Journal of Sports Injuries and Medicine

Mullin TM, et al. Sports Injr Med 01: JSIMD-123.
DOI: 10.29011/2576-9596.100023

Research Article

Use of The SWAY Balance Application for The Apple IPhone as an Objective Assessment for Sports-Related Concussion Balance Testing in High School and College Athletes

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Citation: Mullin TM, Phillips NR, Martinez C, Moorman III CT, Bytomski JR (2017) Use of The SWAY Balance Application for The Apple IPhone as an Objective Assessment for Sports-Related Concussion Balance Testing in High School and College Athletes. Sports Injr Med 01: 123. DOI: 10.29011/2576-9596.100023

Received Date: 25 July, 2017; **Accepted Date:** 27 October, 2017; **Published Date:** 6 November, 2017

Abstract

Objective: Balance assessment is an important component of concussion assessment. We compared an objective measure of balance using the SWAY Balance application for the Apple iPhone to the balance error scoring system (BESS) in non-concussed high school and collegiate athletes.

Design: Cross-sectional study.

Setting: Division I University and High Schools.

Participants: 17 male collegiate athletes, 52 male and female high school athletes.

Interventions: Baseline BESS and SWAY Balance tests were performed on non-concussed high school and collegiate athletes.

Main Outcome Measures: The relationship between the baseline BESS and SWAY Balance tests were compared using linear regression analyses.

Results: Across age and gender, there was an inverse relationship between overall SWAY and the global BESS score ($r= -0.402$, $P<0.001$), the BESS firm score ($r= -0.34$, $P=0.004$) and the BESS foam score ($r= -0.27$, $P=0.024$). For high school age subjects, there was an inverse relationship between the SWAY score and the global BESS score ($r= -0.33$, $P=0.017$) and for BESS Firm ($r= -0.35$, $P=0.01$). For the college age subjects (all were male), there was an inverse relationship between the SWAY score and the global BESS score ($r= -0.52$, $P=0.032$).

Conclusions: There is a significant inverse relationship between BESS testing and SWAY balance testing in non-concussed high school and collegiate athletes. Use of a smart phone with software utilizing the accelerometer may one day provide an objective tool for the assessment of balance in sport-related concussion.

Keywords: Balance error scoring system; College athlete; Concussion; High school athlete; SWAY balance; Traumatic brain injury

Introduction

In 2010, the Centers for Disease Control and Prevention reported that over a 5-year period (2002-2006) more than 500,000 children and adolescents (0-19y) were seen in emergency departments for traumatic brain injuries, over 35,000 were hospitalized, and over 2000 died annually from head injury [1]. These numbers are probably an underestimate and are likely to only exhibit a small portion of the total head injuries in the overall population. In sport and other recreational activities some experts estimate 1.6 to 3.8 million concussions annually [2] making concussions a common occurrence in sports. Over the past 10-15 years, be it through state laws, lawsuits, news media, or documentaries, concussion awareness has increasingly come to the public forefront. The high prevalence and public notoriety demonstrates the importance of understanding current practice patterns in the evaluation and management of concussions. Additionally, the risks of repeat concussion and returning to sport too quickly following head injury are well known, thus making diagnostic accuracy more important. One issue with this injury is the lack of objective clinical tests that are sensitive and specific to concussive injury.

As concussion awareness increases and evaluation becomes more commonplace, a standardized assessment tool or protocol is critical. Objective information, once validated, may likely prove itself useful in the process of concussion assessment, diagnosis, and return-to-play decisions. While there are several methods available to test for and serially follow concussions, each is not without limitation(s) such as time, cost, the subjective nature of evaluator interpretation, and the degree to which the player is forthcoming about symptoms. One sign that is frequently included in sideline screening tools is balance. Through a variety of neural pathways, postural stability can be compromised following a concussive episode [3-5]. The Balance Error Scoring System (BESS) was developed as an attempt to standardize balance testing on the sideline or in the training room and has become an accepted method for balance testing. While many sources accept the variability in scoring subjectivity, others have demonstrated that selected aspects of BESS testing lack sufficient reliability [6,7]. As a result, efforts are underway to improve the objectivity of scoring balance tests [8-10].

Our goal was to determine, in high school and college age athletes, the validity of a recently released application for a smartphone that quantifies postural sway [11] (iPhone; SWAY Balance; SWAY Medical; Tulsa, Oklahoma). SWAY Balance uses similar challenges to the BESS, but provides an objective numeric value about the subject's ability to maintain balance.

