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Effects of cognitive versus motor dual-task on spatiotemporal gait parameters in healthy controls and multiple sclerosis patients with and without fall history

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ABSTRACT

Background: The purpose of the current study was to compare the effects of cognitive or motor tasks on gait performance between healthy controls and multiple sclerosis (MS) patients with and without fall history.

Methods: The investigation included MS patients with fall history (n = 25) and without fall history (n = 25) and matched healthy controls (n = 25). Participants walked at their preferred speed on a motorized treadmill under three walking conditions in a randomized order: walking only, walking while performing a concurrent cognitive task (counting backward aloud by 3 s), and walking while performing a concurrent motor task (carrying a tray with glasses).

Results: The findings showed that in patients with MS, regardless of fall history, spatiotemporal gait parameters were different compared to healthy controls. In contrast to average gait parameters, variability in stride length and stride time could discriminate between MS fallers and non-fallers. Simultaneous performance of cognitive task and walking resulted in higher dual-task costs (DTC) in gait performance compared to the motor dual-task. However, the pattern of change was not different among the three groups. All participants responded to the cognitive task challenges by increasing stride length and decreasing cadence and stride length variability while maintaining cognitive task performance.

Conclusions: The findings may reflect successful adaptation of locomotor system to preserve cognitive task performance under cognitive dual-task condition. Future studies should examine more complex concurrent cognitive and motor tasks to better understand the dual-task-related gait changes and their contribution to falls in patients with MS.

1. Introduction

Multiple Sclerosis (MS) is the most common disabling neurodegenerative disease in adults between the ages of 20 and 50 (Bjartmar and Trapp, 2001; Browne et al., 2014; Compston and Coles, 2008). MS can result in variable neuromuscular deficits including muscle weakness, spasticity, balance impairment, and sensory disturbance (Givon et al., 2009). These impairments can increase the probability of fall occurring in these patients (Giannì et al., 2014; H.J. Gunn et al., 2013). Falls are a serious clinical problem in patients with MS with more than 50% of these patients reporting an injurious fall in a 3-6month period (Etemadi, 2017). Consistently, evidence indicates that the majority of falls occur during dynamic activities such as gait (Comber, 2015; Gunn et al., 2014; Matsuda et al., 2011). Indeed, gait dysfunction has been identified as a significant risk factor for falls in patients with MS (Gunn et al., 2014; Sosnoff and Sung, 2015). Up to 85% of patients with MS report gait disturbances as their main complaint (Comber et al., 2017). Moreover, cognitive impairment has been identified as a risk factor for falls in these patients (D'Orio et al., 2012; Sosnoff et al., 2013; Wajda et al., 2013). Approximately 65% of patients with MS experience cognitive impairment (Chiaravalloti and DeLuca, 2008). Traditionally, walking and cognitive abilities have been examined separately. However, there is increasing evidence for the interaction between cognitive and gait impairments in patients with MS (Wajda and Sosnoff, 2015; Yang et al., 2017). Indeed, in many daily activities, people often require performing an additional cognitive-demanding task while walking (i.e.,

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dual-task performance).

Dual-task can lead to performance decrement in either one or both tasks and this is termed as dual-task interference (Leone et al., 2015; Wajda and Sosnoff, 2015). Several studies have investigated dual-task interference in patients with MS (Allali et al., 2014; Downer et al., 2016; Hamilton et al., 2009; Kirkland et al., 2015; Monticone et al., 2014; Wolkorte et al., 2015). In most studies, adding a concurrent task while walking resulted in a significant reduction in walking speed and stride length, and an increase in gait variability and double support time in MS patients compared to control subjects (Allali et al., 2014; Downer et al., 2016; Hamilton et al., 2009; Monticone et al., 2014). Dual-task deficits can negatively affect activities of daily living, and in prospective studies, gait deterioration under cognitive dual-task conditions has been identified as a risk factor of falls in patients with MS as shown in other clinical populations (Etemadi, 2017; Nilsagard et al., 2009; Wajda et al., 2013).

