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Intra-session test-retest reliability of magnitude and structure of center of pressure from the Nintendo Wii Balance Board™ for a visually impaired and normally sighted population

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ABSTRACT

Individuals with visual impairment (VI) have irreparable damage to one of the input streams contributing to postural stability. Here, we evaluated the intra-session test-retest reliability of the Wii Balance Board (WBB) for measuring Center of Pressure (COP) magnitude and structure, i.e. approximate entropy (ApEn) in fourteen legally blind participants and 21 participants with corrected-to-normal vision. Participants completed a validated balance protocol which included four sensory conditions: double-leg standing on a firm surface with eyes open (EO-firm); a firm surface with eyes closed (EC-firm); a foam surface with EO (EO-foam); and a foam surface with EC (EC-foam). Participants performed the full balance protocol twice during the session, separated by a period of 15 min, to determine the intraclass correlation coefficient (ICC). Absolute reliability was determined by the standard error of measurement (SEM). The minimal difference (MD) was estimated to determine clinical significance for future studies. COP measures were derived from data sent by the WBB to a laptop via Bluetooth. COP scores increased with the difficulty of sensory condition indicating WBB sensitivity (all $p < 0.01$). ICCs in the VI group ranged from 0.73 to 0.95, indicating high to very high correlations, and the normal group showed moderate to very high ICCs (0.62–0.94). The SEM was comparable between groups regardless of between-subject variability. The reliability of the WBB makes it practical to screen for balance impairment among VI persons.

1. Introduction

Optimal performance for postural control in quiet stance is a critical prerequisite to human movement [1]. Sensory input responsible for postural control consists of 3 streams: somatosensory (e.g. proprioception), vestibular (e.g. changes in head position), and visual system (e.g. visual fields) [2]. Under normal, standing conditions, the somatosensory input dominates balance control [3]. When the somatosensory system is perturbed, such as while standing on sand, the visual system plays a more significant role [3]. Individuals with visual impairment (VI) – i.e., vision loss that cannot be corrected optically, surgically, or medically – have irreparable damage to the visual input stream, so postural instability becomes more pronounced if somatosensory feedback is disrupted [4], doubling the risk of falls [5]. Thus loss of vision can lead to fall-related injuries and reduced quality of life [6]. Postural stability, especially during challenging sensory conditions, is an important predictor for falls [7]. There is no recommended functional assessment for VI persons at risk for falls, therefore identifying an accessible, portable, cost-effective tool to determine postural changes may have clinical value.

Measuring sensory inputs to standing balance is typically done using a clinically validated balance protocol [7] and a laboratory-grade, computerized force platform. Such platforms are expensive (~$10K–$60K) and rarely available outside dedicated research labs. The Wii Balance Board (WBB; Nintendo™, Tokyo, Japan), an accessory to the popular Wii Fit video gaming system, has been used as a standalone posturography device for measuring center of pressure (COP), a marker for postural stability. During a double leg stance, the WBB was validated and tested for reliability with a

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normal, younger population (mean age = 24), and was found to have a test-retest intraclass correlation coefficient (ICC) of 0.66–0.94 and a between-device ICC of 0.77–0.89 when compared to a laboratory-grade, computerized force plate, and consistent concurrent validity (ICC = 0.77–0.89) [8]. Use of the WBB as a standalone posturography device has also been validated in clinical populations with Parkinson's disease [9] and musculoskeletal disorders [10], and was found to be sensitive to age differences [11] and different visual tasks [12]. This is evidence of the emerging use of the WBB as a reliable and inexpensive clinical alternative to the research grade force plate and may be important for rehabilitation specialists while evaluating fall risk in the home.

For the WBB to be used for behavioral interventions in patients, identifying intrinsic measurement error is an imperative precursor [13]. Salavati et al. contend that determining reliability in a healthy population can lead to overestimations of measurement error [13]. ICCs depend on between-subject variability [14] and "only have meaning when applied to specific populations", according to Streiner and Norman [15]. The level of reliability is population-specific [13] and has not yet been evaluated for VI individuals.

Accepted measures of postural stability in standing balance characterize the variability of human movement [16]. COP parameters quantify the displacement of balance around the center of mass and the distribution of ground-reaction forces [16]. Linear models of postural control assert that the *magnitude* of COP variability is directly proportional to the intensity of external perturbation, such as changes in environmental conditions that affect components of the postural control system [17]. The magnitude of COP measures has been found to increase with changes in stance, during locomotion, and in the absence of sensory input [12,18]. In contrast, Kiemel et al. proposed that reduced COP variability may not apply to systems that are inherently unstable (e.g. musculoskeletal disorders, elderly) and may instead reflect corrective postural strategies [19]. Regardless, the regulation of postural stability requires the detection of COP displacement in order for the system to adapt to the ever-changing environment.

