IJSPT

ORIGINAL RESEARCH

AN INITIAL EVALUATION OF THE BTRACKS BALANCE PLATE AND SPORTS BALANCE SOFTWARE FOR CONCUSSION DIAGNOSIS

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ABSTRACT

Background: As recently dictated by the American Medical Society, balance testing is an important component in the clinical evaluation of concussion. Despite this, previous research on the efficacy of balance testing for concussion diagnosis suggests low sensitivity (~30%), based primarily on the popular Balance Error Scoring System (BESS). The Balance Tracking System (BTrackS, Balance Tracking Systems Inc., San Diego, CA, USA) consists of a force plate (BTrackS Balance Plate) and software (BTrackS Sport Balance) which can quickly (< 2 min) perform concussion balance testing with gold standard accuracy.

Purpose: The present study aimed to determine the sensitivity of the BTrackS Balance Plate and Sports Balance Software for concussion diagnosis.

Study Design: Cross-Sectional Study

Methods: Preseason baseline balance testing of 519 healthy Division I college athletes playing sports with a relatively high risk for concussions was performed with the BTrackS Balance Test. Testing was administered by certified athletic training staff using the BTrackS Balance Plate and Sport Balance software. Of the baselined athletes, 25 later experienced a concussion during the ensuing sport season. Post-injury balance testing was performed on these concussed athletes within 48 of injury and the sensitivity of the BTrackS Balance Plate and Sport Balance software was estimated based on the number of athletes showing a balance decline according to the criteria specified in the Sport Balance software. This criteria is based on the minimal detectable change statistic with a 90% confidence level (i.e. 90% specificity).

Results: Of 25 athletes who experienced concussions, 16 had balance declines relative to baseline testing results according to the BTrackS Sport Balance software criteria. This corresponds to an estimated concussion sensitivity of 64%, which is twice as great as that reported previously for the BESS.

Conclusions: The BTrackS Balance Plate and Sport Balance software has the greatest concussion sensitivity of any balance testing instrument reported to date.

Level of Evidence: Level 2 (Individual cross sectional diagnostic study)

Keywords: balance, BTrackS, concussion, diagnostic accuracy, sensitivity

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Disclosure of Potential Conflicts of Interest – Dr. Goble holds an equity stake in Balance Tracking Systems Inc, the parent company for BTrackS. This conflict of interest was mitigated by limiting his involvement in all aspects of data collection and analysis. Authors Manyak, Abdenour, Rauh, and Baweja have no conflicts of interest.

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INTRODUCTION

While sports participation offers many benefits to the athletes involved, widespread participation and awareness, has led to an increase in both the prevalence and reporting of sports-related concussions.[1,2] Sports-related concussions are brain injuries caused by biomechanical forces transmitted to the head during participation in sporting activities.[3] The ensuing brain damage is unpredictable and often results in a multitude of symptoms.[4] Given this unpredictable presentation, sports medicine professionals rely on a battery of clinical assessments in order to determine the presence of a concussion. This includes measures of gross symptomology (e.g. blurred vision, nausea), cognitive function (e.g. working memory, attention) and motor ability.

With respect to motor ability, the most recent statement by the American Medical Society[5] advised the use of balance testing in concussion protocols. This recommendation was based on numerous reports showing evidence of balance declines following concussion.[6-9] Despite this, few reports exist quantifying the efficacy (i.e. specificity/sensitivity) of balance testing for sports-related concussion.[10] In one of the only known studies on the topic, McCrea et al[6] found that balance testing had poor concussion sensitivity (~30%), even though it had a high degree of specificity (~90%).

The limited concussion sensitivity of balance testing reported by McCrea et al[6] may be due to the type of balance test administered. These authors report balance based on the Balance Error Scoring System (BESS), an observational tool that relies on tester judgement to count the number of balance errors made by an athlete during standing trials of varying difficulty.[11] The BESS is well accepted in the field of sports medicine, with an estimated 84% usage among athletic trainers who include balance testing in their concussion protocols.[12] Despite its popularity, however, the BESS has reliability issues due to its subjective nature.[13-15] Indeed, it has been shown to require large changes in performance (~62% change from baseline) before a confident determination of a balance decline can be made based on the BESS.[15] For these reasons, the BESS may not be well-suited for picking up the subtle changes in balance associated with concussions of mild to moderate severity.

