

The Balance Tracking System (BTrackS) for Postural Control Assessment/Training – a Decade of Research

Daniel J Goble¹, Harsimran S Baweja², Joshua L Haworth¹

¹Department of Human Movement Science, Oakland University, Rochester, MI, USA; ²College of Education, Auburn University, Auburn, AL, USA

Correspondence: Daniel J Goble, Department of Human Movement Science, Oakland University, 433 Meadow Brook Road, Rochester, MI, 48309, USA, Email dgoble@oakland.edu

Abstract: The Balance Tracking System (BTrackS) is a medical device developed over a decade ago as a low-cost and portable solution to expensive and cumbersome force plate balance measurement instruments. Consisting of the BTrackS Balance Plate and Assess Balance software, this technology is now employed worldwide by thousands of practitioners. An evidence base of more than 80 research studies had been published using BTrackS technology. This includes the positive establishment of device/protocol validity and reliability, normative data, as well as translational work comparing balance amongst a variety of sample populations. In addition, BTrackS has been successfully used for both evaluating the efficacy of balance interventions, manipulations, and devices, including several BTrackS bio-feedback-based training protocols themselves. The present narrative review compiles and summarizes this research in single source as a repository for BTrackS practitioners, and as a guide for informing future research efforts.

Keywords: postural stability, force plate, center of pressure, intervention, evaluation, rehabilitation technology

Introduction

The Balance Tracking System (BTrackS) is a medical device consisting of a force plate and user-friendly software that facilitates objective assessment and training of postural control. Over the past decade, BTrackS has provided thousands of healthcare practitioners with a low-cost alternative to traditional, expensive force plate systems¹ that outperforms the accuracy of inexpensive “toys” like the Nintendo Wii Balance Board.² Indeed, BTrackS is a registered medical device with the United States Food and Drug Association that meets the compliance standards set by the International Organization for Standardization.

Since the first BTrackS research was published in 2016, substantial evidence has been accumulated supporting its growing use worldwide. This is demonstrated in Figure 1, where the number of published BTrackS research papers has seen a clear increase year over year.^{1,3–84} Such research has spanned many topics, including the establishment of device validity, protocol reliability and direct applications of BTrackS with clinical and non-clinical populations. The aim of the present narrative literature review is to compile and summarize this work up to, and including, the year 2024. This was accomplished by conducting a comprehensive, non-systematic search of relevant databases and sources using a set of predefined keywords and inclusion criteria to identify, interpret and synthesize existing research. This important effort serves as a repository of BTrackS findings to guide future research investigations.

BTrackS Validity and Accuracy

Depicted in the forefront of Figure 2 is the force plate component of BTrackS, known as the BTrackS Balance Plate. This device has a 40 x 60 cm rectangular platform surface with enclosed strain gauge sensors on the underside of each corner. These four sensors interface with the ground below the plate via spin-adjustable foot/leg complexes and transduce vertical ground reaction forces into voltage signals in conjunction with a bridge-type circuit board. Sensor information is

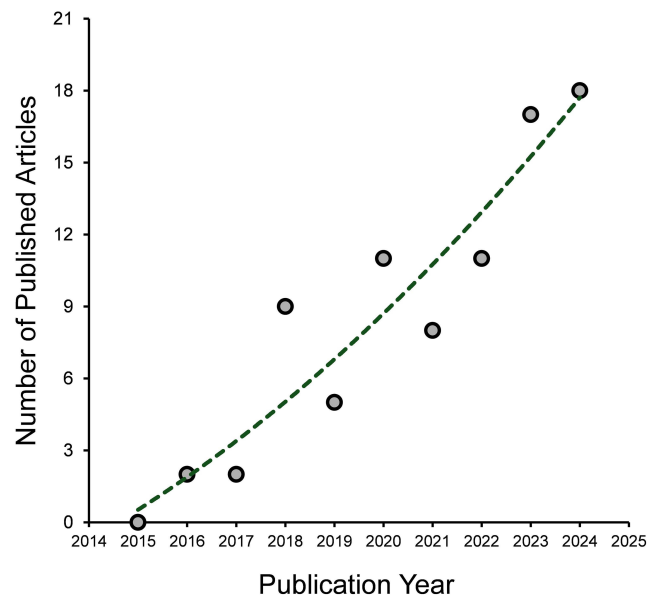


Figure 1 Depiction of the rapidly increasing number of research publications involving the Balance Tracking System (BTrackS) in the decade from 2015 until 2024. Dashed line represents exponential trend of the data.



Figure 2 The Balance Tracking System (BTrackS) Balance Plate and software running on a laptop computer.

relayed via a Universal Serial Bus cord to a Windows computing device running the BTrackS software, shown in background of Figure 2.

