Reliability of spatial–temporal gait parameters during dual-task interference in people with multiple sclerosis. *A cross-sectional study*

Marco Monticone [a,*], Emilia Ambrosini [a,b], Roberta Fiorentini [a], Barbara Rocca [a], Valentina Liquori [a], Alessandra Pedrocchi [b], Simona Ferrante [b]

[a] *Physical Medicine and Rehabilitation Unit, Salvatore Maugeri Foundation, Institute of Care and Research (IRCCS), Scientific Institute of Lissone, Milan, Italy*
[b] *Neuroengineering and Medical Robotics Laboratory (NearLab), Department of Electronics, Information, and Bioengineering, Politecnico di Milano, Milan, Italy*

Received 11 December 2013
Received in revised form 11 June 2014
Accepted 27 June 2014

1. Introduction

Multiple sclerosis (MS) is the most frequent neurological disease causing permanent disability in young adults [1].

People with MS frequently have neuromuscular deficits such as ataxia, early muscle fatigue, spasticity and sensory disturbances, which limit gait and considerably affect their everyday living activities [2,3]. Subtle walking alterations can be detected at an early stage of the disease as patients walk more slowly, with shorter steps, and spend a larger percentage of the gait cycle in double feet support [4].

Although the walking deficits of subjects with MS have traditionally been attributed to neurological impairments of the locomotor system, there is growing evidence that cognition may play an important role [5]. Indeed, simultaneously performing cognitive tasks decreases walking ability [6,7], and the more is the disability, the higher is the dual-task cost [5].

Dual-task difficulties have a strong impact on daily life activities that often require the ability to perform two actions concurrently. The understanding of how the dual-task paradigm affects walking parameters in a specific pathology is crucial in the planning and assessment of rehabilitation, and in monitoring the degenerative process. A population-specific reliability analysis of gait parameters during dual-task paradigms is essential to discriminate a real deterioration or improvement in the gait performance from a normal variability between consecutive measures.

Gait parameters demonstrated to be reliable during dual-task in older adults and subjects with dementia [8,9]. Since it has not been investigated in multiple sclerosis, the aim of this study was to evaluate the reliability of gait parameters in this population during dual-task interference.

2. Methods

This cross-sectional study was approved by the hospital's Institutional Review Board.

* Corresponding author. Tel.: +39.039.4657277; fax: +39 039 4657279.
E-mail address: marco.monticone@fsm.it (M. Monticone).

Table 1
Demographic and clinical characteristics of the study population.

Characteristics	MS subjects ($n = 25$)	Healthy subjects ($n = 25$)	P-value
Age (years)	49.2 ± 11.5	49.9 ± 15.8	0.93
Gender (male/female)	5/20	8/17	
Body mass index (kg/m^2)	23.4 ± 4.1	25.0 ± 5.3	0.33
Disease duration (years)	11.0 ± 7.1	–	
EDSS	5.4 ± 0.8	–	
MMSE	28.6 ± 1.9	–	

EDSS = expanded disability status scale; MMSE = mini mental state examination.

The inclusion criteria were a diagnosis of secondary progressive multiple sclerosis; an expanded disability status scale (EDSS) score of 4–5.5 [10]; an age of 18–65 years. The exclusion criteria were cognitive impairment (Mini Mental State Examination [MMSE] $< 18/30$); orthopedic disorders that may impair balance; pregnancy; steroid, anti-psychotic drug treatment.

The control group consisted of age-matched healthy volunteers.

The spatio-temporal gait parameters (velocity, cadence, step and stride length, step and stride time, double support time, the % of gait cycle in single support and stance phase, and base of support) were acquired and computed by the GAITRite® Walkway System, a mat able to identify footfall contacts. Right and left parameters were averaged. The GAITRite® was embedded in a straight 30-m walking track. Data acquisition was repeated in two consecutive days for each patient. On each day, the subject completed a randomised sequence of two tests separated by a 15-min break:

1) *Motor-cognitive dual task walking (MC):* The patients walked while a word list generation test was administered. The subjects had to say as many words as possible starting with a given initial letter within 30 s. The initial letter was communicated five seconds before the test started; for each subject, same initial letter was used on day 1 ("F") and day 2 ("P").
2) *Motor–motor dual task walking (MM):* The patients walked carrying a tray with glasses.

An *a priori* power analysis showed that 22 was the minimum sample size required to establish that a reliability coefficient of 0.80 was significantly different from a minimally acceptable reliability coefficient of 0.50 considering $\alpha = 0.05$ and $1\text{-}\beta = 0.80$ [11].

A paired t-test was used to compare the test–retest sessions in order to ensure the absence of any systematic error [12].

The relative reliability of the gait parameters was assessed by the intra-class correlation coefficient, ICC(2,1) (0.70–0.85 and $>$0.85 indicated good and excellent reliability, respectively [13]).

