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Research

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Abstract

Background: Evaluation of balance disorders and differentiation of the populations with deficits is necessary for treatment and rehabilitation. The BESTest is used to evaluate balance and posture in various populations and has been shown to distinguish between different neurological populations. This study investigated the validity of the BESTest in measuring balance in the people with multiple sclerosis (PwMS).

Methods: A cross-sectional study conducted with 34 participants including 17 PwMS (42.64 ± 7.8 years old, score 1-5 on the Expanded Disability Status Scale) and 17 healthy controls (42.33 ± 8.65 years old). After a comprehensive medical history, subjective clinical balance assessment (via BESTest) was performed. Then objective measures of balance domains of Anticipatory Postural Adjustments (APAs) and Sensory Orientation were assessed using a force plate, with sway, velocity and the area of sway outcomes calculated. Correlations between the subjective and objective measures of balance were computed.

Results: The anterior-posterior and the medio-lateral sway, sway velocity in the AP direction, and area of displacement were significantly different between the two groups ($P < 0.005$). Significant correlations were found between the BESTest scores with anterior-posterior and medio-lateral sway, sway velocity in anterior-posterior direction, and area of displacement in anterior-posterior direction ($p < 0.005$).

Conclusions: Results indicated that the BESTest assessment tool has a high accuracy and sensitivity to assess balance function in PwMS. It can be used as an outcome measure to test postural balance disorders in these people.

Keywords: Multiple Sclerosis, Balance, Postural Disorders, BESTest, Force Plate.

Validation of the BESTest for Measuring Balance in People with Multiple Sclerosis

Background

Multiple Sclerosis is a chronic and progressive disease of the nervous system (1). It causes extensive destruction of the myelin sheath around the axon of sensory and motor neurons in the central nervous system (2). The clinical picture of people with multiple sclerosis (PwMS) varies according to the variation of disease and the brain structures in which the myelin sheaths are destroyed (3). MS patients are classified by their clinical course, relapsing-remitting MS (RRMS), secondary progressive MS (SPMS), and primary progressive MS (PPMS) (4).

Patients with MS often experience mild to severe motor and cognitive dysfunction such as muscle weakness, spasm, tremor, fatigue, decreased attention and executive function, impaired balance, and coordination (3). Since the About 63% of patients report falls at least once for a period of 2 to 6 months (5), so balance impairment is a major concern in PwMS as it limits independence and reduces quality of life, decreased activity and increased mortality, as the ability to maintain balance is one of the most fundamental aspects of human behavior (6).

PwMS also regularly report fatigue, which is another contributing factor to falls and balance deficit in this population, therefore treatment planning in this group should be well-targeted and accurate to avoid additional fatigue from unnecessary activity. Similarly, an integrated and coherent treatment plan for PwMS requires careful balance assessment (7). Therefore, the variety of symptoms of MS and the deficit of quantitative clinical assessment of gait and balance often cause therapists to have problems evaluating balance (3).

Hitherto, different tests are developed to assess balance which have limitations, for example: (1) the ability to closely monitor disease progression; (2) the limitations of examining the effect of intervention; (3) the insensitivity to differentiation between groups; (4) the poor reliability; (5) those are subjective(8). Recent studies have shown that different domains affect balance in PwMS as well

as single activity measurements cannot measure multiple balance domains and have little value in guiding treatment plans(7).

On other hand, objective evaluation of balance and gait by force plate and motion capture cameras requires a lot of time and is expensive, which is not clinically possible to use such equipment in medical settings (9).

Currently, the Balance Evaluation Systems Test (BESTest) is available that designed by B.Horak to comprehensively examine different balance domains (10). This test evaluates the 6 balance subsystems that include: (1) Biomechanical Constraints; (2) Stability Limits/Verticality; (3) Anticipatory Postural Adjustments; (4) Automatic Postural Responses; (5) Sensory Orientations; (6) Stability in Gait (11). Each known system is partly related to independent neural mechanisms that contribute to the control of postural balance. During the tests, the participants were given break times to rest if they needed it.

