Validity of Postural Sway Assessment on the Biodex BioSway™ Compared With the NeuroCom Smart Equitest

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Context: Current tools for sideline assessment of balance following a concussion may not be sufficiently sensitive to identify impairments, which may place athletes at risk for future injury. Quantitative field-expedient balance assessments are becoming increasingly accessible in sports medicine and may improve sensitivity to enable clinicians to more readily detect these subtle deficits. **Objective:** To determine the validity of the postural sway assessment on the Biodex BioSway™ compared with the gold standard NeuroCom Smart Equitest System. **Design:** Cross-sectional cohort study. **Setting:** Clinical research laboratory. **Participants:** Forty-nine healthy adults (29 females: 24.34 [2.45] y, height 163.65 [7.57] cm, mass 63.64 [7.94] kg; 20 males: 26.00 [3.70] y, height 180.11 [7.16] cm, mass 82.97 [12.78] kg). **Intervention(s):** The participants completed the modified clinical test of sensory interaction in balance on the Biodex BioSway™ with 2 additional conditions (head shake and firm surface; head shake and foam surface) and the Sensory Organization Test and Head Shake Sensory Organization Test on the NeuroCom Smart Equitest. **Main Outcome Measures:** Interclass correlation coefficient and Bland–Altman limits of agreement for Sway Index, equilibrium ratio, and area of 95% confidence ellipse. **Results:** Fair–good reliability (interclass correlation coefficient = .48–.65) was demonstrated for the stance conditions with eyes open on a firm surface. The Head Shake Sensory Interaction and Balance Test condition on a firm surface resulted in fair reliability (interclass correlation coefficient = .50–.59). The authors observed large ranges for limits of agreement across outcome measures, indicating that the systems should not be used interchangeably. **Conclusions:** The authors observed fair reliability between BioSway™ and NeuroCom, with better agreement between systems with the assessment of postural sway on firm/static surfaces. However, the agreement of these systems may improve by incorporating methods that mitigate the floor effect in an athletic population (eg, including a head shake condition). BioSway™ may provide a surrogate field-expedient measurement tool.

Keywords: balance, postural control, posturography

Posturography is the gold standard for the assessment of sensory and motor contributions to postural control.¹ Assessments such as the Sensory Organization Test (SOT) and Head Shake SOT (HS-SOT) represent reliable testing protocols that may be sensitive to subtle, persistent deficits in postural control.² The high cost limits the feasibility of clinical utilization of NeuroCom's SOT and HS-SOT.³ Recently, more affordable and portable technologies, such as the Biodex BioSway™, have allowed the clinician to implement quantitative gold standard testing methods into field-based settings.⁴

The modified clinical test of sensory interaction in balance on the Biodex BioSway™ is commonly used for the quantitative assessment of postural control.^{5–9} The Head Shake Sensory Interaction and Balance Test (HS-SIB) was developed on the Biodex BioSway™ as an adaptation of the modified clinical test of sensory interaction in balance, incorporating 2 head-shake conditions to help identify more subtle impairments in postural control, similar to HS-SOT.

Despite frequent utilization of the Biodex BioSway™, the reliability and validity have yet to be established. The purpose of this study was to evaluate the validity of the postural sway assessment on the Biodex BioSway™ (HS-SIB) compared with the NeuroCom (HS-SOT).

Methods

Forty-nine subjects participated in this study (29 females: 24.34 [2.45] y, height 163.65 [7.57] cm, mass 63.64 [7.94] kg; 20 males: 26.00 [3.70] y, height 180.11 [7.16] cm, mass 82.97 [12.78] kg). Participation was open to healthy adults with no history of vestibular disorders, neuropathy, or recent (<6 mo) musculoskeletal injury. The protocol was approved by the Institutional Review Board of Radford University. All subjects provided written informed consent prior to participation.

