Original Research

Normative Data for the BTrackS Balance Test of Postural Sway: Results from 16,357 Community-Dwelling Individuals Who Were 5 to 100 Years Old

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Background. Postural sway is routinely assessed because increased postural sway is associated with poorer performance of activities of daily living, higher rates of residential care, and increased risk of falling. Force plate technology is one of the most sensitive and objective means of assessing postural sway in the clinic.

Objective. The aim of this study was to provide the first set of normative data for the BTrackS Balance Test (BBT) of postural sway.

Design. The design was descriptive and population based.

Methods. BBT results from 16,357 community-dwelling individuals who were 5 to 100 years old were accumulated and assessed for effects of age, sex, height, and weight. Percentile rankings were calculated for significant groupings.

Results. BBT results were dependent on age and sex but not height or weight. Therefore, percentile rankings were determined for male and female individuals in each age category, with no consideration of participant height or weight.

Limitations. Data were collected by third-party practitioners with various backgrounds in more than 50 locations across the United States and Canada. There was an imbalance in the sample sizes for age and sex groupings.

Conclusions. The findings of this study represent the largest normative dataset ever published for postural sway results. Normative data on the BBT can assist in determining abnormalities in postural sway, which have been linked to negative clinical outcomes.

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Human balance can be defined as the ability to maintain upright standing without falling. This fundamental aspect of motor control is achieved through a mechanism called "postural sway," whereby sustained oscillatory motion occurs about a fixed postural position in the presence of gravity.[1] Over 100 years ago, neurologist Moritz Heinrich Romberg was the first to recognize the clinical utility of measuring postural sway for assessing sensory feedback deficiencies in patients with balance issues.[2] Today, postural sway assessments are routinely performed based on evidence that increased postural sway is associated with poorer performance on activities of daily living,[3] higher rates of residential care,[4] and increased risk of falling.[5,6]

Force plate technology is one of the most sensitive and objective means of assessing postural sway in a clinical setting. Force plates measure postural sway based on a metric called center of pressure (COP), which is the weighted average of forces created while standing on a force plate. Increased COP magnitude (ie, greater postural sway) during quiet standing with eyes open or closed has been shown in many clinical conditions, including multiple sclerosis,[7] mild traumatic brain injury,[8] and stroke.[9] Despite this fact, force plate use in clinical settings has remained somewhat limited, likely because of the high cost and lack of portability inherent in most traditional force plates.

The Balance Tracking System (BTrackS; Balance Tracking Systems, Inc, San Diego, California) was created in 2013, with the objective of overcoming the above stated force plate limitations. The BTrackS consists of the BTrackS Balance Plate, which is more portable (approximately 6.75 kg [<15 lb], no AC power required) and affordable (<$1000 US) than other devices, and user-friendly software that objectively and reliably tests postural sway.[10,11] In particular, the device promotes a method called the BTrackS Balance Test (BBT), which is especially effective for evaluating clinical populations because it is fast (<2 minutes) and easy to administer (software guided) and uses a protocol (ie, four 20-second trials of standing with eyes closed) that most individuals who are ambulatory can complete without falling.

Normative data are critical for any clinical assessment of postural sway. First, comparisons between data from patients and reference data from individuals who are healthy can establish the existence of latent balance dysfunctions, allowing for intervention strategies to be proactively applied. Second, normative results can be effectively used to quantify positive and negative changes that occur over the course of an intervention period, permitting the effectiveness of interventions to be established. Third, normative data can be useful in the diagnosis of balance impairments associated with many neuromuscular conditions. In light of all these reasons, the aim of the present study was to provide the first set of normative data for the BBT. This was accomplished using a very large (N = 16,357) database of results to calculate true percentile rankings stratified by relevant age, sex, height, and weight factors.

Methods

Participants

Postural sway data for this study were provided by the parent company for BTrackS: Balance Tracking Systems, Inc. Data consisted of BBT results collected from 16,357 community-dwelling individuals at more than 50 sites across the United States and Canada (eTable, available at https://academic.oup.com/ptj, shows demographic data). Data were solicited from existing BTrackS users who provided verbal assurance that the BBT protocol was implemented according to its standardized set of instructions and that only community-dwelling individuals who were healthy were tested. The sources included YMCA afterschool programs, educational institutions (high schools, colleges, and universities), wellness fairs, and initial visits to health/fitness clinics. Ethics approval for this study was provided by the local internal review board of Oakland University, and all procedures were conducted in compliance with the Declaration of Helsinki.

