Published in final edited form as:

Physiother Res Int. 2015 March ; 20(1): 45–53. doi:10.1002/pri.1595.

Gait Changes with Balance-Based Torso-Weighting in People with Multiple Sclerosis

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Abstract

Background and Purpose—People with multiple sclerosis (PwMS) commonly have mobility impairments that may lead to falls and limitations in activities. Physiotherapy interventions that might improve mobility typically take several weeks. Balance-based torso-weighting (BBTW), a system of strategically placing light weights to improve response to balance perturbations, has resulted in immediate small improvements in clinical measures in PwMS, but changes in spatio-temporal gait parameters are unknown. The purpose was to investigate the effects of BBTW on gait parameters in PwMS and healthy controls.

Methods—*Design:* non-randomized controlled experiment

Participants—20 PwMS and 20 matched healthy controls

Procedures—PwMS walked on an instrumented mat at their fastest speed for three trials each in two conditions: without BBTW then with BBTW. Healthy controls walked in both conditions at two speeds: their fastest speed, and at velocities equivalent to their matched PwMS.

Results—Averaged gait trials showed that, with BBTW, PwMS had significantly increased velocity ($p=.002$), cadence ($p=.007$), and time spent in single-limb support ($p=.014$), with decreased time in double-limb support ($p=.004$). Healthy controls increased velocity ($p=.012$) and cadence ($p=.015$) and decreased support base ($p=.014$) in fast trials with BBTW; at matched velocities, step length ($p=.028$) and support base ($p=.006$) were significantly different from

PwMS. All gait variables in healthy controls at fast speeds were significantly different from PwMS walking at their fastest speeds.

Discussion—All participants showed increases in gait velocity and cadence during fast walk with BBTW. Improvements in time spent in single- and double-limb support by PwMS with BBTW may reflect greater stability in gait. Future research might ascertain if these immediate improvements could enhance effectiveness of longer-term physiotherapy on functional mobility in PwMS.

Keywords

multiple sclerosis; rehabilitation; gait; walking

Introduction

Multiple sclerosis (MS), a neurodegenerative disease typically diagnosed in people aged 20–50, affects 2.5 million people worldwide. MS causes diverse symptoms depending on the areas of demyelination and axon damage in the central nervous system. Up to 85% of people with MS experience balance and walking impairments related to muscle weakness, sensory changes, ataxia, and/or spasticity.(Peterson, Cho et al. 2008) People with MS rate ambulation as one of their most valuable bodily functions.(Heesen, Bohm et al. 2008) Gait dysfunction may affect quality of life because of its association with frequent falls, (Nilsagard, Lundholm et al. 2009) limitations in activities, and restricted participation in daily roles.(Peterson, Cho et al. 2007; Givon, Zeilig et al. 2009; Matsuda, Shumway-Cook et al. 2012) Finding interventions that impact gait dysfunction in people with MS is an important aim for rehabilitation researchers.

Rehabilitation interventions addressing gait and balance impairments in people with MS have demonstrated variable results. Interventions demonstrating improvements include vibration therapy (Wunderer, Schabrun et al. 2010; Diego, Hernandez et al. 2011), aquatic therapy (Gehlsen, Beekman et al. 1986), strengthening (Gutierrez, Chow et al. 2005; Broekmans, Roelants et al. 2011), general physiotherapy (Wiles, Newcombe et al. 2001), and endurance training.(Rodgers, Mulcare et al. 1999) While several studies report no change in gait function (Gehlsen, Beekman et al. 1986; Broekmans, Roelants et al. 2011; Diego, Hernandez et al. 2011), others report improved TUG score or kinematic changes. (Rodgers, Mulcare et al. 1999; Gutierrez, Chow et al. 2005) Gutierrez et al. (2005) reported changes in the percent of the gait cycle spent in stance, swing, and double-limb support in people with MS after an 8-week strengthening exercise program, although changes in velocity were insignificant. Another study showed improvements in velocity, step length, and double-stance time as recorded on an instrumented gait mat in two participants with MS. (Smedal, Lygren et al. 2006) Interventions for all of these studies lasted 3–8 weeks.

