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Normative Data for the BTrackS Balance Test Concussion-Management Tool: Results from 10 045 Athletes Aged 8 to 21 Years

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Context: Balance tests are a recommended assessment of motor function in concussion protocols. The BTrackS Balance Test (BBT) is a tool for concussion balance testing that uses low-cost force-plate technology to objectively measure postural sway.

Objective: To provide normative data for the BBT in a large population of athletes.

Design: Cross-sectional study.

Setting: Concussion baseline testing at multiple facilities.

Patients or Other Participants: Male and females athletes (n = 10 045) ages 8 to 21 years.

Intervention(s): Athletes performed three 20-second trials of eyes-closed standing on the BTrackS Balance Plate with feet shoulder-width apart and hands on hips.

Main Outcome Measure(s): Postural sway was measured as the average total center-of-pressure path length over 3 testing trials.

Results: Postural sway was reduced (ie, balance improved) as athlete age increased and was less in female athletes than in male athletes. Percentile ranking tables were calculated based on sex and 2-year age groupings.

Conclusions: Our findings (1) provide context for BBT results performed in the absence of a baseline test, (2) can help mitigate athlete malingering, and (3) might identify individuals with latent neuromuscular injuries during baseline tests.

Key Words: postural sway, baseline testing, reference data

Key Points

- The BTrackS Balance Test was an objective, accurate, and reliable concussion-management tool.
- More than 10 000 male and female athletes aged 8–21 years provided normative data for the BTrackS Balance Test.
- Normative data can improve postconcussion evaluation, identify malingering, and enable baseline screening for athletes with neuromuscular impairment.

Millions of concussions are sustained each year by children, adolescents, and adults while playing sports.[1] These mild traumatic brain injuries are complex due to multiple neurologic and biomechanical factors.[2] Not surprisingly, concussions have wide-ranging symptoms that include both psychosomatic variables (eg, nausea, blurred vision, loss of consciousness) and cognitive and motor deficits.[3]

To manage sport-related concussion, the most recent consensus statement by the Concussion in Sport Group[4] advocated balance testing as one component. This recommendation is supported by studies[5–9] that showed many concussed athletes had worse balance than at preseason baseline testing.

The BTrackS Balance Test (BBT; Balance Tracking Systems, Inc, San Diego, CA) was 90% specific and 64% sensitive in identifying individuals with sport-related concussion.[9]

The BBT is a concussion-management tool that uses low-cost force-plate technology to objectively measure postural sway (ie, balance). *Postural sway* was classically defined as sustained oscillatory motion about a fixed postural position during upright standing.[10] Force plates determine postural sway based on a proxy for the body's center of mass called *center of pressure* (COP). Center of pressure is equal to the weighted average of forces created when an individual stands on a force plate. Increased COP magnitude over time indicates more postural sway and poorer balance.[11]

The best practice for concussion management typically involves comparing postconcussion test results with results obtained at baseline.[12] Despite this, normative databases are valuable for further contextualizing performance. For example, it is rarely possible to gather baseline data from all athletes in larger academic settings due to time and manpower constraints. In this case, the ability to compare postconcussion results with age- and sex-matched norms can significantly improve the ability to interpret results. Second, athletes may occasionally *malinger*, or intentionally underperform, on baseline tests to increase the likelihood of later passing a postconcussion test. Using normative data at baseline can reduce this unwanted practice by alerting sports medicine professionals of suspicious results at the time of testing. Alternatively, low baseline test results compared with norms may not