Previous studies suggest that the BESTest is a valid and comprehensive balance assessment tool that has efficacy for clinical use in PwMS (12), but previous studies have been limited to comparison to other subjective clinical tests (e.g. Berg balance scale). However BESTest is an inexpensive test, without the need for special equipment or training, and it provides a lot of information about the underlying mechanisms involved in balance deficits but BESTest takes ~45min to complete, which plays an important role in the assessment of PwMS as this could lead to fatigue. Also, it is yet to be determined whether the subjective clinical BESTest (or its sub-domains) is valid for balance assessment in PWMS compared to objective laboratory “gold-standard” references (e.g. force plates). Therefore, this study aimed to investigate the concurrent validity of the BESTest for balance assessment in PwMS by comparing outcomes to laboratory tests with a force plate. We hypothesized that the BESTest would be valid for balance assessment in PwMS compared to “gold-standard” measures.

Methods

2.1 Subjects:

In a cross sectional study, a total of 32 PwMS with relapsing-remitting and primary progressive types (mean age 42.64 ± 7.8 years old) and 19 HP (mean age 42.33 ± 8.65 years old) participated. According to a study entitled (Equilibrium Disorder in People with Multiple Sclerosis: Preliminary Evidence for Balance System Evaluation Test) the lowest correlation coefficient (for convergence validity) between BESTest and Force plate ($r = 0.69$, $r^2 = 0.48$) was calculated. According to this value and power of 80% and significance level of 95% to estimate the simultaneous validity of instruments with the formula below the sample size of 17 people was determined.

$$\left(n = \frac{(z_{\alpha} + z_{\beta})^2}{d^2} \right) \quad d = (0.5) \ln\left(\frac{1+r}{1-r}\right)$$

The participants were recruited from the Rehabilitation Hospital of Rofeideh, Tehran, Iran. Participants with MS were selected based on the following inclusion criteria: (1) diagnosis by a neurologist; (2) the ability to perform laboratory assessments; EDSS score 1-5; (3) The cognitive function of 24 and more in MMSE. Subjects were excluded if they had psychological disorders, intellectual disability, auditory or visual problems fatigue or special disease which interfere in the process of assessments, fracture or implant (according to case history or self-report). In the case of not fulfilling all the test items, inability to follow commands, deterioration of the disorder and emergencies, participants were excluded from the study. Demographics of age, height and weight were captured. The ethical committee of the USWR.AC.IR approved the study (USWR.AC.IR. 1394.30). Data was collected following participant informed consent.

2.2 instrumentation

2.2.1 EDSS

Expanded Disability Status Scale (EDSS) is used to assess the progression of the disease and the effectiveness of rehabilitation therapies as a clinician-administered assessment scale for evaluating the functional systems of the central nervous system. The inter-rater reliability kappa values of this scale

have been reported between 0.32 to 0.76 (13). It includes 11 degrees between 0-10 that 0 (normal neuro-logical status) to 10 (death due to MS) in 0.5 increments interval (when reaching EDSS 1)(14), Which are graded in this way: (1) No disability; (2) Minimal disability; (3) Moderate disability No impairment to walking; (4) Significant disability but self-sufficient and up and about some 12 hours a day and able to walk without aid or rest for 500 m; (5) Disability severe enough to impair full daily activities and ability to work a full day without special provisions and able to walk without aid or rest for 200 m; (6) Requires a walking aid-cane, crutch, etc. and able to walk about 100 m with or without resting; (7) Unable to walk beyond approximately 5 m even with aid, essentially restricted to wheelchair; though wheels self in standard wheelchair and transfers alone Up and about in wheelchair some 12 hours a day; (8) Essentially restricted to bed or chair or pushed in wheelchair and may be out of bed itself much of the day. Retains many self-care functions, generally, has effective use of arms; (9) Confined to bed and can still communicate and eat; (10) Death due to MS (15).

2.2.2 MMSE

The Mini-Mental State Examination (MMSE) test was developed 40 years ago by Folstein et al, and the American Academy of Neurology has suggested in its guidelines that the MMSE be an important tool in diagnosing primary cognitive impairment, and is currently the most common screening method for assessing the severity of dementia in both clinical and research field (16).

The tool consists of a short battery containing 20 separate tests that cover 11 areas that include orientation, registration, attention or calculation (serial sevens or spelling), recall, naming, repetition, comprehension (verbal and written), writing, and construction and has a total of 30 points, which usually takes 8 minutes to perform in people with cognitive impairment and 15 minutes in people with dementia. Internal consistency appears to be moderate with Cronbach alpha scores reported between 0.6 to 0.9 also, sensitivity of the MMSE was 86% and specificity 92% with cut-off <24/30 (17).

