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Maximum Step Length Test Performance in People with Parkinson Disease

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Abstract

Background and Purpose—The Maximum Step Length Test (MSLT), a measure of one's capacity to produce a large step, has been studied in older adults, but not in people with Parkinson disease (PD). We characterized performance and construct validity of the MSLT in PD.

Methods—Forty participants (mean age: 65.12±8.20; 45% female) with idiopathic PD completed the MSLT while OFF and ON anti-PD medication. Construct validity was investigated by examining relationships between MSLT and measures of motor performance. The following measures were collected: Mini-BESTest, ABC scale, gait velocity, 6MWT, MDS-UPDRS III, and TUG. A repeated measures ANOVA tested for main effects of medication and stepping direction and the interaction between the two. Pearson or Spearman correlations were used to assess the relationships between MSLT and motor performance measures ($\alpha=0.05$).

Results—Regardless of medication status, participants stepped further in the forward direction compared to the backward and lateral directions ($p<0.001$). Participants increased MSLT performance when ON-medication compared to OFF-medication ($p=0.004$). Regardless of medication status, MSLT was moderately to strongly related to Mini-BESTest, TUG, and 6MWT.

Discussion and Conclusions—People with PD stepped furthest in the forward direction when performing the MSLT. Increased MSLT performance was observed ON-medication compared to OFF-medication; however, the small increase may not be clinically meaningful. Given the relationships between the MSLT and the Mini-BESTest, 6MWT, and TUG, MSLT performance appears to be associated with balance and gait hypokinesia in people with PD. **Video Abstract available** for more insights from the authors (see Video, Supplemental Digital Content 1).

Keywords

Outcome measure; Parkinson disease; balance; gait

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Introduction

People with Parkinson disease (PD) typically demonstrate low amplitude, or hypokinetic, movements¹. These stereotypical movements occur during fine motor tasks such as handwriting², as well as gross motor tasks like walking³. In addition to these hypokinetic, planned movements, people with PD also demonstrate under-scaled reactive movements such as stepping in response to a balance perturbation⁴. These poor postural responses are associated with increased fall risk⁵ and occur in the forward, backward, and lateral directions⁶⁻⁸. While reactive stepping responses have been well-studied, to our knowledge, investigators have not yet examined the capacity of individuals with PD to produce a large, single step in a voluntary manner.

The Maximum Step Length Test (MSLT) was first described by Medell and Alexander⁹. It involves an individual stepping as far as possible in a given direction (e.g. forward, backward, lateral) and returning to a standing position without a loss of balance. Performance of the MSLT has been studied in older adults. MSLT performance is related to measures of balance such as the Berg Balance Scale, Functional Reach Test, and Tinetti Performance Oriented Mobility Assessment in older adults^{10,11}. Furthermore, Cho et al¹¹ showed the MSLT accurately identifies older adults who are at risk for future falls. From a clinical perspective, an added advantage of the MSLT is that it can be done quickly and requires only a measuring tape (demarcated in centimeters) to administer. Given the MSLT is feasible for clinical use and can be used to assess movements that are likely difficult for people with PD, we investigated MSLT performance in this population.

The purpose of this study was three-fold. We aimed to: 1) characterize MSLT performance in the forward, backward, and lateral directions in a sample of individuals with PD, 2) determine the effect of anti-PD medication on MSLT performance, and 3) investigate the construct validity of the MSLT by assessing relationships between the MSLT and measures of PD motor severity, balance, balance confidence, functional mobility, and gait. We had several hypotheses. First, MSLT distances would be shorter in the backward direction compared to forward given that people with PD tend to have more difficulty with movement in the backward direction¹². Second, MSLT performance would be worse in the OFF-medication condition compared to ON-medication in people with PD because movement is known to be more difficult in PD without dopamine replacement therapy¹³. Third, MSLT performance in all directions would be related to measures of balance, balance confidence, gait, and PD motor sign severity given that the movement inherent to the MSLT incorporates elements of balance and gait^{9,11}.