A more sophisticated approach to concussion balance testing is the objective measurement of body sway control via a force plate device. Force plate technology is the "gold standard" for balance testing, abstracting the center of pressure (COP) from foot contact forces generated during standing on the plate. COP is a proxy for body sway control and increased center of pressure displacement is a known indicator of balance decline in individuals with traumatic brain injuries, including concussion.[8,16-17] Unfortunately, force plate balance testing is only used by 5% of athletic trainers who perform balance testing as part of their concussion protocols.[12] This under-utilization is most likely due to the high cost (~$5000-$75,000), and general lack of portability, associated with typical force plate systems.

The Balance Tracking System (BTrackS, Balance Tracking Systems Inc., San Diego, CA, USA) consists of a force plate (BTrackS Balance Plate) and software (BTrackS Sport Balance) which can quickly (<2 min) perform concussion balance testing with gold standard accuracy. This instrument is relatively low cost (~$800) compared to other force plates, and extremely portable for multisite use. The present study sought to evaluate the sensitivity of the BTrackS Balance Plate and Sport Balance software for identifying concussed athletes. It was hypothesized that the BTrackS Balance Plate and Sport Balance software would have increased concussion sensitivity compared to that reported previously for the popular BESS test, given the use of objective, accurate and reliable, force plate technology.

METHODS

Participants

A cross-sectional sample of 25 collegiate athletes (mean age = 20.7; 14 women, 11 men) was utilized for this study. Athletes were chosen from a larger sample of 519 collegiate athletes who underwent baseline balance testing with the BTrackS Balance Plate and Sport Balance software when healthy in preseason. Participants were those individuals who later experienced a concussion in the ensuing sport season. This was verified within 48 hours of injury by a trained sports medicine professional (i.e. team physician) using the third version of the Standard Concussion Assessment Tool.[18] Participants were

also required to have performed follow-up balance testing using the BTrackS Balance Plate and Sport Balance software within 48 hours of their concussive event. The 48 hour timeframe utilized was based on previous studies showing that balance deficits resolve between 3 and 10 days following a concussive event.[4,11,16-17] All procedures in this study were approved by the local Human Subjects Institutional Review Board and informed consent was obtained prior to data collection.

Experimental Setup

Experimental testing in this study was conducted using the BTrackS Balance Plate and Sport Balance software (Balance Tracking Systems Inc., San Diego, CA) (Figure 1). The BTrackS Balance Plate is an FDA registered, lightweight (<7 Kg) force plate specialized for determining the COP of foot forces placed on it during standing. The surface of the BTrackS Balance Plate measures 0.4 m by 0.6 m and uses four-sensor technology to determine COP with an accuracy and reliability that is comparable to other, more expensive force plate systems.[19] The BTrackS Balance Plate used in this study was placed on a on a firm (concrete tile), level surface during testing, as per the manufacturer's specifications. Leveling of the board was achieved via the adjustable legs on the BTrackS Balance Plate and verified with a bubble leveling tool.

The BTrackS Sport Balance software is an application-based program which was loaded onto an ASIS laptop (Model X200) with a Windows 8.1 operating system. The BTrackS Sport Balance software is a user-friendly interface that guides the tester through creating an athlete demographic-based profile, running a balance test and viewing relevant results. The BTrackS Balance Plate was connected to the laptop via a USB cable, which also provided power to the plate's electronics (i.e. no AC power required). All balance testing was conducted by the local Athletic Training staff, who were experienced in the use of BTrackS technology.

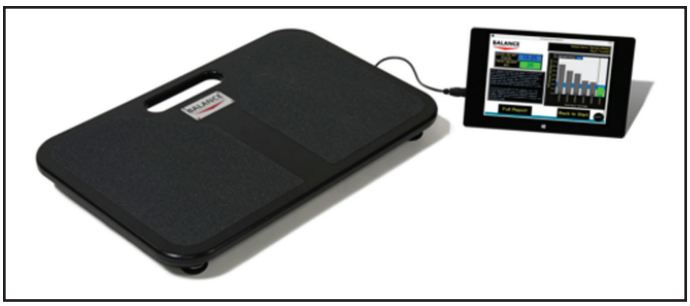

Figure 1. *The BTrackS Sport Balance package, consisting of the BTrackS Balance Plate (left) and the BTrackS Sport Balance software (right) running on a tablet computing device.*

Balance Testing Protocol

Balance testing was administered in preseason and post-concussion according to the BTrackS Balance Test (BBT) protocol. Each BBT took less than two minutes to administer and was performed with the athlete wearing socks. The BBT consists of four, 20s trials with minimal inter-trial delays (<10s), which began and ended with an auditory tone. The athlete stood as still as possible on the BTrackS Balance Plate with eyes closed, hands on hips and feet shoulder width apart during testing (Figure 2). The first trial was for familiarization purposes only, while

Figure 2. *A depiction of the typical BBT administration. The athlete stands quietly on the BTrackS Balance Plate with eyes closed, feet shoulder width apart and hands on hips while the tester collects body sway information with a connected computing device running the BTrackS Sport Balance software.*

the remaining three trials were used to calculate the BBT result. The BBT result was calculated by the Sport Balance software as the average COP excursion (i.e. COP path length) across trials. COP excursion is a proxy for total body sway control and, thus, larger BBT values indicated worse performance.[8,16-17] An example of baseline and post-injury data from an individual with declined balance following concussion is provided in Figure 3.

