RESEARCH ARTICLE

Balance and Gait in People with Multiple Sclerosis: A Comparison with Healthy Controls and the Immediate Change after an Intervention based on the Bobath Concept

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Abstract

Background and purpose. The objective of this study is to compare the balance and gait of 11 people with multiple sclerosis (MS) to 11 healthy controls and to investigate the immediate change after a single intervention based on the Bobath concept on these activities in the MS group. **Methods.** Balance was assessed by ground reaction forces (GRF) and centre of pressure movements during single limb standing (SLS), the Lateral Reach Test (LRT) and the Four Square Step Test (FSST). Gait was evaluated by GRF, ankle kinematics and spatiotemporal measures. **Results.** Baseline measures in the MS group showed significantly greater vertical GRF variability ($p = 0.008$) during SLS reached less distance on the LRT ($p = 0.001$) and were slower completing the FSST ($p < 0.001$). During gait, the MS group walked slower ($p = 0.005$) and had less ankle plantarflexion (PF) ($p = 0.001$) than the control group. Less peak vertical GRF ($p < 0.001$) and peak propulsive GRF ($p = 0.004$) at terminal stance and increased vertical GRF in midstance ($p = 0.005$) were observed. The measures of balance and gait were re-assessed in the MS group immediately after a 20-min intervention based on the Bobath concept delivered to the most impaired foot and ankle. After the intervention, the MS group had significant changes towards the control group values with reduced mediolateral ($p = 0.002$) and vertical ($p = 0.016$) GRF variability in the SLS task, faster FSST time ($p = 0.006$) and increased ankle PF during gait ($p = 0.002$). **Discussion.** This study provides further evidence of balance and gait limitations in people with MS and indicates that a single treatment based on principles of the Bobath concept to the foot and ankle can result in immediate improvements in balance and ankle PF during gait in people with MS. Copyright © 2015 John Wiley & Sons, Ltd.

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Keywords

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Introduction

Reduced balance performance (Frzovic et al., 2000, Martin et al., 2006) and alterations in gait characteristics (Benedetti et al., 1999, Morris et al., 2002) are well documented in people with multiple sclerosis (MS). Compared with healthy individuals, people with MS walk slower, with shorter steps, have altered ground reaction forces (GRF) (Benedetti et al., 1999, Givon et al., 2009) and spend a greater percentage of a stride with both feet on the ground (Martin et al., 2006). People with MS have impaired balance performance when compared with healthy individuals on stabilometric and clinical measures (Frzovic et al., 2000, Sosnoff et al., 2010). Centre of pressure (COP) variables have shown people with MS have greater magnitude of COP area, variance and velocity in quiet standing (Roughier et al., 2007, Sosnoff et al., 2010, Van Emmerick et al., 2010) and reduced limits of stability with a smaller COP excursion for reaching and leaning tasks (Van Emmerick et al., 2010, Karst et al., 2005) when compared with healthy individuals. We were unable to identify any literature investigating COP or GRF variables for higher level balance tasks such as single leg stance (SLS) in people with MS.

The mechanism behind the limitations in balance and gait performance is likely to be multifactorial with reduced postural stability (Benedetti et al., 1999), reduced muscular control (Martin et al., 2006, Chung et al., 2008), spasticity (Sosnoff et al., 2010) and altered sensory processes (Kelleher et al., 2009, Cattaneo and Jonsdottir, 2009) hypothesized as contributing factors. Physiotherapy has been shown to be effective in improving participation restrictions and activity limitations in people with MS (Craig et al., 2003, Rasova et al., 2005). There is less evidence to support the efficacy of any particular approach of physiotherapy in relation to balance and gait (Dalgas et al., 2008, Pollock et al., 2007). The Bobath concept is a physiotherapy approach widely used in the treatment of MS; however, there are few studies investigating the efficacy of this approach, including specific interventions targeting balance and gait (Lord and Halligan, 1998, Smedal et al., 2006). Interventions involving treatment of the foot and ankle are a strong focus of the Bobath concept, with the aim of improving postural control at the dynamic interface between the person and the base of support (Graham et al., 2009).

The aims of this study were to compare balance and gait performance in people with MS with healthy controls and to evaluate the immediate change after one physiotherapy intervention, based on the Bobath concept, delivered to the most impaired foot and ankle on measures of balance and gait for the people with MS. The hypotheses of the study were that the MS group will exhibit different balance and gait patterns and may improve with one treatment based on the Bobath concept.