Methods

Participants

This study was conducted as a cross-sectional study within a large exercise trial (NCT01768832)¹⁴. Participants included in this study were a sample of convenience from the larger trial and were consecutively recruited to perform the MSLT during their scheduled laboratory visit. To be included in the exercise trial, participants must have been: 1)

diagnosed with idiopathic PD, 2) at least 30 years of age, 3) between Hoehn & Yahr stages I–IV, and 4) able to walk independently with or without an assistive device for at least three meters. Participants were excluded if they had: a Mini-Mental Status Exam score less than 24, a neurologic condition other than PD (e.g., stroke), undergone surgical management for PD. All participants provided written informed consent in accordance with the policies and procedures of the Human Research Protection Office at Washington University in St. Louis.

Maximum Step Length Test

Each participant performed the MSLT in three stepping directions: 1) forward, 2) backward, and 3) lateral. This order was the same for each participant for both medication conditions. For the MSLT, the participant wore shoes and stood with the arms folded across the chest. The participant was instructed to step out as far as possible and then return to the original standing position. For each stepping direction, three practice trials were given prior to five recorded test trials with each leg. Trials in which an error occurred were discarded. Errors were defined as one or more of the following occurring during a trial: unfolding of the arms, displacement of the stance limb, inability to return to the starting stance position, non-compliance with stepping direction, or a loss of balance requiring physical assistance to regain stability^{9,11}. For each stepping direction, participants stepped with both dominant and non-dominant legs. Leg dominance was determined by asking each participant, “If a ball were rolled directly at you, with which foot would you kick the ball?” If a participant responded that they would kick the ball with the right leg, the right leg was deemed the dominant leg¹⁵.

For the forward and backward stepping directions, the starting position was with the feet approximately shoulder-width apart. The most anterior portion (i.e. the toe portion of the shoe) of the stepping foot was centered on the measuring tape at zero. The measuring tape was marked in centimeters. The measurement was collected from the point where the most anterior portion (i.e. the toe portion of the shoe) of the stepping foot landed. For the lateral directions, the starting position was with the feet close together but not touching. This was done to maximize each participant’s ability to step in the lateral direction. The mid-point (i.e. middle of the shoe when viewing the participant head-on) of the stepping foot was centered on the measuring tape at zero. The measurement in the lateral direction was collected from the point where the mid-point of the stepping foot landed. All measurements, to the nearest centimeter, were collected using visual observation of the examiner, who immediately recorded each trial on the data collection form. The examiner was not blinded to medication status. A research assistant stood near the participant to provide assistance for safety if needed.

MSLT measures were normalized to leg length to account for the effect of leg length on MSLT performance. This was done by dividing the average MSLT stepping distance for each direction (cm) by the leg length of the stepping leg (cm). The MSLT has been reported to have excellent inter- and intra-rater reliability (ICC=0.96 and ICC=0.95, respectively) in older adults¹⁰. Given the correlation between the MSLT and single limb stance time ($r = 0.68$), TUG ($r = -0.65$), and functional reach test ($r = 0.65$), the MSLT has been reported to be a valid measure of balance performance in older adults¹⁰.

Motor Performance Tests

To assess construct validity of the MSLT, we utilized measures of balance, balance confidence, functional mobility, gait, and PD motor severity. Balance was measured using the Mini-Balance Evaluation Systems Test (Mini-BESTest)¹⁶. This test includes 14 items, each scored on a rank scale of 0–2, with 2 indicating no impairment in balance. Higher scores indicate better balance. There are four subsections of the Mini-BESTest, which assess the following unique balance systems: 1) anticipatory postural adjustments, 2) reactive postural responses, 3) sensory orientation, and 4) stability in gait. For the purposes of this study, we collected the total and individual subsection scores. Self-perceived balance confidence was assessed using the Activity-specific Balance Confidence (ABC) Scale¹⁷. This 16-item questionnaire addresses a participant's perceived balance confidence when performing specific tasks. A score of 0 indicates no confidence in balance during a particular task while 100% indicates complete confidence in balance during a particular task. The average score of the 16 items was calculated. Functional mobility was measured using the Timed Up & Go¹⁸ (seconds), which was collected as part of item 14 within the Mini-BESTest.

Gait velocity was measured using GAITRite, a computerized, 5-meter walk way that collects data related to spatiotemporal gait parameters. Participants performed 3 trials at their self-selected forward walking speed. The average velocity (meters/second) was normalized to leg length. Walking endurance was measured using the 6 Minute Walk Test (6MWT)¹⁹. Participants were instructed to “cover as much ground as possible” over 6 minutes. The distance (meters) traversed over 6 minutes was recorded.