The main function of the BTrackS software is to calculate, display and analyze a key balance parameter known as Center of Pressure (CoP). CoP is the two-dimensional, weighted average of forces generated by a person while standing on the BTrackS Balance Plate, calculated as follows:

$$CoPx = \frac{24.25((TR + BR) - (TL + BL))}{TL + TR + BL + BR}$$

$$CoPy = \frac{15.5((TL + TR) - (BL + BR))}{TL + TR + BL + BR}$$

When viewed from above the BTrackS Balance Plate, CoP_x and CoP_y are the medial-lateral and anterior-posterior coordinates of CoP location respectively. TL, TR, BL and BR are the force values for the Top Left, Top Right, Bottom Left and Bottom Right corners.

CoP is a valuable and widely utilized balance parameter, given its close relationship to a person's center of mass location during static and quasi-static standing.⁸⁴ Gross changes in CoP over time offer a biomechanical marker of postural instability and/or related disruptions in body sway.^{85,86} To this extent, increased CoP displacement during balance activities has been found to be consistent with poorer postural control and increased body sway, as well as a higher likelihood of losing balance (ie falling).⁸⁷

Validation of CoP measurements made by the BTrackS Balance Plate in comparison to traditional force plate devices has been undertaken on several occasions. An initial study using a human-like inverted pendulum to generate controlled sway found that two BTrackS Balance Plates and an expensive, laboratory grade force plate had near perfect agreement for CoP.¹ This included both a very high measurement accuracy (<1% error) and excellent precision (<0.2 mm residuals). These findings held for both the medial-lateral (CoP_x) and anterior-posterior (CoP_y) directions, as well as when comparing a new versus moderately used BTrackS Balance Plate.

Extending the inverted pendulum results, two additional investigations of concurrent CoP measured from BTrackS Balance Plate and traditional force plate devices were made involving human participants. In one study, 30 different CoP metrics were quantified from static standing trials.¹⁴ For all metrics, excellent correlations ($r > 0.93$) were found between devices, regardless of whether the person being tested stood on a compliant foam cushion or not. These findings were affirmed in another study where participants stood still with feet together under eyes open and eyes closed conditions.¹³ In this case, all four analyzed CoP metrics had excellent correlations ($r > 0.80$) between the BTrackS Balance Plate and a traditional force plate device.

Beyond comparisons with traditional force plates, CoP for the BTrackS Balance Plate has also been validated using a “point of application” approach.⁹ Specifically, a computer numerical control device fitted with a hex-nose plunger precisely applied ~155 N of force to 21 different points on the surface of five different BTrackS Balance Plates. Study intraclass correlation (ICC) results showed near perfect agreement ($ICC > 0.99$), with a very high accuracy (<1% error) and precision (<0.1 residuals), between the actual application point and the sensed CoP location by each BTrackS Balance Plate. Additionally, inter-device reliability among devices was found to be essentially perfect ($ICC > 0.99$).

BTrackS Protocols, Reliability and Normative Data

The primary software application for performing balance protocols with the BTrackS Balance Plate is called BTrackS Assess Balance. In Figure 3, a list of the BTrackS Assess Balance protocols currently available (version 8.5.x) is displayed on the right-hand side, which includes seven testing and seven training options. With respect to testing, most of the available protocols are designed to evaluate aspects of static balance, where the person being tested is instructed to be as “still as possible” during the test conditions. Alternatively, there is one protocol (ie Limits of Stability) that aims to evaluate dynamic balance by having individuals “lean as far as possible in all directions” while keeping their feet flat on the plate.

All seven BTrackS Assess Balance training protocols use biofeedback regarding CoP location on the BTrackS Balance Plate to enhance an individual's ability to make controlled changes in body posture. An example of a typical training setup is shown in Figure 4, where the person being trained stands on the BTrackS Balance Plate while looking at a BTrackS Assess Balance software interface on a computer screen in front of them. The interface has an image of the BTrackS Balance Plate surface with the real-time location of CoP superimposed on top of it as a yellow dot. The goal of each training protocol is to make changes in body posture that shift the yellow dot location into targets that appear on the BTrackS Balance Plate image. Each protocol provides targets in different manner that achieves a specific training goal,