BBT Setup and Procedure

BBT assessments of postural sway were conducted using the BTrackS Balance Plate and 1 of 2 BTrackS software applications (BTrackS Assess Balance, BTrackS Sport Balance). The BTrackS Balance Plate (Fig. 1) is a US Food and Drug Administration–registered, lightweight (<7 kg) force plate for determining the COP. This device has been ecologically validated[10] and found to have nearly perfect accuracy and precision for COP measurement compared to a laboratory-grade force plate.[12]

BTrackS software was run on multiple computing devices (personal computers, laptops, or tablets) using the full version of the Windows operating system (Microsoft Corp, Redmond, Washington). Users were guided by the software through all steps of testing, including creation of testing profiles, performance of the BBT, and output of test results. The BTrackS Balance Plate and computing device were connected via a USB cable, which provided power to the BTrackS Balance Plate. Given the user-friendly nature of the BTrackS software, limited training is necessary to learn how to perform a BBT. In most cases, this training consists of performing a single test session under the supervision of an experienced user.

Just prior to testing, users were prompted to read the following instruction to participants via an onscreen dialog box:

> This test consists of four, 20 second trials. The first trial is a practice trial, and the following three trials are used to measure your balance. For each trial, you will stand as still as possible on the BTrackS Balance Plate with your hands on your hips, feet shoulder width apart, and eyes closed. You will hear a tone at the beginning of each trial and another tone when each trial is completed. Do you have any questions?

The BBT protocol was then commenced according to this instruction with minimal intertrial delays (<10 seconds). A depiction of the participant during a testing trial is shown

Figure 1.
Depiction of BTrackS Balance Test (BBT) setup. Participants stood with eyes closed, hands on hips, and both feet on the BTrackS Balance Plate, while BTrackS software guided the tester through the measurement of center-of-pressure path length over 4 trials. Used with permission of Balance Tracking Systems Inc.

in Figure 1. The first trial performed was for familiarization and, thus, was discarded. The remaining 3 testing trials were used to determine the BBT result. It was recommended that all testing be performed with participant shoes off, although previous research has shown that standard footwear does not affect COP measurement during protocols similar to the BBT.[13]

The BBT result was calculated by the BTrackS software and was equivalent to the average total COP path length in centimeters across accountable trials. COP path length is a proxy for postural sway magnitude and, thus, larger BBT values are indicative of greater postural sway. Path length was determined by first determining the distance between successive registered COP locations according to the following formula:

$$\text{distance} = [(COP_{x2} - COP_{x1})^2 + (COP_{y2} - COP_{y1})^2]^{0.5}$$

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. The sum of all distances was then added up to obtain the total path length. The manufacturer specified sampling frequency of BTrackS is 25 Hz for a total of 500 data points in a 20-second trial. No other COP metrics (eg, COP excursion, velocity, area) are directly provided by the BTrackS software.

Data Analysis

BBT results gathered from all testing locations were deidentified and assimilated into a single database prior to analysis. The data were inspected for quality using a series of rules that determined duplicate entries (n = 8), incomplete fields (n = 12), and non-sense values (n = 52). The excluded data represented <0.5% of the total sample and, thus, had a negligible effect on the overall results. The data were grouped according to sex (male, female) and age. Age groups were based on information in *Provisional Guidelines on Standard International Age Classifications*.[14] Level 2 detail was provided except in 2 age categories, for which additional groups were added to increase the resolution of potential postural sway differences. The age categories were: 5 to 9 years, 10 to 14 years, 15 to 19 years, 20 to 29 years, 30 to 39 years, 40 to 49 years, 50 to 59 years, 60 to 64 years, 65 to 69 years, 70 to 74 years, 75 to 79 years, and 80+ years.

To assess the effects of age and sex on postural sway, a 2-factor analysis of variance was computed for BBT results in SPSS (IBM, Armonk, New York) using the factors age and sex as well as the interaction between those 2 factors (age × sex). Significant effects were determined at the $P < .05$ level, and Tukey honestly significant difference (HSD) tests were performed to determine significant ($P < .05$) effects among levels of a given factor. This method was used to control for the occurrence of the type I errors typically associated with multiple comparisons.

To quantify the influence of height and weight on postural sway, linear regressions for each age and sex category were performed in SPSS between BBT results and participant height and weight to obtain R^2 values. R^2 values were between 0 and 1, where 0 indicated that no BBT variance was explained (ie, no relationship) and 1 indicated that all BBT variance was explained (ie, perfect relationship).