Method

Study design

This study has two components: (i) a cross sectional comparison of clinical and laboratory measures of balance and gait of subjects, people with MS compared with healthy controls; and (ii) a within-subject repeated measures design, before and after an intervention for the subjects with MS. This project received Human Research Ethics Committee approval from a large tertiary hospital and was registered with ethics committee of an affiliated university.

Subjects

Subjects with MS were recruited for this study from a large tertiary hospital. Subjects were included if they had a diagnosis of MS, were aged between 18 and 65 years, had perceived difficulty with walking but could walk at least 50 m independently and were able to give informed consent. Additionally, subjects had to be able to balance in SLS for at least 3 s without assistance on their most impaired leg and have motor, sensory or tonal changes in at least one leg or foot. Exclusion criteria included acute exacerbation in the past 3 months and currently receiving intensive rehabilitation. The age-matched and gender-matched healthy control subjects were recruited from the physiotherapy staff of the hospital and university and from family and friends of staff members using flyers.

Materials

The primary outcome measure in this study was GRF variability in stabilization of SLS, with secondary measures of COP characteristics in the SLS task, clinical balance measures and gait performance measures. Assessment of balance in SLS and gait were conducted in a gait laboratory using kinetic, kinematic and spatiotemporal measures. The leg with the greater neurological impairments was chosen as the limb for evaluation, and for the healthy control subjects, the corresponding limb side was selected. We selected stabilization of SLS as a balance task that requires a high level of dynamic control at the interface between the foot and the floor. Force plates (Advance Medical Technology Incorporated USA, AMTI Model No: ORG-7-2000) sampling at 2000 Hz to enable accurate collection of COP velocity data (Hertel et al., 2002, Raymakers et al., 2005) were used for SLS and gait tasks, with three plates spaced 10 cm apart embedded in the floor. During the gait trials, the force plates were concealed by a walkway mat. The outcome measures used in the SLS analysis were triplanar GRF variability (Jonsson et al., 2004, Goldie et al., 1989, Goldie et al., 1992) to quantify postural stability (Shumway-Cook and Woollacott, 2007) and five COP measures (Raymakers et al., 2005) to quantify the postural control strategies of the lower limb (Shumway-Cook and Woollacott, 2007, Winter, 1995) (Table 1). These measures have been commonly used to assess balance (Goldie et al., 1989, Jonsson et al., 2004, Raymakers et al., 2005, Doyle et al., 2007). Kinetic measures of gait included GRF events normalized to body weight at five stages of the stance phase (Smidt, 1990) (Figure 1).

An eight-camera VICON MX System (Vicon Motion Systems and Peak Performance Inc, Oxford, UK.) recorded the sagittal plane angular kinematics of the ankle joint during gait to determine the maximum dorsiflexion (DF) and plantarflexion (PF) during a stride. The choice of the location of the markers were modified from previous gait analysis studies using two-dimensional PEAK systems (Martin et al., 2006, Winter et al., 1990) for calculation of two-dimensional ankle range of movement (ROM). Four spherical passive reflective markers (14-mm diameter) were placed at the first metatarsal phalangeal joint, calcaneus, lateral malleolus and head of fibular. In VICON software, the spatial orientation of the ankle was calculated, and each trial was filtered using a Woltering filtering routine with a predicted mean square error value of 20 (Molloy et al., 2008).

Basic spatiotemporal measures of the gait were captured by a GAITRite® walkway system (CIR systems Inc. Clifton NJ 07012) placed over the force plates along a 10-m walkway.

Two clinical measures of balance were also used. The Lateral Reach Test (LRT) is a valid and reliable measure of lateral stability limits (Brauer et al., 1999) and has been used in MS populations (Martin et al., 2006). The Four Square Step Test (FSST) has established reliability and concurrent validity (Dite and Temple, 2002) and has been shown to identify non-fallers in a group of people with MS (Nilsagård et al., 2009) and to be sensitive in detecting a change in balance performance in people with MS following balance training (Prosperini et al., 2013). The subjects with MS were also rated on the Expanded Disability Status Scale (Kurtzke, 1983) by a neurologist and self-rated their mobility using the 12-item MS Walking Scale-12 (MSWS-12) (Hobart et al., 2003) as background descriptive measures of the subject's current level of function and mobility.