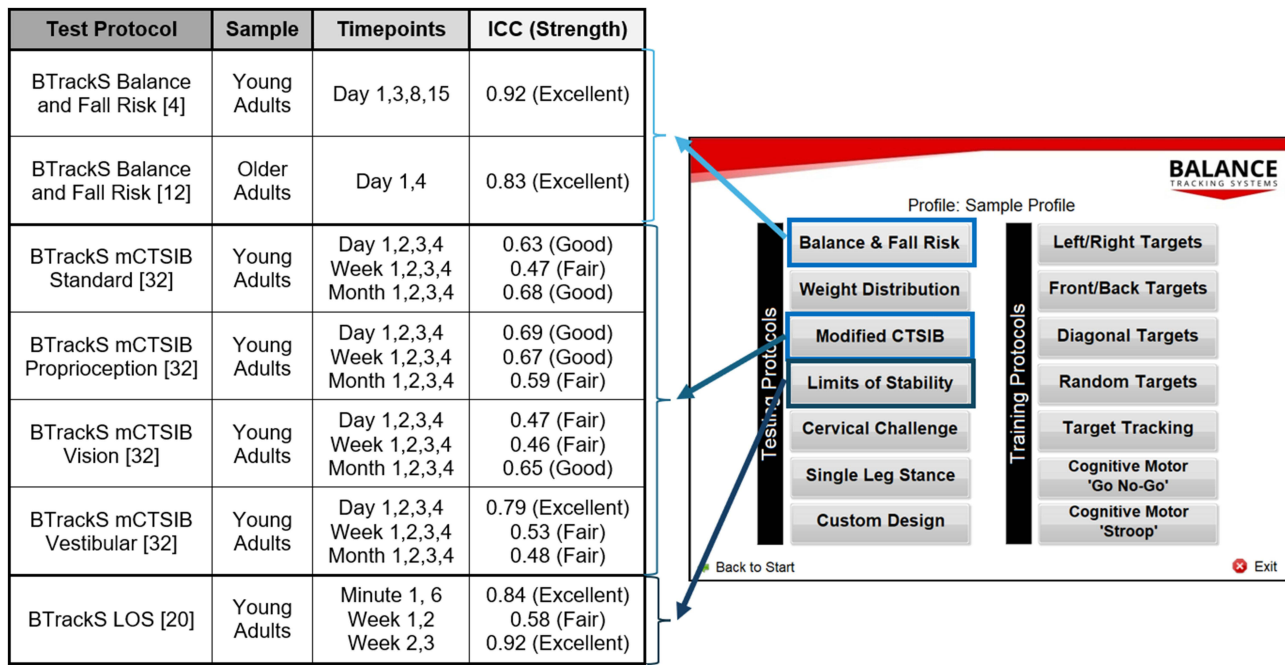


Figure 3 Overview of testing and training protocols included on the protocol screen within the most current Balance Tracking System (BTrackS) software alongside published reliability results based on intra-class correlations (ICC) for the Balance and Fall Risk test, modified Clinical Test of Sensory Integration and Balance (mCTSIB) and Limits of Stability (LOS) test. Categories for ICCs results were based on the following ranges: 0.00–0.39 = Poor, 0.40–0.59 = Fair, 0.60–0.74 = Good and 0.75–1.00 = Excellent.

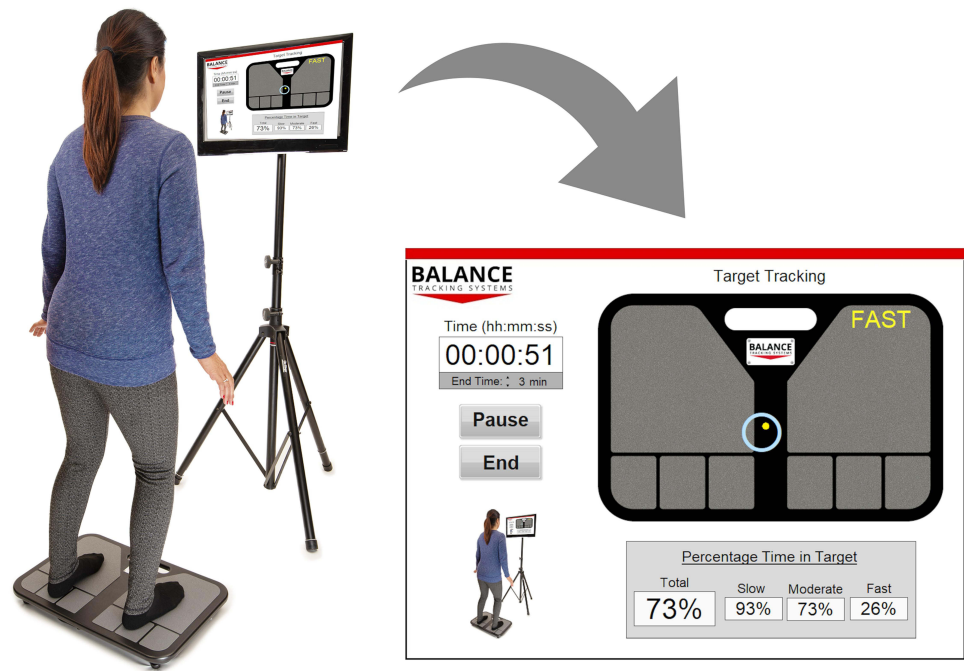


Figure 4 Exemplar of the setup for Balance Tracking System (BTrackS) training protocols being performed. Model participant using body sway to control movement of a yellow dot on the screen in front of them to “hit” targets on the plate surface below them. Time on task and real-time results are provided on the screen during training.

such as requiring unidirectional (ie Left/Right, Front/Back), bidirectional (ie Diagonal) or multidirectional (ie Random, Tracking) control. Two of the training protocols (ie Cognitive Motor: Go No-Go and Stroop) were developed to provide secondary cognitive challenges that allow concurrent training of executive brain processes such as inhibitory control.

