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RESEARCH ARTICLE

Validity of Lower Extremity Postural Sway for Baseline Concussion Testing

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Abstract

Objectives: The Balance Error Scoring System (BESS) and King-Devick (KD) are utilized frequently in the athletic population for baseline testing, despite the BESS lacking sensitivity. Biomechanical testing detects smaller magnitudes of change but has not been validated against clinical tests. The objectives of this study were to examine the distribution of Lower Extremity (LE) sway variables in an athletic population; to examine the relationship between clinical and biomechanical concussion testing measures.

Design: Cross sectional.

Methods: 96 healthy Division I collegiate athletes were tested for both biomechanical and clinical concussion tests. Single Leg Stance (SLS) was performed blindfolded for 2.20 second trials each LE on a force plate system. Center of pressure data (LE sway) was converted to T-score and averaged across the two trials by side. Baseline BESS and KD scores were obtained from the athletes' files. Descriptive statistics assessed the data distribution. Spearman's rho (rho) correlations were used to determine the relationship between clinical and biomechanical test variables. Significance was set to P = 0.05.

Results: LE sway and KD was normally distributed; BESS showed a floor effect. LE sway was significantly correlated to BESS test subsections (SLS, foam: rho = -0.30, 95% CI: -0.47, -0.11 and foam total score: rho = -0.30; 95% CI: -0.47, -0.11), BESS total score (rho = -0.31; 95% CI: -0.48, -0.12), and KD average (rho = -0.38; 95% CI: -0.54, -0.19).

Conclusions: The lower extremity sway scores demonstrate validity when compared to clinical concussion tests. The distribution of sway scores indicates that this test may be better suited to detecting subtle differences in changes, and overcomes the limitations of the conventional clinical evaluations.

Keywords

Concussion, Posturography, Balance

Introduction

The incidence of concussions in contact sports continues to be an issue, with approximately 300,000 sport related concussions occurring every year in the United States [1], with that number increasing with increased sport participation. Guidelines for return to play following a concussion have been previously published; however, not one has emerged as a criterion standard or has been followed consistently by sports medicine clinicians. Additionally, the 2017 Concussion in Sport Group consensus statement advocates the use of neuropsychological test batteries to assess cognitive function, but recognize that there is no single diagnostic test or marker which is used for either diagnosis or as part of a graduated return to play strategy [2]. Additionally, methods to assess physical and balance impairments are particularly ill-defined. As decrements persist after athletes no longer report concussion-related symptoms [3], a multifaceted concussion assessment is warranted, which not only evaluates all affected systems, but also is sensitive to change over time.

Clinical tests such as the Balance Error Scoring System (BESS) and King-Devick (KD) are utilized frequently in the athletic population for baseline testing, and additionally as return to play criteria. Baseline testing is important as several of these tests are influenced by factors including age and previous injury. The Balance Error Scoring System (BESS) was developed to provide clinicians with a rapid, cost effective method of objectively assessing postural stability in athletes on the sports sidelines or training room after a concussion. This test is also collected at baseline for healthy athletes, so

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that the scores may be compared to post-injury for part of the return to play assessment. This test consists of athletes performing three different stances, double, single, and tandem, on both floor and foam surfaces. The number of operationally defined "errors" is used to objectively score the quality of performance. An error was defined as opening eyes, lifting hands off hips, stepping, stumbling or falling out of position, lifting forefoot or heel, abducting the hip by more than 30°, or failing to return to the test position in more than 5 seconds. For the Eyes Closed (EC) condition, opening of the eyes was also considered an error. However, the sensitivity of the BESS has been questioned, as the distribution of scores for an uninjured population demonstrates a floor effect, and substantial inter-rater variability exists. Intra-rater, interrater and test-retest reliability of the BESS ranges is extremely variables, ranging anywhere from 0.13 to 0.88 [4-6], and does not improve with instrumentation over clinical scoring [4]. A systematic review of the BESS agreed that the scoring system had better reliability and validity where large differences in balance existed (for example, immediately post-injury versus healthy controls), but validity should be questioned when subtler differences exist [7]. The BESS has also been scrutinized as it has been shown to having ceiling, fatigue, and learning effects [8,9].

As concussion can cause numerous symptoms, including vestibular, balance, and visual ocular abnormalities, is important to perform testing which assesses all possible symptomatology to accurately gauge the nature and severity of symptoms, and is sensitive to change over time for return to play criteria. It has been reported at 81% of youth athletes diagnosed with concussion demonstrate abnormal gait stability [10]. Additionally, visual impairments are associated with worse neurocognitive performance [11]. The King-Devick (K-D) test is a quick and easily administered visual ocular assessment, assessing saccadic eye movement, language, and concentration [11,12], that requires the athlete to rapidly identify incorrectly name variable space single digits on three separate cards. An increase in the time taken to complete the K-D compared with baseline is indicative of a concussion with sensitivity of 86% in a specificity of 90% [11,13]. The K-D test demonstrates good test-retest reliability (ICC 0.86-0.97) [4,14]. However, the K-D can only be used as part of a battery of clinical tests, as not all systems are stressed.

