Gait & Posture 70 (2019) 90–94

Contents lists available at ScienceDirect

Gait & Posture

journal homepage: www.elsevier.com/locate/gaitpost

Full length article

The ability of the instrumented tandem walking tests to discriminate fully ambulatory people with MS from healthy adults

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A R T I C L E I N F O

Keywords:
Tandem
Dual task
Gait
Multiple sclerosis
Cognition backward

A B S T R A C T

Background: People with multiple sclerosis (PwMS) experience walking and balance deficits at the initial phases of the disease, even when classified as only minimally disabled. Complex balance tasks, such as tandem walking, are probably more sensitive in detecting mild balance difficulties compared to the standard traditional tests in this population.
Research question: The aim was to investigate different types of 3-meter tandem walking tests in fully ambulatory PwMS.
Methods: This observational case-control study included 50 participants; 25 PwMS, 17 women and 8 men, aged 35.2 (S.D = 8.6) and 25 healthy subjects, 18 women and 7 men, aged 34.3 (S.D = 6.1). The 3-meter tandem walk tests were performed during a single session. Each subject completed a sequence of 3 consecutive tests under 3 different task conditions: normal tandem walking, backward tandem walking and cognitive tandem walking. Tandem walking tests were evaluated via three small, lightweight axial wearable accelerometers (APDM, Oregon, USA).
Results: The mean EDSS for the MS group was 1.6 (S.D = 0.6) indicating minimal disability. PwMS walked slower and at a slower pace, with a prolonged double support and decreased swing phase compared to healthy subjects in normal and backward conditions. In contrast, during the cognitive task, non-significant differences were found in gait measures between the PwMS and the healthy controls. Significant differences were found between task conditions for all participants. All reduced their walking speed and walked at a slower pace in both the cognitive and backward conditions compared to the normal tandem walk condition. However, non-significant scores were found for the condition X group factor.
Significance: The study provides new insights into the 3-meter tandem walk test. Findings should improve evaluation and training of dynamic balance in fully ambulatory PwMS.

1. Introduction

Multiple sclerosis (MS) is the most common autoimmune disorder affecting the central nervous system and the most common neurological disease in young adults [1]. MS usually occurs between the ages of 20 and 50 and is twice as common in women as in men [2]. The more common symptoms include walking and balance difficulties, fatigue, weakness, spasticity and cognitive changes [3]. PwMS experience walking and balance deficits at the initial phases of the disease [4], even when classified as only minimally disabled [5,6]. Previous studies have confirmed that minimally impaired PwMS walk slower, with shorter strides, elevated gait variability and increased sway while standing compared to healthy adults [7,8].

Clinical gait and balance tests in PwMS suffer from a ceiling or floor effect in the minimally disabled (e.g Timed Up and Go test, Four Square Step test and Timed 25 foot walk test) [9,10]. Another test in this case should be considered: the 3-meter tandem walk test. This test is simple and well-established for use in a clinical neurological work-up. Previous research studies have found that this test can discriminate between patients with type 2 diabetes, with/without peripheral neuropathy [11,12], predict falls in the elderly [13] and detect people with vestibular impairments [14].

As for the MS population, Herbert et al's study of 249 PwMs found that the 3-meter tandem walk enhanced motor and cerebellar

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https://doi.org/10.1016/j.gaitpost.2019.02.022
Received 16 November 2018; Received in revised form 18 December 2018; Accepted 23 February 2019
0966-6362/

functional systems compared to the traditional Timed 25-foot Walk test [15]. Additionally, this test was found to have excellent sensitivity and specificity values and was able to classify PwMS with and without impairments in the motor or cerebellar functional systems at the early stages of the disease [16]. In the same context, mildly disabled PwMS (n = 20) demonstrated elevated trunk movements compared to healthy adults during the 8-meter tandem walk test [17]. The same research group reported that the neurological disability score, (represented by the EDSS) is correlated with increasing trunk sway during the tandem gait test in 37 PwMS [18].

When PwMS combine walking with a cognitive task such as talking, calculation, or memory recall, the demand for attention and executive function increases in order to control the gait. Moreover, previous studies have reported that walking-cognitive dual task tests are associated with disability, fear and risk of falling in PwMS [19,20]. Hence, performing the 3-meter tandem walk test with a concurrent cognitive challenge (cognitive-motor dual task) is plausible in minimally impaired MS, especially in light of studies demonstrating cognitive deficits very early in the MS disease process [21].