The most widely utilized BTrackS test is the Balance and Fall Risk protocol. This static balance assessment consists of four, 20 s eyes closed standing trials with feet shoulder width apart on the BTrackS Balance Plate, and hands on the hips. The first trial is for familiarization, and the remaining three trials are used to calculate an average CoP Path Length, representing the typical amount of body sway exhibited during standing. This test result is then compared to a large set of published normative data,^{7,8,17} overviewed in [Table 1](#), to determine an age and sex matched percentile ranking, as well as a Fall Risk categorization (ie Low, Moderate, High). The test-retest reliability of the Balance and Fall Risk protocol in terms of ICC is provided on the left side of [Figure 3](#). Results show the protocol has excellent reliability across testing days and throughout the lifespan.^{10,12}

The second most implemented BTrackS protocol is the modified Clinical Test of Sensory Integration and Balance (mCTSIB). Like the Balance and Fall Risk test, the mCTSIB involves four, 20 s trial with feet shoulder width apart and hands of the hips. However, the mCTSIB differs in that each trial utilizes a different combination of eyes open/closed and firm versus foam surface conditions to manipulate three important balance senses (ie proprioception, vision, vestibular). The “Standard” condition has eyes open while standing on the firm surface of the BTrackS Balance Plate, such that all three balance senses are uncompromised. The “Proprioception” condition has closed eyes to remove vision while

Table 1 Normative Data for Center of Pressure (CoP) Path Length (in cm), Based on Sex and Age, on the Balance Tracking System (BTrackS) Balance and Fall Risk Test, as Adapted from Previous Published Work.^{7,8}

Sex	Age (Yrs)	Percentile Ranking								
		10 th	20 th	30 th	40 th	50 th	60 th	70 th	80 th	90 th
Males	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
	60-69	59	47	41	36	33	30	27	25	22
	70-79	79	61	49	43	38	34	31	26	22
	80+	94	77	65	54	46	40	35	30	25
Females	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
	60-69	45	37	33	30	27	25	23	20	17
	70-79	57	45	39	34	31	27	25	22	19
	80+	76	58	50	42	37	32	30	24	20

standing on the firm surface of the plate to increase proprioceptive reliance, based on studies showing a preference for proprioception versus vestibular information when both are available.⁸⁸ The “Vision” condition of the BTrackS mCTSIB has eyes open with the individual being tested standing on a foam cushion to reduce the reliability of proprioception. It has been shown that vision is the dominant uncompromised sense utilized in this situation over vestibular feedback.⁸⁹ The “Vestibular” condition has vision removed (ie eyes closed) and proprioception rendered less reliable via a foam cushion. This manipulation shifts reliance to the uncompromised vestibular system.

For each BTrackS mCTSIB condition (ie Standard, Proprioception, Vision Vestibular), CoP Path Length is first determined as an indicator of total body sway. This value is then translated into a sex-matched percentile ranking, based on published normative data from over 1000 healthy adults aged, 20–59^{16,22} which is overviewed in Table 2. Bottom quartile performance in any condition is “flagged” by the software as a potential deficit in the utilization of that sensory system for the maintenance of balance. As shown in Figure 3, the ICC-based test-retest reliability of the BTrackS mCTSIB protocol ranges from “Fair” to “Excellent” depending on the time between tests (ie Days, Weeks, Months).³³

A third testing protocol that has received particular attention is the BTrackS Limits of Stability Test. This protocol is an evaluation of dynamic balance whereby the participant uses biofeedback of CoP over an image of the BTrackS Balance Plate surface on a computer screen to demonstrate the largest area within which center of mass can be displaced. This “unconstrained” approach differs from the one implemented by traditional force plates, which impose limits on performance by using targets at theoretical maxima. Normative data for the Limits of Stability test were recently

Table 2 Normative Data for Center of Pressure (CoP) Path Length (in cm), Based on Sex and Age, on the Balance Tracking System (BTrackS) Modified Clinical Test of Sensory Integration and Balance (mCTSIB) Test, as Adapted from Previously Published Work.^{16,22}

Task	Sex	Age (Yrs)	Percentile Ranking								
			10 th	20 th	30 th	40 th	50 th	60 th	70 th	80 th	90 th
Standard (Eyes Open, Firm Surface)	Males	18-29	26	22	19	17	16	15	14	12	11
		30-39	21	20	18	16	15	14	13	12	10
		40-49	25	22	20	18	17	15	13	12	10
		50-59	29	24	21	19	18	17	16	14	12
	Females	18-29	22	19	17	16	15	14	13	12	10
		30-39	21	19	17	15	14	13	12	11	10
		40-49	22	18	17	15	15	13	12	11	8
		50-59	25	22	19	18	16	15	13	12	11
Proprioception (Eyes Closed, Firm Surface)	Males	18-29	35	31	28	26	23	21	19	17	15
		30-39	37	31	27	24	23	20	18	17	14
		40-49	43	35	32	27	24	22	20	17	15
		50-59	47	39	34	32	30	25	23	21	18
	Females	18-29	31	28	25	23	21	19	18	17	14
		30-39	32	28	24	22	21	19	18	16	14
		40-49	32	29	25	22	20	18	17	15	14
		50-59	36	31	28	26	23	22	20	17	13

(Continued)

Table 2 (Continued).