The severity of interference has been demonstrated to be related to several factors (Woollacott and Shumway-Cook, 2002). The type of secondary task (motor or cognitive) is one important factor which can impact dual-task performance (Galletly and Brauer, 2005; Madehkhaksar and Egges, 2016; O'Shea et al., 2002). Most dual-task-related studies in MS patients have focused on examining the effects of concurrent cognitive tasks on walking performance (Allali et al., 2014; Downer et al., 2016; Hamilton et al., 2009; Kirkland et al., 2015; Monticone et al., 2014). However, the impact of performing a motor task while walking has been poorly investigated. Motor dual-tasks are also important to be taken into account since in many daily activities, people require to complete a motor task in conjunction with walking (for example, walking while carrying an object). Several studies have demonstrated that in older adults and in other neurological disorders, undertaking a motor task while walking, like a cognitive task can adversely influence walking ability (Galletly and Brauer, 2005; Madehkhaksar and Egges, 2016; O'Shea et al., 2002; Plummer-D'Amato et al., 2012; Wittwer et al., 2014; Yang et al., 2007). Toulotte et al. (2006), for example, found that concurrent execution of a motor task significantly disturbed walking ability in healthy elderly fallers. They decreased cadence and stride length and increased stride time and single support time under motor dual-task condition. In MS patients, disease-related neuromuscular changes can affect the ability to allocate cognitive resources between two motor tasks and cause deterioration in dual-task performance. This issue may increase the risk of falls in patients with MS. Despite numerous studies have investigated the relationship between cognitive-walking interference and fall risk in patients with MS (Etemadi, 2017; H. Gunn et al., 2013; Wajda et al., 2013), to the best of our knowledge, no study has yet compared gait kinematics under motor and cognitive dual-task conditions and their contributions to falls in patients with MS. Hence, the purpose of this investigation was to compare the effects of cognitive or motor tasks on spatiotemporal gait parameters between healthy controls and MS patients with and without fall history.

2. Materials and methods

2.1. Participants

Fifty patients with MS took part in this study. The patients were recruited from the Clinic of Neurology at the School of Rehabilitation Sciences, Ahvaz Jundishapur University of Medical Sciences. The participants with MS were categorized in two groups: non-fallers (n = 25, patients with no history of falls), and fallers (n = 25, patients who reported at least two falls in the 6-month period prior to the testing date). A fall was defined as an event where the subject came to rest on the ground or a lower level (Finlayson et al., 2006). The inclusion/exclusion criteria were chosen in line with previous studies on dual-task interference and gait function in patients with MS (Kalron et al., 2013; Malcay et al., 2017; Mercan et al., 2016; Monticone et al., 2014). Inclusion criteria were: 1) age ≥ 18 years of age; 2) a diagnosis of relapsing remitting MS according to the revised McDonald criteria; 3) the ability to walk 100 m independently; and 4) relapse-free within the past one month. Disability status was determined by the Self-reported Expanded Disability Status Scale ($EDSS_{SR}$). Previous studies have shown that the $EDSS_{SR}$ is highly correlated with neurologist-administered EDSS (Bowen et al., 2001). In this study, the participants with MS had an $EDSS_{SR}$ score < 6. Exclusion criteria were: 1) visual impairment; 2) cognitive impairment (Mini Mental State Examination [MMSE] < 24); 3) any neurological disease except MS; 4) orthopedic impairments that could impair walking ability; 5) cardiovascular disorders; and 6) pregnancy.

Furthermore, 25 healthy age-, education- and gender-matched controls without any orthopedic or neurologic condition participated in this study. The study protocol was approved by the local ethics committee, and all study subjects provided a signed informed consent form.

2.2. Experimental protocols

Spatiotemporal gait parameters were studied by a motorized treadmill (Biometrix^{TM,} length = 1.5 m, width = 0.5 m). Handrails of the treadmill were removed. To provide safety during walking tasks, we used a harness suspend from the ceiling and tied around the waist of each participant. Three-dimensional kinematics during treadmill walking were collected by a 7-camera motion analysis system (Qualisys Inc., Sweden) using two retro-reflective markers positioned on the heel and the 1st metatarsal of both feet. Kinematics data were sampled at 100 Hz.

Prior to commencing gait evaluations, participants walked barefoot on the treadmill for 5 min in order to characterize each participant's preferred walking speed. Beginning at 0.8 km/h speed, the treadmill speed was then increased in 0.1 km/h increments 15 s each until the participants reported their preferred walking speed. When the participants first informed the examiner of their preferred speed, treadmill velocity was again increased and decreased in 0.1 km/h intervals until the participants re-confirmed their preferred speed. After several practice trials, each participant completed three walking conditions including:

1) Single-task gait: The participants walked on the treadmill at their self-selected speed.
2) Cognitive dual- task gait: The participants were instructed to walk while counting backward aloud by 3 s from a randomly selected number between 200 and 300. The answers were recorded using a voice recorder.
3) Motor dual- task gait: The participants were instructed to walk while holding a tray with four empty glasses using both hands. In addition, three retro-reflective markers were placed on the middle, left, and right portions of the tray to calculate motor task performance.

