



The role of sensory systems in the association between balance and walking in people with multiple sclerosis

ARTICLE INFO

Keywords

Walking
Balance
Somatosensory system
Vestibular system
Visual system
Six spot step test

ABSTRACT

Background: In Multiple Sclerosis, it has been demonstrated that balance is related to performances in walking tasks at different levels of complexity. However, it is unknown how the different sensory systems involved in balance control contribute to walking. This observational study investigates the associations between somatosensory, vestibular, and visual systems and measures of self-reported walking and walking capacity at different complexity levels (i.e. low, medium, and high).

Methods: People with MS with EDSS < 6 were assessed through the Sensory Organization Test (SOT), 12-Item MS Walking Scale (MSWS-12), Timed 25-Foot Walk (T25FW), Timed Up-and-Go Test (TUG), and Six-Spot-Step-Test (SSST). T25FW, TUG and SSST are measures of low, medium and high walking capacity, respectively.

Results: Forty-five PwMS were enrolled (EDSS: 3.4 ± 1.3). Capacity/ability walking measures were moderate-to-highly significantly associated ($p < 0.01$). Balance measures from SOT showed significant correlation ($p < 0.05$) between vestibular system and all the walking measures; between visual system and T25FW, SSST and MSWS-12; between the degree to which the patient relies on the visual system to maintain balance with conflicting visual surroundings information (VIS PREF) and T25FW and TUG. In the multivariate analyses, only VIS PREF significantly correlated ($p < 0.05$) with T25FW (std. Beta=0.42) and TUG (std. Beta=0.38).

Conclusions: Vestibular and visual systems are associated with walking capacity. However, tasks with higher complexity levels require more visual attention towards ground obstacles, as often seen in real-life activities, whereas simpler walking tasks seem to require visual attention towards the surroundings.

1. Introduction

Multiple Sclerosis (MS) leads to disability including deterioration of balance and gait (Kalron, 2016) that often prevent people with MS (PwMS) from performing activities of daily living (Callesen et al., 2019). Balance control relies on the integration of inputs from the somatosensory, vestibular, and visual systems, which together with the muscular system ensure sufficient upright posture and stability during walking.

Walking capacity is closely associated with posture balance and increased disability is associated with decreased walking speed and altered gait patterns (Kalron, 2016; Pommerich et al., 2022). Recently, Callesen et al. (2019) demonstrated that static and dynamic balance along with maximal muscle strength of the lower limbs were all significantly associated with walking speed and distance/endurance, whereas only balance was related to more complex walking tasks (e.g. changing direction).

It remains unknown how the different sensory systems are associated with the level of complexity of walking capacity tasks and with self-reported walking ability. Knowledge on these associations could help guide clinicians in interpreting results from different walking outcomes aimed at providing the optimal gait interventions.

This study aims at evaluating the associations between somatosensory, vestibular, and visual systems, assessed through the Sensory

Organization Test (SOT) (EquiTest, Neurocom, Clackamas, OR, USA) (Brichetto et al., 2015), and measures of walking capacity at low (Timed 25-Foot Walk, T25FW), medium (Timed Up-and-Go Test, TUG), and high (Six-Spot-Step-Test, SSST) complexity level and self-reported measures of walking ability (12-Item MS Walking Scale, MSWS-12).

2. Materials and methods

2.1. Participants

In this observational study, participants were recruited at the AISM Rehabilitation Service from July to November 2022. Inclusion criteria: age > 18 years; MS diagnosis; EDSS < 6. Exclusion criteria: relapses < three months; use of drugs interfering with balance performance. The local ethic committee of San Martino Hospital approved the study and all procedures were performed according to the Declaration of Helsinki. All participants provided written informed consent.

2.2. Outcome measures

The assessment consisted of SOT, T25FW, TUG, SSST, and MSWS-12 (Santisteban et al., 2021; Nieuwenhuis et al., 2006), randomly presented among participants.

Research Data: The dataset used and/or analysed during the current study is available from the corresponding author on reasonable request.