Biomechanical analysis of lower extremity postural sway variables has been found to be reliable and valid to quantify balance performance for both healthy individuals and individuals with an injury [15-17]. Lower extremity postural control is controlled by integrated information from the visual, somatosensory, and vestibular systems. The integrity of the postural control system is typically evaluated using posturography, which characterizes the performance of the postural control systems in a static position. In the lower extremity, this is often evaluated in both eyes open and eyes closed trials to estimate the role of the visual system while maintaining balance. This postural steadiness or sway is quantified biomechanically by the displacement of the center of pressure on a force platform, which reflects the orientation of the body segments as well as the movements of the body to keep the center of gravity over the base of support. Biomechanical testing is able to detect smaller magnitudes of change, but has not been validated against all concussion clinical tests.

The purpose of this study was to determine the distribution of lower extremity postural sway variables in the athletic population, and to determine the relationship between clinical and biomechanical baseline concussion testing.

Methods

Approval was obtained from our institution's institutional review board. The inclusion criteria were healthy Division I athletes who participated in any varsity sport. Exclusion criteria were current lower extremity injury, current spine injury, or current concussion.

All data was collected using a force plate (Kistler Inc; Amherst, NY, USA) system connected to a dedicated computer with commercially available software (Sparta Science), a video monitor was connected to the computer which displayed force plate Center of Pressure (COP) movement in real time. Force plate data were collected at 1000 Hz.

Subjects were instructed to stay as still as possible while maintaining single leg stance. The athlete was instructed to maintain his or her balance with as little movement as possible. Two, 20 second trials were performed for each extremity with a 15 second break between trials. The subjects were blindfolded during testing to eliminate the visual component of balance. Center of pressure data was quantified by velocity and frequency of motion. Data was averaged across the two trials by side (left, right).

Baseline concussion testing (BESS and King-Devick) was obtained from the athletes' files in the athletic training room. This testing is performed prior to the beginning of the athletic year for all athletes. BESS testing was performed according to Bell [7]. This test involves 3 stances (double-legged, single-legged, and tandem) and 2 surfaces (firm and foam). For balance in the single-legged stance, patients were instructed to stand as still as possible, with hands on iliac crests and eyes closed, while maintaining balance on the nondominant limb with the dominant limb in approximately 20° of hip flexion and 45° of knee flexion. For balance in the tandem stance, patients were instructed to stand heel-to-toe with the nondominant limb in back, hands on the iliac crests, and eyes closed. Leg dominance was defined as whichever leg the patient would use to kick a soccer ball for maximum distance. Participants were instructed to complete each of these six 20-second trials by remaining in the test position with their eyes closed to the best of their ability. Meanwhile, the clinician observed and documented the error frequency (to a maximum of 10 per trial). Errors could include the following: moving the hands off of the iliac crests; opening the eyes; stepping, stumbling, or falling out of test position; hip abduction or flexion > 30°; lifting the forefoot or heel off the testing surface; or remaining out of the proper test position for > 5 seconds. Moderate to high intraclass correlation coefficients for intertester reliability (0.57-0.96) have been noted in scoring BESS errors. The BESS score for each condition, total score for the floor and foam conditions, and total error score were utilized in our analyses. A lower score indicated better performance for the BESS.

King-Devick testing was performed according to previous literature [11]. The King-Devick test is an assessment of rapid number naming which requires the athletes to quickly read a series of numbers on three test cards. Worsening performance on this test from baseline was shown to be a reliable indicator of concussion [11]. A lower score on the test indicates better performance (faster time). Two trials were performed, and the average of the trials was used for statistical analysis.

Clinical and biomechanical data were collected on all subjects. SPSS Statistics software (SPSS 26, IBM, Armonk NY), was used for assessing normality, and descriptive statistics. T-tests were used to determine if differences existed between sides for biomechanical testing (left versus right). Spearman's rho (ρ) correlations were used to determine the relationship between clinical and biomechanical test variables. Spearman's ρ was used as not all data was normally distributed, and this test can be used for either parametric or nonparametric data [18]. Significance was set to $P = 0.05$. A trend towards significance was also noted at $P = 0.10$. The strength of the correlation was interpreted as follows: small (0.1), medium (0.3), or large association (0.5).

A priori power analysis using G*Power 3 (power = 0.80; alpha 0.05) [19] suggested a sample size of 64 to detect moderate associations between variables. Data analysis was completed for all athletes who had completed both biomechanical and clinical testing (n = 96).

Table 1: Performance means (standard deviations) of clinical and biomechanical tests.