2.2.3 Balance Evaluation Systems Test

The BESTest consists of 36 items divided into 6 domains: (1)Biomechanical Constraints (This system identifies ankle strategy or compensatory steps for postural recovery eg: flexed posture in frail elderly

and Person's with Parkinson diseases); (2)Stability Limits/Verticality(This system shows how far the body's center of mass can be moved over it's base of support) and Verticality (represent gravitational upright); (3)Anticipatory Postural Adjustments(Readiness prior to the voluntary movements which depend on interaction of supplementary motor areas with basal ganglia and brain stem areas which is evaluated by this system); (4)postural Reactions(Impulses carried by short, medium and long proprioceptive feedback loops that affected in diseases such as MS, cerebellar ataxia, and sensory neuropathy are evaluated in this system); (5)Sensory Orientations (Spatial orientation maintain by pathways involving vestibular system and sensory integrative areas of the temporo-parietal cortex) and (6)Stability in Gait (Co-ordination between spinal locomotors and brain stem postural sensorimotor programs) in 36 items (18). Each item is scored on a 4-level, ordinal scale from 0 (worst performance) to 3 (best performance) (11).

2.2.4. Force plate

In this study, a Kistler force plate device (model 9286 AB, and Bioware 4.0.2 software version, 1000Hz) was used to collect the Center of pressure data during static balance tasks. This model of force plate consists of a non-moving plate, piezoelectric sensors, and software designed to measure force, acceleration and torque (momentum). Outcomes included; anterior-posterior (AP) and medial-lateral (ML) Sway, velocity of anterior-posterior and Medio-Lateral Sway (V.ML & V.AP) displacement velocity and an area of displacement. The data processed using MATLAB Software and analyzed using NEXUS Software.

2.3 Procedure

In order to evaluate the validity of BESTest using the force plate and with the specifications mentioned, 11 different tasks were considered. These tasks were selected based on the test items that could be performed in the Motion Analysis and Biomechanics Laboratory so we limited our focus to the balance outcomes that could be obtained during static standing as shown in Table 1, these tasks were selected from subsystems APA and Sensory Orientation of Test BESTest.

Each task in the Motion Analysis and Biomechanics Lab was performed 3 times on each person and the best and most complete data obtained was selected and used to perform calculations. The amount of duration of each task according to the time considered in the BESTest performed, For example, to stand on the force plate, the duration was 30 seconds and to stand after getting up from the chair was 10 seconds (18). And whenever the participants needed to rest, the tests were stopped.

Selected labels for different types of tasks were selected using the research of others who had performed similar tests using the force plate and other new tasks used were named by the authors by convention(19). Then the most complete data obtained from the force plate (Values of Ground Reaction Forces (GRFs) and Location of the Center of Pressure (COP)) were received from the system as output with a frequency of 1000 Hz.

To investigate the balance in this study, the displacement of the center of pressure, the velocity of sway displacement of the center of pressure, and the displacement area were considered. The data obtained from the force plate in different tasks were called in MATLAB Software version 13, respectively, and after that, the calculations were performed in the following order:

In all tasks to calculate the displacement in the anterior-posterior direction of Formula 1, the displacement in the medial-lateral direction of Formula 2 (19).

$$COP_{AP} displacement = \sum_{i=2}^n |copAP_i - copAP_{i-1}| \quad (1)$$

$$COP_{ML} displacement = \sum_{i=2}^n |copML_i - copML_{i-1}| \quad (2)$$

Another parameter to check the balance is the velocity of sway displacement of the center of pressure. The velocity of the center of pressure is an indicator of the performance of the position control system. Pressure center velocity is the most sensitive parameter in patients with different age groups and different neurological diseases in different tasks (20). To calculate the velocity of the pressure center in the anterior-posterior direction, Formula 3 and in the lateral medial direction, Formula 5 was used for all tasks(19).

$$V_{AP} = \frac{\sum_{i=2}^n \sqrt{(copAP_i - copAP_{i-1})^2}}{t} \quad (3)$$

$$V_{ML} = \frac{\sum_{i=2}^n \sqrt{(copML_i - copML_{i-1})^2}}{t} \quad (4)$$

Formula 5 was used to investigate the area of displacement, which was used to calculate the area of the ellipse. (21).

$$Area = \pi(AP_{MAX} - AP_{MIN}) \times (ML_{MAX} - ML_{MIN}) \quad (5)$$

1.4 Statistical analysis:

Data was analyzed using SPSS (version 25, IBM, USA) and Shapiro-Wilk tests showed that data was non-normally distributed. Therefore, non-parametric analysis was used to compare subjective (BESTest) and objective (Force Plate) balance outcomes; specifically, Spearman correlation coefficients. The two groups did not differ significantly in demographic information including age, height and weight (mean and standard deviation) from p-value > 0.05.

