Geriatrics Gerontology International

DOI: 10.1111/ggi.13452

ORIGINAL ARTICLE
EPIDEMIOLOGY, CLINICAL PRACTICE AND HEALTH

Postural sway normative data across the adult lifespan: Results from 6280 individuals on the Balance Tracking System balance test

Daniel J Goble[1] and Harsimran S Baweja[2]

[1]School of Health Sciences, Department of Human Movement Science, Oakland University, Rochester, Michigan, USA
[2]School of Exercise and Nutritional Sciences, Doctor of Physical Therapy Program, San Diego State University, San Diego, California, USA

Correspondence
Associate Professor Daniel Goble PhD, Faculty Research Fellow, School of Health Sciences, Department of Human Movement Science, Oakland University, 433 Meadow Brook Rd, Rochester, MI 48309, USA.
Email: dgoble@oakland.edu

Received: 8 March 2018
Revised: 16 April 2018
Accepted: 25 April 2018

Aim: Postural sway measured using force plate technology is a known risk factor for falls in older adults, but is currently underutilized due to the high cost and lack of portability issues associated with most force plate systems. The Balance Tracking System (BTrackS) is a new force plate that alleviates these barriers and has potential for widespread use. The present study provides important normative data for the BTrackS Balance Test of postural sway that improves its translational value to the field of gerontology.

Methods: BTrackS Balance Test postural sway results were accumulated from 6280 community-dwelling individuals across the adult lifespan. Data were assessed for effects of age, sex and body size. Stratified percentile rankings were then calculated.

Results: BTrackS Balance Test results were dependent on age and sex, but not body size. Percentile rankings were, therefore, determined across various age groups for men and women separately, with no consideration of participant body size. A novel interaction was found between the age and sex factors, suggesting enhanced postural sway ability for women that becomes more pronounced with older age.

Conclusions: The results of the present study represent one of the largest sets of normative postural sway data ever published. These data translate directly into the field of gerontology as a tool for determining abnormalities in postural sway, which have been linked to various poor outcomes in older adults, such as high fall risk. **Geriatr Gerontol Int 2018; 18: 1225–1229.**

Keywords: accidental falls, adult, geriatrics, risk factors, sex factors.

Introduction

More than one-quarter of older adults fall each year, with one in five falls resulting in a serious injury (e.g. broken bone, head trauma), long-term disability or even death.[1] Beyond these adverse outcomes, older adult falls pose an exceptional financial burden to the person affected and healthcare systems involved.[1,2] Taken together, it is clear that a continued emphasis is required towards the development of our knowledge regarding older adult falls and the factors associated with elevated fall risk.

Postural sway is one such fall risk factor, defined as sustained oscillatory motion about a fixed postural position during upright standing.[3] This biomarker of older adult function is objectively and accurately measured using force plate technology.[4] Force plates determine a proxy for postural sway called center of pressure (COP), which is equal to the weighted average of forces created when an individual stands on the force plate device. Older adults without a history of falling have a greater magnitude COP on average than those who fall repeatedly.[5–7] Furthermore, retrospective and prospective analyses have shown a greater likelihood of falling for those with increased postural sway, compared with those with postural sway more typical of young adults.[5–9]

Given the clear value of carrying out older adult postural sway assessments with a force plate, it is somewhat surprising that this methodology is not more widely utilized. The most likely barriers to force plate implementation are the high cost (~$5000–$20 000) and lack of portability (i.e. AC power required, heavy architecture) associated with typical force plate devices. Recently, however, a new force plate was created called the Balance Tracking System (BTrackS). This device addresses the practical limitations of traditional force plates. BTrackS is a force plate that is both highly portable (<7 kg, no AC power required) and relatively affordable (~ $800) compared with other devices. In addition, BTrackS provides a user-friendly software interface that delivers a reliable testing protocol called the BTrackS Balance Test (BBT).[10] The BBT is ideal for evaluating older adult populations, as it purports a short testing time (>2 min) and task conditions that are suitable for most ambulatory older adults.

Normative data is an important component for interpreting any assessment of postural sway. Specifically, normative data allows a comparison to be made between the person being tested and the postural sway abilities of "healthy" peers. This comparison can provide evidence of potential dysfunction, as well as justification for the implementation of intervention strategies to limit poor balance outcomes, such as falling, in older adults. Finally, normative data can be utilized to monitor changes in postural sway that occur over time. This can help optimize any interventions being implemented by allowing their efficacy to be objectively ascertained.