All participants completed assessments of postural sway on both the NeuroCom Smart Equitest Balance System® (NeuroCom International, Inc, Clackamas, OR) and the Biodex BioSway™ Portable Balance System (Biodex Medical System, Shirley, NY). NeuroCom recorded ground reaction forces at 100 Hz using the Balance Manager (version 8.5.0) software interface. Biodex BioSway recorded ground reaction forces at 20 Hz using the Biodex Patient Data Collection Software Utility (version 2.0.2).

The participants were randomly assigned the order for completing the NeuroCom or BioSway™ testing. The NeuroCom testing included the SOT and HS-SOT, per manufacturer guidelines. All trials were 20 seconds in duration, with subjects positioned barefoot and wearing a loosely fitting safety harness.

The HS-SIB, performed on the Biodex BioSway™, was designed to present sensory constraints analogous to those of the SOT and HS-SOT. The subjects performed one 30-second trial in each condition, per manufacturer guidelines. To facilitate a comparison with NeuroCom, only the first 20 seconds of each trial was used.

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The participants self-selected their foot position during initial HS-SIB testing, which was recorded and kept constant for all trials.

For both devices, head shake trials were preceded by a familiarization period with visual and auditory metronome feedback to guide the speed and amplitude of head movement. Metronome cues were turned off prior to data acquisition; however, the testers provided real-time feedback regarding the parameters of head movement based on signals from the head-mounted instruments (gyroscope for NeuroCom, laser for BioSway™). The prescribed head shake parameters involved yaw plane head rotations ± 30 deg from neutral at 1 Hz.

The raw time series data from each system were processed offline to reconstruct the signals required to compute the other system's outcome variables. The raw data from the BioSway™ recordings are exported as sway angles (in degrees) and multiplied by a constant of 250. The NeuroCom exports the forces for each sensor, center of pressure, and estimated center of gravity.

Assuming that the center of mass height in quiet standing is 55.27% of the participant's height, the sway angle can be calculated from the center of gravity. Formulas for calculating outcome scores corresponding to either system can be applied using calculated signal conversions. For the present analyses, the outcome scores were computed from the raw time series exported from each system and the converted time series created using the following equations:

$$\text{Sway Angle}^\circ = \arctan\left(\frac{\text{COG}}{0.5527 \times \text{Height}}\right) \times \left(\frac{180}{\pi}\right). \quad (1)$$

$$\text{COG} = \tan\left(\theta^\circ \times \frac{\pi}{180}\right) \times 0.5527 \times \text{Height}. \quad (2)$$

The NeuroCom and BioSway™ systems provide postural control summary statistics that can be calculated in their respective software suites. Clinically useful metrics include the equilibrium score (ES; NeuroCom) and the Sway Index (BioSway™), calculated using Equations 3 and 4 provided below.

The ES is calculated from the anteroposterior sway angle and expresses the magnitude of the anteroposterior sway range as the percentage of unused space within the hypothetical anteroposterior cone of stability, a 12.5° arc. Lesser usage of the 12.5° arc (eg, higher ES) is interpreted to indicate better postural control.

The Sway Index is the root mean square of the (X , Y) angular displacement. Its interpretation is similar to the ES in that less sway motion indicates better postural control. However, unlike the ES, the Sway Index statistic has a direct (ie, positive) relationship with sway motion.

$$\text{ES} = \frac{12.5^\circ - (\theta_{\max}^\circ - \theta_{\min}^\circ)}{12.5^\circ} \times 100. \quad (3)$$

$$\text{Sway Index} = \sqrt{\frac{1}{n} \left[\sum_{i=1}^n (x_i - \bar{x})^2 + (y_i - \bar{y})^2 \right]}. \quad (4)$$

Finally, because these outcome metrics may be sensitive to extreme sway values within a trial, we computed the area of the 95% COG confidence ellipse for all trials (COG_{A95}).

Agreement between the BioSway™ and NeuroCom metrics was assessed using the intraclass correlation coefficient for absolute agreement ($\text{ICC}_{2,1}$) and Bland–Altman 95% limits of agreement

(LOA). The ICC values were interpreted as follows: .00 to .40 (poor), .40 to .59 (fair), .60 to .74 (good), and .75 to 1.00 (excellent).