2.5 Theory/calculation:

The BESTest as an accurate test to evaluate balance disorders takes an approximately long time to complete, which may lead to fatigue in the PwMS. Therefore, it is necessary to determine whether the subjective clinical BESTest is valid for balance assessment in PWMS compared to objective laboratory references. We aimed to investigate the concurrent validity of the BESTest for balance assessment in PwMS by comparing outcomes to laboratory tests with a force plate.

3. Results

3.1 Participants

In this study 17 PwMS were selected according to inclusion criteria, with a mean age of 42.64 ± 7.8 years, mean height of 162.76 ± 6.79 cm, mean weight of $60.12 \pm 9.9.4$ kg, and mean MMSE score of 26.41 ± 1.46 participated. Further, 17 HP with a mean age of 42.33 ± 8.65 years, mean height of 146.39 ± 38.36 cm, mean weight of 59.83 ± 8.47 kg, and mean MMSE score of 27.11 ± 0.96 participated as the control group. The two groups were not significantly different in terms of demographic characteristics with $p\text{-value} < 0.05$.

3.2 Subjective and Objective Balance Measurement Showed Impairments in PwMS

There were significant differences between groups in several balance domains Biomechanical Constraints, Anticipatory Postural Adjustments, Stability in Gait and total test scores ($p < 0.01$) and in domains postural reactions & Sensory Orientations ($p < 0.05$). However, the limit of stability domain of the BESTest was not significantly different between the two groups (table 2).

The pattern of AP&ML sways during the two tasks related to the Sensory Orientations domains (i.e., standing with a closed eye on the force plate (CS), and standing with open eyes on foam on a force plate (OF)) are shown in Figure 1. Sway in AP & ML directions, sway velocity in the AP direction, and Area of displacement show differences between the healthy subjects and the PwMS. But there was no difference between the two groups in the velocity parameter in the ML direction. Due to a large amount of data in this section, the correlation between the parameters related to ML and AP sways in the two tasks related to the Anticipatory Postural Adjustments domains, and the two tasks related to the Sensory Orientations domains are presented in Table 3.

The pattern of AP&ML sways during the two tasks (STOE), and (STOS) are shown in Figure 2. In the STOS task, AP sway in the PwMS was approximately similar to AP sway in HP, but in ML sway the difference between the two groups is more prominent. In the STOE task, the AP sway in the PwMS is

significantly greater than the sway in HP. While the ML sway in the two groups have fewer differences.

3.3 The BESTest is a valid tool for balance assessment in PwMS compared to force plate analysis

There were significant negative correlations between the parameters related to AP sway in the tasks of OS, CS, OF, TB, CF, and W with domains Biomechanical Constraints, Anticipatory Postural Adjustments & Sensory Orientations and the total BESTest scores. In addition, the OS task had significant negative correlations with substations Biomechanical Constraints, Stability Limits/Verticality, Anticipatory Postural Adjustments, Sensory Orientations & Stability in Gait, and CS task correlates significantly with systems Biomechanical Constraints, Anticipatory Postural Adjustments, postural reactions, Sensory Orientations & Stability in Gait. Although these tasks were designed to simulate the Sensory Orientations System of the BESTest, they were also highly correlated with systems Biomechanical Constraints, Anticipatory Postural Adjustments, Postural Responses & Stability in Gait. Further, significant negative correlations were found between CS tasks with all the BESTest domains in ML sway. The rest of the tasks were highly correlated with almost all of the first and third BESTest' systems. These data indicate that the BESTest is well correlated with the force plate parameters. Regarding the Anticipatory Postural Adjustments domains related tasks, RH had significant negative correlations with almost all BESTest domains except the second domains. In almost all tasks except STOS, AP sway was highly correlated with subjects' scores on domains Biomechanical Constraints. In the ML sway, the STOS task had significant negative correlations with all the BESTest' subsystems except domains postural reactions.