In contrast, one intervention has shown immediate (same session) improvements in balance or walking. (Widener, Allen et al 2009a; Widener, Allen et al 2009b) Balance-based torso-weighting (BBTW) incorporates an assessment of directional balance loss in a specific protocol to place light weights strategically on the torso. Weight placement is based on individual responses to balance perturbations and asymmetry in ability to hold against a

rotational force at the torso. For instance, a weight placed anteriorly to the left may counter inability to hold against a rotational force at the pelvis. The mechanism for the effect of BBTW is unknown, although sensory augmentation may play a role since people do not mechanically shift in the direction of weighting. (Crittendon, O'Neill et al. 2013) Previous research has shown promising results. In a 16-participant quasi-experimental study, people with MS showed an increase in the time spent maintaining position in the sharpened Romberg test with BBTW.(Widener, Allen et al. 2009a) In a trial in which people with MS were randomly assigned to groups, groups with BBTW showed an immediate 8% improvement in a timed 25-foot walk test (significantly different from no-weight controls) or significantly greater improvement in the timed up and go (TUG) compared to a group receiving a standard weight placement of 1.5% of body weight at the waist.(Widener, Allen et al. 2009b) The standard weight placement controlled for a placebo effect or learning effect of weighting in assessing functional gait speed in this population. No previous studies examined specific spatiotemporal gait parameters. In addition, no studies have recorded changes with BBTW in healthy participants to determine if changes occur only in people with MS.

Although not examining intervention effects, multiple studies comparing people with MS and healthy participants have recorded significant between-group differences in gait parameters even at early stages of MS.(Givon, Zeilig et al. 2009; Sosnoff, Weikert et al. 2011) Slower gait velocity can result in additional changes in spatiotemporal parameters, thus, assessment of intervention effects across groups must control for velocity differences.

The purpose of this study was to record immediate effects of BBTW on spatiotemporal gait parameters in people with MS and matched healthy controls. The null hypothesis was that BBTW would make no difference in gait parameters for either group. The unilateral alternative hypothesis was that the primary outcome of quantitatively measured gait velocity would show improvement and secondary outcomes of percent of gait cycle spent in double- and single-limb support, along with cadence, step length, and support base (step width) would also change.

Methods

Design

Non-randomized controlled experiment.

Participants

Volunteers with MS were recruited through online postings and advertisement in a regional MS newsletter. Eligibility criteria included: MS diagnosis, speaks and reads English, understands and follows directions, walks at least 25 feet with or without a cane, has difficulties with balance or mobility, tolerates testing for up to three hours with multiple trials of walking short distances, exacerbation-free for at least two months, and not experiencing pain that could be aggravated by external perturbation. Healthy controls were recruited through Craigslist.com and personal contacts to match individual MS participants by sex, age within seven years, height within five inches, and weight within 20 pounds. We

excluded healthy controls if they had known neurological pathology, or current musculoskeletal conditions or pain that could be worsened by external perturbation.

A power analysis based on previous effect sizes (Widener, Allen et al 2009b) indicated that a sample size of 17 in each group should reveal significant differences in gait velocity. Twenty-two people with MS volunteered, but we analyzed data for only 20 of these; in one case, a diagnosis was changed after data collection, in another case a power outage interrupted data collection. All remaining participants with MS were female, with an average age of 49 years (see Table 1). The average disease duration was 12.8 years with Expanded Disability Status Scale (EDSS) equivalent scores from 2 to 6 (mean 4.1, SD 1.6). The EDSS assesses functional impairments in people with MS and ranges from 0 (normal neurological status) to 10 (death due to MS). A score of 6 indicates restricted walking distance requiring an assistive device for most ambulation.

Ethical considerations. All participants signed informed consent as approved by the San Francisco State University Institutional Review Board.

Procedures

Before gait trials, all subjects provided information about their recent fall history and those with MS described their MS-related symptoms in a screening questionnaire.

An unweighted BBTW vest was applied snugly to the torso prior to testing. Participants walked barefoot in all trials, using their cane if they typically walked with one.

Gait parameters were collected using the GAITRite Analysis system (CIR Systems, Inc., Havertown, PA), an instrumented mat that records foot pressure and calculates spatiotemporal gait variables. The GAITRite system has documented evidence of reliability and validity.(McDonough, Batavia et al. 2001; Youdas, Hollman et al. 2006) Participants walked over the 26-foot (7.9 m) GAITRite walkway at least three times under each condition. We examined average velocity, cadence, step length, between-foot support base, and the percentage of the gait cycle spent in single- and double-limb support.

Participants were instructed to “walk as fast as you can safely” along the walkway. Fast speeds were chosen because they were expected to challenge participants with minimal disability more than self-selected speeds might. Fast speeds may also have a greater association with self-care and mobility, such as crossing the street, than self-selected walking speeds.(Paltamaa, Sarasoja et al. 2007) Three of these “fast trials” were conducted without weights. After the BBTW protocol with application of weights (below) and a mandatory rest break to minimize fatigue, participants performed three more fast trials with the weights. Healthy controls performed fast trials followed by additional trials in which they walked at the average velocity of their matching participant with MS. Healthy controls were able to match velocity within 5% after 1–6 trials. This step controlled for the effect of gait velocity on other spatio-temporal parameters and facilitated comparison of responses to BBTW in participants with MS and healthy matched controls (matched by height, weight, age).