Therefore, the aim of this study was to examine the 3-meter tandem walk test with two distinct manipulations in fully ambulatory PwMS: a concurrent cognitive task and walking backwards. Wadje et al found that walking differences between PwMS and healthy controls were the greatest when walking backwards [22]. An instrumented measurement tool was utilized to improve accuracy. We hypothesized that MS participants will perform the test slower compared to healthy controls and that greater differences between groups would appear in the manipulated situations.

2. Materials and methods

2.1. Study participants

This observational case-control study included a convenience sample of 50 participants; 25 PwMS, 17 women and 8 men, aged 35.2 (S.D = 8.6), recruited from the Multiple Sclerosis Center, Sheba Medical Center, Tel-Hashomer, Israel. Twenty-five healthy subjects, 18 women and 7 men, aged 34.3 (S.D = 6.1) with no history of walking and/or cognitive impairments, served as controls. Inclusion criteria for the MS participants included: (1) a neurologist-confirmed diagnosis of definite MS according to the revised McDonald criteria [23]; (2) ≤ 3.0 on the Expanded Disability Status Scale (EDSS) [24], equivalent to fully ambulatory PwMS; (3) age range from 20 to 50 years; and (4) relapse-free for at least 90 days prior to testing. Exclusion criteria included: (1) orthopedic disorders that could negatively affect mobility; (2) major depression or cognitive decline hindering test instructions; (3) pregnancy; (4) blurred vision; (5) cardiovascular disorders; (6) respiratory disorders; (7) or ingestion of steroids or fampridine. All participating subjects signed an informed consent. The study was approved by the Sheba Institutional Review Board.

2.2. Experimental protocol

The 3-meter tandem walk tests were performed during a single session at the Sheba MS Center by a physical therapist experienced in neurological rehabilitation. Each subject completed a sequence of 3 consecutive tests under 3 different task conditions with a 1-min rest period between tests:

1) Normal tandem walking - Subjects were requested to walk across a 3-meter marked line, heel-to toe at a self-selected speed, with no gaps between steps and wearing their own casual footwear.
2) Backward tandem walking - Identical conditions to normal tandem walking. Subjects were requested to walk backwards while looking straight ahead.
3) Cognitive tandem walking - Identical conditions to normal tandem walking. Subjects were instructed to perform the Serial-7 Backward Tests [25] while walking tandem.

The Serial-7 Backward Test - starting from a 3-digit number (e.g. 350 or 400), the subjects were instructed to subtract 7 and articulate aloud the calculated number (e.g. 400, 393, 386, etc) while walking. In order to minimize a learning effect between the 3 consecutive tests, the tester presented different 3-digit numbers to be used by the subject when beginning to count backwards. Scores were recorded for the correct numbers.

2.3. Outcome measures

Tandem walking tests were evaluated via three small, lightweight axial wearable accelerometers (APDM, Oregon, USA) positioned on the dorsum of both feet and at the level of the lumbosacral junction, attached with elastic straps. The sensors and the respective APDM's Mobility Lab^{TM} Software analyzed the spatio-temporal parameters of gait. This system is both accurate and repeatable for measuring spatiotemporal gait parameters [26] and was used in a MS research study, demonstrating its ability to detect mobility differences between PwMS and healthy controls when traditional timed walking tests could not [27]. Spatiotemporal parameters extracted by the sensors included total time, stride velocity, cadence, double support and swing phase. The number of errors occurring while walking were recorded by the tester. Errors included taking a side step, touching a nearby object with the upper limb and/or creating a gap between the feet. The normal tandem condition was always given first. The tester stood beside the participant, ensuring the patient's safety during the tests. All tests were performed in a quiet room.

2.4. Statistical analysis

Data analysis was performed using IBM SPSS statistics software (Version 25.0 for Windows, SPSS Inc. NY, USA) and was initially examined for normality violations, outliers, errors and missing values. Descriptive statistics determined the demographic and clinical characteristics of the study participants. Group differences in age and gender distribution were determined using an independent sample-t and chi-square test, respectively. For each tandem test condition, the score was calculated as the mean of the 3 trials. Repeated measures analysis of variance (ANOVAs) were used to examine the differences between tandem walk conditions (normal, backward, cognitive) and between groups (PwMS vs. healthy). The task cost (TC) (%) for the tandem walk tests was determined by calculating the percentage change from normal tandem (NT) to cognitive-tandem (CT) and between NT to backward tandem (BT) using the following formula: (TC = ([NT – (CT or BT)]/NT x 100)).