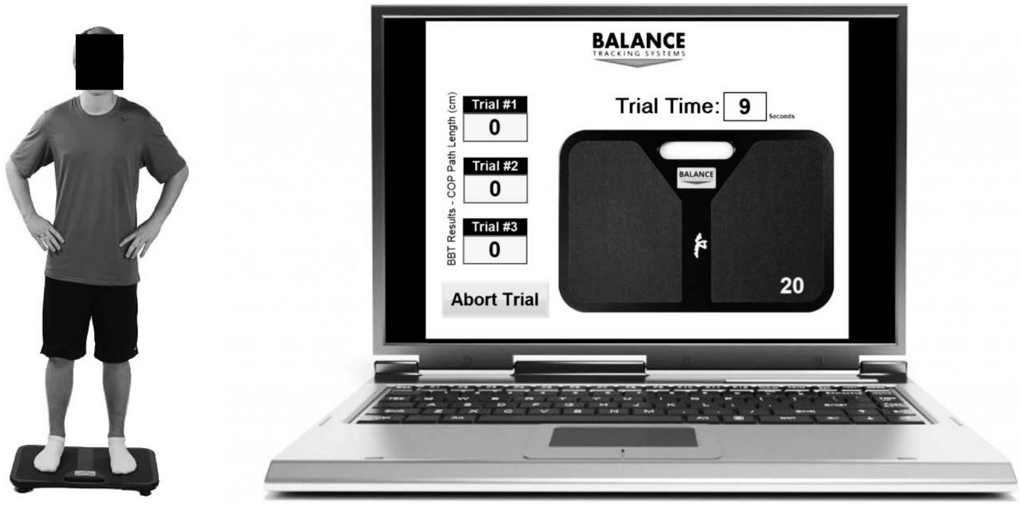

Figure 1. Depiction of the BTrackS Balance Test testing setup. Athletes stood as on the left with eyes closed, hands on hips, and 2 feet on the BTrackS Balance Plate (Balance Tracking Systems, Inc, San Diego, CA). During testing, the BTrackS Sport Balance software shown on the right guided the tester through measurement of center-of-pressure path length. In this screen shot, the first of 3 trials is in progress with a center-of-pressure path length of 20 shown on the BTrackS Balance Plate image.

reflect malingering but rather latent neuromuscular concerns from previous concussions or musculoskeletal injuries.

The purpose of our study was to provide athlete-specific normative data for the BBT. We accomplished this by calculating percentile rankings for the baseline BBT results of athletes aged 8 to 21 years using 1 of the largest balance datasets of postural sway collected (n = 10 045). In line with previous authors,[13–20] we hypothesized that older athletes would perform better (ie, have less postural sway) than younger athletes and that females would outperform males. Our goal was to enhance the efficacy of BBT testing and the management of patients with sport-related concussion.

METHODS

Participants

We analyzed BBT postural sway data from 10 045 male (n = 6624) and female (n = 3421) athletes aged 8 to 21 years. Data were provided by the parent company for the BBT, which solicited results from 40 test sites across the United States according to the inclusion criteria requiring that (1) standardized BBT instructions were followed and (2) only baseline test results from presumably healthy athletes would be considered. Most of the test sites were educational settings such as high schools and universities; however, data from some community-based sports teams and youth sports were used. The sample consisted of athletes from 34 sports, with the highest percentage of data collected from individuals playing football (n = 2732, 27.2%), soccer (n = 1638, 16.3%), basketball (n = 1266, 12.6%), baseball (n = 658, 6.6%), volleyball (n = 628, 6.3%), and water polo (n = 434, 4.3%). Due to the secondary, deidentified nature of the data, the study was deemed exempt by the internal review board at Oakland University. All procedures were aligned with the Declaration of Helsinki.

Experimental Setup

The assessments of postural sway were conducted at each testing site using a BTrackS Balance Plate and BTrackS Sport Balance software (version 4; Balance Tracking Systems, Inc; Figure 1). The BTrackS Balance Plate is a low-cost (<\$1000, no per-test fees), Food and Drug Administration-registered, and portable (<7 kg) force plate used to measure COP. Validity of the BTrackS Balance Plate has been established against several other accepted methods of COP measurement. Specifically, BTrackS has shown excellent accuracy (intraclass correlation coefficient [ICC] = 0.999), precision (ICC = 0.999), and reliability (ICC = 0.999) against a laboratory-grade force plate and a computer numerical control-administered point-of-application test.[21,22] The BTrackS Sport Balance is a user-friendly software application for conducting the BBT. This software was run on computing devices (personal computers, laptops, or tablets) using full versions of the Windows operating system (Microsoft, Inc, Redmond, WA).

