A Soft, Flexible Skin-Mounted Sensor for Monitoring Balance Deficits in People with Multiple Sclerosis

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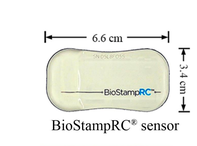
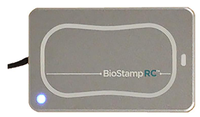
BACKGROUND

- Impaired balance affects 75% of MS patients during the progression of the disease[1].
- Degradation in balance increases the risk of falls[2].
- Clinical balance rating scales (i.e. Berg Balance Test) often lack precision and depend on clinician's expertise.
- Force platform-based balance assessment is immobile and expensive.
- The BioStampRC® sensor is a soft, flexible wireless inertial sensor that can be attached to skin with minimal preparation.

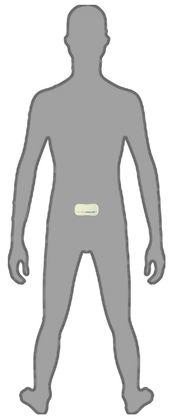


BioStampRC® sensor


BioStampRC® adhesive



BioStampRC® charger


Posterior View

Objective: Investigate the validity of BioStampRC® sensor to assess the balance performance of individuals with MS (with and without a history of falling) and healthy control subjects.

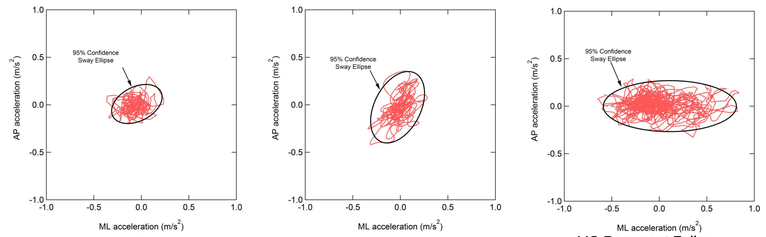
METHODS

- Participants: 40 MS participants + 12 Healthy Controls

	Healthy Control	MS Non-Faller (no falls in the past 6 month)	MS Recurrent Faller (>=2 falls in the past 6 month)
N (Male/Female)	12 (5/7)	23 (4/19)	17 (8/9)
Age	58.1 (36-73)	56.3 (29 - 68)	59.1 (48 -79)
Years since diagnosis	NA	16.4 (1-37)	19.1 (5-35)
EDSS median (range)	NA	3.5 (0-6.5)	6 (3.5-7)
ABC	95.4 (92.5 -100)	74.1(8.8 - 100)	59.9 (26.6 - 88.1)

- ABC – Activity Specific Balance Confidence Scale
- EDSS – Self-reported Expanded Disability Status Scale

- The balance assessment consisted of two 30-second standing trials in three conditions:
  - Eyes Open/Firm Surface (EO)
  - Eyes Closed/Firm Surface (EC)
  - Eyes Open/Foam Surface (FEO)
- Postural sway was measured with a BioStampRC® sensor placed on the lower back (L5), as well as by a force plate placed under the feet.



Sway acceleration trace for three representative subjects in EC condition

Measure abbreviation	Description	Characterization
JERK	Sway jerkiness, time derivative of acceleration	Sway smoothness
CEA	95% confidence sway ellipse area	Sway amplitude
SP	Total length of sway trajectory	Sway amplitude
MV	Mean sway velocity	Sway velocity
TP	Total power of sway	Sway power