In dual-task conditions, the speed of walking was similar to the preferred walking speed defined in initial measurement. The participants were asked to perform walking and concurrent tasks in the best of their capacity without prioritization to any tasks. Each walking condition was assessed during 2 min and the participants were given a rest period of 5 min between conditions to decrease the influence of fatigue. In addition, the cognitive task was performed in a seated position, which was considered as a control or single-task condition for cognitive performance. The participants began serial-3 subtraction with a different number in the sitting position than walking. Data were also collected for the motor secondary task in standing position as a baseline measure of motor task performance. All experimental tests were performed in a random order.

2.3. Data analysis

A custom-written MATLAB program (Math Works Inc.) was used to calculate spatiotemporal gait parameters. Gait events were determined using the velocity- base algorithm described by Zeni et al. (2008). The method has shown to be efficient for detecting gait events during treadmill walking in patients with MS (Zeni et al., 2008). In each trial, the accuracy of event detections was confirmed visually. The walking performance was assessed by cadence (steps/min), stride length (cm), step width (cm), and swing time (%gait cycle). In addition, gait variability was calculated for stride length, stride time, and step width parameters using coefficient of variation (CoV = standard deviation (SD)/mean × 100). The parameters were calculated over the first 70 successive gait cycles in each trial. Moreover, the walking performance was examined using walk ratio index using formula (1) (Sekiya and Nagasaki, 1998):

$$\text{Walk ratio} = \text{mean step length (mm)}/\text{cadence (steps/ min)} \tag{1}$$

The walk ratio is a speed-independent index for assessing gait coordination. Previous studies have reported that walk ratio is associated with fall risk and disability level in patients with MS (Kalron, 2016).

Cognitive task performance was assessed by calculating correct response rate (CRR) using formula (2) (Galletly and Brauer, 2005):

$$\text{CRR} = \text{response rate per second} \times \text{percentage of correct responses} \tag{2}$$

Secondary motor task performance was quantified as the average deviation of the tray from horizontal position. Using three retro-reflective markers on the tray, the vector perpendicular to the tray surface was determined. The angle between this vector and the global up-down axis of the lab was calculated using inner products. Average value of this angle, which is the deviation angle of the tray from horizontal position, has been considered as the secondary motor task performance value. Furthermore, in order to estimate dual-task interference during motor and cognitive dual-task conditions, we calculated dual-task cost (DTC) for each spatiotemporal gait parameter, secondary cognitive and motor tasks using formula (3) (Hamilton et al., 2009).

$$\text{DTC} = ([\text{S} - \text{D}/\text{S}]) \times 100 \tag{3}$$

where S equals single-task performance and D is equal to dual-task performance for each parameter.

2.4. Statistical analysis

Statistical analyses were completed using SPSS version 16.0 (SPSS, Inc., Chicago, IL.). The data for all gait parameters, cognitive task performance, and motor task performance were normally distributed based on the Kolmogorov-Smirnov test. Differences in the demographic characteristics between groups were determined by one-way analysis of variance (ANOVA).

For each spatiotemporal gait parameter, Paired *t*-test demonstrated no significant difference between limbs. Therefore, mean values from both limbs of each participant were applied for statistical purposes. To determine the effects of group and walking condition on gait parameters, a 2-way mixed model ANOVA, with group (3 levels: healthy controls, MS fallers, and MS non-fallers) as between–group factor and condition (3 levels: single-task gait, cognitive dual-task gait, and motor dual-task gait) as within-group factor was used. The effects of group and walking condition on the DTC of gait parameters were examined using the same model, with group (3 levels: healthy controls, MS fallers, and MS non-fallers) as between–group factor and condition (2 levels: cognitive dual-task gait and motor dual-task gait) as within-group factor.