Subjects in the MS group received an intervention based on the Bobath concept that was tailored to address the individual impairments of the foot and ankle identified in each subject. Specific therapeutic strategies in the Bobath concept have been described by Holland and Lynch-Ellerington (2009)) as '(i) provision of sensory information to the foot; (ii) stretch to the intrinsic muscles of the foot in order to selectively activate the foot; (iii) improving alignment of the talo-crural joint; (iv) activation of gastrocnemius facilitates eccentric control of soleus; and (v) facilitation of ankle strategy' (p124) (Holland and Lynch-Ellerington, 2009). To tailor the intervention, the therapist conducted a detailed assessment including observation of the alignment of the foot and ankle in standing and sitting. Further, a more detailed observation and palpation assessment was conducted in sitting to identify stereotypical and inefficient patterns of activity, muscle compliance, joint stiffness and sensory awareness (Gjelsvik, 2008).

Subjects were seated in a chair while receiving the intervention with the therapist kneeling beside the lower limb being treated. The subject's foot was placed on the therapist's thigh, freeing both hands to guide the movements. Areas of joint malalignment and soft tissue tightness were mobilized directly and indirectly through movements of the joints. The mobilization aimed to re-align the joints of the ankle and foot to a more biomechanically efficient posture and to create tonically active foot arches through mobilization of the sole of the foot and facilitation of activity in the interossei muscles. The subject was then manually guided by the therapist's hands, while specific

Table 1. Baseline and post intervention values for all measures

	Test (family-wise Bonferroni correction)	Variable	Control group median (IQR) $n = 11$	MS group $n = 11$: Pre-intervention median (IQR)	MS group $n = 11$: Post-intervention median (IQR)	Control versus MS group: p-value	Control versus MS group: Group ES	MS pre-intervention versus MS post-intervention: p-value	MS pre-intervention versus MS post-intervention: Pre-post treatment ES
Balance	Single limb standing GRF – 3 variables ($\frac{0.05}{3} = 0.017$)	V GRF variability (N)	9.0 (6.6)	14.3 (20.2)	13.8 (6.3)	**0.008****	**−0.82**	***p* = 0.016***	0.03
		ML GRF variability (N)	4.8 (2.5)	6.0 (6.3)	5.0 (4.9)	0.033	−0.46	***p* = 0.002***	0.15
	COP – 4 variables ($\frac{0.05}{4} = 0.013$)	AP GRF variability (N)	9.6 (5.0)	10.0 (8.1)	10.7 (3.4)	0.122	−0.08	$p = 0.465$	−0.09
		COPvel (mm/s)	812.2 (853.1)	628.9 (270.4)	649.6 (265.7)	0.500	0.22	$p = 0.107$	−0.08
		PD (mm)	10.8 (3.4)	15.3 (6.1)	12.2 (5.2)	0.014	**−1.31**†	$p = 0.013$	**0.51**†
		ML (range) (mm)	34.9 (12.7)	47.3 (23.2)	35.7 (11.8)	0.038	**−0.98**†	$p = 0.031$	**0.50**†
		AP (range) (mm)	23.6 (11.8)	24.9 (7.2)	27.0 (8.7)	0.239	−0.12	$p = 0.021$	−0.29
	Clinical measures – 3 variables ($\frac{0.05}{3} = 0.017$)	LRT 1 (cm/m)	20.1 (10.3)	10.4 (3.2)	11.1 (3.3)	**0.001***	**0.94**†	$p = 0.164$	−0.17
		LRT 2 (cm/m)	23.2 (12.2)	9.6 (4.3)	11.4 (3.5)	**0.001***	**1.12**†	$p = 0.297$	−0.41
		FSST (s)	5.9 (1.9)	10.5 (4.1)	9.5 (4.7)	**<0.001***	**−2.43**†	***p* = 0.006***	0.26
Gait	Ground reaction forces – 5 variables ($\frac{0.05}{5} = 0.010$)	F1 (%BW)	112.9 (19.2)	113.7 (16.9)	113.8 (14.9)	0.260	−0.04	$p = 0.212$	−0.01
		F2 (%BW)	66.9 (7.9)	82.5 (12.7)	76.3 (14.3)	**0.005***	**−1.98**†	$p = 0.031$	0.49
		F3 (%BW)	117.1 (7.6)	102.3 (6.3)	104.6 (7.4)	**<0.001***	**1.95**†	$p = 0.046$	−0.36
		F4 (%BW)	−16.3 (7.0)	−14.1 (10.9)	−11.8 (5.4)	0.303	−0.31	$p = 0.107$	−0.21
		F5 (%BW)	20.6 (5.0)	13.0 (9.7)	15.5 (9.7)	**0.004***	**1.53**†	$p = 0.187$	−0.27
	Ankle range of movement – 2 variables ($\frac{0.05}{2} = 0.025$)	DF (degrees)	13.0 (4.9)	12.4 (4.4)	11.8 (9.8)	0.475	0.11	$p = 0.329$	0.14
		PF (degrees)	17.6 (7.4)	7.5 (8.2)	9.1 (8.5)	**0.001***	**1.36**†	***p* = 0.002***	−0.19
	GAITRite Spatiotemporal gait characteristics – 5 variables ($\frac{0.05}{5} = 0.010$)	Velocity (cm/s	143.9 (19.3)	114.2 (59.3)	124.6 (51.1)	**0.005***	**1.53**†	$p = 0.091$	−0.17
		Cadence (step/min)	118.7 (16.0)	111.4 (17.2)	110.1 (15.3)	0.033	0.46	$p = 0.212$	0.08
		Step length 1 (cm)	73.0 (6.6)	61.2 (26.1)	59.7 (22.8)	0.038	**1.79**†	$p = 0.046$	0.06
		Step length 2 (cm)	73.5 (8.5)	60.6 (26.1)	65.5 (20.0)	0.010	**1.52**†	$p = 0.066$	−0.19
		%DLS	18.9 (2.5)	21.6 (7.8)	21.7 (6.0)	**0.005***	**−1.11**†	$p = 0.297$	−0.01