Alternatively, recent models of human movement posit that variability exists on a continuum from learning a new task (i.e. greater variability as a result of uncertainty) to the acquisition of a high level skillset (i.e. variability arising from multiple fine-tuned adjustments) and should be assessed by measuring *structure*, or repeatability, of COP variability hidden in the time series signal [17,20]. Approximate Entropy (ApEn) quantifies the regularity or predictability of a time series as a dimension-less value between 0 and 2 [21]. Higher values indicate more system irregularity or random noise, whereas, lower values are indicative of greater temporal structure [21]. Evidence of high system regularity (i.e. values closer to 0) are suggestive of system rigidity that can lead to postural constraints reflective of injury as in athletes after concussion [20], or poor postural control as in Parkinson's patients [21], while values closer to 2 indicate greater irregularity or random noise.

One limitation of previously published WBB reliability studies has been the use of a single measure of postural stability (e.g. COP path length) [22]. In this study, we evaluate the intrasession test-retest reliability of the WBB measuring COP *magnitude* and *structure* in a VI population using a clinically validated protocol for balance assessment under different sensory conditions that increase in difficulty. To help evaluate the reliability of the WBB we also tested a population of healthy, normally sighted individuals. These intrasession reliability measures assess the presence of random fluctuations in the instrument and/or the biological phenomena being measured [23]. Appraising reliability under different sensory conditions in the spatial and temporal domains may lead to better screening and more targeted rehabilitation strategies for VI persons at risk for falls. In addition, we can estimate the minimal difference (MD) of the reliability measures required for a change at follow-up visits to be considered clinically relevant [15].

2. Methods

2.1. Participants

Fourteen legally blind participants (age $\mu = 51$, $\sigma = 16.03$; 4 Males) and 21 participants with corrected-to-normal vision (age $\mu = 25.95$, $\sigma = 7.92$; 5 Males), completed the modified Clinical Test of Sensory Interaction on Balance (mCTSIB) [7]. Inclusion criteria for VI participants were legal blindness (best corrected visual acuity worse than 20/200 and/or visual field less than 20° in diameter, in the better eye) based on vision records obtained with consent. VI participant visual history is listed in Table 1. Participants with vestibular disorders, history of neurologic disease, pregnancy, acute orthopedic problems affecting ambulation, or on medication that could affect balance (e.g. sleeping pills) were excluded. The protocol for the study was approved by the Institutional Review Board of the Johns Hopkins University School of Medicine and followed the tenets of the Declaration of Helsinki. All participants provided informed consent.

2.2. Procedures

A single tester obtained postural measurements for each participant in a one- to 1.5 hour session. The mCTSIB was used to evaluate how well the participant used somatosensory (firm or unstable surface) and visual (eyes open or closed) inputs when one or both sensory systems are compromised [7]. The participant's bare feet are placed on the WBB so that the inner edges of both feet are one foot length (their own) apart, in four sensory conditions increasing in difficulty: standing on a firm surface with eyes open (firm-EO); a firm surface with eyes closed (firm-EC); an unstable (3″ thick [7]) surface with EO (foam-EO); and an unstable surface with EC (foam-EC). The participants were asked to perform the whole mCTSIB battery twice in the same session, separated by a 15-minute rest period, to determine the intrasession test-retest reliability. The conditions within the balance tests were randomly ordered in both sessions. Participants performed each

Table 1
Visual history for legally blind participants.

Subject #	Diagnosis	OS	OD
SBJ01	Stargardt's Disease	5 ft./225	5 ft./300
SBJ02	Congenital Cataracts, Glaucoma, enucleated OD	LP	NLP
SBJ03	Ischemic Optic Neuropathy	LP	LP
SBJ04	Age-Related Macular Degeneration	CF @ 3′	HM
SBJ05	Congenital cataracts, aphakia with band keratopathy, phthisis OD	CF @ 1′	NLP
SBJ06	Retinitis Pigmentosa	BLP	BLP
SBJ07	Nystagmus, Congenital Cataracts, Band Keratopathy	HM	NLP
SBJ08	Optic Nerve Damage	LP	LP
SBJ09	Retinopathy of Prematurity	NLP	BLP
SBJ10	Stargardt's Disease	20/320	20/320
SBJ11	Retinitis Pigmentosa	20/70*	20/70*
SBJ12	Retinitis Pigmentosa	LP	LP
SBJ13	Stargardt's Disease	20/300	20/300
SBJ14	End-stage Glaucoma	LP	LP