All reported *P*-values were two-tailed. The level of significance was set at $P < 0.05$.

3. Results

Demographic and clinical data of the participating subjects are presented in Table 1. The mean EDSS for the MS group was 1.6 (S.D = 0.6) indicating minimal disability. Mean disease duration was 3.4 (S.D = 3.6) years. In terms of EDSS categories, the scores of the pyramidal, cerebellar and sensory divisions were 1.4 (S.D = 0.5), 1.3 (S.D = 0.5) and 1.4 (S.D = 0.5), respectively. No differences were observed between PwMS individuals and healthy controls in terms of age, height, body mass and gender ratio. The mean score of the MSWS-12 was 22.5 (S.D = 9.6) indicating mild-moderate walking difficulties due to MS. Demographic and clinical characteristics of the study sample are provided in Table 1.

Table 2 details the 3-meter tandem walk test results according to task condition and group allocation. PwMS walked slower and at a

Table 1
Clinical characteristics of the Study Sample.

P-value	Healthy (n = 25)	MS (n = 25)	Variables
0.679	34.3 (6.1)	35.2 (8.6)	Age (years)
0.987	18/7	17/8	Gender (F/M)
0.809	165.4 (11.7)	164.7 (6.0)	Height (cm)
0.244	66.8 (14.8)	62.6 (9.8)	Body mass (kg)
	–	3.4 (3.6)	Disease duration (years)
	–	1.6 (0.6)	EDSS (score 0-10)
	–	1.4 (0.5)	Pyramidal
	–	1.3 (0.5)	Cerebellar
	–	1.4 (0.5)	Sensory
	–	22.5 (9.6)	MSWS-12 (score 12–60)

Scores are mean (S.D).
EDSS: expanded disability status scale; MSWS-12: multiple sclerosis walking scale.

slower pace, with a prolonged double support and decreased swing phase compared to healthy subjects in normal and backward conditions. In contrast, during the cognitive task, non-significant differences were found in gait measures between the PwMS and the healthy controls (Supplement 1). Furthermore, no differences between groups were recorded as to the number of mistakes occurring during the cognitive task.

Significant differences were found between task conditions for all participants. All reduced their walking speed and walked at a slower pace in both the cognitive and backward conditions compared to the normal tandem walk condition. However, non-significant scores were found for the condition X group factor. This finding was verified by the task cost scores (Table 3). Task costs were calculated as the change in gait between normal tandem to the tandem cognitive condition and between NT to the BT condition. No differences between PwMS and heathy participants were found for 9 (out of 10) task cost parameters. Fig. 1 illustrates the stride velocity scores according to tandem condition and group allocation.

4. Discussion

The current study's aim was to investigate different types of tandem walking tests in fully ambulatory PwMS. The rationale behind this investigation was the belief that complex balance tasks are probably more sensitive in detecting mild balance difficulties compared to the standard traditional tests. Moreover, complex tasks might be a promising option which can generate enough stress to minimize floor/ceiling effects. Worth noting, the 3-meter tandem walk is an early marker of motor and cerebellar impairment in fully ambulatory PwMS [16]. Furthermore, early detection of gait and balance deficits may improve the management of this growing segment of PwMS [28].

Several interesting findings were discovered in this study. Firstly, the PwMS group performed the normal and backward 3-meter tandem walking tests slower than the age-gender matched healthy adults. This finding is in agreement with previous studies investigating dynamic balance in mildly disabled PwMS [17,18]. Corporaal et al (2013) reported that balance deficits, expressed in trunk sway during tandem gait, were highly correlated with the EDSS and the Dizziness Handicap Inventory (DHI) questionnaire scores in PwMS with normal performance on the clinical Romberg test [18]. Peebles et al's (2016) research also strengthens our findings [30]. The authors found that PwMS without clinical gait impairment (mean EDSS 1.6) walk with a greater step width compared to age matched healthy controls, indicating poor dynamic balance. Therefore, it is logical that when this patient subgroup is required to tandem walk, the dynamic balance difficulties will be more pronounced, as demonstrated by the present study. Additionally, Rosenblum & Melzer (2016) who examined a test similar to the tandem walk test (the narrow path walking test) performed with/without a cognitive challenge [29]. The number of step errors and trial velocity under the single task condition was moderately related with measures of dynamic balance in the MS subjects. Deficits in dynamic balance are most likely multifaceted in nature in PwMS [31]. Nevertheless, we believe that our results reinforce the view that these deficits are considerable despite the relatively low EDSS and young age of our participants.