In addition, cognitive performance was evaluated using a 2-way mixed model ANOVA with group (3 levels: healthy controls, MS fallers, and MS non-fallers) as between–group factor and condition (2 levels: sitting vs. walking) as within-group factor. Motor task performance was also examined using the same model with group (3 levels: healthy controls, MS fallers, and MS non-fallers) as between–group factor and condition (2 levels: standing vs. walking) as within-group factor. A post-hoc Bonferroni test was used for multiple comparisons. The level of significant was set at $p < 0.05$.

Table 1
Demographic and clinical characteristics of controls and both MS groups.

Characteristics	Controls (n = 25)	MS fallers (n = 25)	MS non-fallers (n = 25)
Age (years)	32.48 (6.32)	33.92 (8.90)	33.00 (8.12)
Gender	Female = 20; Male = 5	Female = 20; Male = 5	Female = 20; Male = 5
Body mass index (kg/m^2)	23.17 (2.87)	25.17 (3.54)	24.31 (3.77)
Years of education (years)	14.88 (3.00)	13.12 (2.43)	13.92 (2.56)
Disease duration (years)	N/A	5.48 (4.41)	3.36 (3.80)
EDSS$_{SR}$	N/A	4.16 (0.49)[a]	2.96 (1.31)
MMSE	N/A	27.76 (1.80)	28.24 (1.66)

EDSS$_{SR}$: Self-reported expanded disability status scale; MMSE: Mini-mental state examination; N/A: not applicable.

[a] $p < 0.05$ difference between MS fallers and non-fallers.

3. Results

There were no significant differences between the three groups except for EDSS$_{SR}$ score (Table 1). The other information can be found in Table 1.

The mean and SD of all gait parameters during different walking conditions for the three subject groups are reported in Table 2. As shown, in the control group, self-selected walking speed was significantly higher than that in both MS groups ($p < 0.01$); however, no significant difference was found between the MS fallers and non-fallers ($p = 1.00$).

The obtained results in Table 3 showed no significant interaction between group and condition for cadence, stride length, and swing time. While the main effect of group was significant for stride length and swing time ($p < 0.01$). Analyzing the differences between groups by the post-hoc test showed that both MS groups had shorter stride length ($p < 0.01$) and spent a lower percentage of each gait cycle in swing phase ($p < 0.01$) compared to the control group. However, the mean values of stride length and swing time were not different between the MS fallers and non-fallers ($p = 1.00$). In addition, condition had a significant effect on stride length and cadence ($p < 0.01$). All participants showed a longer stride length and slower cadence under cognitive dual-task compared to the motor dual-task and single walking conditions ($p < 0.01$). However, no significant differences were found between the motor dual-task and single walking conditions ($p = 1.00$, $p = 0.91$ for the stride length and cadence, respectively).

Based on the results attained for the stride length and cadence, analysis of walk ratio demonstrated that walk ratio score was lower in both MS patients compared to healthy controls ($p < 0.01$). But this was not different between MS fallers and non-fallers ($p = 1.00$). Furthermore, in all participants, walk ratio score increased during cognitive dual-task compared to motor dual-task and single walking conditions ($p < 0.01$). While, there was no significant difference between motor dual-task and single walking conditions ($p = 1.00$) (Table 3).

For stride length variability, there was no significant interaction between group and condition ($p = 0.06$). Analysis revealed a significant main effect of group ($p < 0.01$). Post-hoc analysis showed that both MS fallers and non-fallers had higher stride length variability than the control group ($p < 0.01$). Moreover, stride length variability was significantly higher in the MS fallers than MS non-fallers ($p < 0.01$).

Table 2
Mean (SD) of gait parameters in single and dual-task conditions for healthy controls and both MS fallers and non-fallers.