<https://doi.org/10.1016/j.msard.2024.105440>

Received 26 September 2023; Received in revised form 9 December 2023; Accepted 8 January 2024

Available online 9 January 2024

2211-0348/© 2024 Published by Elsevier B.V.

SOT objectively identifies the presence of postural control problems through a composite score (COMP). In addition, the sensory analysis allows determining the subject' ability to maintain balance by using visual (VIS), proprioceptive (PROP) and vestibular (VEST) sensory inputs, and the degree to which the patient relies on the visual system to maintain balance with conflicting visual surroundings information (visual preference score, VIS PREF). Lower scores indicate worse performances.

T25FW is a simple walking test, whereas TUG and SSST challenge functional mobility and add traits of complexity to walking (Fig. 1). The MSWS-12 is a self-report questionnaire of MS impact on walking ability (Cavanaugh et al., 2011).

2.3. Statistical analysis

Descriptive statistics are listed as mean ± SD for demographic and clinical information and as median and quartiles for outcome measures (not normally distributed data). Simple associations between SOT variables and walking capacity/ability outcomes were determined by Spearman's correlation analyses; correlations among capacity/ability walking outcomes were also evaluated. Correlation was considered as low for $r < 0.30$; moderate for $r: 0.30-0.59$; and high for $r \geq 0.60$. Multiple linear regression was used to determine the contribution of SOT measures as explanatory variables for walking capacity/ability. An a priori defined multivariate statistical model was applied with age and sex and SOT measures significantly correlated to walking in the bivariate analysis. Statistical significance was set at $p < 0.05$. Results are reported as standardized regression coefficients (Beta±SE) to directly compare the associations of the covariates across diverse measurement scales. Furthermore, r-squared is reported for each model.

No missing data were present.

3. Results

3.1. Participants

Forty-five PwMS were enrolled (32 females; age: 49.7 ± 10.8 years;

disease course: 34 RRMS, 9 SPMS and 2 PPMS; EDSS: 3.4 ± 1.3 ; and disease duration since diagnosis: 16.4 ± 11.1 years).

3.2. Outcome measures

Table 1 shows SOT scores and walking outcome measures.

The bivariate analysis revealed significant moderate-to-high associations between capacity/ability outcomes (T25FW vs. TUG, $r = 0.72$; T25FW vs. SSST, $r = 0.65$; T25FW vs. MSWS-12, $r = 0.51$; TUG vs. SSST, $r = 0.85$; TUG vs. MSWS-12, $r = 0.56$; SSST vs. MSWS-12, $r = 0.58$; all $p < 0.01$). (Fritz et al., 2016)

Walking measures were significantly correlated with COMP as well as vestibular and visual (VIS and VIS PREF) sensory systems (Table 1). No significant correlations were found for the somatosensory system and, for this reason, it was excluded from the multivariate analyses.

In the multivariate analyses, COMP was significantly correlated with all walking capacity/ability outcomes corresponding to standardized Beta values of -0.47 to -0.48 for TUG, SSST, and MSWS-12 but higher (-0.61) for T25FW. VIS PREF was significantly correlated to T25FW (std. Beta= 0.42) and TUG (std. Beta= 0.38). No correlations were found for VEST and VIS. COMP and VIS PREF explained 31–45 % of gait outcomes variance (Table 1).

4. Discussion

The findings of the present study add novel insight into the association between sensory systems involved in balance maintenance and walking capacity/ability in PwMS. Overall, our results show that a better postural control was significantly correlated to and the main predictor of better walking capacity and self-perceived walking ability. As demonstrated by the correlation between walking measures and composite score, stronger than with any individual measure in the SOT, multiple sensory factors appear to be involved in maintaining gait integrity. After all, patients with problems in the organization and integration of information from multiple sensory systems involved in balance maintenance could have difficulty safely navigating in environments with conflicting visual surroundings information, surfaces