Testing Procedures

For data collection at each site, a BTrackS Balance Plate was connected via universal serial bus to its associated computing device and the BTrackS Sport Balance software was opened. The BTrackS Sport Balance then guided users in a step-by-step deterministic fashion through all phases of collecting the postural-sway data according to the BBT protocol. Limited training was needed to conduct a BBT and typically consisted of administering the test once under the supervision of an experienced user. To minimize variance across testers, each BBT was administered followed a standardized, script-based protocol consisting of three 20-second trials with minimal intertrial delays (<10 seconds). Each trial began and ended with an auditory tone and required the participant to stand as still as possible on the BTrackS Balance Plate with eyes closed, hands on hips, and feet shoulder-width apart (Figure 1). Although

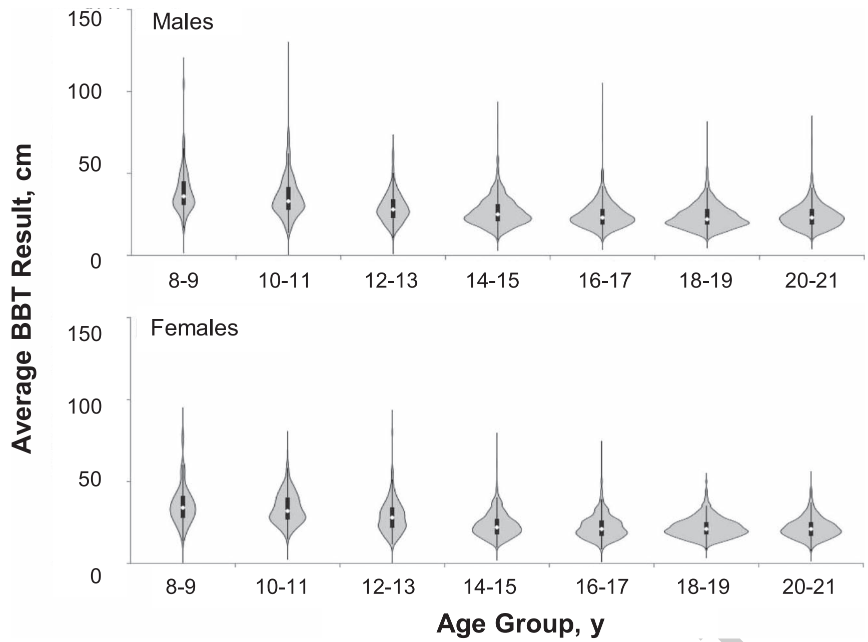

Figure 2. Violin plots displaying the BTrackS Balance Test (Balance Tracking Systems, Inc, San Diego, CA) results for males (top) and females (bottom) in each age group. Each plot has an outer layer in gray consisting of all possible results; the width of the layer represents how common the occurrence of a result is (ie, wider = more common). Inside the gray is a box plot of the relevant data. The box of the box plot, in black, covers the 25th to 75th percentiles (ie, interquartile range). The white diamond in the box represents the median of the data.

testing in socks with the participant's shoes off has been recommended, previous researchers[23] showed that standard footwear did not affect COP measurements during protocols similar to the BBT.

The result of each BBT was calculated by the BTrackS Sport Balance software and was equivalent to the average total COP path length (cm) across the 3 trials. Center-of-pressure path length is a proxy for postural-sway magnitude whereby larger BBT values indicate greater postural sway.[11] Path length was determined by first quantifying the point-to-point path length between successive time points of COP data according to the following formula:

$$\text{path length} = \left(\left[COP_{x2} - COP_{x1}\right]^2 + \left[COP_{y2} - COP_{y1}\right]^2 \right)^{0.5},$$

where COP_{x2} and COP_{x1} are adjacent time points in the COP_x (medial-lateral) time series and COP_{y2} and COP_{y1} are adjacent time points in the COP_y (anterior-posterior) time series. All path lengths were then summed for total path length. The manufacturer-specified sampling frequency of the BTrackS Balance Plate is 25 Hz for a total of 500 data points in a 20-second trial. No other COP metrics (eg, COP sway area) are provided by the BTrackS Sport Balance; thus, only path length was assessed.