	Groups		
	MS faller	**MS non-faller**	**Healthy**
Single-task gait			
Velocity	**1.74 (0.31)**	**1.76 (0.25)**	**2.37 (0.34)**
Cadence	9.52 (1.3)	9.16 (1.05)	9.42 (3.03)
Stride length	63.02 (15.37)	65.61 (12.66)	84.88 (11.78)
Swing time	29.41 (2.34)	29.30 (1.43)	31.62 (1.36)
Stride length variability	8.48 (2.79)	5.99 (2.15)	3.97 (1.47)
Stride time variability	5.23 (2.21)	3.62 (1.44)	2.62 (0.71)
Step width	1.17 (4.18)	1.03 (3.50)	1.04 (2.96)
Step width variability	2.46 (2.11)	2.44 (1.92)	2.14 (5.19)
Walk ratio	3.43 (1.16)	3.67 (1.05)	4.55 (0.81)
Cognitive dual-task gait			
Velocity	**Similar to the preferred walking speed**		
Cadence	9.1 (1.16)	8.77 (1.14)	9.05 (2.78)
Stride length	65.80 (15.71)	68.59 (12.51)	88.39 (12.16)
Swing time	29.31 (2.35)	29.39 (1.56)	31.89 (1.28)
Stride length variability	6.99 (3.25)	5.52 (2.65)	3.12 (0.94)
Stride time variability	4.68 (1.87)	3.67 (1.56)	2.31 (0.51)
Step width	1.18 (3.80)	1.13 (4.03)	1.02 (3.48)
Step width variability	2.09 (1.14)	2.29 (2.19)	2.20 (1.21)
Walk ratio	3.74 (1.20)	4.02 (1.08)	4.94 (0.89)
Motor dual-task gait			
Velocity	**Similar to the preferred walking speed**		
Cadence	9.38 (1.11)	9.16 (1.04)	9.34 (2.35)
Stride length	63.71 (15.34)	65.45 (11.36)	85.73 (12.21)
Swing time	29.58 (2.29)	29.47 (1.52)	31.78(1.52)
Stride length variability	9.29 (4.42)	6.23 (2.58)	3.89 (1.86)
Stride time variability	5.14 (1.81)	3.44 (1.29)	2.61 (0.99)
Step width	1.16 (4.25)	1.02 (3.86)	1.00 (3.19)
Step width variability	2.71 (2.15)	2.73 (2.86)	2.34 (6.03)
Walk ratio	3.50 (1.15)	3.65 (0.94)	4.63 (0.83)

Scales: Velocity (km/h), Cadence (steps/min), Stride length (cm), Swing time (%gait cycle), Stride length variability (CoV%), Stride time variability (CoV%), Step width (cm), Step width variability (CoV%), Walk ratio [mm/(steps/min)].
CoV: Coefficient of variation.

Condition had also a significant effect on stride length variability ($p < 0.01$). In all participants, stride length variability decreased under cognitive dual-task condition compared to the motor dual-task and single walking conditions ($p < 0.01$), but the difference was not significant between the motor dual-task and single walking conditions ($p = 0.60$) (Table 3).

Regarding stride time variability, analysis indicated a significant effect of group on stride time variability ($p < 0.01$). There was no significant effect of condition ($p = 0.16$) and no significant interaction between condition and group ($p = 0.29$). Post-hoc analysis showed that both MS fallers ($p < 0.01$) and non-fallers ($p = 0.01$) had higher stride time variability compared to the control group. Furthermore, the MS fallers showed more variability than MS non-fallers ($p < 0.01$) (Table 3).

Analysis of step width showed no significant effect of group ($p = 0.31$), condition ($p = 0.06$) or interaction between group and condition ($p = 0.13$) (Table 3).

Table 4
Mean (SD) dual-task cost for each gait parameters under cognitive and motor dual-task conditions for healthy controls and both MS fallers and non-fallers.

	Groups		
	MS faller	**MS non-faller**	**Healthy**
Cognitive dual-task			
Cadence	4.08 (6.38)	4.09 (8.1)	3.89 (4.77)
Stride length	−4.61 (7.15)	−4.97 (8.71)	−4.29 (5.03)
Swing time	0.3 (2.53)	−0.29 (2.16)	−0.88 (1.82)
Stride length variability	16.44 (26.93)	3.83 (41.79)	14.92 (20.78)
Stride time variability	7.71 (20.69)	−7.32 (43.8)	7.43 (27.08)
Motor dual-task			
Cadence	1.14 (5.35)	−0.39 (10.69)	0.74 (4.71)
Stride length	−1.34 (5.54)	−0.47 (8.49)	−1.06 (4.61)
Swing time	−0.61 (1.94)	−0.59 (2.94)	−0.49 (1.83)
Stride length variability	−10.4 (34.26)	−6.55 (26.85)	−0.18 (36.46)
Stride time variability	−3.23 (26.17)	0.95 (25.64)	−1.66 (30.26)

Scales: Cadence (steps/min), Stride length (cm), Swing time (%gait cycle), Stride length variability (CoV%), Stride time variability (CoV%).
CoV: Coefficient of variation.