*(Bold text) significant unidirectional $\acute{\alpha} = 0.05$. Group comparison Mann–Whitney *U*; pre-post treatment effect comparison Wilcoxon sign-ranked testing for two related samples; ES, Effect Size

†(Bold text) moderate to large effect size

Balance measures: GRF, ground reaction force; V GRF variability, vertical GRF variability; ML GRF variability, mediolateral GRF variability; AP GRF variability, anteroposterior GRF variability; COPvel, centre of pressure velocity; PD, planar deviation; COP, centre of pressure; ML (range), total COP excursion range in mediolateral plane; AP (range), total COP excursion range in the anteroposterior plane. *Clinical measures*: LRT, lateral reach test; LRT1, (LRT) to intervention/most impaired side; LRT2, LRT to non-intervention/least impaired side; FSST, Four Square Step Test.

Gait measures: GRF, F1, maximum vertical force at initial contact; F2, minimum vertical force at midstance; F3, maximum vertical force at terminal stance; F4, maximum anteroposterior braking force; F5, maximum anteroposterior propulsion force. *Kinematic*; DF, maximal dorsiflexion in a stride; PF, maximal plantarflexion in a stride; *Spatiotemporal*: step length 1, step length of intervention/most impaired side; step length 2, step length of non-intervention/least impaired side; %DLS, percentage of gait cycle in double limb support.

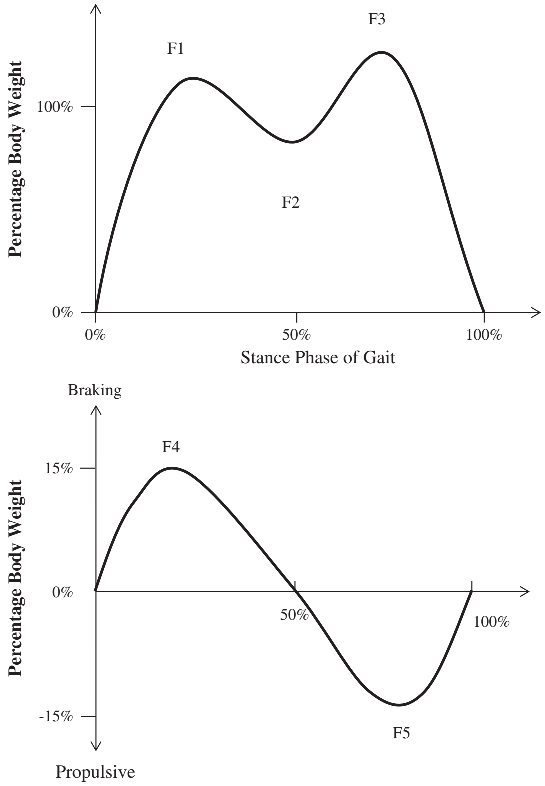


Figure 1. Ground reaction force measures in gait: F1, maximal vertical force in loading response; F2, minimal vertical force in midstance; F3, maximal vertical force in terminal stance; F4, maximal fore-aft braking force; F5, maximal fore-aft propulsive force

facilitation was provided to assist the subject to perform a more selective active movement. The facilitation skills required to perform these interventions are taught in postgraduate courses on the Bobath concept at introductory, basic and advanced levels.