OS, Left Eye; OD, Right Eye; CF, Counting Fingers; HM, Hand Motion; LP, Light Perception; BLP, Bare Light Perception; NLP, No Light Perception; *Legal Blindness determined by Visual Fields.

condition for 3 successive trials of up to 30 s with a one-minute rest period in between. Prior to each condition, participants had a 30-s familiarization period. Participants were instructed to maintain a neutral head position to minimize vestibular activation and when possible, to binocularly fixate on a black "X" taped on a white wall at eye level 35 inches in front of them; while keeping their arms crossed over the chest. Target distance was kept constant to minimize possible effects of change in visual input on postural stability.

2.3. Instrumentation

The WBB has four pressure sensors under a rigid platform, placed near the corners. During testing, COP positional data for the X (X-COP) and Y (Y-COP) axes were computed by combining data from the 4 sensors. Custom software was developed to interface wirelessly with the WBB in order to collect sensor data [8]. The software was developed in C# using Microsoft Visual Studio and the .NET framework. The linearity of the signal was verified by placing known weights (5, 15, 25, 45, 65, 90lbs.) over each sensor, one at a time, with zero loads on the other sensors [8]. High linear correlations were found for all sensors. In order to determine the correct calibration scale factors for loads placed on the platform between the sensors, a known weight was placed at regularly spaced calibration points on the board [24]. We found the distribution of these factors to be linear and centered on the platform, suggesting that the WBB provides an accurate measure of static COP. We used the same device for all testing, which was suggested by Bartlett et al. for greater repeatability [25].

2.4. Data processing

During testing, the WBB sent a stream of data from the 4 force plate sensors to a laptop via Bluetooth. For COP calculations, the data were sampled at 100 Hz and filtered using a Butterworth filter with a low pass cut-off frequency of 10 Hz per Salavati et al. [13]. COP data extraction software was written in MATLAB. COP *magnitude* was determined as the standard deviation (SD) of the COP velocity (mm/s) and amplitude (mm) in the AP and ML directions, and the combined AP-ML mean total velocity (MTV, mm/s) [13]. The regularity of COP temporal *structure* was assessed by calculating the ApEn in the AP and ML directions from the unfiltered data, using an algorithm published extensively elsewhere [26,27]. Briefly, ApEn is calculated for a time series by counting how many short subsets of data points are similar to a basis subset, and repeating this for every possible subset of consecutive data points of a specific length. The advantage of ApEn is that it can be used with small data sets and is not affected by outliers [21]. Each time series contained 3000 data points (100 Hz sampling frequency $\times$ 30 s). We sought to evaluate ApEn to distinguish among different sensory conditions and therefore selected $m = 2$ and $r = 0.1$*SD as parameter settings based on recommendations in the literature [26,28].

2.5. Statistical analysis

Descriptive statistics were used to summarize the COP measures for each sensory condition. The mean of 3 trials in each condition from each session was used to determine reliability measures. Systematic bias was assessed by a paired samples *t*-test between test-retest sessions. Individual data displayed a non-normal distribution and were transformed logarithmically for analysis. To determine the effect of sensory condition on the WBB, a one-way repeated measures ANOVA was conducted. Relative test-retest reliability was determined using a two-way random model with absolute agreement intraclass correlation coefficient ($ICC_{2,\ k}$) [15] using SPSS software (SPSS Inc. Chicago, IL). To interpret the degree of reliability, Munro's classification for

Table 2
COP magnitude and structure (Mean (SD)) data in different sensory conditions for both Normal ($n = 21$) and Visually Impaired groups ($n = 14$).