For step width variability, the results were similar to step width except for step width variability, analysis revealed a significant effect of condition ($p < 0.01$). In all participants, step width variability decreased under the cognitive dual-task compared to the motor dual-task condition ($p < 0.01$) (Table 3).

Table 4 displays the mean and SD of DTC for each gait parameter under cognitive and motor dual-task conditions for the three subject groups. The results showed a significant effect of condition on DTCs of cadence, stride length, and stride length variability ($p < 0.01$), while the effects of group and interaction between group and condition were non-significant. Post-hoc analysis showed that for cadence, stride length, and stride length variability, DTCs were higher under the cognitive dual-task than the motor dual-task ($p < 0.01$) (Table 5).

The mean (SD) results on the backward counting task were 31.79 (12.14) and 34.02 (13.47) in sitting and walking conditions for the healthy controls and 23.29 (14.15) and 24.32 (13.95) in the similar conditions for the non-faller group. In addition, CRR was 23.09 (11.7) and 25.21 (14.25) in described conditions for the faller group. Group (F = 4.48; $p = 0.01$) had a significant effect on cognitive performance, while the effect of condition (F = 3.65; $p = 0.06$) and interaction between group and condition was not significant (F = 0.18; $p = 0.83$). In both MS groups, CRR was significantly lower than that obtained in the control group, but no significant difference was observed between the MS fallers and non-fallers. No significant differences were found between the three groups in DTC of cognitive task ($p = 0.80$).

The mean (SD) results on the average deviation of the tray from horizontal position were 5.6 (4.00) and 5.8 (3.83) in standing and walking conditions for the healthy control and 5.73 (2.93) and 5.5

Table 3
Summary of analysis of variance for gait parameters: F-Ratios and P-values by variable.

		Cadence	**Stride length**	**Swing time**	**Stride length variability**	**Stride time variability**	**Step width**	**Step width variability**	**Walk ratio**
Main effect									
Group	F	0.63	21.75	15.10	24.19	23.61	1.17	0.02	9.70
	P	0.53	**< 0.01**	**< 0.01**	**< 0.01**	**< 0.01**	0.31	0.97	**< 0.01**
Condition	F	14.53	17.79	2.10	13.90	1.79	2.82	7.13	18.08
	P	**< 0.01**	**< 0.01**	0.12	**< 0.01**	0.16	0.06	**< 0.01**	**< 0.01**
Interaction									
Group × condition	F	0.15	0.25	1.19	2.32	1.24	1.78	0.56	0.25
	P	0.96	0.90	0.31	0.06	0.29	0.13	0.68	0.90

Significant P-values are presented in bold.

Table 5
Summary of analysis of variance of dual-task costs for each gait parameter. F-Ratios and P-values by variable.

		Cadence	Stride length	Swing time	Stride length variability	Stride time variability
Main effect						
Group	F	0.11	0.02	0.54	0.65	0.44
	P	0.89	0.97	0.58	0.52	0.64
Condition	F	14.07	17.75	0.81	19.17	1.1
	P	< **0.01**	< **0.01**	0.37	< **0.01**	0.29
Interaction						
Group × condition	F	0.26	0.22	1.49	1.51	2.68
	P	0.76	0.79	0.23	0.22	0.07

Significant P-values are presented in bold.

(1.91) in the similar conditions for the non-faller group. In addition, this was 5.97 (3.57) and 6.49 (3.67) in described conditions for the faller group. Analysis showed no significant effect of condition ($F = 0.24$; $p = 0.61$), group ($F = 0.27$; $p = 0.75$) or interaction between group and condition ($F = 0.44$; $p = 0.64$) on motor task performance. For the DTC of secondary motor task, the results showed no significant difference between the three groups ($p = 0.86$).

4. Discussion

The purpose of the current study was to compare spatiotemporal gait parameters under single-task gait, cognitive dual-task gait and motor dual-task gait among healthy controls and MS patients with and without fall history. The findings showed that in MS patients, regardless of fall history, spatiotemporal gait parameters were different compared to healthy controls. Furthermore, gait variability parameters revealed the difference in gait performance between MS fallers and non-fallers. In all participants, performing a concurrent cognitive task markedly altered gait parameters compared to a concurrent motor task. Moreover, the DTC analysis of the gait parameters under both cognitive and motor dual-task conditions demonstrated higher DTC of the gait parameters under cognitive dual-task compared to motor dual-task.