A novel aspect of the study involves the tandem walk conditions. In addition to the standard tandem walk test, we examined the test via two separate manipulations, a concurrent cognitive task and while walking backwards. Previous research studies have demonstrated various versions of the tandem walk test. Usually the test is performed on the ground surface, however, several studies have examined the subjects while on narrow beams [32], with eyes closed [33], walking on different surface textures (e.g foam) [34] and during a cognitive dual-task [35]. The tandem walking test also ranges from 3 to 20 m long [13].

Interestingly, in contrast with the normal and backward conditions, no differences were recorded between the groups in the cognitive situation. Additionally, no differences were found for the task cost scores between the PwMS and healthy controls. We offer several explanations for this finding. Firstly, we speculate that the relatively short distance of the tandem test may be related to our findings. There is a possibility that fewer gait deviations occur at the initial phase of the dual-task trial, with more occurring during the later stages. Secondly, the cognitive-tandem test condition was challenging not only for the PwMS but also for the healthy participants. We believe that there is an upper limit in terms of the level of difficulty in which the tandem test is effective. At a certain level, the test cannot distinguish between healthy individuals and patients. Rosenblum & Melzer's (2016) findings strengthen this speculation. In a group of 30 PwMS, no relationships were found between balance tests (Functional Reach Test, Four Square Step test) and the narrow path walk test in the cognitive dual task condition [29]. Despite these assumptions, a combined cognitive-tandem walk trial can be used for training. A recent systematic review presented the benefits of cognitive-motor exercise programs in improving mobility and cognition in individuals with neurodegenerative disease [36].

A unique contribution of our study included the instrumented 3-meter gait assessment. Traditionally, scores of the 3-meter tandem walk include the total time measured with a stopwatch and the tracking of missteps and wobbling judged by the naked eye. In the present study, we evaluated the tandem walk tests via three small light motion

Table 2
Comparison of the Instrumented Tandem Outcome Measures According to Task Condition.

Variables	MS (n = 25)			Healthy (n = 25)			*P*-value for condition factor	*P*-value for condition X group factor
	Normal	Cognitive	Backward	Normal	Cognitive	Backward		
Total time (s)	24.9 (6.3)	45.6 (27.8)	27.8 (8.0)	20.5 (2.8)	32.9 (11.9)	21.6 (3.3)	< 0.001	0.173
Stride velocity (%stature/s)	25.1 (9.5)	20.9 (7.1)	17.5 (7.9)	33.0 (7.6)	21.9 (9.6)	24.3 (8.0)	< 0.001	0.217
Cadence (steps/min)	66.3 (20.3)	54.7 (15.4)	58.6 (19.3)	84.5 (17.8)	56.6 (19.5)	77.2 (18.5)	< 0.001	0.079
Double support (%GC)	50.0 (6.3)	51.1 (5.1)	46.7 (14.1)	45.8 (5.5)	51.2 (7.0)	36.5 (11.7)	< 0.001	0.335
Swing (%GC)	25.0 (3.2)	24.5 (2.6)	26.6 (7.1)	27.1 (2.8)	24.4 (2.6)	31.7 (5.8)	< 0.001	0.335

Values are expressed as mean (S.D). **P*-Value < 0.05.

Table 3
Tandem Walk Task Costs (%) According to the Study Groups.