		FIRM-EO		FIRM-EC		FOAM-EO		FOAM-EC		One-way Repeated Measures ANOVA*	Effect Size
		Test	Retest	Test	Retest	Test	Retest	Test	Retest		
Normal											
Magnitude											
SD amplitude (mm)	AP	3.41 (1.05)	3.49 (1.64)	4.33 (1.26)	4.19 (1.67)	7.82 (4.18)	6.75 (3.82)	14.10 (5.67)	12.11 (3.80)	$F(3, 18) = 34.01$, $p = 0.001$	0.85
	ML	1.16 (0.37)	1.38 (0.67)	1.33 (0.60)	1.30 (0.51)	3.27 (1.70)	3.35 (1.75)	4.47 (2.13)	4.12 (1.43)	$F(3, 18) = 41.98$, $p = 0.001$	0.88
SD velocity (mm/s)	AP	9.20 (4.85)	10.29 (5.23)	12.77 (6.71)	13.45 (6.18)	14.45 (5.98)	16.11 (8.45)	32.66 (17.06)	32.74 (14.06)	$F(3, 18) = 43.38$, $p = 0.001$	0.88
	ML	7.37 (3.26)	8.35 (3.47)	7.18 (2.90)	8.56 (3.46)	8.41 (3.50)	9.63 (4.81)	11.48 (5.06)	13.44 (5.36)	$F(3, 18) = 33.40$, $p = 0.001$	0.85
MTV (mm/s)		9.34 (1.70)	9.89 (2.03)	11.55 (2.26)	12.15 (2.75)	13.72 (2.98)	12.98 (2.83)	26.58 (5.82)	23.17 (4.42)	$F(3, 18) = 144.47$, $p = 0.001$	0.96
Structure											
ApEn	AP	0.57 (0.15)	0.56 (0.17)	0.47 (0.11)	0.50 (0.13)	0.29 (0.12)	0.32 (0.11)	0.25 (0.10)	0.25 (0.09)	$F(3, 18) = 29.03$, $p = 0.001$	0.83
ApEn	ML	1.30 (0.17)	1.27 (0.23)	1.27 (0.18)	1.26 (0.22)	0.82 (0.27)	0.85 (0.29)	0.70 (0.23)	0.68 (0.21)	$F(3, 18) = 153.19$, $p = 0.001$	0.96
Visually impaired											
Magnitude											
SD amplitude (mm)	AP	4.53 (1.09)	4.42 (1.60)	5.05 (1.85)	4.48 (1.66)	10.71 (4.38)	9.62 (2.98)	10.90 (3.98)	10.55 (3.10)	$F(3, 11) = 23.57$, $p = 0.001$	0.87
	ML	1.78 (0.86)	1.54 (0.63)	1.36 (0.56)	1.49 (0.59)	4.66 (2.96)	5.02 (3.08)	4.39 (2.14)	4.83 (2.55)	$F(3, 11) = 11.46$, $p = 0.001$	0.76
SD velocity (mm/s)	AP	15.30 (10.31)	14.79 (11.35)	16.40 (14.25)	15.54 (11.22)	33.97 (19.66)	31.23 (17.46)	36.07 (18.03)	34.44 (16.83)	$F(3, 11) = 21.69$, $p = 0.001$	0.86
	ML	7.18 (5.15)	7.08 (4.40)	6.89 (5.45)	7.15 (4.02)	10.77 (7.53)	10.29 (5.79)	10.68 (6.11)	11.01 (6.90)	$F(3, 11) = 11.29$, $p = 0.001$	0.76
MTV (mm/s)		13.32 (4.69)	12.31 (4.06)	13.74 (4.62)	12.51 (4.15)	26.83 (9.54)	24.01 (8.84)	29.97 (9.10)	26.03 (6.88)	$F(3, 11) = 30.42$, $p = 0.001$	0.89
Structure											
ApEn	AP	0.39 (0.10)	0.40 (0.12)	0.41 (0.15)	0.39 (0.13)	0.33 (0.13)	0.32 (0.10)	0.36 (0.13)	0.32 (0.13)	$F(3, 11) = 6.84$, $p = 0.007$	0.65
ApEn	ML	1.05 (0.22)	1.08 (0.26)	1.11 (0.26)	1.08 (0.25)	0.57 (0.25)	0.53 (0.23)	0.52 (0.26)	0.52 (0.23)	$F(3, 11) = 32.74$, $p = 0.001$	0.90

SD: Standard Deviation; MTV: Mean Total Velocity; EO: Eyes Open; EC: Eyes Closed; ApEn: Approximate Entropy; AP: anteroposterior; ML: mediolateral. *The one-way repeated measures ANOVA was conducted on the averaged test and retest scores for each condition.

reliability coefficients was used: 0.00–0.25—little, if any correlation; 0.26–0.49—low correlation; 0.50–0.69—moderate correlation; 0.70–0.89—high correlation and 0.90–1.00—very high correlation [13]. To determine the absolute reliability and allow for comparison between COP measures using the same units of interest, the *standard error of measurement (SEM)* was estimated as the square root of the mean square error term from an ANOVA [14,15]. The SEM is independent of the population and thus is not affected by between subject reliability differences or the range of values. To define a 95% CI for future intervention studies, beyond which one could be confident that a real change occurred in a retest score, an estimate of the minimum difference (MD) was calculated as $\pm 1.96 \times SEM \times \sqrt{2}$ [15].