Congruent with previous studies (Sosnoff et al., 2012; Givon et al., 2009; Comber et al., 2017; Kaipust et al., 2012; Kalron et al., 2013; Malcay et al., 2017), MS patients walked with shorter stride length (lower walk ratio score), spent a lower percentage of the gait cycle in swing phase, and indicated more variability in stride length and stride time than healthy controls. Additionally, despite the level of neurological disability was higher in MS fallers compared to non-fallers, no significant differences in preferred walking speed nor in the average spatiotemporal gait parameters were observed between two groups. However, gait variability was higher in MS fallers compared to non-fallers. The association between walking speed and fall status in patients with MS is not yet well understood. While several studies reported slower walking in MS fallers compared to non-fallers (Kalron, 2014; Socie et al., 2013; Tajali et al., 2017), in some other studies, walking speed was not different between two groups (Sosnoff et al., 2011; Kalron, 2017). One possible explanation for our findings may be related to the differences in the context of walking. In most studies that observed slower walking speed in MS fallers, walking performance was assessed on a walkway (Kalron, 2014; Socie et al., 2013). To our knowledge, this is the first study that examined walking performance in MS fallers and non-fallers on a motorized treadmill. Similar to findings of current study, Shishov et al. (2017) reported that self-selected speed on the treadmill walking was not different between older fallers and non-fallers. Moreover, our findings are in agreement with previous research in MS patients and other clinical populations suggesting gait variability as a more sensitive marker than average gait parameters to distinguish between fallers and non-fallers (Callisaya et al., 2011; Hausdorff, 2009; Moon et al., 2015). Researchers have suggested that factors such as decreased muscle strength, spasticity, fatigue, and increased postural sway might be contributing to increased gait variability and subsequently falls in MS patients (Moon et al., 2015; Socie et al., 2013). Further investigations are warranted to identify more completely contributing factors. This would be beneficial for the development of falls prevention interventions for these patients.

Interestingly, in all participants, concurrent execution of a cognitive task while walking resulted in substantial changes in gait performance compared to single-task walking and motor dual-task conditions. It seems that cognitive dual-task gait was probably a more challenging condition for the participants. These observations are in line with the study by Monticone et al. (2014), which also showed that performing a concurrent cognitive task had more effects on gait performance in patients with MS than a motor task. Our findings could be further supported by the findings of the study by Freire Junior et al. (2017), in which older adults demonstrated more significant changes in gait performance with the concurrent cognitive task than the concurrent motor task.

During cognitive dual-task condition, all participants increased their stride length and decreased cadence. Therefore, walk ratio score increased in all participants. Moreover, they decreased variability in stride length and step width. However, the findings showed no changes in cognitive performance. Consistent with the findings of this study, Malcay et al. (2017) reported increased walk ratio score with the concurrent cognitive task in patients with MS. In addition, Lövden et al. (2008) found that older adults decreased stride length variability during cognitive dual-task condition. Similar findings have also reported by Decker et al. (2016) that observed decreased step width variability while performing a simultaneous cognitive task in both young and older adults. A possible explanation for these findings might be that under cognitive dual-task condition, participants prioritized cognitive task performance over walking. Under such circumstance, cognitive resources divert away from walking toward cognitive performance. Increased stride length, as postulated by Li et al. (2012), decreases the number of gait cycles and subsequently could slow the cadence. Slowing the cadence appeared to be a regression to their preferred cadence with a minimum of conscious cognitive involvement. Indeed, increased walk ratio score may indicate a strategy adopted by the neuromuscular system to adapt walking performance in the face of cognitive challenge. Furthermore, decreased variability in stride length and step width exhibits enhanced automaticity and stability in gait (Decker et al., 2016; Lovden et al., 2008; Meyer and Ayalon, 2006). Taken together, it seems that participants successfully adapted their gait pattern to maintain cognitive performance, because this strategy would serve more cognitive resources for the accurate performance of cognitive task (Li et al., 2012; Lovden et al., 2008). These findings can explain why the DTCs for the cadence, stride length, and stride length variability were significantly higher when the secondary task was the cognitive rather than motor task.