For each group of subjects, absolute reliability was assessed computing the standard error of measurement (SEM), estimated as the square root of the mean square error term in the repeated measure ANOVA [12].

The smallest change in score for each relevant gait parameter that is likely to reflect a true change rather than a measurement error was estimated by the minimum detectable change (MDC). The MDC was calculated as follows: $\text{MDC} = \text{SEM}\,1.96\sqrt{2}$, where 1.96 is the z-score associated with the 95% level of confidence, and the square root of 2 reflects the additional uncertainty introduced by using difference scores based on measurements made at two time points.

The coefficient of variation (CV) was first computed separately for the two tests and then averaged [12].

3. Results

Table 1 reports the subjects' characteristics. There were no significant differences in age or in the body mass index between the two populations.

The gait speed in MC condition was lower than MM condition for both groups. A reduction of 35% and 21% was obtained in the control and MS group, respectively (Table 2). The paired t-test showed the absence of any systematic error ($p > 0.05$) in most conditions. However, for the patients' group a significant improvement in six gait parameters of the retest trial was found for the MM condition, and in one parameter (single support phase) for the MC condition.

The relative reliability of all of the gait parameters was good to excellent under both conditions in the two groups (Table 3). In the control group, SEM and MDC values were always below 18% and 49% of the mean, respectively. Patients showed comparable values (SEM $<$17% and MDC values $<$44%). In both groups, the highest values were found for the double support time and the base of

Table 2
Mean and standard deviation of gait parameters in healthy and MS subjects during test and re-test trials.

Gait Parameter	Task	Healthy subjects			MS subjects		
		Test	Re-test	P-value	Test	Re-test	P-value
Velocity (cm/s)	MM	129.15 ± 21.53	132.51 ± 24.28	0.17	69.11 ± 25.40	75.59 ± 26.93	<0.01
	MC	83.27 ± 16.36	84.61 ± 15.07	0.56	54.73 ± 17.59	57.65 ± 19.34	0.14
Cadence (steps/min)	MM	116.05 ± 10.83	117.21 ± 11.06	0.32	88.29 ± 16.71	91.06 ± 16.58	0.01
	MC	89.70 ± 12.99	91.23 ± 12.94	0.36	76.20 ± 14.23	77.80 ± 13.60	0.32
Step length (cm)	MM	66.61 ± 7.93	67.62 ± 9.27	0.20	45.87 ± 10.17	48.58 ± 10.49	<0.01
	MC	55.50 ± 5.96	55.62 ± 6.39	0.87	42.73 ± 8.97	43.93 ± 10.04	0.11
Stride length (cm)	MM	133.41 ± 15.38	135.37 ± 18.40	0.21	92.04 ± 20.38	97.32 ± 20.86	<0.01
	MC	111.37 ± 11.83	111.29 ± 12.76	0.96	85.56 ± 18.00	87.99 ± 20.12	0.11
Step time (s)	MM	0.52 ± 0.05	0.52 ± 0.05	0.34	0.70 ± 0.15	0.68 ± 0.13	0.07
	MC	0.68 ± 0.11	0.67 ± 0.10	0.30	0.81 ± 0.15	0.80 ± 0.15	0.31
Stride time (s)	MM	1.04 ± 0.10	1.03 ± 0.10	0.31	1.41 ± 0.30	1.37 ± 0.27	0.08
	MC	1.37 ± 0.24	1.35 ± 0.20	0.29	1.63 ± 0.30	1.59 ± 0.29	0.36
Double support time (s)	MM	0.28 ± 0.06	0.27 ± 0.07	0.44	0.57 ± 0.24	0.52 ± 0.21	0.05
	MC	0.45 ± 0.11	0.44 ± 0.09	0.77	0.71 ± 0.28	0.66 ± 0.25	0.06
Single support phase (% gait cycle)	MM	36.62 ± 1.82	36.99 ± 2.27	0.11	30.39 ± 4.28	31.48 ± 3.91	0.01
	MC	33.77 ± 1.60	33.52 ± 2.17	0.46	28.91 ± 4.31	29.84 ± 4.07	0.03
Stance phase (% gait cycle)	MM	63.38 ± 1.81	63.03 ± 2.26	0.12	69.41 ± 4.24	68.33 ± 3.86	0.01
	MC	66.23 ± 1.61	66.49 ± 2.16	0.45	70.90 ± 4.28	70.17 ± 4.15	0.07
Base of support (cm)	MM	7.70 ± 1.79	7.42 ± 2.29	0.47	11.90 ± 4.46	11.05 ± 4.42	0.08
	MC	8.52 ± 2.78	8.32 ± 2.36	0.67	12.07 ± 4.56	11.98 ± 5.42	0.86

The P-value of the paired Student t-test is reported. MM = motor–motor dual task; MC = motor-cognitive dual task.