Methods

Sixty-nine healthy high school and collegiate athletes between 14 and 22 years (overall mean age=16.7±2.1 years) participated in the study. There were 28 females (41%, age=15.4±1.3 years) and 41 males (59%, age=17.6±2.1 years). A total of 17 were NCAA Division I collegiate athletes (all male, 25%, age=19.5±1.4 years) and 52 were high school athletes (75%, age= 15.8±1.3 years; Table 1). Subjects were excluded if they had more than two self-reported previous concussions, if a concussion occurred in the previous six months, if they had residual concussion symptoms or had not been cleared for return to play (defined as full sporting activities without restriction) and if they had any injury or condition (lower extremity or otherwise) that affected their balance or ability to perform testing, e.g. ankle sprain, fracture, etc. The Duke University Institutional Review Board approved all protocols. All participants and their parent or legal guardian provided written informed consent.

	High School		College	
	Male	Female	Male	Female
N	24	28	17	0
Age, Years (SD)	16.3 (1.2)	15.4 (1.3)	19.5 (1.4)	
Primary Sport[a]				
Football	22	0	15	0
Soccer	0	16	0	0
Lacrosse	0	0	1	0
Track	0	0	1	0
Wrestling	1	0	0	0
Unknown	2	12	0	0
[a]One high school male identified both football and wrestling.				

Table 1: Subject characteristics.

Experimental Protocol

There were two separate tests for balance assessment performed for this study. A familiarization period was given to allow participants to experience the stance and surface conditions of the BESS and SWAY protocols. SWAY Balance (SWAY Medical; Tulsa, OK, USA) is an Apple iPhone application that uses the smartphone's triaxial accelerometer to quantify postural sway during the performance of five stationary positions. Each position was performed for 10 seconds on a firm surface in a quiet room with the eyes closed. The iPhone was turned on and the SWAY application was started. The subject's basic demographic data was entered into the SWAY application. The subject was verbally informed about what the test would involve and what to expect; all questions were answered prior to beginning the test. Once each subject was fully informed about the test, each subject was given the iPhone, instructed to press the start button, bring their arms to their chest to hold the iPhone firmly against their chest and then close their eyes. Each position was held for 10-seconds at which time the iPhone played a tone indicating the end of the particular balance position. The subject was instructed to open their eyes, reset him or herself and when ready to position themselves for the next trial. The subject then pressed start and the above procedure was followed identically for each subsequent trial. The SWAY application uses five test positions: standing with the feet together, tandem stance (heel-to-toe) with right foot forward, tandem stance with left foot forward, left single leg stance, and right single leg stance (Figure 1).

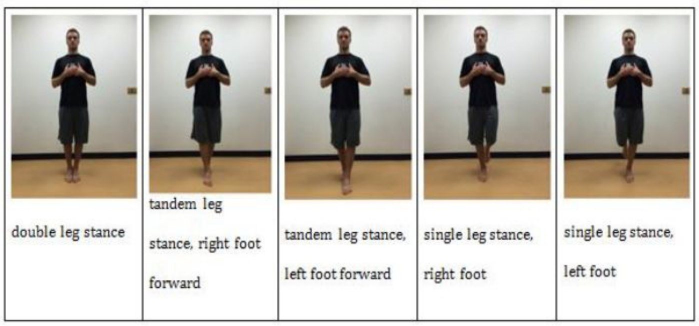

Figure 1: SWAY Balance test positions[a]. [a]Eyes are closed for each trial. Each position held for 10-seconds. iPhone is pressed against the sternum with both hands. A tone indicates the end of each 10-second trial.

Output of the triaxial accelerometer was reported as a SWAY score after completion of the five stationary positions. The SWAY score is based on a proprietary algorithm to determine thoracic SWAY on a scale of 0 to 100 where a score of 100 is perfectly stable and a score of 0 is unstable. The score is displayed on the iPhone at the completion of the test and was recorded on a paper data sheet. The data was entered into an Excel spreadsheet and securely stored. Throughout the course of the study two medical doctors and one licensed doctor of physical therapy conducted the SWAY Balance portion of the study; only one provider was required to test each individual subject.

The BESS testing portion of the study requires identifying the dominant leg (defined as the preferred kicking leg). BESS testing is performed barefoot. Balance is assessed during six positions.

- Position 1: Double-leg stance on a firm surface.
- Position 2: Single-leg stance on a firm surface.
- Position 3: Tandem stance on a firm surface.
- Position 4: Double-leg stance on a foam surface.
- Position 5: Single-leg stance on a foam surface.
- Position 6: Tandem stance on a foam surface.