All signal processing and statistical computations were performed in R programming language (version 3.6.1; The R Foundation, Vienna, Austria). The ICC and LOA analyses were performed using functions from the psych (version 1.8.12) and blander (version 0.5.1) packages, respectively.

Results

Out of 298 NeuroCom trials, 10 extreme (exceeding sample mean ± 3 SD) values were identified and subsequently discarded. One out of 270 BioSway™ trials was discarded. The data from one subject was excluded listwise, following the discovery of a pathology unrelated to the present study. Table 1 provides a descriptive summary. The agreement and reliability results are summarized in Tables 2 and 3, respectively.

All outcome variables in eyes closed (EC)-Stable, eyes open (EO)-Unstable, EC-Unstable, and EC-Unstable with head shake demonstrated poor reliability between systems. We observed fair reliability between systems in the EO-Stable and EC-Stable with head shake conditions, and good reliability for COG_{A95} in the EO-Stable model.

The patterns of reliability for specific summary metrics varied across the stance conditions. The Sway Index and ES reliability coefficients were within ± 0.05 units of each other for all stance conditions. The reliability of COG_{A95} was greater than that of the Sway Index and ES in the EO-Stable and EC-Unstable conditions. The reliability of COG_{A95} was lower than that of the Sway Index and ES in the EC-Stable and EC-Unstable with head shake conditions. The reliability of COG_{A95} was most comparable with that of the Sway Index and ES in the EO-Unstable and EC-Stable with head shake conditions.

The Bland–Altman analyses show a general pattern of 95% LOA encompassing a large range in comparison to the spread of their respective variables. The most compelling results for LOA and ICC relate to the EO-Stable conditions (SOT1 vs BSway1) and the EC-Stable conditions with head shake (HS-SOT1 vs BHSY1). We also observed a bias (greater magnitude of sway motion on the NeuroCom) for trials involving a sway-referenced platform.

Discussion

This is the first study to investigate the validity of the Biodex BioSway™ (HS-SIB) in quantifying postural sway compared with the NeuroCom Balance Master (HS-SOT). The outcome variables of these 2 systems demonstrated large ranges for 95% LOA, indicating that these systems should not be used interchangeably.

The most significant difference between these 2 systems is likely related to differences in static posturography compared with dynamic posturography. The stance conditions for NeuroCom (conditions 4, 6, and HS-SOT5) and BioSway™ (conditions 3, 4, and 6), which present inaccurate somatosensory information for postural control, do so via different mechanisms. Though the sensory constraints are similar, the postural control strategies elicited by the sway-referenced platform of the NeuroCom may differ from those elicited by the foam of the BioSway™.

One other study has reported on the validity of the Biodex BioSway™.¹⁰ Dewan et al.¹⁰ utilized 3-dimensional motion capture to investigate Biodex BioSway™ validity. Kinematically derived center of mass trajectories were compared with the

Table 1 Descriptive Summary

Test	Descriptive summary			
	Condition	Sway Index, deg	ES	COG _{A95} , cm ²
NeuroCom				
SOT1	EO, Stable	0.37 (0.22)	94.94 (3.72)	0.52 (1.11)
SOT2	EC, Stable	0.54 (0.21)	92.42 (3.25)	0.59 (0.45)
SOT4	EO, Sway Ref	1.32 (0.91)	83.44 (9.18)	2.21 (1.92)
SOT5	EC, Sway Ref	2.41 (0.85)	67.23 (10.33)	7.34 (4.90)
HS-SOT1	EC, Stable	0.55 (0.19)	92.43 (2.47)	0.94 (0.77)
HS-SOT2	EC, Sway Ref	3.47 (1.20)	53.17 (14.84)	16.32 (17.90)
BioSway™ mCTSIB				
Bsway1	EO, Stable	0.35 (0.12)	95.25 (1.94)	0.39 (0.34)
Bsway2	EC, Stable	0.55 (0.18)	91.73 (2.92)	0.80 (0.57)
Bsway3	EO, Foam	0.61 (0.15)	91.15 (4.15)	1.42 (0.83)
Bsway4	EC, Foam	1.66 (0.37)	74.99 (7.25)	9.63 (4.87)
BHSY1	EC, Stable	0.66 (0.20)	90.55 (3.03)	1.35 (0.75)
BHSY2	EC, Foam	2.79 (1.01)	60.17 (13.88)	29.00 (27.44)