Determination of BTrackS Concussion Sensitivity

The sensitivity of the BTrackS Balance Plate and Sport Balance software for concussion was quantified by calculating the percentage of concussed athletes who showed a decline in balance from baseline testing to post-concussion testing. The criterion for determining whether a decline in balance had occurred was an increase in the BBT result of more than 5 cm (i.e. more than 5 cm greater sway following concussion compared to baseline), as prescribed by the BTrackS Sport Balance software. This criterion value established by Balance Tracking Systems Inc[19] and represents the minimum detectable change (MDC) for the BBT with a 90% confidence interval. Otherwise stated, 90% of healthy individuals tested show a BBT result that varies 5cm or less from one test to the next. This criteria is also equivalent to a testing specificity of 90%, which aligns well with that reported previously for the BESS.[6]

Figure 3. *Example baseline (top) and post-concussion (bottom) COP data from a single BBT trial. The amount of body sway is shown by the path length (i.e. excursion) of the yellow COP trace, which is quantified in centimeters in the bottom right hand corner of each respective depiction of the BTrackS Balance Plate. Note the increase in COP path length following concussion.*

RESULTS

Baseline and post-concussion BBT results, as well as the difference from baseline to post-concussion (i.e. BBT change), is presented for all participants in Table 1. Based on the MDC criterion of the BTrackS Sport Balance Software, 16 of the 25 concussed athletes were identified as having a balance decline (i.e. had 6 cm or greater sway following concussion compared to baseline). This ratio corresponds to an estimated concussion sensitivity of 64.0%. Overall, in all participants the average change from baseline following concussion was more than three times (18.8 cm) as large as the MDC criterion, with a range of -5.0 cm to 94.0 cm. Of those individuals identified as having a balance decline, the average change in BBT result was 30.0 cm, which is six times greater than the criterion value.

DISCUSSION

The increasing number of sports-related concussions has become a public health issue and, thus, there is a distinct need to more accurately identify athletes who have sustained a concussion.[1,2] Poor sensitivity (~30%) has been shown previously for the most popular balance testing protocol for concussions (i.e. the BESS).[6] The present study provided an initial estimate of the concussion sensitivity of a new, low-cost force plate device called the BTrackS Balance Plate and its associated Sport Balance software. It was determined that the BTrackS Balance Plate and Sport Balance software is more than twice as sensitive (64%) as the BESS for concussion diagnosis. Given that the criterion value for establishing a balance deficit was at a level of specificity similar to that of the BESS (i.e. 90%), the present study's findings support adapting concussion protocols for

Table 1. *Summary of BBT results from baseline to post-concussion and evaluation of balance decline according to the BTrackS Sport Balance criterion of 5 cm minimal detectable change*

Concussed Athlete #	Baseline BBT (cm)	Post-Concussion BBT (cm)	BBT Change (cm)	Balance Decline Exists?
1	22	41	19	**Yes**
2	38	88	50	**Yes**
3	22	18	-4	No
4	13	33	20	**Yes**
5	17	12	-5	No
6	27	27	0	No
7	16	13	-3	No
8	23	19	-4	No
9	20	26	6	**Yes**
10	21	41	20	**Yes**
11	20	27	7	**Yes**
12	23	26	3	No
13	27	44	17	**Yes**
14	45	60	15	**Yes**
15	39	131	92	**Yes**
16	18	28	10	**Yes**
17	28	35	7	**Yes**
18	21	23	2	No
19	31	55	24	**Yes**
20	51	145	94	**Yes**
21	17	15	-2	No
22	20	45	25	**Yes**
23	18	24	6	**Yes**
24	20	23	3	No
25	16	84	68	**Yes**

the use of the BTrackS Balance Plate and Sport Balance software over less effective alternatives such as the BESS.

