately 13 years) relative to the recommended age for the Child SCAT3 (which is recommended for children aged 5 to 12 years). Therefore, the applicability of eliminating these stances for younger children should be determined on a case-by-case basis at the evaluator's discretion. Future research may be helpful to fully elucidate if the double-leg stances are needed and the impact of eliminating these stances on total BESS score.

Although the single-leg foam and single-leg firm trials and subsequently the total BESS score may be the most useful measures for detecting post-mTBI deficits from a content validity standpoint, these measures may also be the most likely to be confounded by other variables. For example, more challenging tasks such as the single-leg firm and single-leg foam are likely to yield the most errors for the person who is performing the BESS.[25] The more errors a person makes while performing the test, the more opportunities there are for a rater to make a mistake in observing and recording an error correctly.[25] From a biomechanical perspective, it is well recognized that good postural stability in a unipedal stance necessitates good neuromuscular control and strength of the lower extremity (hip, knee, and ankle) musculature.[42-44] Numerous biomechanical studies indicate that lower extremity and neuromuscular control are affected by maturational processes.[32,34,45-48] Therefore, the reliability and validity of these stances relative to detection of post-mTBI impairments may be even more uncertain for adolescents.

Bell et al's[17] systematic review highlighted several other potential validity-related limitations of the BESS: (1) Individuals with functional ankle instability tend to perform worse on the BESS. (2) Performance on the BESS can vary by training backgrounds. (3) Fatigue can affect performance on the BESS. (4) Performance on the BESS tends to improve with serial administrations. In addition, clinically and statistically significant improvements in BESS score have been observed over the course of an athletic season.[18] As there is a known learning effect with serial administrations of the BESS,[49] utilization of the BESS as a post-mTBI assessment is likely ideal when the test has been practiced enough to establish a relatively consistent baseline preinjury score that then can be used for comparison purposes after an injury is sustained. However, many patients present with an mTBI without having been assessed for baseline values, so comparison to established normative values is necessary. Normative data has been established for adults ranging in age from 20 to 69 years.[50] According to these established norms, BESS score and age are correlated for adults, with poorer performance on the BESS after about age 50.[50] For healthy adults aged 20 to 39 years, the mean score was 10.97 ± 5.05. However, normative values specific to children and adolescents remain vague. One study reported a mean total BESS score of 12.49 ± 4.45 for children and adolescents aged 11 to 18 years.[41] However, this is a large age range during which pubertal maturation is expected to occur.

Based on these results, clinicians should be aware of the potential limitations of the BESS for post-mTBI assessments performed on children and adolescents aged 8 to 18 years. Researchers seeking to study post-mTBI postural control deficits in this population should also be cautious about using the BESS as a sole measure of postural control impairments, as it is an instrument that may mask the presence of true underlying postural control deficits. Future research may help to confirm or refute the findings from the study presented here with larger, more controlled samples. In particular, it may be beneficial to establish some age-specific norms with relatively narrow age bands for each gender and then evaluate the sensitivity and specificity of the BESS relative to these smaller age ranges. It may also be beneficial to explore other options for modified versions of the BESS or develop more age-appropriate tests for the assessment of post-mTBI postural control in children and adolescents. For example, studies with older, college-level athletes provide compelling evidence that force plate assessments of postural sway could be a more sensitive and powerful way to capture and monitor post-mTBI postural control impairments.[15,51,52] This is particularly true for postural sway complexity measures. Such measures may offer opportunities to minimize rater reliability concerns as well as utilize easier postural tasks and shorter protocols that would be less affected by age-specific confounders. To date, the utility of such measures for use with children and adolescents has not been explored. Thus, future research should include exploration of the reliability, validity, and feasibility of post-mTBI force plate assessments for children and adolescents.

Conclusion

The results of this study suggest that, in its current form, the clinical utility of the BESS for post-mTBI assessment with children and adolescents aged 8 to 18 years may be relatively limited. A synthesis of the samples studied in the literature and the pilot studies presented in this review indicate that the ability to interpret post-mTBI BESS scores for this population may be much more challenging than when used with adults. Moreover, researchers should be cautious about using the BESS as a test to study post-mTBI impairments and recovery trajectories in children and adolescents, as the reliability and validity issues may mask the true postural control deficits that may occur with children and adolescents following an mTBI.