Motor sign severity was measured using the Movement Disorder Society-Unified Parkinson Disease Rating Scale subsection III (MDS-UPDRS III)²⁰. This 33-item scale is a gold standard for assessment of bradykinesia, rigidity, tremor, postural instability, and gait difficulty in persons with PD.

Procedures

Participants completed the full test battery in both the OFF- and ON-medication conditions in the following order: 1) MDS-UPDRS III, 2) Mini-BESTest, 3) GAITRite, and 4) MSLT. The tests were done in a fixed order given the protocol of the original clinical trial. Because the MSLT was not part of the protocol for the original clinical trial, it was completed last to avoid impacting performance of any other measures. The MDS-UPDRS III and Mini-BESTest were scored by a rater trained in administering and rating these assessments. The rater was blinded to medication status. The ABC scale was completed prior to each participant's laboratory visit. Off-medication was defined as greater than or equal to 12 hours since last intake of anti-PD medication. ON-medication evaluations began at least 45 minutes and no more than 1.5 hours after intake of anti-PD medication.

Data Analysis

Descriptive statistics were used to characterize the sample. Normality was assessed using Shapiro-Wilk tests. A 2-factor repeated measures analysis of variance (ANOVA) was used to assess for main effects of medication (OFF vs. ON) and direction (forward vs. backward vs.

lateral), as well as interactions between medication condition and stepping direction ($\alpha=0.05$). Post-hoc tests were conducted as appropriate. The relationships between MSLT and motor performance tests for OFF- and ON-medication conditions were assessed using Pearson or Spearman correlations ($\alpha=0.05$) as appropriate. OFF-medication MSLT stepping distances were used in correlations run for physical performance measures collected OFF-medication. Similarly, ON-medication MSLT stepping distances were used in correlations run for physical performance measures collected ON-medication. Correlations were run between the ABC score and both OFF- and ON-medication MSLT stepping distances.

Results

Of 49 eligible participants, forty participants with mild to moderate PD completed testing in both OFF- and ON-medication conditions (Table 1). Nine participants did not perform the MSLT for the following reasons: not on levodopa ($n=5$), excessive fatigue ($n=3$), and hip pain ($n=1$). Of the nine participants not performing the MSLT, seven were H&Y II with OFF-medication state MDS-UPDRS III scores ranging from 26–43 indicating their motor sign severity was similar to the sample completing the MSLT. The additional two participants not performing the MSLT, both due to excessive fatigue, were H&Y III with OFF-medication state MDS-UPDRS III scores of 50 and 52, respectively. There were no adverse events associated with MSLT performance.

All MSLT data were normally distributed. Although there were statistically significant differences in MSLT stepping distance between dominant and non-dominant legs, the mean raw data indicates these differences were small (i.e. 3.71 cm regardless of medication status for each direction (see Supplementary Table 1)). Furthermore, the relationships between motor performance measures and MSLT dominant and non-dominant stepping distances were similar (see Supplementary Tables 2 and 3). As such, for all analyses, we used the average stepping distance (overall mean, collapsing across dominant and non-dominant legs) normalized to leg length.

There was a significant effect of direction ($(F(2,38)=23.86, p<0.001)$) such that participants stepped further in the forward direction when compared to the backward ($t=8.95, p<0.001$) and lateral ($t=2.58, p=0.012$) directions (Figure 1). Participants also stepped further in the lateral direction than they did in the backward direction ($t=-5.95, p<0.001$). There was a significant effect of medication condition on MSLT performance such that participants had increased stepping distance when ON-medication compared to OFF-medication, regardless of stepping direction ($F(1,39)=9.52, p=0.004$) (Figure 1). There was no direction by medication interaction ($p=0.44$).