Task	Sex	Age (Yrs)	Percentile Ranking								
			10 th	20 th	30 th	40 th	50 th	60 th	70 th	80 th	90 th
Vision (Eyes Open, Foam Surface)	Males	18-29	44	36	34	30	28	25	22	21	18
		30-39	44	35	31	29	26	24	22	20	17
		40-49	48	42	37	34	31	28	25	23	20
		50-59	59	48	43	36	34	31	29	24	21
	Females	18-29	36	33	30	28	26	24	22	19	16
		30-39	39	35	32	30	28	25	23	20	18
		40-49	45	37	33	27	26	24	22	20	17
		50-59	55	48	42	37	34	31	29	25	21
Vestibular (Eyes Closed, Foam Surface)	Males	18-29	97	83	74	69	63	59	54	50	45
		30-39	109	90	80	75	70	62	59	50	43
		40-49	129	105	90	77	74	70	62	56	46
		50-59	132	118	104	96	87	76	72	62	54
	Females	18-29	80	70	63	58	54	50	46	41	38
		30-39	101	89	75	69	64	61	56	51	42
		40-49	120	92	78	68	64	59	53	49	43
		50-59	127	102	95	85	77	71	64	59	54

published for young adults,⁸¹ as over-viewed in Table 3. Test-retest reliability ICC data have also been determined for the BTrackS Limits of Stability protocol²³ showing fair to excellent reliability when compared across short (ie Minutes) and longer (ie Days) duration time frames in healthy adults (Figure 3).

Table 3 Normative Data for Center of Pressure (CoP) Area (in cm²), Based on Sex and Height, on the Balance Tracking System (BTrackS) Limits of Stability Test, as Adapted from Previously Published Work.⁸¹

Sex	Height	Percentile Ranking								
		10 th	20 th	30 th	40 th	50 th	60 th	70 th	80 th	90 th
Males	Shorter (≤180cm)	382	418	440	462	486	510	534	556	605
	Taller (≥181cm)	428	455	487	505	522	553	569	602	638
Females	Shorter (≤180cm)	322	352	378	403	425	445	463	485	516
	Taller (≥181cm)	347	388	420	435	453	471	486	521	539

Determining Group Balance Differences with BTrackS

One of the most prevalent research uses of BTrackS in the scientific literature is as a means of evaluating and comparing the balance abilities of different participant populations or sub-groups. An overview of these efforts is provided in Table 4, consisting of 15 studies across a variety of non-clinical and clinical conditions. Non-clinically, BTrackS has been used to differentiate the balance ability of persons who have or have not been exposed to cannabis use,^{38,49} residents of different geographical locations,⁴⁶ self-selected slow versus fast walkers,⁵⁰ individuals of differing activity levels⁵³ and athletes participating in different sport types.⁸⁴ On the clinical side, populations investigated include Chikungunya chronic arthralgia,⁶ multiple sclerosis,¹¹ diabetes,^{44,79} neurological soft signs,⁵¹ pre-clinical Alzheimer's disease,⁶⁸ Huntington's disease,⁷⁰ migraines⁷³ and amblyopia.⁷⁵

When comparing different groups of individuals, a variety of standard and custom BTrackS protocols have been utilized. Of the standard assessments, the BTrackS Balance and Fall Risk test has most commonly been implemented,^{6,46,53,84} with only two studies measuring balance performance via the mCTSIB protocol.^{44,79} Interestingly, the majority of researchers opted for a custom protocol to determine group differences.^{11,38,49–51,68,70,73,75} However, none of these nine studies followed the exact same testing parameters. Rather, many variations of testing conditions were utilized including manipulations of stance type, trial duration, sensory feedback condition and cognitive load.

Despite the protocol variety, the principal metric underlying most determinations of group differences with BTrackS was CoP Path Length, calculated as the total displacement of CoP over time. This included both direct comparisons of CoP Path Length across groups and calculated derivatives of CoP Path Length, such as performance ratios and change across conditions (eg Dual Task Cost).^{68,70} A smaller number of studies have determined group balance differences using alternative measures of CoP that quantified aspects of postural control such as sway velocity⁵⁰ and entropy-derived irregularity.⁴⁹

Balance Intervention Efficacy Evaluated with BTrackS

Beyond providing one-time “snapshots” of balance status in various sample populations, a key feature of BTrackS is its ability to track long-term changes in balance performance. This is particularly important for the purpose of establishing the efficacy of various balance interventions. In Table 5, a dozen studies are detailed that have sought to quantify balance using BTrackS before and after implementing training or rehabilitation regimens. While early work in this area focused on improving balance in healthy young and older adults,^{5,24,26,27,29,42,52,54,60} more recent intervention studies looked at clinical populations such as individuals with acquired brain injuries⁷² and chiropractic patients.^{82,83}

A wide variety of intervention types have been explored for their efficacy using BTrackS protocols. In young adult athletes, for example, participation in a season of colligate athletics has been evaluated using the Balance and Fall Risk test.²⁴ This research revealed that body sway was reduced from pre- to post-season assessment. Similarly, non-athlete young adults have also shown improvement in balance following intervention.⁵⁴ Specifically, 12-weeks of training were performed on the BTrackS Target Tracking protocol, which required participants to spend three minutes a day, five days a week, controlling CoP location within a target using biofeedback on a computer screen. Participants in this study improved dynamic balance by an average of 30%, as measured by the BTrackS Limits of Stability test.