On the basis of the age, sex, height, and weight findings, relevant percentile rankings were calculated at every 10th

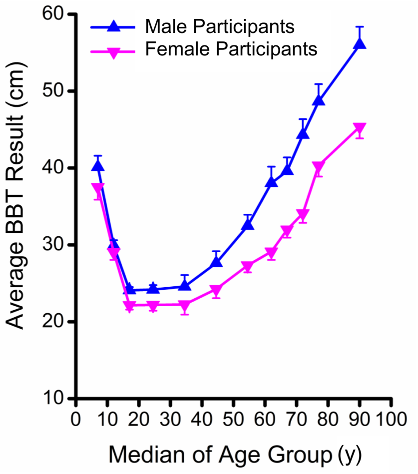

Figure 2.
Mean (95% CI) BTrackS Balance Test (BBT) results for various age and sex groupings.

percentile from 10th to 90th according to the following formula:

percentile ranking = P/100 (N+1).

In this formula, P represents the percentile rank and N represents the number of BBT results in the distribution of interest.

Results

Results of the analysis of variance showed a significant interaction for the age × sex factor ($F_{11,16357}$ = 13.9, P < .001), whereby sex differences in BBT results were dependent on age group. This interaction (Fig. 2) showed that, on average, females outperformed (ie, had lower BBT results, less postural sway) males across the lifespan, with an increasing mean difference between sexes as age group increased. Interestingly, there were no significant differences (Tukey HSD) between males and females in the 2 youngest age groups (ie, 5–9 years and 10–14 years). However, all other age categories (ie, 15–19 years, 20–29 years, 30–39 years, 40–49 years, 50–59 years, 60–64 years, 65–69 years, 70–74 years, 75–79 years, 80+ years), showed that females had significantly (Tukey HSD) less postural sway (ie, lower BBT results) than males.

The trajectory of BBT results over the lifespan was similar for males and females. BBT results were relatively high in the youngest age group (ie, 5–9 years), but showed a significant improvement for individuals who were 10 to 14 years old and a significant (Tukey HSD) improvement again for individuals who were 15 to 19 years old. BBT results were stable, with no significant (Tukey HSD) differences, between the group of individuals who were 15 to 19 years old and the next 2 age categories (ie, 20–29 years and 30–39 years). At age 40 to 49 years, postural sway began to significantly (Tukey HSD) increase and continued to increase throughout the remainder of the lifespan. This included significant (Tukey HSD) increases in BBT results for males and females who were 50- to 59 years old versus 40 to 49 years old, 60 to 64 years old versus 50 to 59 years old, 70 to 74 years old versus 60 to 64 years old, 75 to 79 years old versus 70 to 74 years old, and 80+ years old versus 75 to 79 years old.

With respect to the effects of height and weight, regression analysis showed that there was very little relationship between BBT results and participant height or weight. The R^2 values for each age and sex category are given in Table 1 (height) and Table 2 (weight). These findings show that, on average, only 2% of the BBT results could be explained by participant height and only 3.7% by weight. The maximum amount of variance explained by any age/sex category was 8.9% for the height of female individuals in the 10- to 14-year-old age group. In most age/sex categories, less than 1% of BBT variance was explained by participant height or weight.

Given the above results, percentile rankings were only stratified by age and sex groupings, without consideration for height and weight. These percentile rankings are provided in Tables 3 and 4 for male and female individuals, respectively. For illustration purposes, 11th to 100th percentile BBT results (≤33 for males and ≤30 for females) are shown in bold type, and BBT results in the bottom 10 percentiles are not shown in bold type. These codes provide an indication of whether or not a given result for a particular age group is within the range of results displayed by most (90%) individuals in the 20- to 29-year-old age group (ie, is this result "typical" of that seen in most young adults). For example, a female who is 75 years old and has a BBT result of 38 may have a relatively "good" percentile ranking for her age group (ie, top 50th percentile). However, compared to typical young adults, this individual might be considered to have "poor" postural sway (ie, bottom 10th percentile).

Discussion

The present study involved the use of a uniquely large database of 16,357 individuals to provide normative, percentile rankings for the BBT assessment of postural sway. Results were stratified by age and sex based on a significant interaction between these factors. This interaction was such that females increasingly outperformed males across the lifespan, and both sexes experienced typical improvements in postural sway from 4 to 15 years of age and declines starting in the fifth decade of life. There was no meaningful relationship between height or weight and BBT results. These findings provide valuable insight for clinicians who utilize the BBT for postural sway assessment, and a framework for the interpretation of abnormalities in postural sway.