Data Analysis

The BTrackS Balance Test results were deidentified and assembled in a single database on receipt from the systems. We then inspected the data for quality using a series of rules that identified improper use of the testing protocol, invalid demographics, and testing outliers. The rules were that (1) data were provided for all 3 testing trials, (2) participant age and sex were given, and (3) a valid sport was indicated. Less than 1% of the original sample of 10 141 athletes was excluded. Next, we sorted the athlete data by sex (male, female) and age group (8–9, 10–11, 12–13, 14–15, 16–17, 18–19, or 20–21 years). The age groups approximated academic grade levels and represented level 2 detail according to the "Provisional Guidelines on Standard International Age Classifications" of the United Nations for "Health, Health Services and Nutrition."[24]

After preprocessing, we calculated the statistical effects of sex and age on the BBT results, as well as the interaction between sex and age (sex × age) using a 2-factor analysis of variance. This analysis was conducted in SPSS (version 24; IBM Corp, Armonk, NY) with significance determined at the $P < .05$ level. Where significant effects were found, we used Tukey honest significant difference tests to identify differences between levels of a given factor. Lastly, based on the analyses for sex and age, percentile rankings were calculated for every 10th percentile from the 10th to the 90th according to the following formula:

$$\text{percentile ranking} = P/100(N + 1),$$

where P represents the percentile rank and N represents the number of BBT results in the distribution of interest.

RESULTS

Based on the analysis of variance, BBT results were affected by athlete sex ($F_{1,10031} = 93.8$, $P < .001$), age ($F_{6,10031} = 334.3$, $P < .001$), and a sex × age interaction ($F_{6,100.1} = 2.2$, $P = .04$; Figure 2). With regard to sex, females had better BBT results (ie, less postural sway) than males in all age groups ($P < .05$) except 12–13 years ($P > .05$). For male athletes only, BBT results demonstrated less postural sway as age increased from 8–9 to 18–19 years ($P < .05$), with no differences between male athletes 18–19 and 20–21 years ($P > .05$). For female athletes only, age did not affect BBT ($P > .05$) across the 2 youngest age

Table 1. The BTrackS Balance Test Percentile Rankings for Male Athletes by Age Group

Age Group, y	No.	Percentile Rankings[a]								
		10th	20th	30th	40th	50th	60th	70th	80th	90th
8–9	140	53	48	43	39	36	33	32	30	27
10–11	310	50	44	39	36	33	31	29	27	23
12–13	311	40	35	32	30	28	26	24	22	19
14–15	1333	38	33	29	27	25	23	21	20	17
16–17	1240	34	30	27	25	23	22	20	19	16
18–19	2064	33	29	26	24	22	21	19	18	15
20–21	1226	33	29	27	25	23	21	20	18	16

[a] The BTrackS Balance Test (Balance Tracking Systems, Inc, San Diego, CA) results represent the average center-of-pressure path length (cm) of postural sway.

groups (ie, 8–9 versus 10–11 years) and the 3 oldest age groups (ie, 16–17 versus 18–19 versus 20–21 years). In contrast, female athletes aged 10–11 to 12–13 years, 12–13 to 14–15 years, and 14–15 to 16–17 years had better BBT results (ie, less postural sway; $P < .05$).

Given these sex and age effects, we determined that percentile rankings for this dataset should be stratified by both factors. Percentile ranking information by age group is provided for males (Table 1) and females (Table 2). These tables serve as tools for understanding the performance of an individual relative to others of similar sex and age. For example, a 15-year-old male with a BBT of 27 is in the 40th percentile. This means that his BBT result is as good as or better than 40% of males his age.