The intervention was limited to a non-weight bearing position to prevent practice effects from weight bearing activities influencing post intervention assessments.

Procedure

For the subjects with MS, the assessment of foot and ankle neurological impairment was conducted 1 to 2 weeks prior to attending the movement laboratory. This assessment was to identify specific impairments, select the leg with the greater impairments for the assessment and intervention and then formulate a treatment plan based on those identified impairments. This treatment plan was then carried out on the day of the laboratory testing.

At the laboratory assessment, the clinical measures of balance were conducted first. For the LRT, mean distance reached from three trials to each side normalized for height was recorded (Martin et al., 2006). The subjects then completed three trials of the FSST with the fastest time used for analysis (Dite and Temple, 2002).

For the assessment of SLS, the subjects stood with each foot on adjacent force plates aligned on a stencil with feet parallel and 20 cm apart. They were instructed to keep weight evenly distributed while baseline force plate readings were taken for 5 s. On a verbal cue, the subjects lifted one leg and balanced on the selected leg for 3 s. A trial was excluded if the subject could not maintain SLS, touched down with the lifting foot, uncrossed the arms or required support from the investigator to prevent falling. In this project, data were analysed for the first 1.5 s of SLS for three successful attempts.

For the gait assessment, the subjects started 2 m from the beginning of the GAITRite® mat and walked at a comfortable pace along the mat to a mark 2 m beyond it. A trial was accepted if the entire foot of the selected limb contacted one of the force plates during stance phase. Subjects completed as many trials as necessary to capture six acceptable trials.

Following the baseline testing, the subjects with MS were given a 10-min rest period, and then the intervention to the foot and ankle was carried out for 20 min. Immediately following the intervention, the baseline testing was repeated.

The force plate and two-dimensional sagittal ROM data were collected through the Vicon system, saved as an ASCII file and then exported into Microsoft Excel. The force plate measures and the basic trigonometry calculations for sagittal ankle angle were completed in Excel format. The GAITRite® data were saved as an ASCII file and then exported into Microsoft Excel.

The mean and standard deviation for each subject were calculated in Microsoft Excel, and these values were exported to the Statistical Package for Social Sciences (SPSS, Inc., Chicago IL), Version 15.0 software for analysis of group differences and change pre-post treatment.

Preliminary review of the data demonstrated non-normally distributed data for the group comparison and the change pre-post treatment comparison, and therefore non-parametric analyses were undertaken. Mann–Whitney *U* was used for the group comparison, while the change pre-post treatment comparison used

Wilcoxon sign-ranked testing for two related samples. A uni-directional alpha level of 0.05 was applied based on the assumptions that people with MS would have impaired walking and balance when compared with healthy controls and that the intervention would improve the performance of these activities towards the control group values. Furthermore, a family-wise Bonferroni error correction for both analyses was applied to control for multiple analyses (Table 1). To support *p*-values in the critical evaluation of the results (Houle et al., 2005, Moran, 2003), effect size (ES) calculations were conducted using median and interquartile range values (Kazis et al., 1989), with $ES < 0.20$ defined as small, ES 0.50 moderate and 0.80 or greater as large (Cohen, 1988).

Results

A total of 25 people with MS were screened for inclusion in the study; 12 people with MS did not proceed to the assessment phase because of an exacerbation ($n = 2$) or declining to participate ($n = 10$). Two people with MS were unable to complete the testing protocol because of equipment failure or performance difficulties, leaving a total of 11 MS subjects who completed all testing procedures.

There were no significant differences in demographic characteristics between the MS and control groups (Table 2). Baseline values for both groups and post intervention values for the subjects with MS for laboratory measures of gait and balance are shown in Table 1.

The subjects with MS exhibited impaired performance in the balance activities compared with the healthy control group with increased vertical GRF variability (VGRF) ($Z = -2.397$, $p = 0.008$), (Figure 2), less distance reached in the LRT to the most impaired side (LRT1) ($Z = -3.185$, $p = 0.001$) and to the least impaired side (LRT2) ($Z = -3.185$, $p = 0.001$), and required more time to complete the FSST ($Z = -3.644$, $p < 0.001$). Large ES values supported the statistical significance for these variables. The remaining GRF variability and COP values in the balance assessment did not show significant differences between the groups. Moderate to large group ES values indicating impaired SLS balance performance were found for mediolateral GRF (MLGRF) variability ($ES = -0.46$), planar deviation (PD) ($ES = -1.31$) and mediolateral (ML) range ($ES = -0.98$).