In the OFF-medication state, all MSLT directions were strongly related to each other ($r=0.89, p<0.001$) (Table 2). The strength of correlations between all MSLT distances, regardless of direction, and measures of motor performance ranged from weak to strong (range of $r: -0.38$ to 0.81) (Table 3). The MSLT was most strongly related to the Mini-BESTest ($r=0.72, p<0.001$) and 6MWT ($r=0.73, p<0.001$). In the ON-medication state, all MSLT directions were strongly related to each other ($r=0.86, p<0.001$) (Table 2). Except for the relationships between MSLT Forward and Lateral with MDS-UPDRS III as

well as MSLT Lateral with ABC, all MSLT distances were significantly related to all measures of motor performance (range of r : -0.26 to 0.76), with the strongest relationship between MSLT and 6MWT ($r = 0.75$, $p < 0.001$) (Table 3).

Discussion

To our knowledge, this is the first study of MSLT performance in people with PD. According to our results, regardless of medication state, forward MSLT performance is greater than both backward and lateral directions. This finding is not surprising given that people with PD are known to have difficulty with postural responses^{21,22} and gait^{23,24} in the backward direction¹². Our findings extend this previous work by demonstrating people with PD have greater voluntary stepping hypokinesia in the backward direction when compared to forward. Interestingly, Medell and Alexander⁹ reported no directional differences in MSLT performance in unimpaired young, unimpaired older, and impaired older women. This further supports the notion that difficulty moving in the backward direction distinguishes people with PD from neurologically healthy individuals. It is possible that the poorer backward MSLT is due to hypokinesia and to poorer and more variable anticipatory control^{xx} in persons with PD. With respect to raw stepping distance, the sample with PD had greater stepping distances (ranging from 70.82 to 84.96 cm – see Supplementary Table 1), regardless of direction, compared to impaired older adults (i.e. 2 or more falls in the past year and complaints of frequent unsteadiness; approximately 65 cm), but lower stepping distances than unimpaired older adults (approximately 90 cm)⁹. The lack of postural instability in our sample of participants with PD (i.e. 35 of 40 participants at H&Y II or less) may explain their larger stepping distance compared to impaired older adults. However, these comparisons should be interpreted with caution as Medell and Alexander⁹ included only women who used only the right leg to perform the MSLT.

Biomechanical factors cannot be ruled out as having unique contributions to MSLT performance in the PD population. For example, stooped posture, which is common in PD¹³, may disproportionately shift the center of mass anteriorly thus making backward movement more difficult. Lower extremity muscle rigidity¹³, particularly in the hip flexors, may limit the ability to extend the hips during the backward stepping movement. Finally, muscle strength^{25,26}, if impaired in the stepping or stance limb, may negatively impacted postural control during MSLT performance. Investigators should measure these biomechanical factors in the future to determine how they impact performance of each MSLT direction in PD.

We also show that people with PD demonstrate a statistically significant improvement in MSLT performance when ON-medication compared to OFF. However, the magnitude of the differences between OFF- and ON-medication MSLT performance (normalized to leg length) are small (Figure 1, Supplementary Table 1) and may not be clinically meaningful as Goldberg et al¹⁰ have reported the MSLT to have a minimal detectable change of 7.32 inches (18.6 centimeters) in older adults. None of the differences between OFF- and ON-medication conditions exceed 5 centimeters (Supplementary Table 1), suggesting these differences may not reflect a meaningful change. Investigators have reported that improved gait velocity with levodopa is driven by an increase in step length, suggesting levodopa

uniquely impacts movement size^{27–29}. While our results fail to show a large increase in MSLT stepping distance when ON-medication compared to OFF-medication, the MSLT should not be considered solely as a measure of movement amplitude capacity. The MSLT involves many elements of postural control during performance of the test (e.g. anticipatory weight shift, single limb stance, maintaining balance within a new base of support); the strong relationship between the MSLT and Mini-BESTest is evidence of these requirements. The effects of levodopa on postural control and balance are less clear. While investigators have reported improved Mini-BESTest³⁰ and Functional Gait Assessment³¹ scores ON-medication compared to OFF, others have noted worsened sway during static stance with levodopa^{32,33}. Our sample demonstrated only a 1-point increase in the Mini-BESTest score ON- compared to OFF-medication, which is similar to the small magnitude OFF to ON change in MSLT performance. As such, if the MSLT is assumed to be reflective of balance in PD, our results are in keeping with those studies reporting no clinically meaningful improvement in postural control when on levodopa.