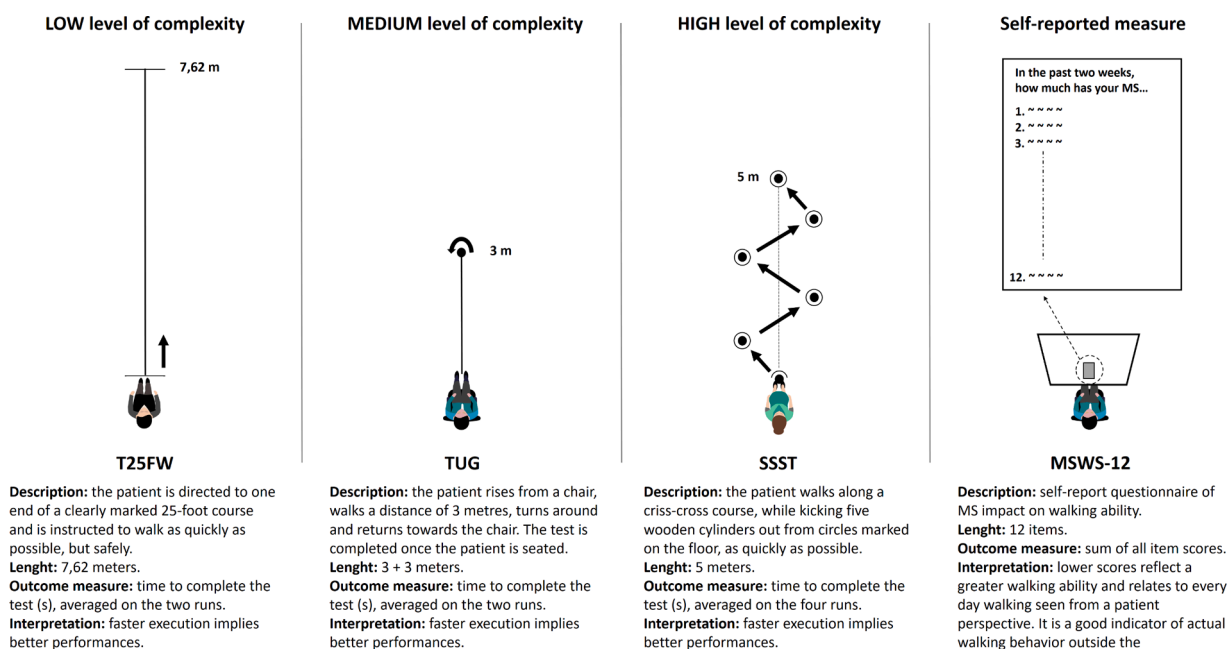


Fig. 1. Walking capacity/ability tests.

Visualization, description and interpretation of three walking capacity outcomes, i.e. the Timed 25-Foot Walk (T25FW), the Timed Up-and-Go Test (TUG), the Six-Spot-Step-Test (SSST); and self-perceived walking ability, i.e. the 12-Item MS Walking Scale (MSWS-12).

Table 1

Associations between gait outcomes and components of balance from the sensory organization test (SOT).

Median, [min; Q1; Q3; max]	COMP	SOM	VIS	VEST	VIS PREF			
	71.29 [40.83, 64.55, 78.37, 82.27]	1.11 [0.69, 0.97, 1.18, 1.48]	0.96 [0.54, 0.86, 1.05, 1.16]	0.74 [0.38, 0.68, 0.80, 0.93]	0.99 [0.75, 0.94, 1.05, 1.29]			
Median, [min; Q1; Q3; max]	T25FW (s)	TUG (s)	SSST (s)	MSWS-12				
	5.47 [3.81, 4.75, 6.94, 10.40]	9.28 [5.77, 7.85, 10.82, 15.95]	12.27 [7.43, 9.93, 14.67, 22.08]	31 [12, 20, 38, 53]				
Spearman correlation (r)								
COMP	-0.49*	-0.35*	-0.43*	-0.56*				
SOM	-0.04	0.06	0.20	-0.01				
VIS	-0.37*	-0.29	-0.31*	-0.33*				
VEST	-0.41*	-0.30*	-0.30*	-0.35*				
VIS PREF	0.30*	0.33*	0.25	0.12				
Multivariate analyses								
	Beta (SE)	R ²	Beta (SE)	R ²	Beta (SE)	R ²	Beta (SE)	R ²
COMP	-0.61 (0.18)*	0.45 †	-0.49 (0.20)*	0.34 †	-0.47 (0.18)*	0.31 †	-0.48 (0.18)*	0.33 †
VIS	-0.31 (0.21)		-		-0.20 (0.23)		-0.29 (0.22)	
VEST	0.43 (0.29)		0.14 (0.25)		0.10 (0.25)		0.13 (0.25)	
VIS PREF	0.42 (0.17)*		0.38 (0.18)*		-		-	
AGE	-0.07 (0.13)		-0.06 (0.13)		-0.03 (0.14)		-0.14 (0.14)	
SEX	0.03 (0.13)		0.17 (0.13)		0.17 (0.14)		-0.07 (0.14)	