The AIREX Balance Pad, Model 81000, (Airex AG; Sins, Switzerland) was used for the foam surface positions. For each position, the participants were instructed to keep their hands on their hips and eyes closed. The double-leg stance conditions required that the participant keep both feet on the testing surface with medial malleoli in contact. Single-leg stances were performed on the non-dominant leg while lifting the foot of the dominant leg off the testing surface. Tandem stance positions had participants place their feet heel to toe with the non-dominant foot in the rear. 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 subject was stable for a minimum of one second and gave a verbal cue to begin the test. A digital timer with an alarm set for 20 seconds kept timing consistent for all BESS assessments. At the end of each testing position the subjects were allowed to reset themselves prior to beginning the next position. BESS testing was performed by one college level sports medicine physician and three collegiate athletic trainers. There was one provider used to perform the BESS test per subject. The medical physician had five years of BESS experience performing a minimum of 50 BESS tests per year. The BESS experience for the athletic trainers ranged from 3 years to 12 years with a range of 75 -100 BESS tests per year. Converse to the SWAY score, where a higher score indicates better balance, BESS testing measures the errors performed meaning that a higher score indicates worse balance. Scoring involves assigning one point for each of the following balance errors. Errors are summed for the three conditions on the floor (FIRM), the three conditions on the foam pad (FOAM) and for all six conditions (Overall):

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

Statistical Analyses

Routine descriptive statistics were used to summarize the data. Linear regression analyses were performed to evaluate the relationship between the three BESS score measures (overall BESS, BESS firm, and BESS foam) and the SWAY score. In addition to comparing the scores across all participants, relationships were also determined for various subsets (gender, competitive level). A P-value ≤ 0.05 was considered statistically significant. SAS version 9.2 (SAS Institute; Cary, North Carolina, USA) was used for all analyses.

Results

Scores for all the balance tests are presented in Table 2. There were no differences for any of the tests by gender (P values ranged from 0.29 to 0.69) or by competitive level (P values ranged from 0.25 to 0.91). The absence of college-age females precluded an analysis of the full gender by competitive level interaction.

	High school		College		Overall		Overall		
	Male (n=24)	Female (n=28)	Male (n=17)	Female (n=0)	Male (n=41)	Female (n=28)	HS (n=52)	College (n=17)	OVERALL (N=69)
SWAY Score	80.0±14.5	80.2±14.7	75.1±18.1		77.9±16.1	80.25±14.7	80.1±14.5	75.1±18.1	78.9±15.5
Bess Score	15.0±6.4	14.5±5.4	7.8±1.9		15.4±6.9	14.5±5.4	14.7±5.9	16.0±7.8	15±6.4
Bess Firm	4.3±3.6	3.4±2.9	2.9±0.7		4.2±3.3	3.4±2.9	3.8±3.2	4.0±2.9	3.8±3.1
Bess Foam	3.8±0.8	11.1±3.3	10.8±3.0		10.8±3.5	11.1±3.3	10.9±3.5	10.8±3.0	10.9±3.4

Table 2: Means and standard deviations of errors by test scores.

The results of the linear regression analyses are summarized in Table 3. There was a significant negative correlation between overall SWAY and the global BESS score (r=-0.402, P<0.001), the BESS firm score (r=-0.34, P=0.004) and the BESS Foam score (r=-0.27, P=0.024).

BESS scores	r=	P=	Y-intercept	slope	s.e.e
Overall	–0.40	<0.001	28.06	–0.16	5.86
Firm	–0.34	0.004	9.27	–0.07	2.97
Foam	–0.27	0.024	15.57	–0.06	3.27

Table 3: Summary of the overall (n=69) linear regression analysis of SWAY with the BESS scores s.e.e = standard error of estimate.

Subgroup analyses (gender, competitive level) were also performed to evaluate the correlation between the SWAY score and the various BESS scores. For males (n=41), there was a significant negative correlation between the SWAY score and the global BESS score (r=-0.47, P=0.002) and the BESS Foam (r=-0.42, P=0.007), but not for BESS Firm (r=-0.28, P=0.7). For females (n=28, all were high school aged), there was no correlation between the SWAY score and the global BESS score (r=-0.25, P=0.203) or with BESS Foam (r=-0.04, P=0.85), but there was a significant correlation with BESS Firm (r=-0.43, P=0.023).