Table 3
Reliability results obtained in healthy and MS subjects during dual task trials.

Gait Parameter	Task	Healthy subjects				MS subjects			
		ICC (95% CI)	SEM	MDC	CV (%)	ICC (95% CI)	SEM	MDC	CV (%)
Velocity (cm/s)	MM	0.87 (0.72–0.94)	8.44	23.39	17.49	0.97 (0.93–0.99)	4.71	13.04	36.19
	CM	0.80 (0.55–0.91)	7.12	19.75	18.73	0.87 (0.72–0.94)	6.78	18.78	32.84
Cadence (steps/min)	MM	0.87 (0.72–0.94)	4.02	11.15	9.39	0.95 (0.90–0.98)	3.62	10.02	18.56
	CM	0.84 (0.65–0.94)	5.11	14.17	14.22	0.84 (0.67–0.93)	5.56	15.42	18.08
Step length (cm)	MM	0.90 (0.79–0.96)	2.72	7.54	12.81	0.95 (0.88–0.98)	2.43	6.75	21.88
	CM	0.85 (0.66–0.94)	2.40	6.64	11.11	0.93 (0.85–0.97)	2.54	7.05	21.93
Stride length (s)	MM	0.90 (0.79–0.96)	5.39	14.95	12.73	0.94 (0.88–0.98)	4.91	13.63	21.79
	CM	0.86 (0.68–0.94)	4.64	12.85	11.05	0.93 (0.84–0.97)	5.12	14.21	21.95
Step time (s)	MM	0.86 (0.72–0.94)	0.02	0.05	9.73	0.91 (0.81–0.96)	0.04	0.12	20.54
	CM	0.88 (0.73–0.95)	0.04	0.10	15.74	0.82 (0.63–0.92)	0.06	0.18	18.76
Stride time (s)	MM	0.86 (0.72–0.94)	0.04	0.10	9.79	0.91 (0.80–0.96)	0.09	0.25	20.63
	CM	0.89 (0.73–0.95)	0.07	0.21	16.11	0.80 (0.60–0.91)	0.13	0.37	18.54
Double support time (s)	MM	0.82 (0.63–0.92)	0.03	0.07	22.33	0.85 (0.69–0.93)	0.09	0.24	40.53
	CM	0.85 (0.65–0.94)	0.04	0.11	22.57	0.88 (0.75–0.95)	0.09	0.25	38.20
Single support phase (% gait cycle)	MM	0.86 (0.71–0.94)	0.77	2.14	5.55	0.91 (0.80–0.96)	1.25	3.47	13.25
	CM	0.69 (0.37–0.87)	1.06	2.94	5.61	0.88 (0.75–0.95)	1.45	4.01	14.27
Stance phase (% gait cycle)	MM	0.86 (0.71–0.94)	0.77	2.13	3.22	0.90 (0.78–0.96)	1.28	3.54	5.88
	CM	0.69 (0.37–0.87)	1.06	2.95	2.84	0.90 (0.79–0.96)	1.31	3.62	5.98
Base of support (cm)	MM	0.70 (0.37–0.87)	1.19	3.29	27.07	0.86 (0.71–0.94)	1.66	4.60	38.76
	CM	0.71 (0.39–0.88)	1.49	4.13	30.48	0.89 (0.76–0.95)	1.69	4.69	41.53

MM = motor–motor dual task; MC = motor-cognitive dual task; ICC = intraclass correlation coefficient; SEM = standard error of measurement; MDC = minimum detectable change; CV = coefficient of variation.

support. Concerning CV, slightly higher values were found for patients with respect to normal controls, with a maximal value of 41.53% for patients and 30.48% for healthy.

4. Discussion

This study established the test–retest reliability of gait spatial–temporal parameters under dual-task conditions in healthy subjects and people with MS.

Under dual task interference, subjects with MS walked slower, with shorter steps, spent a greater percentage of the gait cycle in double support, and obtained a shorter single support phase than healthy subjects. All of these gait abnormalities are present also during normal gait [4].

Both groups achieved a higher walking speed, a longer step length, and a lower step and stride time during MM trials than during MC trials. The difference between the two conditions was greater for healthy volunteers than for people with MS. Indeed, the between group difference in gait speed was greater under MM conditions (47% on the first day and 43% on the second) than under MC conditions (35% on the first day and 32% on the second), thus suggesting the higher cost of the motor–motor interference for the people with MS.

The test–retest reliability of all of the gait parameters was good to excellent under both conditions and in both populations (ICCs always $>$0.69 and in the majority of the cases $>$0.85). Our results are largely in line with previous findings on other categories of adults [14,15].