The subjects with MS exhibited greater stability in the SLS standing task following the intervention with significant reductions in MLGRF ($Z = -2.934$, $p = 0.002$) and VGRF ($Z = -2.134$, $p = 0.016$) variability (Figure 2). There were no statistically significant changes to COP variables following the intervention, although moderate ES values suggested a potential reduction in median PD ($ES = 0.51$) and ML range ($ES = 0.50$). Improvement in balance performance observed in the laboratory measures was supported by a significant reduction in the FSST ($Z = -2.535$, $p = 0.006$).

The gait assessment showed statistically significant differences in GRF characteristics between the groups for increased F2 ($Z = -2.528$, $p = 0.005$), and reduced F3 ($Z = -3.710$, $p = 0.000$) and F5 ($Z = -2.659$, $p = 0.004$) for the MS group. These results were supported by large group ES values (Table 1). The F1 ($Z = -0.689$, $p = 0.260$) and F4 ($Z = -0.558$, $p = 0.303$) GRF's were not significantly different between the groups. The MS group exhibited significantly less maximal PF in a stride ($Z = -2.988$, $p = 0.001$) when compared with the control group and showed reduced gait velocity ($Z = -2.528$, $p = 0.005$) and increased percentage double limb support (%DLS) ($Z = -2.528$, $p = 0.005$).

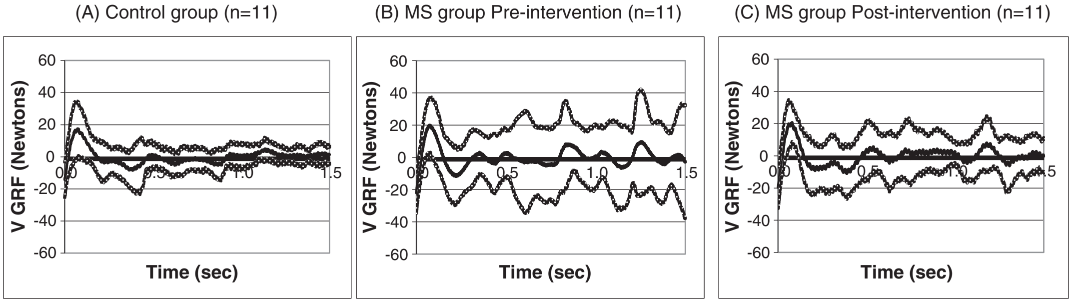
After the treatment, the MS group showed a significant increase in maximum range of PF ($Z = -2.845$, $p = 0.002$) while DF was unchanged ($Z = -0.445$, $p = 0.329$). No statistically significant changes were found for GRF or spatiotemporal data after the intervention.

The trends in the baseline and post-intervention data for each individual in the MS group were examined by visual inspection of graphs of pre-intervention and post-intervention trials for all variables to investigate

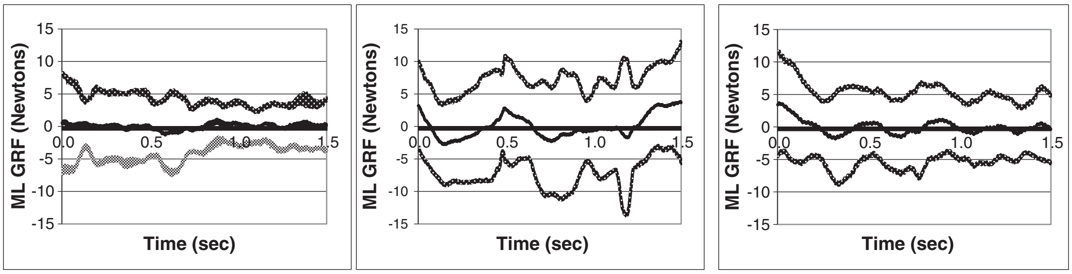
Table 2. Participant demographics (median and IQR)

	MS group ($n = 11$)	Control group ($n = 11$)
Age (years)	47 (9), range 37–61	44 (12), range 32–59
Gender	7 F, 4 M	7 F, 4 M
Height (m)	1.65 (0.21), range 1.53–1.83	1.68 (0.22), range 1.57–1.87
Mass (kg)	72.40 (33.60), range 47.8–91.6	67.6 (27.7), range 57.0–103.0
Years since diagnosis	8 (8), range 2–33	N/A
EDSS	4.5 (4.0), range 2–6	N/A
MSWS-12	43.30 (23.30), range 15–63.3	N/A

EDSS, Expanded Disability Status Scale; MSWS-12, 12-Item MS walking scale; N/A, not applicable.