Within the MSLT, all directions were strongly related to one another regardless of medication status. The positive, strong correlations suggest that those who step farther in the forward direction also step farther in the backward and lateral directions. This suggests the underlying construct measured by the MSLT is similar regardless of direction, and calls into question whether the information gained from each direction is unique. However, the fact that people step farther forward than they do backward or to the side suggests that although the underlying construct measured by the MSLT may be similar regardless of direction, other factors (e.g. biomechanical factors) might account for the observed differences in stepping length across directions. Investigators should continue to study the properties of the MSLT to determine if each of the three directions provide unique clinical information and determine how biomechanical factors impact MSLT performance.

Regarding the relationships between MSLT and measures of motor performance, the strongest relationships exist between MSLT (regardless of direction) and the Mini-BESTest, Timed Up & Go, and 6MWT, respectively. The relationships between the MSLT and Mini-BESTest and TUG are not surprising given that assessment of anticipatory postural control and stability in gait are included within the Mini-BESTest¹⁶ and TUG¹⁸. These constructs seem to overlap with the MSLT; however, the unexplained variance in the relationships suggest the MSLT is measuring something not captured within the Mini-BESTest and TUG, particularly when assessed ON-medication. Interestingly, except for the Stability in Gait sub-section in the ON-medication condition, all of the correlations between the individual Mini-BESTest sub-sections and MSLT directions were weaker than those between the Mini-BESTest total score and MSLT directions. As previously noted, the MSLT requires multiple balance components including anticipatory postural adjustment, single limb balance with concurrent movement of the opposite lower extremity, static balance control in-stride with an extended base of support. It is possible the correlations between the individual subsections of the Mini-BESTest were weaker because they capture performance of a singular construct, while the MSLT likely captures performance spanning multiple constructs. The similarities between the correlations of the Stability in Gait sub-section with MSLT and Mini-BESTest total with MSLT potentially suggest this sub-section and the MSLT are measuring similar constructs ON-medication. However, the relationships in the

OFF-medication condition do not confirm this. The relationship between MSLT performance and measures of balance has been reported in the older adult population and the strength of these relationships are similar to that of relationships reported herein^{10,11}. The strong relationship between the MSLT and the 6MWT, regardless of medication status, was not expected. However, Falvo and Earhart³⁴ reported that 6MWT distance is partly explained by impaired balance in PD, while Canning et al³⁵ reported that gait hypokinesia impacts 6MWT performance. Taken together, this suggests the relationship between the 6MWT and MSLT may be explained by the constructs of balance and gait hypokinesia in the PD population.

Limitations

This study is not without limitations. First, this was a relatively small sample of people with PD with mild to moderate motor severity. To this point, 87.5% of the study sample was classified as H&Y I or II indicating no postural instability as measured by the MDS-UPDRS III²⁰. As such, the results may not be generalizable to the PD sub-population with significant postural instability, creating the need for validation of these findings in a sample with PD exhibiting a wider range of motor sign severity. Related to the procedures, OFF-medication testing was always completed before ON-medication testing, so we cannot rule out that a learning effect may have contributed to the results. This testing order was chosen to minimize participant burden by avoiding two separate laboratory visits. Also, the examiner was not blinded to medication status; however, the small magnitude of differences between OFF- and ON-medication performance suggest that potential bias is unlikely to have influenced the results. Future studies should randomize the order of testing, blind the examiner, and attempt to study OFF- and ON-medication MSLT performance on separate days. Because this was a cross-sectional study and reflects participant performance at only one point in time, investigators should also study the variability in MSLT performance on different days within the same medication state allowing for calculation of the minimal detectable change, this will facilitate determination of the stability of the MSLT over time in PD. Finally, we lacked a sufficient number of participants with a fall history prohibiting further analyses. However, these results warrant further investigation into the ability of the MSLT to predict fall risk in people with PD.

Conclusion

In people with PD, stepping distances for the MSLT were greatest in the forward direction followed by lateral and backward stepping. They demonstrated improved MSLT performance, albeit small in magnitude, in the ON-medication state compared to OFF-medication. Irrespective of medication status, the MSLT has moderate to strong relationships with the Mini-BESTest, TUG, and 6MWT. Overall, MSLT performance appears to be explained by balance and gait hypokinesia in people with PD.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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Figure 1.