In the MM trial, patients improved some gait parameters between test–retest probably because of a learning effect, possibly due to a too short interval between measurements. The same did not happen during MC trials probably because the initial letter was changed.

For the majority of the gait parameters, the SEMs, estimating response stability, were low, thus indicating minimal variability for both group of subjects. The results of a previous study in older adults were similar [9]. In both groups, the highest level of variability was found for the double support time and the base of support.

The obtained MDC scores can be considered as valid measurement references for people with MS evaluated by the GaitRite® during gait under dual-task conditions.

As previously observed [4], walking patterns during dual-task interference were slightly more variable in the MS subjects than in the controls (CVs ranged between 5.88 and 41.53% for patients and between 2.84 and 30.48% for healthy). These altered gait patterns should be carefully taken into account when planning and evaluating gait rehabilitation programmes, considering that gait variability during dual-task interference is an early predictor of future falls [9].

This study has some limitations. First, it only included people with MS who required no supervision when walking, hence the findings are to be considered applicable and validated only for this subgroup. Second, the design did not include walking at self-selected speed with no dual task interference because we decided to reduce the task conditions to avoid patients to get fatigue. Finally, caution is required when extrapolating our results to instruments other than GAITRite®.

In conclusion, the results obtained from healthy subjects and people with MS under both dual-task conditions were highly reliable. In the future, computing minimal important changes through a longitudinal study could be a very important prospect of the present results so to offer a valid and complete reference database for the planning and assessing of rehabilitation studies under dual-task conditions in multiple sclerosis.

Acknowledgements

We would like to thank Kevin Smart for his help in preparing the English version of the manuscript.

Conflict of interest statement

The authors report no conflict of interest.

References

[1] Ramagopalan SV, Sadovnick AD. Epidemiology of multiple sclerosis. Neurol Clin 2011;29(2):207–17.

[2] Givon U, Zeilig G, Achiron A. Gait analysis in multiple sclerosis: characterization of temporal–spatial parameters using GAITRite functional ambulation system. Gait Posture 2009;29:138–42.
[3] Cameron MH, Wagner JM. Gait abnormalities in multiple sclerosis: pathogenesis, evaluation, and advances in treatment. Curr Neurol Neurosci Rep 2011;11(5):507–15.
[4] Sosnoff JJ, Sandroff BM, Motl RW. Quantifying gait abnormalities in persons with multiple sclerosis with minimal disability. Gait Posture 2012;36:154–6.
[5] Sosnoff JJ, Boes MK, Sandroff BM, Socie MJ, Pula JH, Motl RW. Walking and thinking in persons with multiple sclerosis who vary in disability. Arch Phys Med Rehabil 2011;92:2028–33.
[6] Hamilton F, Rochester L, Paul L, Rafferty D, O'Leary CP, Evans JJ. Walking, talking: an investigation of cognitive-motor dual tasking in multiple sclerosis. Mult Scler 2010;15:1215–27.
[7] Kalron A, Dvir Z, Achiron A. Walking while talking—difficulties incurred during the initial stages of multiple sclerosis disease process. Gait Posture 2010;32:332–5.
[8] Montero-Odasso M, Casas A, Hansen KT, Bilski P, Gutmanis I, Wells JL, Borrie MJ. Quantitative gait analysis under dual-task in older people with mild cognitive impairment: a reliability study. J Neuroeng Rehabil 2009;6:35.
[9] Hollman JH, Childs KB, McNeil zML, Mueller AC, Quilter CM, Youdas JW. Number of strides required for reliable measurements of pace, rhythm and variability parameters of gait during normal and dual task walking in older individuals. Gait Posture 2010;32:23–8.
[10] Kurtzke JF. Rating neurologic impairment in multiple sclerosis: an expanded disability status scale (EDSS). Neurology 1983;33:1444–52.
[11] Walter SD, Eliasziw M, Donner A. Sample size and optimal designs for reliability studies. Stat Med 1998;17:101–10.
[12] Atkinson G, Nevil AM. Statistical methods for assessing measurement error (reliability) in variables relevant to sports medicine. Sports Med 1998;26(4):217–38.
[13] Terwee C, Bot S, de Boer M, van der Windt D, Knol D, Dekker J, Bouter L, de Vet H. Quality criteria were proposed for measurement properties of health status questionnaires. J Clin Epidemiol 2007;60:34–42.
[14] Bilney B, Morris M, Webster K. Concurrent related validity of the GAITRite walkway system for quantification of the spatial and temporal parameters of gait. Gait Posture 2003;7:68–74.
[15] van Uden CJT, Besser MP. Test–retest reliability of temporal and spatial gait characteristics measured with an instrumented walkway system (GAITRite®). BMC Musculoskel Disord 2004;5:13.