The sway velocity in the AP axis in all the Sensory Orientation tasks had significant negative correlations with the scores of subjects in all the BESTest' domains except system Stability Limits/Verticality (Table 4). In the tasks based on Anticipatory Postural Adjustments domains, RH was significantly correlated with all domains except domains Stability Limits/Verticality & Stability in Gait. No significant correlations were found in the ML axis between the sway velocities with the

BESTest scores. Table 5 shows the correlations between the area of displacement during the tasks on the force plate and the BESTest scores.

The area of displacement during different Sensory Orientation tasks had significant negative correlations with BESTest scores. Especially CS had significant correlations with all the domains. Among the tasks based on anticipatory postural adjustment, RH significantly correlates with almost all domains except the second domains. The STOS had the most correlation with the second domains.

4. Discussion:

The results showed that the scores of the different BESTest domains except for domains Stability Limits/Verticality were significantly different in PwMS and healthy individuals. Besides, the two groups had significant differences in the AP&ML sway during the tasks based on the BESTest domains. However, the difference between the two groups in the AP sway was higher than ML sway. There were significant differences between the two groups regarding the amount of sway in the AP&ML directions, and the area of displacement. However, significant difference in the sway velocity only observed in the AP but not in ML axis. These findings indicate that both the BESTest as accurate as force plate differentiates balance disorders. The precise findings of the force plate support the functional outcomes of the BESTest.

Investigation of the correlation between the BESTest scores and the force plate measurements showed significant negative correlations between the sway parameters in the AP direction. Besides, the sways in the ML direction correlated negatively with the scores of the BESTest. This finding confirms that the higher a people score in the BESTest systems, the lower the sway in the AP&ML directions. Furthermore, the area of displacement had a significant negative correlation with the BESTest' scores. That is, the higher a person's score is in the BESTest, the lower his or her sway area. These findings support that the individual's scores in the BESTest can clearly and precisely predict the sways due to balance problems in the PwMS.

Presence of correlation only in AP, but not ML, between displacement velocities with the BESTest scores, is consistent with the previous report by Ch.Lee et al and Negahban et al (19, 22) .

Furthermore, the researchers have reported that the ML direction was less affected by balance disorders in static conditions than AP directions (23). Hence, it is acceptable that velocity in ML direction show no difference between the two groups. According to table 3, each task in the ML direction is also less correlated with the domains from which it is derived. Also, the velocity of sway in the ML direction was not significantly correlated with any of the BESTest domains. This is justified by the fact that the ML direction is less affected in static conditions

In a previous study, the validity of the BESTest measured using laboratory tests, force plate, motion recording, and EDSS testing in PwMS (n=13) and healthy people (n=13). The results showed a significant correlation between BESTest Scores with laboratory tests on the speed of the steps when starting the walking (Pearson correlation coefficient 0.48, $p < 0.01$). It also showed a good correlation between the changes in pressure center on both sides (Pearson correlation coefficient 0.55, $p < 0.005$), and Postural response (Pearson correlation coefficient 0.76, $p < 0.0001$). The BESTest's overall score was accurate in diagnosing people at risk of falling from the people without risk of falling. It also showed a significant correlation with EDSS (Pearson correlation coefficient 0.85, $P < 0.0005$) (24).

In another study, 110 PwMS tested and retested by two examiners, in two stages. Kronach's alpha coefficients calculated to be above 0.70 in all domains of the BESTest questionnaire. Also, the range of ICC values of each domain of the BESTest in test-retest was 0.84 to 0.99. In addition, the intrarater correlation coefficients in all 6 domains calculated from 0.76 to 0.99. (12). also, to validate the Norwegian version of BESTest and Mini BESTest, 3 groups (people over 65, people with a history of stroke or MS) assessed and correlation validity measured by FES_I test. BESTest showed good interrater reliability (ICC = 0.98)) and test-retest reliability (ICC = 0.89), and a moderate correlation was found between the FES_I test with the BESTest (Spearman rho = 0 / 51, $P < 0/01$). (25).

Further, in a cohort study, 49 patients with acute stroke selected with an average age of 57.8 $\pm$ 11.8 and Mini BESTest, BESTest, BBS, and CB&M tests performed before and after rehabilitation, this study showed that BEST compared to CB&M and Mini BESTest is more sensitive to equilibrium changes, has no ceiling and floor effects compared to other equilibrium tests. Post-test accuracy and

specificity of this test are higher than the two CB&M and PASS tests in patients whose balance has improved ($P < 0.01$) (26).