For all the aforementioned reasons, the aim of the present study was to provide normative data for the BBT across the adult lifespan. This was accomplished by compiling one of the largest datasets of adult postural sway ever collected (n = 6280), and calculating stratified percentile rankings. There were three hypotheses for this work based on results reported previously in the literature.[11–16] First, it was expected that postural sway would increase with age, indicating a decrease in balance ability. Second, it was anticipated that postural sway would be less in women, showing their enhanced balance compared with men. Finally, it was expected that the effects of body size, determined by body mass index (BMI), would be minimal for both men and women.

Methods

Participants

Postural sway data for the present study were provided by the parent company for BTrackS (i.e. Balance Tracking Systems, San Diego, CA, USA). Data consisted of BBT results from 6280 community-dwelling individuals aged ≥20 years, collected at 30 sites across the USA and Canada. Participants were 1988 men (age 52.9 ± 19.1 years, age range 20–100 years) and 4292 women (age 58.7 ± 16.8 years, age range 20–100 years). Data were solicited from existing BTrackS users according to the inclusion criteria that the BBT protocol was implemented according to its standardized instructions, and done so for only healthy, community-dwelling individuals. Ethical approval for this study was provided by the internal review board of the lead author, and all procedures were in compliance with the Declaration of Helsinki.

Experimental setup

BBT assessments of postural sway were carried out at each testing site using a BTrackS Balance Plate and BTrackS Assess Balance software (Fig. 1). The BTrackS Balance Plate is a Food and Drug Administration-registered, portable force plate for determining COP. The validity of BTrackS has been tested against several other methods of COP measurement, showing near perfect accuracy and precision of results.[17,18] BTrackS Assess Balance software was run on computing devices (personal computers, laptops or tablets) with a full version of the Windows operating system. Each BTrackS Balance Plate and computing device was connected through a USB cable that also provided power to the BTrackS Balance Plate.

Testing procedures

The BTrackS Assess Balance software guided users through all phases of collecting postural sway data according to the BBT protocol. Given the user-friendly nature of the BTrackS Assess Balance software, limited training was required to learn how to carry out a BBT. In most cases, training consisted of administering the test once under the supervision of an experienced user. Each BBT followed a standardized, script-based protocol consisting of four, 20-s trials with minimal inter-trial delays (<10 s). 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 (Fig. 1). The first BBT trial was for familiarization and was discarded before analysis. The remaining three, non-familiarization trials were used to determine the BBT result. It was recommended that all testing be carried out with participants' shoes off, although previous research has shown that standard footwear does not impact COP measurement during BBT-like protocols.[19]

The BBT result for each test was calculated by the BTrackS Assess Balance software, equivalent to the average total COP path length in centimeters (cm) across accountable trials. COP path length is a proxy for postural sway magnitude where larger BBT values are indicative of greater postural sway.[4] Path length was determined by first quantifying the distance between successive registered COP locations according to the following formula:

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

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. The sum of all distances was then added together 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-s trial. No other COP metrics (e.g. COP excursion, velocity, area) are provided by BTrackS Assess Balance, thus, only the path length variable was assessed.

Data analysis

All BBT results from the various testing locations were de-identified and assimilated into a single database. Before statistical analysis, data were inspected for quality using a series of rules that determined improper use of the testing protocol (n = 13), invalid demographics (n = 53) and testing outliers (n = 59). This excluded <2% of the original sample (n = 6405) and resulted in the existing sample of 6280 individuals. Data were next grouped according to age in years and sex (male, female). Age groups were based on the "Provisional Guidelines on Standard International Age Classifications" document of the United Nations for "Health, Health Services and Nutrition" with level 2 detail.[20] The specific age categories used were: 20–29 years, 30–39 years, 40–49 years, 50–59 years, 60–69 years, 70–79 years and ≥80 years.