However, the current findings are in contrast to a number of studies conducted on patients with MS demonstrating decreased stride length and increased stride length variability during concurrent performance of a cognitive task (Kirkland et al., 2015; Monticone et al., 2014; Wajda and Sosnoff, 2015). These discrepancies could be a result of the differences in the walking instruments. In these previous studies, participants walked on a walkway (Kirkland et al., 2015; Monticone et al., 2014; Wajda and Sosnoff, 2015), but in our study, they walked on a motorized treadmill. Walking on the treadmill is performed under controlled environment and walking speed is constant. Therefore, treadmill walking is nearly controlled by automatic process (Simoni et al., 2013). In this case, more cognitive resources may free up for performing concurrent cognitive task during cognitive dual-task condition. On the contrary, over-ground walking requires wider brain cortex control. Therefore, over-ground walking would be more vulnerable to the dual-task interference (Simoni et al., 2013).

The current study indicated that performing a concurrent motor task caused no significant changes in gait performance compared to single-task walking. In addition, motor task performance was also preserved under motor dual-task condition. It seems that no dual-task interference was produced under this condition. These findings may be explained by the fact that walking while carrying a tray with four empty glasses might not be sufficiently attention-demanding to produce interference with gait. Further studies using more difficult concurrent motor tasks would be helpful in exploring interference of motor tasks on gait performance in patients with MS.

In the current study, the lack of interaction between group and gait condition for any of the gait parameters demonstrates that the effects of concurrent motor and cognitive tasks on gait performance were similar among the three groups. In a recent meta-analysis, Learmonth et al. (2017) have concluded that the overall effect of cognitive-walking interference on gait performance was similar in both MS patients and healthy controls. Our finding could be further supported by the reported findings by Dujmovic et al. (2017), who also demonstrated that under cognitive and motor dual-task conditions, gait pattern alterations were similar between patients with MS and healthy controls. In addition,Freire Junior et al. (2017) found that the impact of cognitive and motor tasks on walking ability was similar between older fallers and non-fallers. One possible reason for this finding may be the secondary tasks utilized in this study. It is possible that the additional cognitive task required an increased cognitive demand that was equally challenging for all participants. Hence, for future investigations, we suggest using a more challenging cognitive task to further explore dual-task interference and its contribution to falls in patients with MS. In support of this possibility, Learmonth et al. (2017) suggested that discrimination and decision making tasks such as the Stroop paradigm may better identify the difference in cognitive-walking interference between patients with MS and healthy controls.

This study has some limitations that need to be considered. Firstly, the sample consisted of patients with MS who were independent ambulatory and did not require assistive device (e.g., a cane or walker) when walking, hence our results may be generalizable only for this subgroup. Secondly, retrospective recall of falls was used to classify patients with MS. Since cognitive deficits are commonly exhibited in these patients (Chiaravalloti and DeLuca, 2008), it is possible that patients did not truly report falling. Therefore, our results have to be interpreted cautiously. However, there is evidence indicating retrospective report of falls is a strong predictor of future falls in patients with MS (Cameron et al., 2013). Furthermore, the cross-sectional study design prevents us from drawing any conclusion regarding the ability of gait variability to predict future falls in patients with MS. Further work is warranted to investigate this probability. This study focused on the spatiotemporal features of gait pattern in patients with MS. The identification of the actual gait pattern requires a more detailed gait analysis including analysis of joint kinematics, kinetics, EMG data and kinematic coordination as well (Kelleher et al., 2010; Kelso, 1995). More research is needed to better understand gait patterns in patients with MS. Finally, slowing walking speed has been found as the most significant changes in gait performance under dual task condition (Al-Yahya et al., 2011; Leone et al., 2015). The changes in walking speed can probably affect some spatiotemporal gait parameters (stride length, cadence,…) (Bertram and Ruina, 2001; Larish et al., 1988). By using the treadmill, on the one hand, we could control the walking speed and examine the net effects of concurrent tasks (cognitive or motor) on gait parameters (Malcay et al., 2017). On the other hand, the constant speed imposed by the treadmill may cause the changes in gait kinematics compared to over-ground walking (Hollman et al., 2016). However, each subject was assessed relative to his/her own speed. Therefore, the similar findings may not necessarily achieve during over-ground walking.

5. Conclusion

The results of this investigation confirm the difference in gait characteristics between persons with MS and healthy controls. Moreover, gait variability can discriminate between MS fallers and non-fallers. Dual-task affects MS patients and healthy controls in a similar fashion, with a concurrent cognitive task leads to higher DTC in gait performance compared to a concurrent motor task.

Conflict of interest

None.

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