In another observational study, BESTest's validity and reliability measured for people with acute stroke. Seventies patients included in the study for convergent validation. BBS, PASS, CB&M and Mini BESTest tests performed. Good reliability ($ICC = 0.99$) and a high correlation with other equilibrium tests observed (Spearman correlation coefficient in BBS, CB&M, and Mini BESTest tests were 0.96, 0.96, and 0.91, respectively)(27). This test has also been shown to be highly convergent. The ceiling- floor effects were not seen in this test. Further the correlation coefficient between BEST, BBS and ABC_Brazil is reported 0.78 and 0.59, respectively (28). To investigate the relationship between BEST and BSS, 100 patients with stroke and 20 healthy people with a range of 60-45 years evaluated. There was a strong negative correlation between BESTest and BSS ($r = -0.8672$, $p < 0.0001$)(29).

Limitations

There were several limitations to this study. Specifically, the sample size of each group was small ($n=17$), despite this the differences across all BESTest balance domains were significant.

5. Conclusions

This study has provided evidence to support the use of the BESTest in PwMS for balance assessment, as the subjective clinical evaluation with the BESTest was comparable to the laboratory reference of force plate analysis and shows good validity to assess PwMS. In general, According to the obtained results, it can be said that test BESTest has a high sensitivity in showing COP changes, and considering that each task has a better correlation with its related subsystem, therefore it can be said that this test has also specificity, as a result BESTest can help therapists in planning treatment and evaluating the rehabilitation outcomes of MS patients.

Declarations

Ethics approval and consent to participate: The ethical committee of the USWR.AC.IR approved the study (USWR.AC.IR. 1394.30).

Consent for publication: There is no individual person's data in the article.

Availability of data and materials: Data are available in:

<https://data.mendeley.com/drafts/58tft58vd4>

Competing interests: there is no competing interest.

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Authors' contributions:

Fatemeh Hossein poor: evaluated patients using the Bestest and preparing the manuscript (Writing Original Draft, investigation and conducting research)

Mozhgan Valipour: evaluated patients using the Bestest

Hossein Taghadosi was involved in conducting and controlling the research process, Software, Data curation, formal analysis.

Samaneh Hossein Zadeh was corresponding for application of statistical analyses, validation, and computation.

Haghgoo, Hojjat Allah: was corresponding to designing the research, controlling the execution, preparing the manuscript and submission (conceptualization, Writing-Review& Editing, Supervision, Project administration). All authors read and approved the final manuscript."

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Conflict of interest statement: all authors disclose any financial and personal relationships with other people or organizations that could inappropriately influence this work

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Figure 1: the pattern of anterior-posterior and Mediolateral sways during the tasks related to Sensory Orientation domains (CS and OF)

The pattern of Anterior-Posterior sway in CS task in PwMS and Healthy participants

The pattern of Anterior-Posterior sway in OF task in PwMS and Healthy participants

The pattern of Medial-Lateral sway in CS task in PwMS and Healthy participants

The pattern of Medial-Lateral sway in OF task in PwMS and Healthy participants

Figure 2. The pattern of the AP and ML sways during the STOE and STOS.

The pattern of Anterior-Posterior sway in STOS task in PwMS and Healthy participants

The pattern of Medial-Lateral sway in STOS task in PwMS and Healthy participants

The pattern of Anterior-Posterior sway in STOE task in PwMS and Healthy participants

The pattern of Medial-Lateral sway in STOE task in PwMS and Healthy participants

Table 1 – Objective balance measurement tasks on the Force Plate

Sensory Orientation	Anticipatory Postural Adjustments
1) Standing with Open Eye (OS)	1) Standing on the toe (STOE)
2) Standing with a closed eye (CS)	2) Stand on the right leg (OLSR)
3) Standing on Open Eye Foam (OF)	3) Standing on the left leg (OLSL)
4) Standing on closed foam (CF)	4) Sit down and lift (STOS)
5) Standing on wedge with closed eyes (W)	5) Stand and Raise the Hand in 90 degrees flexion
6) Standing on the tilt board (TB)	while holding a weight of 2.5 kilograms (RH)

Table 2. Mean and standard deviation in domains of BESTest in both healthy and MS groups

Domains	Mean(SD) Healthy	Mean(SD) PwMS	P_Value
Biomechanical Constraints	14.667±.485	9.706±3.057	<0.001
Stability Limits/Verticality	20.444±.784	19±3.279	0.195
Anticipatory Postural Adjustments	17.5±1.2	12.529±3.43	<0.001
postural reactions	17.389±.978	13.823±5.294	0.006
Sensory Orientations	15±0.000	13.471±3.338	0.007
Walking instability	20.556±.616	16.588±5.1	<0.001
Total score	105.2.148	85.118±19.968	<0.001

Table 3. The correlation between the sway in the ML and AP during the tasks related to the Anticipatory Postural Adjustments, and the Sensory Orientation domains on the force plate and the participants' scores in the BESTest domains.