DISCUSSION

In this study, we sought to provide normative data for the BBT, a balance test of postural sway for concussion management that uses a portable, low-cost force plate. Specifically, we analyzed baseline BBT results of more than 10 000 athletes 8 to 21 years of age and provided percentile rankings based on sex and age differences. These normative results provide additional insight into an athlete's balance status when baseline BBT results are not available for comparison with postconcussion testing. Further, normative BBT data can assist in identifying athletes suspected of malingering during baseline tests and those who are experiencing a latent neurologic or musculoskeletal injury.

Across the various age groups tested, we found clear differences in BBT results for male and female athletes. These results were generally well aligned with a relatively large body of literature[16–20] that has demonstrated a reduction in postural sway with increasing age. The mechanism of this balance improvement is most likely developmental, with maturation of the brain and sensorimotor systems occurring from childhood through early adulthood.[25–27] Interestingly, improvements in postural sway in our study were seen until age 18 to 19 years in males and 17 to 18 years in females. These results are in contrast to previous findings[17–19] that suggested adult-like postural-sway control was achieved by age 14 or younger. This discrepancy in results is probably due to the large sample size in our study and the subsequent increased statistical power for determining age differences. Indeed, other recent investigators[16] studying a large sample (n = 889) of athletes' force-plate data also noted improvements in postural sway up to 18 years of age.

The BTrackS Balance Test results in our research were also in general agreement with previous literature[16–20] demonstrating enhanced balance ability (ie, less postural sway) in females compared with males. The exact mechanism underlying this sex difference in postural sway remains elusive. Although it is tempting to attribute this finding to known anthropometric differences between male and female athletes, most authors[16,18–20] did not observe relationships between measures of height or weight and postural sway. To this extent, an alternative explanation may lie in a study[28] that showed females outperformed males on tests of vibrotactile foot sensitivity and that increased sensitivity was associated with enhanced performance on various tests of postural sway.

Several limitations are worth noting in relation to our results. First, the data were collected at multiple sites with limited oversight by us. This approach has the potential to affect internal testing validity due to site-specific differences in the testing environment and how the test was implemented. Some variation in results was also likely due to the individual(s) administering the test, although procedures were standardized and a medical device was used to objectively measure postural sway. For reasons of

Table 2. The BTrackS Balance Test Percentile Rankings for Female Athletes by Age Group

Age Group, y	No.	Percentile Rankings[a]								
		10th	20th	30th	40th	50th	60th	70th	80th	90th
8–9	119	50	42	39	36	34	32	29	27	23
10–11	243	46	42	38	35	32	29	28	25	23
12–13	143	40	35	32	30	28	24	23	20	17
14–15	449	33	29	26	24	22	21	19	17	15
16–17	490	32	27	25	23	21	19	18	16	14
18–19	1298	30	26	24	23	21	20	18	17	15
20–21	679	30	26	24	22	21	19	18	17	14

[a] The BTrackS Balance Test (Balance Tracking Systems, Inc, San Diego, CA) results represent the average center-of-pressure path length (cm) of postural sway.

user privacy, the data in this study were not linked to the collection site and, therefore, no assessment of these factors was possible. However, a previous study[14] involving more subjective clinical assessments showed no effects related to testing athletes' balance at multiple locations.

In addition, the sample size reflected an imbalance across the sex and age groups. At least 100 individuals were tested from each sex and age group to permit a true percentile ranking, yet some groups were overrepresented with more than 1000 athletes. Similarly, we made no attempt to provide normative data by sport due to insufficient sample sizes for most sports in the database. In future work, we hope to increase the number of athletes in smaller sex, age, and sport groupings.

Our study has clinical relevance, given that the BTrackS is a tool can be used for concussion balance testing with evidence of diagnostic efficacy[9] and resistance to fatigue[29] and practice[30] effects, limitations that have been associated with other concussion balance testing tools. The existing BTrackS Sport Balance software (version 4) has normative data integrated into its analytics based on larger age groupings than those used in our study (ie, 5–9, 10–14, 15–19, and 20–29 years). Efforts should be made to incorporate our work into the next generation of BTrackS Sport Balance software to further enhance its efficacy in the field for sport medicine professionals.

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