The age and sex effects shown in this study are consistent with over a century of investigations on postural sway.[2,15–26] However, the mechanisms underlying these age and sex differences remain unclear. With respect to age, postural sway requires young children to organize sensory inputs from vision, proprioception, and vestibular systems, which mature along different developmental timelines.[27] In this case, it has been proposed that these systems do not mature adequately enough to achieve adult-like postural sway until 14 years of age.[27] This proposal is supported by the findings from the present study, which show that adult-like BBT results are only present by 15 to 19 years of age. Interestingly, balance declines were first seen in the present

Table 1.

R^2 and Percentage of BTrackS Balance Test (BBT) Result Variance Explained by Height

Age Group (y)	Male		Female	
	R^2	% of Variance Explained	R^2	% of Variance Explained
5–9	0.047	4.7	0.011	1.1
10–14	0.042	4.2	0.089	8.9
15–19	0.011	1.1	0.015	0.2
20–29	0.008	0.1	0.005	0.5
30–39	0.007	0.1	0.019	1.9
40–49	0.031	3.1	0.003	<0.1
50–59	0.014	1.4	0.007	0.1
60–64	0.003	<0.1	0.010	1.0
65–69	0.002	<0.1	0.013	1.3
70–74	0.033	3.3	0.004	<0.1
75–79	0.049	4.9	0.006	0.1
80–100	0.007	0.1	0.033	3.3

Table 2

R^2 and Percentage of BTrackS Balance Test (BBT) Result Variance Explained by Weight

Age Group (y)	Male		Female	
	R^2	% of Variance Explained	R^2	% of Variance Explained
5–9	0.018	1.8	0.002	<0.1
10–14	0.026	2.6	0.027	2.7
15–19	0.019	1.9	0.022	2.2
20–29	0.023	2.3	0.017	1.7
30–39	0.058	5.8	0.068	6.8
40–49	0.053	5.3	0.069	6.9
50–59	0.044	4.4	0.058	5.8
60–64	0.007	0.1	0.052	5.2
65–69	0.074	7.4	0.059	5.9
70–74	0.018	1.8	0.034	3.4
75–79	0.035	3.5	0.020	2.0
80–100	0.019	1.9	0.055	5.5

study starting with the 40- to 49-year-old age group, and continued for every decade thereafter. Although many systems related to balance are negatively affected by age, a recent study showed that peripheral proprioceptive loss was among the most pertinent predictor of postural sway increases.[28,29] These results are further supported by brain imaging studies that have identified several proprioceptive regions of the aging brain that are significant predictors of poor balance performance in older adults.[30] To what extent this loss of proprioception is related to an age-related neuropathic degeneration is unclear. However, it is likely that this known consequence of the aging process is a factor.

The mechanism underlying sex differences in postural sway control also remains elusive. Although some studies have suggested that differences between males and females on tests of postural sway can be attributed to differences in height and weight,[31,32] most researchers have found no relationship between measures of height and weight and postural sway.[19,20,22–25] The present study aligns with the latter set of findings, showing that, on average, only a small percentage (<4%) of the BBT results could be attributed to height or weight. In this case, an alternative explanation for sex differences may be found in studies showing that that tactile and vibrotactile thresholds of the feet are lower in females than males, and these differences predict postural sway performance.[33,34]

The present study has several inherent limitations to its design. First, data was collected at multiple sites, with no direct oversight by the authors. This was necessary to obtain such a large sample size, which is more than 2 times larger than any previously published study of postural sway.[26] Despite this, BBT data relied on the self-reported adherence of test sites to using the standardized instructions of the BBT protocol to ensure internal test validity and fidelity. This may have been more difficult for some populations tested (eg, kids, older adults) than for others, and it is likely that 100% adherence to the instructions was not achieved for the entire sample. In addition, it is unknown to what extent visual, qualitative, or quantitative performance feedback was provided to the individuals being tested during the test or after a given trial.