Tasks. Axis	APAs	Sensory Orientation	Total
OS.AP	-.67**	-.57**	-.63**
CS.AP	-.79**	-.68**	-.78**
OF.AP	-.55**	-.36*	-.43**
CF.AP	-.60**	-.48**	-.57**
TB.AP	-.63**	-.62**	-.59**
W.AP	-.49**	-.48**	-.390*
STOE.AP	-.356*	-.16	-.32
STOS.AP	-.328	-.353*	-.312
RH.AP	-.83**	-.700**	-.78**
OLSL.AP	-.58**	-.343*	-.56**
OLSR.AP	-.52**	-.17	-.47**
OS.ML	-.637**	-.518**	-.516**
CS.ML	-.691**	-.700**	-.695**
OF.ML	-.423*	-.313	-.416*
CF.ML	-.588**	-.450**	-.537**
TB.ML	-.537**	-.540**	-.550**
W.ML	-.558**	-.482**	-.561**
STOE.ML	-.354*	-.32	-.351*
STOS.ML	-.599**	-.474**	-.622**
RH.ML	-.382*	-.297	-.369*
OLSL.ML	-.076	.139	-.122
OLSR.ML	-.348*	-.009	-.30

Abbreviations: AP: Anterior-posterior; ML: Medio-lateral, Sub: the BESTest' domains; tasks are mentioned in laboratory activities

Table 4. The correlation between the sway velocity in ML and AP directions during the tasks related to the Anticipatory Postural Adjustments and the Sensory Orientation domains on the force plate and the participants' scores in BESTest domains.

Speed in m/s	APAs	Sensory Orientation	Total
V.OS.AP	-.731**	-.634**	-.747**
V.CS.AP	-.695**	-.637**	-.682**
V.OF.AP	-.609**	-.513**	-.606**
V.CF.AP	-.616**	-.466**	-.641**
V.TB.AP	-.544**	-.460**	-.574**
V.W.AP	-.544**	-.34*	-.535**
V.STOE.AP	-.33	-.27	-.351*
V.STOS.AP	-.199	-.35	-.22
V.RH.AP	-.553**	-.602**	-.580**
V.OLSL.AP	-.26	-.15	-.295
V.OLSR.AP	-.47**	-.22	-.437**
V.OS.ML	-.007	-.1	-.018
V.CS.ML	-.126	-.24	-.12
V.OF.ML	-.019	-.09	-.011
V.CF.ML	-.116	-.16	-.13
V.TB.ML	-.07	-.14	-.04
V.W.ML	-.128	-.21	-.16
V.STOE.ML	-.19	-.32	-.19
V.STOS.ML	-.07	-.25	-.02
V.RH.ML	.038	-.097	.020
V.OLSL.ML	-.15	.021	-.16
V.OLSR.ML	-.32	-.13	-.27

Abbreviations: AP: Anterior-posterior; ML: Mediolateral, m/s: meter per second; Sub: the BESTest' domains; V: Velocity; tasks are mentioned in laboratory activities.

Table 5. The correlation between the areas of sway during the tasks related to the Anticipatory Postural Adjustments and the Sensory Orientation domains on the force plate and the participants' scores in the BESTest domains.

Area	APAs	Sensory Orientation	Total
A.OS	-.787**	-.628**	-.724**
A.CS	-.764**	-.685**	-.736**
A.OF	-.528**	-.391*	-.471**
A.CF	-.680**	-.558**	-.648**
A.TB	-.606**	-.648**	-.600**
A.W	-.570**	-.517**	-.535**
A.STOE	-.32	-.28	-.323
A.STOS	-.33	-.356*	-.33
A.RH	-.737**	-.643**	-.694**
A.OLSL	-.192	-.058	-.24
A.OLSR	-.391*	-.049	-.345*

Abbreviations: A: Area of displacement; Sub: the BESTest' domains; tasks are mentioned in laboratory activities.