The BBTW protocol (Gibson-Horn 2008) began with an assessment of directional impairments in postural control. Participants stood with feet together and eyes open. The clinician systematically applied manual brisk perturbations (nudges) to participants' shoulders and pelvis in anterior/posterior and lateral directions, noting the latency, amount of body sway or loss of balance, and directions of occurrence. The clinician then applied a strong rotational force at the shoulders and pelvis both right and left while asking the participant to resist being moved; asymmetries in resistance were noted. Based on the individual responses, 0.25 and 0.5 pound (0.11 and .23 kg) weights were applied to the vest to counter the identified deficiencies. The clinician repeated the perturbations and added or relocated weights until the participant showed a reduction in directional balance loss or increase in symmetrical resistance to rotational forces. The total amount of weight ranged between 0.75 and 2.75 pounds, average 0.92% of body weight. Throughout the assessment, one researcher guarded the participant from behind to prevent falls if participants could not recover from balance loss on their own.

Statistical analysis

After determination that both groups' data were normally distributed (MS and healthy controls) a comparison of the means and standard deviations of each gait variable were conducted based on the averaged values of the pre-weighted and weighted trials. Paired t-tests (Microsoft Excel 2010) were used to evaluate differences between the two conditions. The alpha value was set at .05. Because our alternative to the null hypothesis of no difference was unidirectional with this intervention, we report one-tailed p-values throughout.

Results

In people with MS, the primary outcome measure of mean velocity changed significantly between unweighted and weighted trials (Table 2). Secondary spatiotemporal variables of gait, cadence and percentage of gait cycle in single- and double-limb support, also show a significant improvement from the unweighted to the weighted trials. Step length and support-base (step width) did not change sufficiently to be statistically significant.

At walking velocities similar to their respective matched MS participants, healthy participants showed statistically significant within-group changes in the primary outcome measure of gait velocity and all secondary gait variables between weighted and non-weighted trials (Table 2). Between-group differences in average velocity, cadence and single- and double-limb support were not significant when healthy controls matched velocities of participants with MS. However, step length and step width differed significantly from the values observed in people with MS ($p = 0.028$ and $p = 0.006$, respectively).

When walking at their fastest speeds, healthy participants showed significant improvements for velocity, cadence, and support base measures when wearing weights applied using the BBTW protocol. Neither time spent in single-limb support, double-limb support, nor step length at the fastest speeds changed significantly with weighting. As expected, when healthy participants walked at fast speeds, all gait variables (primary and secondary) differed

significantly from those observed in people with MS when walking at their fastest speeds (Figure 1).

Discussion

This study documents improved gait velocity with application of light weights using the BBTW protocol for people with MS and healthy controls. The averaged values for the 3 trials of each condition were expected to provide greater reliability compared to other investigations that were based on single trials of the timed 25-foot walk. Averaged trials also reduced the influence of trial to trial learning or adaptation as participants experienced walking in an unfamiliar environment. As in previous studies with BBTW, participants were asked to walk at their fastest safe speed. This instruction could have provided a more challenging walking condition than a self-selected pace, and may have contributed to fatigue in some participants with MS such that they required additional time (10–20 minutes) during the mandatory rest period between unweighted and weighted trials. Even under these conditions, the average velocity increased by almost 7 cm/sec after BBTW was applied, confirming the results from clinical measures of gait in previous studies. (Gibson-Horn 2008; Widener, Allen et al. 2009a; Widener, Allen et al. 2009b) This increase is greater than the 2.7 cm/sec increase in velocity Morris et al. (2002) recorded in people with MS performing multiple gait trials in a single day with no intervention, and surpasses the 3.3 cm/sec Morris et al. claimed as the minimum to consider clinically significant. Their results also provide a potential standard for expected learning or adaptation effects from multiple gait trials for people with MS; our results exceed this standard.

Secondary outcome measures of additional spatiotemporal gait parameters also changed with BBTW. Both participants with MS and healthy controls showed increased cadence more than step length to achieve higher gait velocity during fast walking trials with BBTW. However, at matched gait speeds, healthy participants increased both cadence and step length to achieve the higher gait velocity with BBTW. These observations may be related to a real or perceived ceiling for step length occurring at higher gait velocities. Further increases in walking velocity beyond this ceiling may require relatively greater changes in cadence. Changes in gait parameters were not expected in healthy controls. A placebo effect could have resulted in these differences although previous work had ruled out a placebo effect of BBTW on gait speed in people with MS. (Widener, Allen et al. 2009b)