In older adults, two types of balance intervention have been evaluated for effectiveness using BTrackS assessment protocols. First, a novel Physio-feedback Exercise pRo-gram (PEER) has been studied that relies on the BTrackS Balance and Fall Risk test to provide a physiological measure of balance status.^{26,27,29} This objective result, combined with subjective measures of balance confidence, is used to guide cognitive reframing efforts while older adults participate in combined group- and home-based exercises by a trained PEER coach. Based on pre- to post-intervention BTrackS Balance and Fall Risk values, research indicates that PEER is effective in maintaining or even reducing in body sway.

The second intervention validated by BTrackS for improving older adult balance has been resistance exercise training. In one study, 90 days of an accredited program called Geri-Fit was completed with a certified trainer in a community setting.⁵ While all participants on average showed an improvement in balance on the BTrackS Balance and Fall Risk protocol, older adults with the worst balance prior to intervention showed the greatest improvement. In two additional resistance training studies using custom BTrackS protocols for validation, one did not show balance benefits following

Table 4 Overview of Studies Utilizing the Balance Tracking System (BTrackS) to Determine Group Balance Differences

Author (Year)	Population (Group Size)	BTrackS Protocol	Statistical Significance
Forechi et al (2018) ⁶	Older Adults w PCCA (n = 30) Older Adults wo PCCA (n = 32)	Balance and Fall Risk	Multiple CoP metrics: All significantly worse with PCCA
Kindred et al (2018) ¹¹	Cannabis users w MS (n = 8) Cannabis users wo MS (n = 8)	Custom – 30s, eyes open, feet together	CoP Path Length: No difference between groups
Workman et al (2021) ³⁸	Older cannabis Users (n = 8) Matched Controls (n = 8)	Custom – 60s, eyes open, bipedal	Multiple CoP metrics: No significant group differences
Lopatin et al (2022) ⁴⁴	Type 2 diabetes (n = 10) Published norms	mCTSIB	Lower than average percentile rankings
Souza et al (2022) ⁴⁶	North American men (n = 44) North American women (n = 151) South American men (n = 44) South American women (n = 151)	Balance and Fall Risk	CoP Path Length: South American women above other groups; $p < 0.05$
Workman et al (2022) ⁴⁹	Cannabis users (n = 8) Matched controls (n = 8)	Custom – 60s, eyes open, bipedal	Multiple CoP metrics: Only AP sample entropy larger in users vs controls; $p = 0.01$
Alenazy et al (2023) ⁵⁰	Slow walkers (n = 12) Fast walkers (n = 14)	Custom – 30s, mCTSIB with feet together	Sway area rate best CoP metric to discriminate slow and fast walkers
Bonke et al (2023) ⁵¹	Adolescent with NSS (n = 26) Adolescent without NSS (n = 115)	Custom – Foam and no foam conditions	Multiple CoP metrics: No group differences
Choudhury et al (2023) ⁵³	Active-Low sedentary (n = 17) Active-High sedentary (n = 12) Inactive-Low sedentary (n = 29) Inactive-High sedentary (n = 33)	Balance and Fall Risk	CoP Path Length: No group differences
Bollinger et al (2024) ⁶⁸	Pre-clinical Alzheimer's disease (n = 65) Cognitively normal (n = 138)	Custom – Single and dual task (Serial 3/7s)	CoP Path Length dual task cost: Less for cognitively normal; $p < 0.05$
Churchill et al (2024) ⁷⁰	Huntington's disease (n = 31) Prodromal Huntington's (n = 17) Healthy adults (n = 20)	Custom – Single and dual task (PASAT)	CoP Path Length Dual Task Cost: Greater with disease expression; $p < 0.05$ and $p < 0.001$
Imaz et al (2024) ⁷³	Women with migraine (n = 37) Women control group (n = 37)	Custom – Dual and Single leg Stances	Multiple CoP Metrics: Mostly no differences
Kim et al (2024) ⁷⁵	Amblyopia patients (n = 24) Normal vision controls (n = 20)	Custom – Bipedal Eyes Open and Closed	Multiple CoP Metrics in Eyes Open: Amblyopia worse balance; $p < 0.05$
Lopatin et al (2024) ⁷⁹	Type 2 diabetes (n = 10) Matched controls (n = 10)	mCTSIB	CoP Path Length: More sway in individuals with diabetes; $p < 0.05$
Palazzolo et al (2024) ⁸⁴	Collision sports (n = 3017) Contact sports (n = 2822) Limited contact sports (n = 1321) Non-contact sports (n = 1933)	Balance and Fall Risk	CoP Path Length: Highest in collision vs other sports; $p < 0.01$

Abbreviations: AP, Anterior-Posterior; CoP, Center of pressure; mCTSIB, modified clinical test of sensory integration and balance; MS, multiple sclerosis; NSS, neurological soft signs; PASAT, paced auditory serial addition test; PCCA, post-Chikungunya chronic arthralgia.