An additional limitation of the present study was an imbalance in the sample sizes within the various age categories. Although more than 100 individuals were tested in each age/sex grouping, allowing true percentile rankings to be determined, some groups were "overrepresented" with over a thousand samples of data. In the future, gathering a more balanced sample of BBT results across the lifespan will determine whether minor corrections to the existing values is necessary. Further, the sample selected may not be truly representative of the population at large. Testing sites were primarily located in large urban areas with higher socioeconomic status and, thus, results may not represent those of more rural locations

Table 3.
Percentile Rankings for Male BTrackS Balance Test (BBT) Results by Age Group[a]

Age Group (y)	Percentile Ranking for BBT Result (cm)								
	10th	20th	30th	40th	50th	60th	70th	80th	90th
5–9	56	49	44	41	37	35	**32**	**30**	**26**
10–14	42	37	**33**	**31**	**28**	**26**	**24**	**22**	**19**
15–19	34	**30**	**27**	**25**	**23**	**21**	**20**	**18**	**16**
20–29	**33**	**29**	**27**	**25**	**23**	**22**	**20**	**18**	**16**
30–39	34	**30**	**27**	**25**	**23**	**21**	**19**	**17**	**15**
40–49	41	**33**	**30**	**28**	**26**	**24**	**22**	**19**	**16**
50–59	51	38	34	**31**	**28**	**26**	**23**	**22**	**18**
60–64	54	43	38	34	**32**	**30**	**28**	**25**	**23**
65–69	64	49	42	36	**33**	**30**	**27**	**23**	**21**
70–74	74	55	48	44	37	**33**	**31**	**26**	**21**
75–79	83	70	56	43	39	36	**33**	**28**	**23**
80–100	98	79	66	54	48	43	36	**31**	**25**

[a]Values in bold type represent performance consistent with the top 90th percentile of young adults who are 20–29 years old; values not in bold type represent the bottom 10th percentile.

Table 4.
Percentile Rankings for Female BTrackS Balance Test (BBT) Results by Age Group[a]

Age Group (y)	Percentile Ranking for BBT Result (cm)								
	10th	20th	30th	40th	50th	60th	70th	80th	90th
5–9	56	45	41	37	35	32	**29**	**27**	**23**
10–14	42	37	33	**30**	**27**	**25**	**23**	**21**	**18**
15–19	31	**27**	**25**	**23**	**21**	**20**	**18**	**17**	**15**
20–29	**30**	**27**	**24**	**23**	**21**	**20**	**18**	**17**	**14**
30–39	31	**27**	**25**	**23**	**21**	**20**	**18**	**16**	**14**
40–49	34	**29**	**27**	**24**	**22**	**21**	**19**	**18**	**15**
50–59	39	33	**30**	**27**	**26**	**23**	**21**	**19**	**17**
60–64	43	36	33	**29**	**27**	**25**	**22**	**20**	**17**
65–69	49	40	35	31	**29**	**25**	**23**	**21**	**18**
70–74	55	42	37	32	**29**	**27**	**24**	**22**	**19**
75–79	62	51	43	38	33	**30**	**27**	**24**	**20**
80–100	78	60	51	43	38	33	**30**	**24**	**20**

[a]Values in bold type represent performance consistent with the top 90th percentile of young adults who are 20–29 years old; values not in bold type represent the bottom 10th percentile.

with lower socioeconomic status. That said, there is no known evidence linking these demographic factors and postural sway in the existing literature.

A recent literature review found that physical therapy–based exercise interventions can effectively reduce postural sway and improve overall function.[35] It has further been shown that prescreening individuals using the BBT to target those with abnormally high postural sway can improve the efficiency of using balance interventions.[36] Although the COP path length results in this study could equally be obtained from any number of commercially available force plates running a similar protocol, the BTrackS Balance Plate and Assess Balance software can be seen as offering high clinical utility to the practitioner. Testing is relatively low-cost and reimbursable by some insurances. It is also highly portable and easy to implement in a short time duration and imposes minimal demands on the patient.

In conclusion, BTrackS is an emerging clinical tool that, combined with the normative percentile rankings in this study, can provide an objective means of determining abnormalities in postural sway. These abnormalities have been associated with various clinical outcomes including performance on activities of daily living,[3] rates of residential care,[4] and fall risk.[5,6] As such, the BBT has potential to improve physical therapy outcomes as they relate to postural sway and balance.

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Providing institutional liaisons: D.J. Goble, H.S. Baweja
Consultation (including review of manuscript before submitting): D.J. Goble

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Ethics Approval

Ethics approval for this study was provided by the local internal review board of Oakland University, and all procedures were conducted in compliance with the Declaration of Helsinki.

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Disclosures

The authors completed the ICJME Form for Disclosure of Potential Conflicts of Interest. D.J. Goble receives royalties from a pending patent (OMB 0651-0032) related to the technology used in this study. In addition, he has an equity stake (stock options) in Balance Tracking Systems Inc. This conflict is mitigated by a management plan put in place by his academic institution to ensure the integrity of his research. H.S. Baweja has no conflict of interest to declare.

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