3. Results

Descriptive statistics summarize the COP magnitude and structure for each sensory condition in Table 2. Paired samples *t*-tests found no systematic bias between test and retest for any variables (all $p > 0.05$), so test and retest values were averaged for further analysis and plotted by condition in Fig. 1, for both groups.

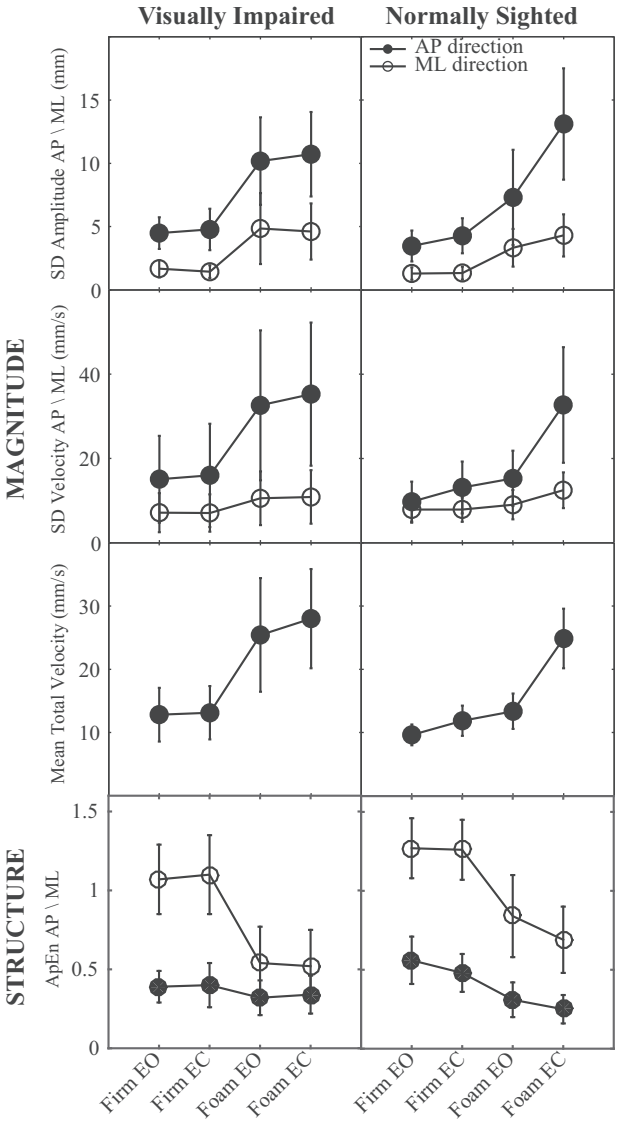

Fig. 1. COP test-retest magnitude and structure values averaged and plotted by condition for Visually Impaired ($n = 14$) and Normally Sighted ($n = 21$). Note: Mean total velocity combines AP-ML data.

Table 3
Bonferroni corrected pairwise comparisons.