For the high school subjects (n=52), there was a significant correlation between the SWAY score and the global BESS score (r= 0.33, P=0.017) and for BESS Firm (r= 0.35, P=0.01), but not with the BESS Foam (r=0.23, P=0.11). For the college age subjects (n=17, all were male) there was a significant correlation between the SWAY score and the global BESS score (r= 0.52, P=0.032), but not for BESS Firm (r= 0.32, P=0.21) or with BESS Foam (r=0.33, P=0.08),

Discussion

Our purpose was to determine the validity of the SWAY Balance mobile phone application with the established Balance Error Scoring System. Our results suggest that the SWAY B**alance ap**plication correlates with standard BESS testing when evaluating the balance of high school and college age athletes who have no ongoing concussive symptoms. This study does not conclude that the SWAY Balance application should then be considered to be the solitary tool evaluation or diagnosis of concussion. Our results indicate that this quick and easy to administer test can objectively identify balance ability in non-concussed athletes by giving results that are consistent with the previously-validated BESS testing; both appear to be evaluating similar constructs.

The overall mean for the SWAY test was 78.9±15.5, which is consistent with current reports [12] or marginally higher [13]. The mean overall BESS score was 15±6.4, which is also consistent with other reports [7.10,14]. Various aspects of reliability for the BESS range from 0.50 to 0.98 [7]; similar results for the SWAY have yet to be established. While a significant negative correlation was noted for most overall group analyses, this was not the case in all groups-there were no statistically significant correlations between SWAY and BESS Global and BESS Foam in females nor was there a correlation between SWAY and BESS Firm in males. This may likely be attributed to our small sample size and should be further evaluated in future studies. Specifically, college-age female athletes will need to be further studied as none were included in our study.

While the significant correlations indicate that SWAY and BESS appear to be measuring similar constructs, if SWAY is used to predict the various BESS scores, there is a noticeable amount of prediction error. In this sample, the mean score for the global BESS test was 15 and the prediction error was 5.86. Thus, if SWAY were to be used to predict the global BESS score, the prediction has a 39% error. Corresponding error for FIRM and FOAM are 78% and 30% respectively. The ability of the SWAY application to discriminate balance differences between concussed and non-concussed athletes, or to establish clinical points that identify normal vs. abnormal balance, has yet to be established. Forman, et al. failed to find any differences between concussed and non-concussed athletes using an accelerometer-based assessment of balance.(14) Based on our results, a 'normal' SWAY score would be 79 (95% CI: 75.2, 82.6). Whether a SWAY score of less than 75 obtained on an athlete suspected of a concussion should be considered as worthy of further evaluation remains to be determined.

Thus, the SWAY may be a reasonable sideline method to evaluate balance, but the prediction error would probably discourage its use for serial assessments given that the inter-rater and intra-rater minimum detectible change in BESS scores are 9.4 and 7.3 points respectively. There may be many advantages for using this method to test postural stability. First, subjectivity of the examiner is replaced by the objectivity of the device making the requirement of high inter-rater and intra-rater reliability less critical. While further studies are needed to document validity and reliability, the SWAY should be consistent whether administered by a trainer, medical assistant, or provider. Second, no additional cumbersome equipment is needed. While an iPhone with the application must be available, there would now be no need to have a foam pad. Also, this evaluation can be performed quickly and efficiently as it utilizes fewer total positions at a reduced duration than BESS testing (SWAY tests five positions for 10 seconds each while the BESS tests six positions for 20 seconds each).

One clear limitation is the lack of an accepted gold standard. We compared balance using the novel SWAY application to another system, in the form of BESS, that itself is clearly not perfect. We tried to minimize our variability in BESS testing by limiting the number of trained evaluators obtaining this data**. Another limi**tation is the constraint of the electronic hardware. We have to accept the accuracy of the device's accelerometer as we were unable to specifically validate the accelerometer's accuracy or access the proprietary software used to calculate the SWAY score. However, the accuracy of the Apple iPad accelerometer and gyrometer hardware has been validated using 3-D camera motion analysis [15]. Further, this version of the manufacturer's software is currently limited to iPhones. Finally, the application requires purchase of the SWAY software with annual membership and these costs could prove prohibitive for some

Additional work is necessary to confirm the reliability and validity of SWAY testing across a wider spectrum of age ranges, especially in a population with concussion who are at differing time points during the recovery process. Our data can be viewed as a starting point for further study of its use for balance testing after concussive injury.

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