Table 5 Overview of Studies Utilizing the Balance Tracking System (BTrackS) to Evaluate Intervention Efficacy

Author (Year)	Intervention	Population (Group Size)	BTrackS Protocol	Balance Results
Goble et al (2017) ⁵	90-day resistance exercise program called Geri-Fit	Older adults (n = 25)	Balance and Fall Risk	CoP Path Length: Significant reduction, particularly in those with high sway; $p < 0.05$
Morrison et al (2020) ²⁴	Pre-season to post-season Collegiate athletics training	College athletes (n = 47)	Balance and Fall Risk	CoP Path Length: Decreased sway from pre to post season; $p < 0.05$
Thiamwong et al (2020) ²⁶	8-week physio-feedback exercise program	Older adults (n = 1)	Balance and Fall Risk	Low Fall Risk category maintained throughout intervention
Thiamwong et al (2020) ²⁷	8-week physio-feedback exercise program	Older adults (n = 19)	Balance and Fall Risk	CoP Path Length: Mean reduction, but not significant; $p > 0.05$
Thiamwong et al (2020) ²⁹	8-week physio-feedback exercise program and attentional control group	Older adults (n = 41)	Balance and Fall Risk	CoP Path Length: Physio-feedback maintained balance, attentional control got worse; $p < 0.05$
Fernandes et al (2022) ⁴²	8-week resistance training with and without Pilates breathing technique	Older adults who did only resistance (n = 22) Older adults who did resistance and breathing (n = 22)	Custom – One-legged stance with eyes open	Multiple CoP metrics: Only resistance and breathing improved; $p < 0.05$
Carzoli et al (2023) ⁵²	9-session tempo-controlled resistance training in non-dominant hip or ankle	Older adults (n = 28)	Custom – Feet together and arms crossed	CoP Sway Area Rate: Did not change with training; $p > 0.05$
Conner et al (2023) ⁵⁴	6-week BTrackS Target Tracking Training protocol with and without foam	Young adults (n = 15)	Limits of Stability	Limits of Stability Area: Increased after 3 and 6 weeks; $p < 0.01$
Pan et al (2023) ⁶⁰	3 or more day nurse-driven mobility intervention	Older adults (n = 24) from progressive care unit	Balance and Fall Risk	CoP Path Length: Improved with intervention; $p < 0.001$
Hernandez-Sarabia et al (2024) ⁷²	8-week yoga group exercise	Chronic acquired brain injury (Yoga: n = 13, Group exercise: n = 10))	Custom – mCTSIB with 30s trials	Multiple CoP metrics: Improved with yoga or group exercise; $p < 0.05$
Oakley et al (2024) ⁸²	10-month chiropractic biophysics and balance rehabilitation	Spinal deformity (n = 1)	mCTSIB – Vestibular condition	CoP Path Length: 102cm reduction
Oakley et al (2024) ⁸³	4-month chiropractic biophysics, power plate and gait exercises	Chronic hip and lower back pain/stiffness (n = 1)	mCTSIB	CoP Path Length: Reduction in 3/4 sensory conditions

Abbreviations: CoP, Center of pressure; mCTSIB, modified clinical test of sensory integration and balance.

resistance training targeting only the hip and ankle.⁵² In contrast, a second study reported positive balance results with resistance exercise,⁴² but only when a simultaneous Pilates breathing technique was employed.

For clinical populations, several intervention types have been tested for efficacy using the BTrackS mCTSIB protocol, or a custom variation of it. Specifically, in a study involving individuals with acquired brain injury, the impact of both yoga and group exercise training on balance was assessed with BTrackS.⁷² Results showed that both interventions were capable of reducing CoP path length and, therefore, improving balance. Positive results were also reported in two chiropractic case studies looking at individuals with spinal deformity⁸² and chronic hip/back pain,⁸³ respectively. Large BTrackS mCTSIB improvements in CoP Path Length for various sensory conditions were found in both cases following a course of chiropractic biophysics, gait/balance exercise and/or power plate exposure.