Abbreviations: BHSY, BioSway plus Headshake; Bsway, Biodex BioSway; COG A95, area of center of gravity 95% confidence ellipse; EC, eyes closed; EO, eyes open; ES, equilibrium score; Foam, medium density foam standing surface; HS-SOT, Head Shake SOT; mCTSIB, modified clinical test of sensory interaction and balance; SOT, Sensory Organization Test; Stable, stable standing surface (equivalent to firm); Sway Ref, sway-referenced standing surface.

Table 2 Bland–Altman 95% LOA Analysis

Model	LOA			
	Bias ± SD	SEM	LOA (low)	LOA (high)
SOT1 (EO, Stable) vs Bsway1 (EO, Firm)				
Sway Index, deg	0.01 ± 0.14	0.04	−0.28	0.29
ES	0.12 ± 1.98	0.51	−3.75	4.00
COG A95, cm ²	−0.00 ± 0.39	0.10	−0.76	0.76
SOT2 (EC, Stable) vs Bsway2 (EC, Firm)				
Sway Index, deg	−0.01 ± 0.23	0.06	−0.46	0.45
ES	0.67 ± 3.67	0.94	−6.51	7.86
COG A95, cm ²	−0.19 ± 0.66	0.17	−1.48	1.09
SOT4 (EO, Sway Ref) vs Bsway3 (EO, Foam)				
Sway Index, deg	0.67 ± 0.91	0.24	−1.12	2.46
ES	−7.31 ± 8.54	2.27	−24.04	9.42
COG A95, cm ²	0.69 ± 1.74	0.46	−2.71	4.09
SOT5 (EC, Sway Ref) vs Bsway4 (EC, Foam)				
Sway Index, deg	0.77 ± 0.90	0.23	−0.99	2.54
ES	−8.17 ± 11.80	3.00	−31.31	14.96
COG A95, cm ²	−2.07 ± 5.33	1.35	−12.53	8.38
HS-SOT1 (EC, Stable) vs BHSY1 (EC, Firm)				
Sway Index, deg	−0.10 ± 0.18	0.05	−0.46	0.25
ES	1.76 ± 2.55	0.67	−3.24	6.76
COG A95, cm ²	−0.38 ± 0.66	0.17	−1.68	0.92
HS-SOT2 (EC, Sway Ref) vs BHSY2 (EC, Foam)				
Sway Index, deg	0.70 ± 1.30	0.35	−1.85	3.25
ES	−7.70 ± 18.15	4.82	−43.27	27.87
COG A95, cm ²	−11.64 ± 31.85	8.47	−74.06	50.79

Abbreviations: BHSY, BioSway plus Headshake; Bsway, Biodex BioSway; COG A95, area of center of gravity 95% confidence ellipse; EC, eyes closed; EO, eyes open; ES, equilibrium score; Firm, equivalent to stable; Foam, medium density foam standing surface; HS-SOT, Head Shake SOT; SOT, Sensory Organization Test; Stable, stable standing surface; Sway Ref, sway-referenced standing surface.