	SD amplitude AP (mm)		SD amplitude ML (mm)		SD Velocity AP (mm/s)		SD Velocity ML (mm/s)		Mean Total Velocity (mm/s)		ApEn AP		ApEn ML	
	95% CI of the Mean Difference	*p*-Value	95% CI of the Mean Difference	*p*-Value	95% CI of the Mean Difference	*p*-Value	95% CI of the Mean Difference	*p*-Value	95% CI of the Mean Difference	*p*-Value	95% CI of the Mean Difference	*p*-Value	95% CI of the Mean Difference	*p*-Value
Normal														
Change from EO to EC														
Firm EC – Firm EO	0.81 (0.11; 1.52)	**0.018**	0.06 (−0.19; 0.28)	**n.s.**	3.37 (1.34; 5.39)	**0.001**	0.01 (−1.25; 1.27)	**n.s.**	2.23 (1.29; 3.18)	**0.001**	−0.08 (−0.14; −0.03)	**0.002**	−0.01 (−0.19; 0.17)	**n.s.**
Foam EC – Foam EO	5.81 (3.07; 8.56)	**0.001**	0.98 (−0.12; 2.09)	**n.s.**	17.42 (10.82; 24.02)	**0.001**	3.44 (1.88; 5.01)	**0.001**	11.52 (8.40; 14.65)	**0.001**	−0.05 (−0.12; 0.02)	**n.s.**	−0.15 (−0.28; −0.02)	**0.02**
Change from Firm to Foam														
Foam EO – Firm EO	3.84 (1.99; 5.70)	**0.001**	2.04 (1.31; 2.77)	**0.001**	5.53 (3.51; 7.56)	**0.001**	1.16 (0.16; 2.16)	**0.017**	3.74 (2.50; 4.98)	**0.001**	−0.26 (−0.34; −0.18)	**0.001**	−0.43 (−0.63; −0.24)	**0.001**
Foam EC – Firm EC	8.85 (6.23; 11.46)	**0.001**	2.98 (2.12; 3.83)	**0.001**	19.59 (14.19; 24.99)	**0.001**	4.59 (3.21; 5.97)	**0.001**	13.03 (10.85; 15.20)	**0.001**	−0.23 (−0.32; −0.14)	**0.001**	−0.57 (−0.65; −0.49)	**0.001**
Visually impaired														
Change from EO to EC														
Firm EC – Firm EO	0.29 (−0.34; 0.91)	**n.s.**	−0.23 (−0.69; 0.22)	**n.s.**	0.93 (−2.04; 3.90)	**n.s.**	−0.11 (−1.30; 1.08)	**n.s.**	0.31 (−1.11; 1.73)	**n.s**	0.01 (−0.04; −0.05)	**n.s.**	0.03 (−0.07; 0.13)	**n.s.**
Foam EC – Foam EO	0.56 (−0.60; 1.72)	**n.s.**	−0.24 (−1.16; 0.69)	**n.s.**	2.65 (−3.69; 8.99)	**n.s.**	0.32 (−1.35; 1.99)	**n.s.**	2.57 (−0.81; 5.95)	**n.s.**	0.01 (−0.02; 0.05)	**n.s.**	−0.03; (−0.13 0.08)	**n.s.**
Change from Firm to Foam														
Foam EO – Firm EO	5.69 (3.39; 7.99)	**0.001**	3.18 (1.21; 5.15)	**0.001**	17.56 (9.63; 25.49)	**0.001**	3.40 (1.27; 5.54)	**0.002**	12.61 (7.56; 17.66)	**0.001**	−0.07 (−0.44; −0.01)	**n.s.**	−0.52 (−0.68; −0.36)	**0.001**
Foam EC – Firm EC	5.96 (3.26; 8.66)	**0.001**	3.18 (1.54; 4.82)	**0.001**	19.28 (12.14; 26.42)	**0.001**	3.83 (1.59; 6.06)	**0.001**	14.87 (10.23; 19.51)	**0.001**	−0.06 (−0.17; −0.05)	**n.s.**	−0.57 (−0.75; −0.40)	**0.001**

The normal group shows a progressive increase in all magnitude measures as the somatosensory and visual input are removed, more pronounced in the AP than in the ML direction; An opposite trend is observed for ApEn, suggesting greater rigidity as sensory input is reduced, most noticeably in the ML direction. Similarly, trends are seen in the VI group, with one important exception: Closing the eyes has little or no effect in this group, suggesting that these individuals do not (or no longer) rely on vision for posture stabilization.

A one-way repeated measures ANOVA was conducted to determine WBB sensitivity to changes in sensory conditions (Table 2). There was a significant effect for condition in all variables in both groups, all $p < 0.007$. Effect sizes ranged from 0.65 to 0.96 (Table 2). A Bonferroni-corrected post-hoc pairwise comparison evaluated the sensitivity of the WBB to changes in sensory conditions (i.e. from EO to EC and from Firm to Foam) (Table 3). In the normal group, consistent sensitivity was found for changes between firm and foam conditions (all $p < 0.01$). Results were mixed for changes from EO to EC, with the more stable conditions (Firm surface and/or ML component) not reaching statistical significance. In VI, as already noted above, no significant changes were observed for EO to EC conditions. However, significant sensitivity was observed for all changes from firm to foam conditions where the somatosensory system is also challenged, with the exception of ApEn in the AP direction. This may be related to the low ApEn values in the AP direction in all conditions, signaling possible postural rigidity along this (inherently less stable) axis.