Research on Novel BTrackS Uses and Methods

Beyond cross-sectional balance comparisons and intervention studies, BTrackS has been leveraged for a wide array of alternative research purposes. For example, in some of the earliest BTrackS research, an attempt was made to look at the diagnostic efficacy of the Balance and Fall Risk test as a tool for concussion evaluation.³ Balance testing is part of the recommended guidelines for determining whether an athlete can return to sport following a head injury, and typically involves an assessment known as the Balance Error Scoring System or BESS.⁹⁰ Although the BESS is widely utilized in the field of athletic training, it suffers from a lack of sensitivity to concussion due to poor test-retest reliability. In comparison, a series of BTrackS studies were conducted to show that it was both valid and reliable for concussion assessment and had twice the diagnostic sensitivity of the BESS.^{3,4,10}

Another use of BTrackS has been for determining a broader picture of older adult fall risk by combining self-reported falls efficacy measures with an objective assessment of balance using the BTrackS Balance and Fall Risk test.^{20,28,35,64,65} This approach allows the identification individuals with a misalignment between their perceived and physiological balance status. Importantly, individuals who underestimate their balance and, therefore, have an unwarranted fear of falling, tend to display unnecessary reductions in physical activity, social isolation, and decreased independence. Alternatively, individuals who overestimate their balance are also potentially problematic, as they were shown to be more vulnerable to catastrophic balance events due to a lack of fall risk awareness.

Virtual reality (VR) technology has evolved from simple environments to highly immersive, interactive simulations. Postural control is critical to ensuring users wearing VR headsets can move, interact, and engage with virtual environments without losing balance or experiencing physical strain. VR is also increasingly being used in rehabilitation programs to help patients improve their postural control and balance through virtual exercises and interactive environments. In a pair of studies, healthy young adults wore a VR headset and were presented a “moving wall” simulation, such that the walls in a virtual room appeared to be moving towards or away from the participant.^{40,55} Continuous CoP capture from a BTrackS custom protocol showed decreased sway magnitude with increased velocity in both studies when the walls were “closing in” and/or moving unpredictably.

Another use of BTrackS for basic research has been determining the presence or absence of relationships between balance and/or balance associated factors. While one study failed to show a correlation between BTrackS CoP data on a custom, eyes open balance protocol and medical imaging results,³⁶ research on end-stage renal disease found a correlation between a custom BTrackS mCTSIB protocol and diabetes. A number of other studies with large samples of healthy adults across the lifespan have shown complementary findings. This includes a significant relationship between age and the results from both BTrackS mCTSIB and Balance and Fall Risk protocols.^{7,8,17,22,81}

One primary characteristic that has shown very consistent relationships to BTrackS results is birth assigned sex. Specifically, the influence of sex on balance performance has been looked at across both static (ie Balance and Fall Risk, mCTSIB, Single Leg Stance) and dynamic (ie Limits of Stability) protocols.^{7,8,17,22} Interestingly, results show that females have better static balance based on CoP magnitude metrics, while males outperform females in dynamic balance tests measured by the total area of CoP excursion. Future work is necessary to determine the genesis of these sex effects, although sensory feedback and strength differences have been hypothesized. It should be noted that estrogen fluctuations during the menstrual cycle do not appear to have any influence on BTrackS results.⁶¹

While postural control is largely mediated at the subconscious level, higher level cognition also appears to play a role in BTrackS balance performance.⁷⁶ One means of demonstrating this phenomenon has been using dual task paradigms, which combine performance of a cognitive task during the sensorimotor task of maintaining one's balance. For example, a recent study found that inclusion of a paced, serial addition cognitive task during standing was able to differentiate between disease state in individuals who were healthy, had prodromal Huntington's disease or who fully expressed Huntington's disease. Specifically, sway was demonstrably greater in prodromal compared to healthy adults, and in Huntington's compared to prodromal adults, only in the dual task versus single task test condition.

The remaining research studies that have utilized CoP information from BTrackS are quite diverse and largely exploratory. These studies range from efforts to determine the existence of placebo/nocebo effects on balance,⁵⁶ exploration of advanced CoP metrics,²⁵ to testing balance-related factors/methods/devices. In the latter case, examples include establishing the ideal gaze direction during squat lifting,⁴³ assessment of back carrying techniques on balance,⁶³ evaluation of postural sway during compression sock use,⁴¹ transcutaneous electrical nerve stimulation,⁴⁸ post-activation potentiation,³¹ chiropractic extremity manipulation,³⁴ lysergic acid diethylamide ingestion,²¹ cerebellar transcranial direct current stimulation,³⁰ exercise-induced fatigue⁴ and prism lens corrections.⁵⁷ Many of these studies have shown positive results supporting translation in real-world settings.

Conclusion

A little more than a decade into its existence, it is clear that a critical mass of research now exists supporting use of BTrackS as a valid, reliable and versatile tool for balance assessment and training. This evidence base can both help inform future assessment and intervention work with BTrackS, as well as support its growing use amongst clinicians and researchers worldwide. Future work will no doubt continue to develop existing theoretical models of balance and create new application-based approaches to improving balance in both healthy and vulnerable populations. This includes the careful deployment of new custom protocols, further expansion of existing normative databases and clinically driven application of balance training regimens.

Disclosure

DJG is eligible for royalties from a patent (US Patent 10,660,558,2020) related to the technology that is the focus of this review. In addition, DJG has an equity stake in Balance Tracking Systems, Inc, the company that sells the BTrackS Balance Plate and Assess Balance Software. This financial conflict of interest is mitigated by a management plan put in place by his academic institution to ensure the integrity of research. The authors report no other conflicts of interest in this work.

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