Greater sensitivity for the BTrackS Balance Plate and Sport Balance software likely stems from the use of force plate technology, widely considered to be the gold standard for balance assessment. Unlike the subjective BESS method, the BTrackS Balance Plate and Sport Balance software uses an objective measure of balance (i.e. COP) with a reliable balance testing protocol.[20-21] The more accurate and reliable a clinical tool is, the smaller the amount of measured change needed to make a confident decision regarding a clinical outcome. Previous research on the BESS has estimated that a large average change in performance (~62%) is necessary to confidently determine the existence of a balance decline.[15] The results of the present study suggest that the BTrackS Balance Plate and Sport Balance software can detect, on average, a much smaller balance change relative to baseline.

Only one other known study has assessed the sensitivity of a force plate system for concussion diagnosis.[22] In that study, changes in body sway were measured in concussed athletes using the Sensory Organization Test (SOT). The SOT tracks an athlete's COP with a force plate system similar to the BTrackS Balance Plate and Sport Balance software, but does so during six conditions designed to isolate various sources of sensory feedback (i.e. visual, proprioceptive, vestibular). The SOT efficacy results showed a similar concussion sensitivity (62%) to that reported in the present study for the BTrackS Balance Plate and Sport Balance software (64%). However, the criterion used to determine an SOT balance decline was reduced performance greater than one standard deviation from baseline on any of four outcome measures. When each outcome measure was considered in isolation, SOT sensitivity was greatly reduced (range 24%-36%). This is in addition to the practical limitations inherent to the force plate system needed to run the SOT, which has a cost of ~$75,000 and poor portability for multi-site use.

One limitation of the present study is that it focused on the diagnostic sensitivity of BTrackS Balance Plate and Sport Balance software within a 48-hour time period following concussion. Future studies are needed to determine whether the length of recov-

ery following concussion might also be tracked more accurately using this tool, since previous research suggests balance issues resolve within 3-10 days.[1,4,16-17] As well, it may be possible that use of a different COP outcome measure, could further increase the efficacy of the BTrackS Balance Plate and Sport Balance software. One outcome measure of particular interest to explore in future work would be approximate entropy of COP during quiet standing. This non-linear COP metric has previously been shown to have an increased effect size post-concussion compared to more standard spatial measures of COP size and displacement, including the path length measure used in the BTrackS Sport Balance Software.[23]

In order to maximize applicability to the field, only the prescribed BBT protocol and MDC metric included with the BTrackS Sport Balance software was evaluated in this study. While it is beyond the scope of the present work, future studies are warranted which are aimed at further improving the sensitivity of concussion assessment with the BTrackS Balance Plate and Sport Balance Software. This may include exploration of such factors as the standardization of foot position, utilization of a different MDC threshold, or the application of compliant (foam) surfaces on top of the BTrackS Balance Plate. In this way, the present findings may actually represent the most conservative sensitivity estimate for the BTrackS Balance Plate and Sport Balance software's potential as a concussion diagnostic.

While the present study provides highly valuable information regarding the efficacy of the BTrackS Balance Plate and Sport Balance software for concussion assessment, it should be noted that a direct comparison of this device and other balance testing tools was not made. That is, the athletes tested in this study were not concurrently assessed with either the BESS method or a more expensive force plate system. Such a comparison of balance testing tools may prove valuable in future studies, but was not feasible for this initial evaluation of the BTrackS Balance Plate and Sport Balance software due to logistical reasons. First, the BESS method was not being used as a standard component of the local university's concussion protocol due to a lack of trained personnel and confidence in results. Second, expensive force plate systems were not available for widespread baseline testing of athletes, which would have limited the available sample for this study.

It is possible that some of the athletes in this study were able to mask a balance decline by intentionally underperforming during their baseline test. This seems unlikely however, as the baseline BBT results were generally quite good compared to those individuals who did not show a balance decline following concussion. Interestingly, there appears to be partial relationship between the baseline balance score the magnitude of drop-off in performance following concussion. Three of the four individuals with the greatest drop-off in balance (≥50cm) had baseline scores that were in bottom five of all concussed athletes tested. This suggests that the BTrackS Balance Plate and Sport Balance software may also be useful as an early identification system for individuals at high risk of concussion.

CONCLUSION

The present results provide important clinical insight regarding the effectiveness of the BTrackS Balance Plate and Sport Balance software for determining the existence of sports related concussions. While the sensitivity is still subject to improvement, it is superior to more subjective methods, such as the BESS. In this case, future studies are planned to demonstrate the combined efficacy of the BTrackS Balance Plate and Sport Balance software with other standard concussion metrics (i.e. symptomology and cognitive function). This approach will ultimately provide clinicians the greatest chance of preventing potentially life-threatening conditions such as second impact syndrome, and/or limit the long term effects of repetitive brain injuries such as chronic traumatic encephalitis.

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