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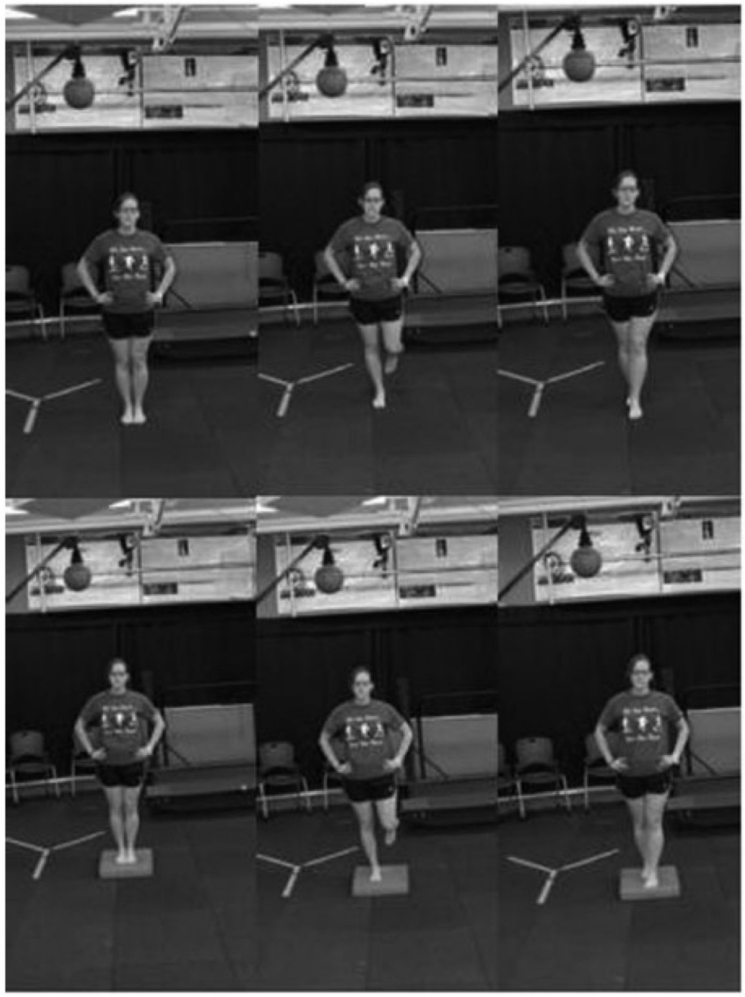

View: Figure 1. The 6 stances and surface conditions for the Balance Error Scoring System

View: Table 1

Descriptive Statistics for the Results of Stage 1

Assessment	Range	Mean	Standard Deviation
ImPACT			
Verbal composite	53.00–100.00	80.60	11.08
Visual composite	55.00–95.00	73.21	11.24
Visual motor speed	11.83–49.70	33.14	7.15
Reaction time	0.43–0.96	0.64	0.10
Impulse control			
PCSS			
Number of symptoms	0–18	8.70	5.36
Total symptom score	0–71	21.81	19.77
BESS			
Double-leg firm	0–2	0.05	0.31
Single-leg firm	0–6	2.90	1.75
Tandem firm	0–5	1.62	1.32
Double-leg foam	0–2	0.17	0.44
Single-leg foam	3–10	6.10	1.71
Tandem foam	1–10	4.26	1.94
Total BESS score	5–34	15.10	5.49

Abbreviations: BESS, Balance Error Scoring System; ImPACT, Immediate Postconcussion Assessment and Cognitive Testing; PCSS, Post-Concussion Symptom Scale.

View: Table 2

Descriptive Statistics for the Results of Stage 2

BESS Measure	Healthy Cohort Range	Injured Cohort Range	Healthy Cohort Mean (± SD)	Injured Cohort Mean (± SD)
Double-leg firm	0–0	0–0	0	0
Single-leg firm	0–4	0–7	2.10 ± 1.45	3.5 ± 1.82
Tandem firm	0–2	0–4	0.70 ± 0.80	1.35 ± 1.09
Double-leg foam	0–2	0–2	0.30 ± 0.57	0.20 ± 0.52
Single-leg foam	4–7	4–10	5.20 ± 1.01	6.30 ± 1.42
Tandem foam	0–5	0–7	3.25 ± 1.37	3.65 ± 1.37
Total BESS score	5–18	7–28	11.55 ± 3.58	15.00 ± 4.70

Abbreviation: BESS, Balance Error Scoring System