Test Variable	Mean (SD)
Left Lower Extremity Sway (T score)	49.1 (7.6)
Right Lower Extremity Sway (T score)	46.7 (6.0)
BESS, double leg stance, floor	0.08 (1.9)
BESS, single leg stance, floor	2.13 (2.0)
BESS, tandem stance, floor	0.83 (1.2)
BESS, floor total	2.97 (2.7)
BESS, double leg stance, foam	0.22 (0.55)
BESS, single leg stance, foam	6.36 (2.7)
BESS, tandem stance, foam	3.21 (2.5)
BESS, foam total	9.86 (4.7)
BESS Total	12.83 (4.8)
King-Devick Average	40.6 (6.6)

Results

96 healthy Division I athletes were tested for both biomechanical and clinical concussion tests (41 females). No difference was seen between left and right lower extremities for biomechanical testing ($P > 0.05$). Means and standard deviations of test variables are represented in Table 1. Relationships of biomechanical tests and clinical tests are presented in Table 2. Only the left lower extremity sway data was utilized as there was no difference between sides.

Lower extremity sway was significantly correlated to BESS test subsections (single leg stance, foam and foam total score), BESS total score, and King-Devick score. All correlations were classified as medium in magnitude.

Discussion

The BESS is a clinical evaluation of balance that is widely used to detect deficits in patients with concussion and fatigue. Previously considered to have moderate reliability, certain confounders like age, ankle stability, and training have been shown to alter BESS scores [7]. Additionally, in the literature BESS scores have been shown to be inconsistent, as evidenced by low inter-rater and intra-rater reliabilities [5]. The BESS has been shown to be limited in its utility by its floor and ceiling effects. Significant scoring differences have also been shown to exist with BESS in "error scoring method" compared to those detected in mobile scoring technologies [20]. Therefore, increased efforts have been placed into determining more sensitive assessment for concussions than utilizing the BESS alone, including the Sports Concussion Assessment Tool which recommends a more sensitive modified BESS, and new pursuits into biomechanical testing to improve reliability by automating the assessment of BESS errors [21,22]. With commercially available products, however, there is evidence that they

Table 2: Correlations of biomechanical lower extremity sway test and clinical tests.

	Lower Extremity Sway
BESS, single leg stance, floor	-0.91 (-0.94, -0.86)
BESS, tandem stance, floor	-0.06 (-0.26, 0.14)
BESS, floor total	-0.09 (-0.29, 0.11)
BESS, double leg stance, foam	0.23 (0.03, 0.41)
BESS, single leg stance, foam	-0.30* (-0.47, -0.11)
BESS, tandem stance, foam	-0.06 (-0.26, 0.14)
BESS, foam total	-0.30* (-0.47, -0.11)
BESS Total	-0.31* (-0.48, -0.12)
K-D Average	-0.38* (-0.54, -0.19)

Spearman's rho values (95% CIs); *significant at $P < 0.05$

BESS = Balance error scoring system; K-D = King-Devick too may display poor agreement in certain circumstances, with low inter-rater consistency in difficult stances like single-limb and tandem [23].

On the other hand, the King-Devick test is known for its fast and simple administration to allow sports medicine physicians to make quick sideline decisions. It has been found to have good test-retest reliability, high sensitivity and specificity as a sideline screening test for suspected sports-related concussions [24,25]. While there is a concern for observable learning effects between tests, it has demonstrated reliability with predictable improvements in score [26].

The purpose of this study was to determine the distribution of lower extremity postural sway variables utilizing a novel commercially available software (Sparta Science) in an athletic population, and to determine the relationship between clinical and biomechanical baseline concussion testing. Using the 96 healthy collegiate athletes who underwent both clinical and biomechanical baseline concussion testing, we demonstrated that lower extremity sway and KD were evenly distributed in our population, which was verified statistically. Additionally, as previously determined, our study supported that BESS showed a floor effect. Furthermore, we were able to demonstrate that there was no difference in biomechanical testing in left and right lower legs ($P > 0.05$). Therefore, when comparing LE sway to BESS and K-D, we found LE sway correlates with BESS test subsections (single leg stance, foam; foam total score), BESS total score, and K-D average. All correlations were medium in magnitude, validating the use of force plate testing for baseline concussion assessment. Given the even distribution and LE sway's significant correlation to both BESS and K-D, Sparta Science software offers a new and effective method to perform concussion testing that is supported by previous testing modalities. Additionally, our study demonstrates that LE sway does not suffer the same vulnerability to floor effects as BESS testing, as shown by the normative distribution of the sway data.

Although none of the athletes included in the study had a current concussion and or prolonged sequela of a previous concussion, the study did not account for if an athlete has a previous concussion historically (e.g., in high school or previous competing years). Future studies should include tracking the use of lower extremity postural sway measures post-concussion to better understand the progression post injury. Additionally, future work should include assessing the difference in sway measures post-injury between athletes who have sustained their first concussion, versus potential cumulative effects associated with recurrent concussions.

Practical Implications

- The ultimate aim of this study was to assess lower extremity postural sway as a biomechanical baseline for concussion testing and to determine its relationship to previously established clinical baselines such as BESS and K-D.
- The lower extremity sway scores demonstrate validity when compared to clinical concussion tests.
- The distribution of sway scores in the athletic population indicates that this test may be better suited to detecting subtle differences in changes, and overcomes the limitations of the conventional clinical evaluations.

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