Normalized MSLT distances OFF (black) and ON (gray) anti-PD medication categorized by direction. Solid black line indicates significant differences between MSLT directions.

Brackets indicate significant differences between OFF- and ON-medication within an MSLT stepping direction. Values are means $\pm$ 2 Standard Error.

Table 1

Participant Demographics (n=40)

Gender (n(%) female)	18 (45%)
Age *	65.1 $\pm$ 8.2
Years with PD *	4.8 $\pm$ 3.7
Levodopa Equivalent Daily Dose (mg)	898.4 $\pm$ 601.1
Hoehn & Yahr (Stage(n))	I (1), II (34), III (5)
OFF MDS-UPDRS III ^	34.0 (27.0, 39.0)
ON MDS- UPDRS III ^	29.5 (24.3, 36.8)
OFF Mini-BESTest ^	20.0 (18.0, 23.0)
ON Mini-BESTest ^	21.0 (19.0, 23.0)
ABC ^	84.4 (56.4, 91.6)
OFF TUG (s) *	10.5 $\pm$ 2.7
ON TUG (s) *	9.7 $\pm$ 2.4
OFF 6MWT (m) *	449.6 $\pm$ 99.1
ON 6MWT (m) *	483.6 $\pm$ 105.3
OFF Gait Velocity (m/s) *	1.4 $\pm$ 0.2
ON Gait Velocity (m/s) *	1.5 $\pm$ 0.3

* - values are mean $\pm$ SD;

^ - values are median (IQR)

Table 2

Correlations (Pearson) between MSLT directions.

OFF Medication				ON Medication			
	Forward	Backward	Lateral		Forward	Backward	Lateral
Forward	-	0.89**	0.92**	Forward	-	0.88**	0.93**
Backward	-	-	0.89**	Backward	-	-	0.86**
Lateral	-	-	-	Lateral	-	-	-

* - indicates p < 0.05;
** - indicates p < 0.01

Table 3

Correlations between MSLT and motor performance.

OFF Medication				ON Medication			
	Forward	Backward	Lateral		Forward	Backward	Lateral
MDS-UPDRS III [^]	-0.39 ^{**}	-0.58 ^{**}	-0.38 [*]	MDS-UPDRS III [^]	-0.31	-0.56 ^{**}	-0.26
Mini-BESTest [^]	0.72 ^{**}	0.81 ^{**}	0.73 ^{**}	Mini-BESTest [^]	0.68 ^{**}	0.69 ^{**}	0.59 ^{**}
Mini-BESTest - APA [^]	0.56 ^{**}	0.65 ^{**}	0.52 ^{**}	Mini-BESTest - APA [^]	0.35 [*]	0.54 ^{**}	0.27
Mini-BESTest - PR [^]	0.57 ^{**}	0.61 ^{**}	0.61 ^{**}	Mini-BESTest - PR [^]	0.53 ^{**}	0.51 ^{**}	0.38 [*]
Mini-BESTest - SO [^]	0.42 ^{**}	0.42 ^{**}	0.38 [*]	Mini-BESTest - SO [^]	0.41 ^{**}	0.32 [*]	0.39 [*]
Mini-BESTest - SG [^]	0.54 ^{**}	0.66 ^{**}	0.59 ^{**}	Mini-BESTest - SG [^]	0.66 ^{**}	0.72 ^{**}	0.70 ^{**}
ABC [^]	0.41 ^{**}	0.49 ^{**}	0.43 ^{**}	ABC [^]	0.31 [*]	0.39 ^{**}	0.30
TUG	-0.57 ^{**}	-0.62 ^{**}	0.65 ^{**}	TUG	-0.64 ^{**}	-0.67 ^{**}	0.64 ^{**}
6MWT	0.76 ^{**}	0.73 ^{**}	0.80 ^{**}	6MWT	0.75 ^{**}	0.75 ^{**}	0.76 ^{**}
Gait Velocity	0.49 ^{**}	0.46 ^{**}	0.58 ^{**}	Gait Velocity	0.55 ^{**}	0.62 ^{**}	0.59 ^{**}

[^] - indicates Spearman correlation.

* - indicates p < 0.05;

** - indicates p < 0.01;

PA - Anticipatory Postural Adjustments; PR - Postural Responses; SO - Sensory Orientation; SG - Stability in Gait