The ICC, 95% CI, SEM and MD measures are listed in Table 4. COP amplitude and velocity for the VI group yielded high to very high ICCs across all sensory conditions in the AP (0.85–0.95) and the ML (0.73–0.94) direction. Similarly, the normal group showed moderate to very high reliability in the AP (0.74–0.91) and the ML (0.62–0.84) directions. High ICCs for COP MTV were 0.76–0.94 in both groups. The ApEn ML ICCs were 0.86–0.94 for the Normal group and 0.82–0.91 for the VI group. For ApEn AP, ICCs ranging between 0.76 and 0.95 were found for VI and ICCs between 0.82 and 0.93 were found for Normals. The SEM, an indicator of absolute reliability (and unaffected by between-subject variability) [15], was comparable between groups in both the COP magnitude and structure domains. The MD was calculated for each COP measure of magnitude in each condition and ranged from ±0.85 to ±29.38 in the normal group and ±1.07 to ±21.14 in the VI group; note that the higher values are all for velocity measures, primarily in the AP direction, underscoring the more frequent, rapid, and variable posture adjustments along that axis, in both normals and VI subjects. MD for ApEn was similar for both groups with a range of ±0.12 to ±0.38 and ±0.09 to ±0.39 in normal and VI groups, respectively.

4. Discussion

Test-retest reliability of the WBB was evaluated in two groups; a healthy, young adult group and a legally blind VI group. Moderate to very high correlations were found across all magnitude and structure variables in both groups indicating reliability for the WBB as a measurement device consistent with other reports [29]. ICCs are sensitive to between-subject variability and therefore, the varying degrees of vision loss between subjects in our VI population may have contributed to the slightly greater ICCs for COP magnitude than observed in the normal group. However, the absolute reliability measure (SEM) was found to be comparable among groups, for each COP measure despite variability in visual ability and age. The MD is a useful guide to determine clinically significant changes between measurements and to calculate sample sizes in future studies [23]. The WBB COP measures were mostly sensitive to changes in sensory conditions. The selection of which COP measurement to use in the future will depend on the research question or study population.

Table 4
Test-retest reliability for normal ($n = 21$) and visually impaired ($n = 14$) groups in different sensory conditions.

		FIRM-EO			FIRM-EC			FOAM-EO			FOAM-EC		
		ICC (95% CI)	SEM	MD	ICC (95% CI)	SEM	MD	ICC (95% CI)	SEM	MD	ICC (95% CI)	SEM	MD
Normal													
Magnitude													
SD amplitude (mm)	AP	0.79 (0.48; 0.92)	2.91	±8.06	0.88 (0.71; 0.95)	0.73	±2.02	0.85 (0.61; 0.94)	1.91	±5.30	0.79 (0.47; 0.92)	2.80	±7.75
	ML	0.80 (0.51; 0.92)	0.34	±0.94	0.84 (0.61; 0.94)	0.31	±0.85	0.76 (0.41; 0.90)	1.22	±3.38	0.82 (0.57; 0.93)	1.01	±2.81
SD velocity (mm/s)	AP	0.84 (0.60; 0.93)	2.42	±6.72	0.91 (0.77; 0.96)	2.73	±7.56	0.84 (0.60; 0.93)	4.60	±12.76	0.74 (0.36; 0.90)	10.60	±29.38
	ML	0.80 (0.52; 0.92)	1.85	±5.14	0.81 (0.51; 0.92)	1.93	±5.34	0.69 (0.26; 0.88)	3.35	±9.28	0.62 (0.12; 0.84)	4.28	±11.87
MTV (mm/s)		0.78 (0.46; 0.91)	1.25	±3.47	0.90 (0.75; 0.96)	1.10	±3.06	0.90 (0.73; 0.96)	1.09	±3.01	0.76 (0.19; 0.92)	3.01	±8.35
Structure													
ApEn	AP	0.82 (0.55; 0.93)	0.09	±0.25	0.93 (0.77; 0.97)	0.04	±0.12	0.85 (0.62; 0.94)	0.05	±0.15	0.88 (0.71; 0.95)	0.045	±0.12
ApEn	ML	0.94 (0.84; 0.97)	0.07	±0.20	0.91 (0.79; 0.97)	0.08	±0.23	0.86 (0.66; 0.94)	0.14	±0.38	0.94 (0.85; 0.98)	0.077	±0.21
Visually impaired													
Magnitude													
SD amplitude (mm)	AP	0.85 (0.54; 0.95)	0.80	±2.21	0.90 (0.63; 0.97)	0.89	±2.47	0.93 (0.78; 0.98)	2.03	±5.62	0.89 (0.66; 0.97)	1.78	±4.93
	ML	0.73 (0.15; 0.91)	0.47	±1.30	0.78 (0.34; 0.93)	0.38	±1.07	0.91 (0.71; 0.97)	1.58	±4.37	0.83 (0.48; 0.95)	1.12	±3.11
SD velocity (mm/s)	AP	0.88 (0.64; 0.96)	4.65	±12.88	0.88 (0.60; 0.96)	5.33	±14.76	0.94 (0.82; 0.98)	7.63	±21.14	0.95 (0.84; 0.98)	5.47	±15.17
	ML	0.92 (0.76; 0.98)	1.59	±4.42	0.79 (0.34; 0.93)	2.57	±7.13	0.90 (0.69; 0.97)	3.07	±8.51	0.94 (0.82; 0.98)	1.90	±5.27
MTV (mm/s)		0.90 (0.71; 0.97)	1.54	±4.27	0.88 (0.61; 0.96)	1.65	±4.58	0.94 (0.70; 0.98)	2.76	±7.65	0.88 (0.23; 0.97)	2.62	±7.27
Structure													
ApEn	AP	0.76 (0.24; 0.92)	0.07	±0.20	0.95 (0.85; 0.98)	0.04	±0.12	0.93 (0.77; 0.98)	0.04	±0.12	0.93 (0.70; 0.98)	0.03	±0.09
ApEn	ML	0.82 (0.43; 0.94)	0.14	±0.39	0.92 (0.75; 0.97)	0.10	±0.28	0.91 (0.72; 0.97)	0.10	±0.28	0.87 (0.59; 0.96)	0.12	±0.34