The effects of age and sex, as well as their interaction (age × sex), on postural sway (i.e. BBT) were tested using a two-way analysis of variance (ANOVA) carried out in SPSS (IBM, Armonk,

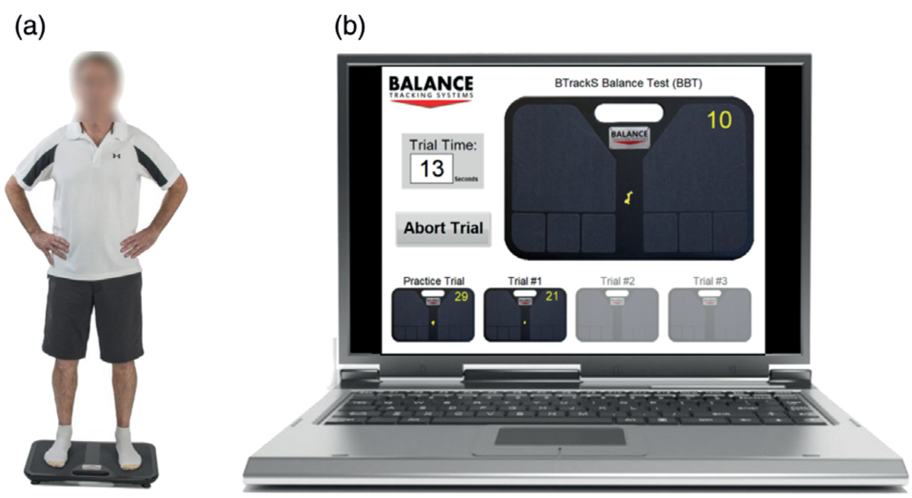

Figure 1 Depiction of the Balance Tracking System (BTrackS) Balance Test (BBT) testing setup with a non-participating individual. (a) Participants stood with eyes closed, hands on hips and two feet on the BTrackS Balance Plate, while the (b) BTrackS Assess Balance software guided the tester through measurement of center of pressure path length over four, 20-s trials.

Table 1 ANOVA results

Sources	Degrees of freedom	Sum of squares	Mean squares	*F*-values	*P*-values
Age	6	312 759	52 126	158.2	<0.001
Sex	1	39 425	39 425	119.7	<0.001
Age × sex	6	13 258	2209	6.7	<0.01
Error	6266	2 064 265	329		
Total	6279	8 557 424			

NY, USA). Significant effects were determined at the $P < 0.05$ level, and Tukey's honest significant difference (HSD) post-hoc tests were carried out to determine significant differences between levels of a given factor. This single-step multiple comparisons method was used to control for the occurrence of type I errors.

To quantify the influence of body size on postural sway, BMI was calculated for each individual according to the following formula:

$$\mathrm{BMI} = \mathrm{weight}/\mathrm{height}^2$$

where weight was measured in kilograms (kg) and height was measured in meters (m). For each age and sex category, linear regressions were then carried out in SPSS between BBT results and BMI to obtain R^2 values. R^2 values were between 0–1, where 0 indicated that no BBT variance was explained by BMI (i.e. no relationship), and 1 indicated that all BBT variance was explained by BMI (i.e. perfect relationship).

Following the above analyses for age, sex and body size effects, appropriate percentile rankings were calculated every 10th percentile from 10th to 90th according to the following formula:

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

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

Results

Based on the ANOVA (Table 1), BBT results for postural sway were significantly affected by age ($F_{6,6266} = 158.2$, $P < 0.001$), sex ($F_{1,6266} = 119.7$, $P < 0.001$) and an age × sex interaction ($F_{6,6266} = 6.7$, $P < 0.01$). These findings are depicted in Figure 2, showing that on average women outperformed (i.e. had lower BBT results, less postural sway) men in each age group across the adult lifespan. Female BBT performance was also less impacted by age than males, as shown by an increasing mean difference between sexes as the age group increased.