Table 3 Reliability Analysis of NeuroCom Versus Biodex BioSway™

Model	Reliability/agreement metrics						
	ICC (CI)	F	Significance	SEM	MDC	Correlation	Significance (Corr.)
SOT1 (EO, Stable) vs Bsway1 (EO, Firm)							
Sway Index, deg	.49 (.24 to .69)	2.95 _{44,44}	<.01	0.11	0.32	0.50	<.01
ES	.48 (.22 to .68)	2.85 _{44,44}	<.01	1.36	3.78	0.47	<.01
COG A95, cm ²	.65 (.45 to .79)	4.79 _{44,44}	<.01	0.33	0.90	0.72	<.01
SOT2 (EC, Stable) vs Bsway2 (EC, Firm)							
Sway Index, deg	.29 (.00 to .54)	1.83 _{44,44}	.02	0.17	0.48	0.28	.06
ES	.30 (.01 to .54)	1.85 _{44,44}	.02	2.73	7.55	0.30	.04
COG A95, cm ²	.04 (−.23 to .31)	1.08 _{44,44}	.40	0.41	1.14	0.04	.79
SOT4 (EO, Sway Ref) vs Bsway3 (EO, Foam)							
Sway Index, deg	.01 (−.17 to .23)	1.04 _{41,41}	.46	0.91	2.51	0.07	.66
ES	.02 (−.14 to .22)	1.06 _{41,41}	.43	8.25	22.86	0.05	.73
COG A95, cm ²	.08 (−.19 to .35)	1.18 _{41,41}	.29	1.68	4.65	0.16	.31
SOT5 (EC, Sway Ref) vs Bsway4 (EC, Foam)							
Sway Index, deg	.03 (−.13 to .22)	1.09 _{45,45}	.38	0.83	2.31	0.06	.69
ES	.08 (−.12 to .31)	1.27 _{45,45}	.21	9.83	27.23	0.13	.41
COG A95, cm ²	.37 (.11 to .59)	2.34 _{45,45}	<.01	3.87	10.72	0.40	.01
HS-SOT1 (EC, Stable) vs BHSY1 (EC, Firm)							
Sway Index, deg	.53 (.22 to .73)	3.99 _{42,42}	<.01	0.14	0.38	0.60	<.01
ES	.50 (.14 to .72)	3.92 _{42,42}	<.01	1.85	5.12	0.60	<.01
COG A95, cm ²	.59 (.28 to .77)	4.74 _{42,42}	<.01	0.54	1.49	0.66	<.01
HS-SOT2 (EC, Sway Ref) vs BHSY2 (EC, Foam)							
Sway Index, deg	.23 (−.04 to .48)	1.75 _{41,41}	.04	1.01	2.81	0.28	.08
ES	.18 (−.09 to .44)	1.52 _{41,41}	.09	13.51	37.46	0.21	.19
COG A95, cm ²	.03 (−.24 to .31)	1.07 _{41,41}	.42	18.02	49.94	0.04	.82

Abbreviations: BHSY, BioSway plus Headshake; Bsway, Biodex BioSway; CI, confidence interval; COG A95, area of center of gravity 95% confidence ellipse; EC, eyes closed; EO, eyes open; ES, equilibrium score; Firm, equivalent to stable; Foam, medium density foam standing surface; HS-SOT, Head Shake SOT; ICC, interclass correlation coefficient; LOA, limits of agreement; MDC, minimum detectable change; SOT, Sensory Organization Test; Stable, stable standing surface; Sway Ref, sway-referenced standing surface.

BioSway™ sway angles during volitional postural sway tasks. The authors found BioSway™ to be a valid tool for postural sway assessment compared with 3-dimensional motion capture.

Outside of the aforementioned methodological distinctions (ie, static vs dynamic posturography), the primary limitations of this study relate to hardware discrepancies between the systems. Apparent differences in spatial resolution and known differences in the sampling rates of ground reaction force data between NeuroCom (100 Hz) and BioSway™ (20 Hz) likely impact the reliability between systems. While data transformations and postprocessing can improve comparability to an extent, these hardware limitations likely place an upper limit on achievable reliability.

Due to the cost, the NeuroCom dynamic posturography assessments are not feasible in most settings. BioSway™ is a more portable, accessible, and affordable method for quantitative posturography.

Future research should focus on identifying more accessible alternatives for the quantitative assessment of postural sway and developing methods to increase the clinical feasibility of their implementation and utilization.

Conclusions

BioSway™ may provide a surrogate field-expedient measurement methodology in static platform conditions. Postural sway motion

on foam is not comparable to sway-referenced platform. The addition of a head shake condition in the assessment of postural sway may help mitigate the floor effect of this assessment in an athletic population.

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