(i) Vertical ground reaction force (VGRF) variability (mean [solid line] +/-SD [hatched lines]): Control versus MS pre-intervention (p=0.008*), MS pre-intervention versus MS post-intervention (p=0.016*), *significant. Greater postural stability is indicated by the mean (solid) line of VGRF variability approaching zero.



(ii) Medio-lateral ground reaction force (MLGRF) variability (mean [solid line] +/-SD [hatched lines]): Control versus MS pre-intervention (p=0.033), MS pre-intervention versus MS post-intervention (p=0.002*), *significant. Greater postural stability is indicated by the mean (solid) line of MLGRF variability approaching zero.

Figure 2. Group data: Ground reaction force variability in single-limb standing task

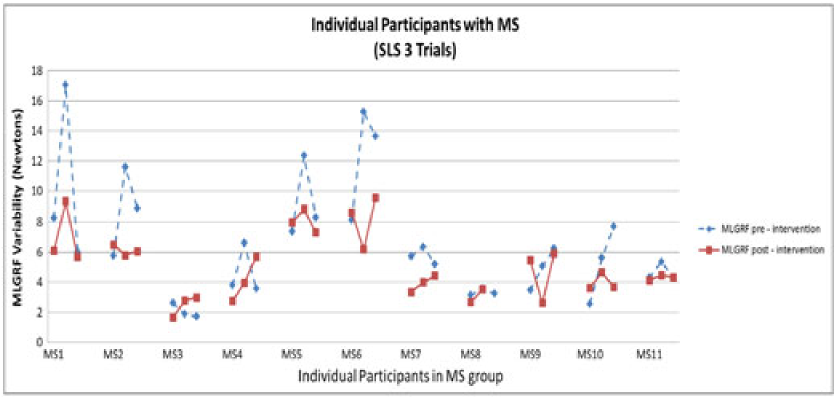


Figure 3. Raw data for mediolateral ground reaction force variability in individual participants with multiple sclerosis

whether the changes in SLS performance observed post intervention may have occurred as a practice effect of the relatively novel SLS task (Figure 3). Figure 3 shows these values for MLGRF variability for each subject, indicating that there is no trend for improved performance with repetition of the task in the pre-intervention or post-intervention phase. Similar patterns were observed for other variables.

Discussion

This study showed that balance and gait task performance was reduced in people with moderate neurological impairment because of MS when compared with age-matched and gender-matched healthy individuals. The MS group exhibited a reduction in balance performance in SLS balance, LRT and FSST and had significant differences in the gait measures for GRF characteristics, ankle motion and spatiotemporal gait measures compared with the control group. The study demonstrated improvement in balance following one intervention based on the Bobath concept, with reductions in MLGRF and VGRF variability in the SLS task, reduced time to complete FSST, and increased PF ROM during gait. Reductions in GRF variability has been associated with improved postural stability (Goldie et al., 1989, Goldie et al., 1992, Jonsson et al., 2004). In the task of stabilization of SLS balance in this study, the GRF variability measures were better able to discriminate between the MS subjects and the control group and detect change following an intervention than COP measures. After treatment, the MS group showed a significant reduction in time to complete the FSST, indicating increased stepping speed in all directions and suggesting more efficient control of movements of the centre of mass (Patla et al., 1993). The change in the MS group following the intervention shown by the improvement in SLS balance and the reduction in time to complete the FSST, indicates improved postural stability and the ability to step quickly in all directions which, if sustained, may avert falls (Dite and Temple, 2002). No improvements were observed in the LRT following the intervention.

In gait, a significant reduction in PF ROM during a stride was observed in the MS group while DF was comparable to the healthy control group, similar to the findings of previous studies (Benedetti et al., 1999, Martin et al., 2006). Following the intervention, the PF ROM significantly increased, approaching the median control group value.