RESULTS

		Force Plate							BioStampRC®						
		HC		MS Non-Faller		MS Recurrent Faller			HC		MS Non-Faller		MS Recurrent Faller		
EO	JERK (m^2/s^5)	NA		NA		NA			1.19	(0.10)	2.82	(0.49)	3.73	(0.65)	
	CEA (mm^2, m^2/s^4)	107.84	(11.98)	349.71	(74.87)	589.80	(129.27)	*	0.02	(0.00)	0.04	(0.01)	0.06	(0.01)	*
	SP(mm, m/s^2)	261.04	(11.41)	449.30	(42.11)	533.26	(44.35)	*	7.06	(0.26)	9.60	(0.66)	11.17	(0.87)	
	MV(mm/s, mm/s)	8.67	(0.39)	14.95	(1.40)	17.78	(1.48)	*	20.65	(1.75)	33.78	(3.53)	38.92	(4.56)	
	TP(m^2, $m2/s^4$)	8.48	(0.28)	13.58	(1.19)	16.43	(1.38)	*	6.24	(0.39)	9.48	(0.84)	11.71	(1.22)	*
EC	JERK (m^2/s^5)	NA		NA		NA			1.80	(0.17)	10.25	(2.61)	9.78	(2.75)	*
	CEA (mm^2, m^2/s^4)	130.02	(12.79)	812.03	(175.77)	1182.31	(291.26)	*+	0.02	(0.00)	0.11	(0.03)	0.14	(0.04)	*
	SP(mm, m/s^2)	373.46	(17.53)	816.82	(87.81)	842.56	(72.46)	*+	8.46	(0.38)	15.80	(1.87)	16.66	(1.87)	*+
	MV(mm/s, mm/s)	12.45	(0.58)	27.23	(2.93)	28.09	(2.42)	*+	26.43	(1.90)	46.58	(5.07)	56.39	(8.40)	*
	TP(m^2, $m2/s^4$)	11.46	(0.36)	21.46	(2.16)	24.26	(1.99)	*+	8.41	(0.44)	14.88	(1.66)	17.61	(2.46)	*
FEO	JERK (m^2/s^5)	NA		NA		NA			5.62	(1.68)	9.93	(1.69)	11.81	(2.02)	*
	CEA (mm^2, m^2/s^4)	665.33	(65.38)	1339.98	(182.61)	1886.68	(399.34)		0.05	(0.01)	0.16	(0.03)	0.23	(0.07)	*
	SP(mm, m/s^2)	659.63	(46.85)	893.58	(58.70)	1040.84	(75.51)	*	13.80	(1.58)	17.59	(1.33)	19.73	(1.26)	
	MV(mm/s, mm/s)	21.99	(1.56)	29.79	(1.96)	34.69	(2.52)	*	36.50	(2.87)	60.77	(6.26)	76.55	(13.27)	*
	TP(m^2, $m2/s^4$)	19.46	(1.26)	25.00	(1.54)	30.40	(3.37)	*	11.27	(0.95)	16.28	(1.41)	18.70	(1.73)	*

Mean and SE of sway measurements by BioStampRC® and force plate. ⋆ significant difference between HC and MS Recurrent Faller , + significant difference between HC and MS Non-Faller (p<0.017). .

- CEA and TP sway metrics (derived from force plate and BioStampRC®) can differentiate MS Recurrent Faller from HC in all test conditions.
- Force plate based metrics (CEA,SP,MV, TP) and SP metric from BioStampRC® can additionally differentiate MS Non-Faller from HC in EC condition.
- Sway JERK, a unique metric for accelerometry measure, can differentiate MS Recurrent Faller from HC in EC/FEO conditions.

Spearman Rho	EO	EC	FEO
CEA	0.88	0.89	0.88
SP	0.90	0.95	0.87
MV	0.66	0.74	0.80
TP	0.87	0.94	0.88

- Moderate to strong correlation (rho >0.66) between BioStampRC® and force plate based sway metrics.

AUC	Force Plate	BioStampRC®
JERK	NA	0.648
CEA	0.660	0.630
SP	0.653	0.648
MV	0.653	0.630
TP	0.666	0.660

- BioStampRC® based sway metrics were as effective for differentiating individuals with poor balance as the force plate sway metrics.

DISCUSSION

- The BioStampRC® sensor is a valid and objective measurement tool for postural sway assessment.
- MS recurrent faller swayed more than healthy controls, and their postural sway increased more than those in controls with altered sensory conditions.
- This soft, flexible wireless inertial sensor offers a portable and easy-to-administer balance assessment, and provide key information on individual's falls risk.
- Future work is needed to examine whether body motion quantified by this skin-mounted inertial sensor are predictive of falls.

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