Gait variable	Normal-Backwards		p-Value	Normal-Cognitive		p-Value
	MS	Healthy		MS	Healthy	
Total time	11.6 (15.5)	6.7 (8.1)	0.174	77.4 (88.3)	60.7 (58.1)	0.436
Stride velocity	29.1 (23.5)	26.9 (15.7)	0.692	27.5 (14.7)	36.1 (18.3)	0.140
Cadence	10.4 (18.5)	8.3 (12.0)	0.642	25.6 (14.0)	33.8 (16.2)	0.114
Double support	6.4 (25.8)	20.7 (22.8)	0.044*	−9.8 (10.3)	−12.8 (15.7)	0.522
Swing	−6.8 (27.3)	−17.5 (20.2)	0.121	7.9 (9.0)	9.6 (13.7)	0.667

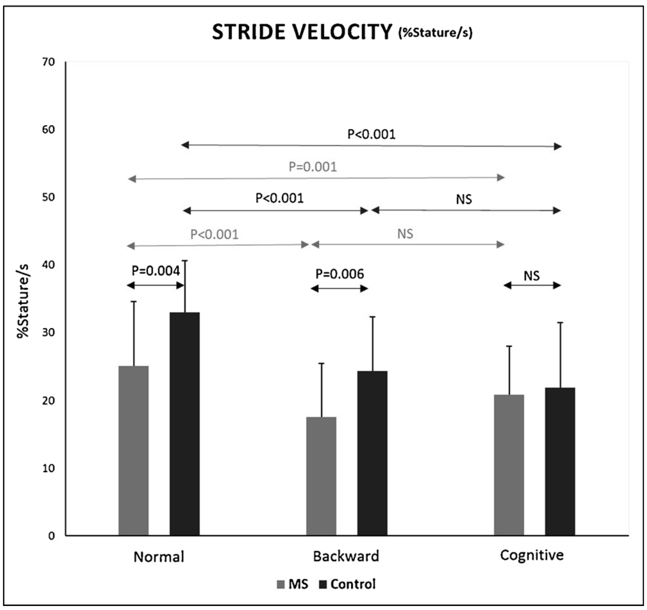

Fig. 1. Stride velocity scores according to group and task condition.

sensors, thus allowing us to report on several spatiotemporal parameters of the tandem walk trials. We believe that evaluating the 3-meter tandem walk tests with instrumental devices provides additional benefits compared to the traditional way of measurement, as these tools are objective, sensitive and accurate [37]. In the same context, our recent publication presents the advantages of combining an instrumental measurement device during common mobility tests in PwMS in order to detect risks and fear of falling [38].

Our study is not clear of limitations. Firstly, the sample size was relatively small and individuals with progressive MS were not included. Secondly, the tandem walking tests were performed in a fixed manner, always beginning with the normal tandem condition. Results may have differed in cases of randomization between the three conditions. Nevertheless, the decision to start with the normal condition is in concurrence with previous studies examining dual-task in PwMS. Additionally, performance on the tandem walk tests may be affected by day-to-day fluctuations or practice. Only PwMS with minimal disabilities were examined, therefore future research studies should examine whether our findings are accurate for PwMS with moderate and severe disabilities. Our system did not collect trunk sway movements while tandem walking. This parameter might have added interesting information to the present findings. Finally, we did not collect data on fall history of our sample, mainly due to the low incidence in minimally impaired PwMS. Nevertheless, future research studies should investigate the contribution of the tandem walk tests in detecting the risks of falling in PwMS.

5. Conclusions

The instrumented tandem walk test is an objective assessment of dynamic balance that can be assessed in most clinical settings. Our study provides new insights into the tandem walk test in the MS population. Firstly, PwMS perform the test slower compared to healthy adults which is correct for the normal and backward conditions. Secondly, the cognitive-motor interference in conjunction with the tandem test in PwMS, appears to adversely affect performance in a similar fashion as healthy adults. Physical rehabilitation professionals should be aware of these findings when evaluating and training dynamic balance in PwMS.

Conflict of interest statement

There are no financial or personal relationship with other people or organization that could inappropriately influence this work.

Sources of funding

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

Contributors

YG contributed to the design of the study, data collection, analysis, interpretation of results and drafting the manuscript. SB played an active role in extracting and analyzing the data. LH played an active role in data collection and drafting the manuscript. OM played an active role in data collection and drafting the manuscript. AK contributed to the design of the study, analysis, interpretation of the results and writing the manuscript. All authors have approved the final article.

Acknowledgement

The authors thank Mrs. Phyllis Curchack Kornspan for her editorial services.

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