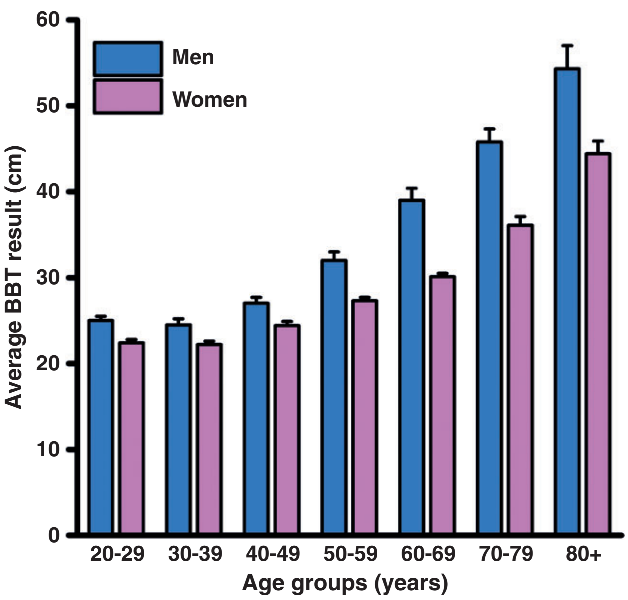

Figure 2 Mean (standard error) Balance Tracking System Balance Test (BBT) results for men and women within various age groups.

With respect to the effects of age, BBT results across the lifespan were similar for males and females. Both sexes had the lowest BBT results in the youngest age group (i.e. 20–29 years) and did not significantly differ (Tukey HSD, $P > 0.05$) compared with those individuals in the next oldest age group (30–39 years). At age 40–49 years, postural sway began to significantly (Tukey HSD, $P < 0.001$) increase (i.e. higher BBT results) for both sexes, and continued to increase throughout the remainder of the lifespan. This included significant (Tukey HSD, $P < 0.001$) increases in BBT for men and women aged 50–59 years versus 40–49 years, 60–69 years versus 50–59 years, 70–79 years versus 60–69 years and ≥80 years versus 70–79 years.

With respect to the effect of body size, regression analysis showed that there was very little relationship between BBT results and participant BMI (Table 2). On average, <2% of BBT results (1.1% in women, 0.5% in men) were explained by participant body size (i.e. BMI). The maximum amount of variance explained by any age/sex category was 6.1% for women in the 40–49 years age group. The minimum variance explained was 0.1% in men aged 70–79 years. In light of these findings, percentile rankings were only calculated stratified by age and sex, without consideration of body size. These percentiles are provided in Table 3 based on each age and sex grouping, as well as the mean ±standard error, median and range of BBT results.

Discussion

BBT assessments of older adult postural sway are becoming more common in practice, based largely on the portability and low cost of BTrackS relative to other force plates. In the present study, a large normative sample of BBT postural sway data was analyzed for men and women across the adult lifespan. It was shown that BBT results (i.e. postural sway path lengths) increased starting in the fifth decade of life (i.e. 40–49 years age group) and continued to increase in all subsequent decades up to, and including, ≥80 years-of-age. These aging trends were more significant in men than women, with a larger sex difference favoring older women. There was no meaningful relationship between body size (i.e. BMI) and BBT performance. These findings were used to provide valuable percentile ranking information that can assist in

Table 2 R^2 and percentage of Balance Tracking System Balance Test variance explained by body mass index

	Men		Women	
Age group	R^2	Variance explained	R^2	Variance explained
20–29 years	0.009	0.9%	0.002	0.2%
30–39 years	0.022	2.2%	0.055	5.5%
40–49 years	0.010	1.0%	0.061	6.1%
50–59 years	0.015	1.5%	0.042	4.2%
60–69 years	0.024	2.4%	0.041	4.1%
70–79 years	0.001	0.1%	0.014	1.4%
80 + years	0.002	0.2%	0.009	0.9%

Table 3 Balance Tracking System Balance Test percentile rankings, means ± standard error, medians, and ranges by sex and age group.

			Percentile rankings for BBT results (cm)											
Sex	Age group	*n*	10th	20th	30th	40th	50th	60th	70th	80th	90th	Mean ± SE	Median	Range
Males	20–29 years	331	36	31	28	26	24	22	19	17	15	25 ± 1	24	8–88
	30–39 years	258	33	30	27	25	23	21	18	16	15	25 ± 1	23	9–112
	40–49 years	274	39	32	29	26	25	23	21	18	16	27 ± 1	25	11–113
	50–59 years	313	51	38	33	30	28	25	23	21	18	32 ± 1	28	10–186
	60–69 years	368	59	47	41	36	33	30	27	25	22	39 ± 1	33	10–249
	70–79 years	316	79	61	49	43	38	34	31	26	22	46 ± 2	38	11–210
	80 + years	128	94	77	65	54	46	40	35	30	25	54 ± 3	46	16–233
Females	20–29 years	366	31	28	25	23	21	20	18	17	14	22 ± 1	21	10–74
	30–39 years	313	31	28	24	23	21	19	18	16	14	22 ± 1	21	10–59
	40–49 years	451	34	29	27	24	22	21	19	17	14	24 ± 1	22	8–122
	50–59 years	821	39	33	30	27	25	23	21	19	16	27 ± 1	25	8–118
	60–69 years	1209	45	37	33	30	27	25	23	20	17	30 ± 1	27	9–166
	70–79 years	807	57	45	39	34	31	27	25	22	19	36 ± 1	30	9–185
	80 + years	325	76	58	50	42	37	32	30	24	20	44 ± 2	37	10–212