SD: Standard Deviation; MTV: Meant Total Velocity; EO: Eyes Open; EC: Eyes Closed; ApEn: Approximate Entropy; AP: anteroposterior; ML: mediolateral.
ICC: Intraclass Correlation Coefficient; SEM: Standard Error of Measaurement: MD: Minimal Difference; All correlations are significant at $p < 0.01$.

COP magnitude and structure showed consistent and pronounced differences between the AP and the ML direction for both groups indicating that the WBB has sufficient sensitivity to detect differences among postural control axes. Cavanaugh et al. identified ApEn ranges in young, healthy adults across several sensory conditions for 0.50–0.84 anterior-posterior (AP) and 0.75–0.93 medial-lateral (ML) using a research grade forceplate [20]. Our ApEn values, while higher than those of Cavanaugh et al., show the same axial difference [20]. Moreover, the data are reliable in changing sensory conditions and between groups, confirming that COP structure data can be reliably obtained with the WBB.

4.1. Limitations

The WBB is a static device, similar in concept and design to a force plate, and thus limited to static posturography measures. Measuring dynamic posturography or gait in the future remains necessary to determining anticipatory movements (e.g. obstacle avoidance) or compensatory components of postural adjustments after unpredictable perturbations during walking in order to reduce fall risk. However, the mCTSIB provides a basic estimate of the vestibular, somatosensory, and visual sensory contributions to an individual's balance-stabilizing response. Determining these sensory contributions with the WBB will be useful as a screening tool for a VI population.

Specific inclusion and exclusion criteria were implemented to minimize heterogeneity in the VI population, however, there are likely to be individual differences in visual function according to severity, duration, and type of disease that may affect postural stability [2]. The ICC calculation depends on such between-subject variation and the differences in vision loss in our population are representative of the subject population seen in low vision clinics. Therefore we do not believe that the composition of our subject group limits the value of this study.

Due to the transportation limitations of our VI population, data for this study were collected during a single session with a 15-minute delay in between the two mCTSIB administrations. In the future, intersession reliability may need to be evaluated to determine stability of the measurement over longer delays or to determine the effects of attentional demands [30]; such measures will be helpful for longitudinal clinical evaluations.

5. Conclusion

The reliability of the WBB makes it a practical screening tool to assess potential balance impairment among patients with acquired vision loss or age related changes in vision.

Author contributions

PJ, JW and GD conceived and designed the study. PJ, CR, MC acquired the data. PJ and JW analyzed and interpreted the data. PJ drafted the manuscript. PJ, JW, and GD revised the manuscript critically for important content. MB wrote the software to generate structural data and helped interpret the data. JG and LY developed the custom software, conducted preliminary testing and calibration of the device. GD gave final approval of the version to be submitted.

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