The MS group also exhibited reduced velocity and increased %DLS (related to the reduced velocity) when compared with the control group. These spatiotemporal differences coupled with a flattening of the vertical and anteroposterior GRF curves (i.e. reduced magnitudes) has been described in the elderly (Winter et al., 1990) and people with MS (Kelleher et al., 2009) as an adoption of a 'cautious gait pattern'. The gait pattern of the subjects with MS in this study differed from the patterns previously reported for healthy individuals walking at reduced velocity. The GRF patterns of typical gait at reduced velocity is (i) and increase in VGRF F2 and reductions in F1 and F3; and (ii) reductions in anteroposterior (AP)GRF's F4 and F5 (Jordan et al., 2007, Winter, 1991, Neptune and Sasaki, 2005). In contrast, subjects with MS showed similar GRF characteristics of the loading response (F1) and braking (F4), and a flattening of the GRF curves (increased F2, reduced F3 and F5) at mid to late stance compared with the control group, indicating a reduction of force generation in late stance. Similarly, Martin *et al.* 2006 found that people with MS had different timing of muscle activity, step length and different ankle kinematic patterns compared with healthy subjects walking at comparable speed. The lack of propulsion force (F5), concomitant with reduced VGRF (F3) and reduced maximum PF range, is suggestive of reduced calf muscle compliance/activation in the MS group which in turn contributes to the altered spatiotemporal characteristics.

Limitations of this study include the small cohort of subjects and assessment of the change after the intervention was limited to a change in performance immediately following the intervention only. Effect size values were included to support the statistical analysis to assist in the interpretation of the results given the small study size. The change in performance in the people with MS immediately following the intervention may have been short lived, and the efficacy of the intervention for producing sustained changes in balance and gait performance in people with MS is unknown. The improvements post intervention may have been influenced by a practice effect; however, a review of the data for individual subjects in the MS group for each trial does not indicate this. The inclusion of control group of people with MS who would be assessed on the measures without receiving the intervention would assist in the interpretation of the results and identify whether any change in performance was due to the intervention or a practice effect. This did not occur in the current study because of difficulty with the recruitment of participants. The results in this study need to be evaluated in a larger sample of subjects incorporating a control group of people with MS, and the duration of the change in performance following the intervention should be considered in future research.

The intervention investigated in this study differs from normal practice of the Bobath concept in that the changes achieved at the foot and ankle in sitting were not integrated into functional activities of standing balance and walking (Gjelsvik, 2008). In this study, we chose to limit the intervention to sitting only to reduce potential practice effects from performing related tasks in standing prior to reassessment. Therefore, this study is limited to examining an aspect of an intervention based on the Bobath concept, rather than a more holistic investigation of the Bobath concept.

The improvement in stability in SLS in subjects with MS observed in this study resulted from interventions aimed at improving compliance of muscles and joints, normalizing areas of increased or decreased muscle tone and facilitating improved motor activity to support a change in postural alignment (Keating, 2005, Holland and Lynch-Ellerington, 2009). Provision of specific sensory stimulation is an important component of the intervention. The integration of sensory afferent information has been demonstrated to be impaired in people with MS (Cattaneo and Jonsdottir, 2009, Kelleher et al., 2009) and increasing sensory feedback through the feet using textured insoles reduced body sway in standing (Ramdharry et al., 2006) and increased forwards propulsion during gait (Kelleher et al., 2010) in people with MS. Improved proprioception and tactile sensation of the foot and ankle may play a significant role in perception of the body schema and the body's position in space (Kavounoudias et al., 2001), enhancing postural control. Activation of low-threshold mechanoreceptors of the sole of the foot can cause reflex modulation of voluntary contraction of muscles acting around the ankle (Fallon et al., 2005), and interventions based on the Bobath concept have demonstrated improved muscle compliance and normalization of the tone of the ankle plantarflexors in people following stroke (Ansari and Naghdi, 2007). Increased compliance and selectivity in muscular activity in the foot and ankle complex may improve muscular responsiveness, resulting in faster adjustments when controlling postural sway and a reduction in GRF variability and COP movements. Enhancing the sensory awareness of the sole of the foot and increasing proprioceptive input from muscles and joints may have contributed to increased stability.

Following a single intervention to the foot and ankle based on the Bobath concept, subjects with MS had a significant change in SLS balance performance, FSST time and maximum PF range during gait, towards the values demonstrated by age and gender-matched healthy controls. These changes may have been due to optimizing calf muscle function, changing sensory awareness of the foot and/or changing postural alignment. These results demonstrate that the GRF variability in SLS, the FSST and maximal PF ROM during gait are able to detect changes in performance immediately following an intervention in a group of people with MS with moderate neurological impairments.

Implications for physiotherapy practice

This study provides further evidence of limitations in postural stability, postural control strategies and gait performance in people with MS. It also indicates an ability to create immediate positive change in performance of these tasks after one intervention to the foot and ankle based on principles of the Bobath concept. Further investigations are warranted to explore the potential of physiotherapy treatments to improve balance and gait in people with MS.

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