assessing the postural sway abnormalities known to be a risk factor for falling in older adults.[5–9,21,22]

The age effects on postural sway shown in the present study are consistent with a multitude of previous works on age-related changes in postural sway.[11–15] From a mechanistic standpoint, age-related postural sway reductions are most often ascribed to deficits in sensory feedback from the visual, proprioceptive and vestibular systems.[23] Recent evidence, however, supports the notion that peripheral proprioceptive loss might be the largest contributing factor to increased postural sway in older adults.[24] This tenet is supported by brain imaging work that has identified a number of cortical and subcortical proprioceptive processing regions that correlate with the magnitude of postural sway shown by older adults.[25]

While there are previous reports showing that women have, on average, less postural sway than men, this is the first known study to show an increased sex gap over the course of the adult lifespan.[14,15] This result does not appear to be related to body size, as the present study is in line with previous investigations that failed to show a strong relationship between postural sway and body size factors.[14–16] Rather, these results might better be explained based on previous work showing sex differences in the vibro-tactile thresholds of older adult feet.[26,27] This form of proprioceptive information, and its acuity, has been connected to postural sway performance in older adults.[28]

Several limitations are worth noting in relation to the present work. First, data were collected at multiple sites, with no direct oversight by the authors. This was necessary to obtain such a large sample size, which it is believed is the second largest postural sway dataset ever published.[15] A second limitation of this study was that BBT data relied on the self-reported adherence of test sites to implementing the standardized BBT protocol correctly. This might have been more difficult for the older age groups tested, and it is unlikely that 100% compliance was achieved across the entire sample. Additionally, it is unknown to what extent performance feedback was provided to the individuals during testing or after a given trial.

A further limitation of the present study is that there was a sample imbalance across the various age/sex groups compiled. Although ≥100 individuals were tested in each age/sex group to allow a true percentile ranking to be determined, some groups were "overrepresented" with >1000 samples collected. In the future, gathering a more balanced sample of BBT results across age and sex groups might serve to correct small errors in the present values. Furthermore, geographic demographic factors are also worth considering in future efforts to obtain normative BBT data. The present sample might not have been truly representative of the global population at large, as testing sites were primarily located in larger North American cities that might have had a greater percentage of higher socioeconomic status individuals. That said, there is currently no known evidence linking such demographic factors to postural sway.

In conclusion, BTrackS is an emerging clinical tool that, combined with the percentile ranking normative data in the present study, translates into the field as an objective means of determining abnormalities in postural sway. Such abnormalities have previously been associated with a number of poor clinical outcomes including, importantly, increased fall risk.[5–9,21,22] Fortunately, once identified, postural sway deficits can be treated by using exercise-based training interventions.[29] To this extent, it is worth noting that a recent study showed that BBT (i.e. postural sway) reductions were possible for older adults using a 90-day resistance training intervention.[30]

Acknowledgements

The authors thank Balance Tracking Systems for supplying the data used in this study, and the partner sites that voluntarily collected and contributed the data.

Disclosure statement

One author (Goble) is eligible for 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. This financial conflict of interest is mitigated by a management plan put in place by his academic institution to ensure the integrity of his research. The other author of this work (Baweja) declares no conflict of interest.

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How to cite this article: Goble DJ, Baweja HS. Postural sway normative data across the adult lifespan: Results from 6280 individuals on the Balance Tracking System balance test. Geriatr. Gerontol. Int. 2018;18:1225–1229. https://doi.org/10.1111/ggi.13452