Abbreviations; Central tendencies and dispersion of the gait outcome measures is expressed by median and quartiles [min; Q1; Q3; max]. Spearman correlations (r) depicts associations between gait outcomes and balance measures. Multivariate analyses show the association between gait outcomes (T25FW, TUG, SSST and MSWS-12) and balance measures (VIS, VEST, VIS PREF, and COMP). Standardized regression coefficients Beta and their corresponding standard errors is used to allow direct comparison of the associations of the covariates across the diverse measurement scales. R² is reported for each model and all models were age and sex adjusted.

* = $p < 0.05$, † = $p < 0.01$, T25FW = Timed 25-Foot Walk, TUG = Timed Up-and-Go Test, SSST = Six-Spot-Step-Test, MSWS-12 = Twelve Item MS Walking Scale, COMP = composite score, VIS = visual sensory system, PROP = proprioceptive sensory system, VEST = vestibular sensory system, VIS PREF = visual preference score.

changes/irregularities or obstacles on the ground.

However, by looking at the contribution of the individual sensory systems, vestibular but not somatosensory information was correlated to walking. As expected, the integration of vestibular information can be impaired in PwMS even in the presence of normal reflexive vestibular functions leading to reduced walking capacity (Cochrane et al., 2021).

In addition, although we did not use any eye-trackers to track gaze, one could speculate that the visual system was differently involved in balance maintenance depending on the type of the walking test. Recent evidence suggests that PwMS strongly rely on visual feedback for motor planning and execution, which could explain the fundamental role played by the visual system during walking (Selgrade et al., 2020).

In T25FW and TUG, no obstacles are present - apart from the TUG turning point - making safe to look ahead while walking. Moreover, in these clinical tests, the optical flow is not altered with perturbations in the medio-lateral and antero-posterior directions that could affect walking balance (Selgrade et al., 2020). Subjects showing a higher VIS PREF (higher discrimination ability) would likely need a longer optical flow elaboration to discern accurately between conflicting and not-conflicting visual information from the surroundings, which would be reflected in increased test completion time.

Conversely, as SSST requires subjects looking down while criss-crossing and kicking the cylinders, the visual attention is focused towards the targets. This would contribute to spatial coordination, agility and balance on one leg that, consequently, would result in better performance (Fritz et al., 2016). The analogous correlations found with MSWS-12 also suggests a similar engagement of the visual system while performing real-life walking (Fritz et al., 2016).

5. Conclusions

Overall, both vestibular and visual systems are involved in balance maintenance and walking performance. However, walking-related tasks with higher levels of complexity would require visual attention towards obstacles on the ground, as is often seen in real-world activities, rather than looking ahead, which is usually the choice during simpler walking tasks.

For future studies, the clinical interpretation could benefit from the

use of an eye-tracker during walking tests as well as a larger sample-size that would strengthen these results and make stratification on disability level possible.

Funding

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

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Declaration of competing interest

The author(s) declared no potential conflicts of interest with respect to the research, authorship and/or publication of this article.

Acknowledgments

We would like to acknowledge the significant contribution of Maria Madera and Giulia Bignone (secretariat) to the implementation of this protocol.

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