The percentage of the gait cycle spent in single-limb versus double-limb support changed between non-weighted and weighted trials in this sample of people with MS and healthy participants walking at matched gait speeds. Previous research indicates that lower gait velocity and increased percentage of gait cycle in double-limb support may be linked to the effort of creating a more stable walking pattern to compensate for reduced balance. (Rosengren, McAuley et al. 1998; Cromwell and Newton 2004) This observation has been confirmed in studies investigating dual-task walking in people post-stroke (Plummer-D'Amato, Altmann et al. 2010) and in people with MS when walking with a cane. (Gianfrancesco, Triche et al. 2011) Based on this reasoning, BBTW may improve dynamic balance sufficiently for people to feel more stable during gait, allowing them to rely on single-limb support for more of the gait cycle. Interestingly, in healthy participants, this

increase in time spent in single-limb support occurred while walking at matched velocities but not at their fastest walking speed. We hypothesize that these healthy participants reached a ceiling in their percent of time in single-limb support during walking at fast speeds, and thus could not show improvements in these parameters with BBTW.

The gait parameters observed in this study parallel those reported in other studies of gait in people with MS using instrumented gait mat systems (Table 3). Givon et al. (2009) reported that at self-selected walking speeds, gait parameters of younger people with minimal impairments from MS differed from the gait parameters of healthy controls in their samples. While our study looked at fast walking, we saw similar between-group differences in gait parameters. Sosnoff et al. (2011) reported slightly lower velocities and wider support bases in people with MS who were older than the average age of those in the Givon et al study (2009) with higher scores (indicating more disability) on the EDSS. The current study extends the results of these previous studies to include people with MS with minimal to moderate disability walking at fast speeds. Our results indicate that people with MS do not reach the same velocities as healthy controls walking at their fastest gait even with the improvements from BBTW (see Figure 1). When controlling for velocity, people with MS in the current sample showed a shorter step length and a wider support base than healthy controls walking at matched speeds. Shorter step length independent of gait speed in people with MS compared to healthy controls confirms results Martin et al. (2006) reported using footswitches and video-recording instead of GAITRite technology.

The present study differs from previous investigations of interventions in MS in several ways. First, the current study focuses on spatiotemporal changes to gait. If BBTW can increase the percent of the gait cycle spent in single-limb support and decrease the time in double-limb support, such changes may indicate a potentially stabilizing effect of this intervention in addition to increasing velocity. Second, in contrast with previous interventions that were conducted over a period of weeks to months, BBTW was provided during a single session and resulted in immediate improvements in gait parameters. Finally, no participants were required to refrain from other interventions for this study, so these BBTW effects were apparent beyond any concurrent effects of other interventions such as pharmaceuticals or exercise. The immediate effect was rather small (average 4% improvement in velocity for both MS and healthy controls), but such an effect might increase an individual's potential for increased daily activity with less effort. Future studies could investigate the long-term effect of BBTW when worn for several hours daily, or as an enhancement to additional therapeutic interventions. Future studies could also examine the dose and duration that optimizes response to BBTW, and the participant characteristics associated with greater response, such as number of falls or the amount of weight added.

Limitations

The limitations of this study include the relatively small number of subjects, the lack of male volunteers who were eligible to participate, lack of statistical correction for multiple outcomes, and lack of randomization in the order of testing weighted versus unweighted conditions. MS is more common in women; a higher proportion of women were expected to volunteer. Recruitment elicited responses from men, but all were ineligible because of

timing of exacerbations and changes in medical diagnoses. No Bonferroni or other correction of the significance level was made for groups of statistical tests, so spurious findings are possible, but the number of significant findings within and between these small groups indicates that these findings are reasonably robust. Actual p values are presented to assist readers in interpreting the results. The order of testing was fixed to test the unweighted condition first because previous observations had shown that some participants retain the effects of BBTW for several minutes to hours following removal of the weights. (Widener, Allen et al. 2009b) Including a wash-out period of several days would have increased the variance attributable to daily changes in the function of people with MS. However, conducting a post-test after longer times with BBTW and after removal of BBTW in future studies could provide further information on possible continuing effects of this intervention.

Implications for Physiotherapy Practice

Both people with MS and healthy controls showed immediate improvements in gait parameters upon application of strategically placed light weights using the BBTW protocol. These findings imply that BBTW may have a more universal application than just those with MS. The change in the proportion of the gait cycle spent in single- and double-limb support indicates a potential for greater stability during gait with BBTW. Future studies could examine the long-term effects of BBTW on gait over longer distances, other activities of daily living, or fall risk when used alone or in conjunction with additional therapeutic interventions in people with MS.

Acknowledgements

This study was supported by Award Number R15HD066397 from the Eunice Kennedy Shriver National Institute of Child Health and Human Development. The content is solely the responsibility of the authors and does not necessarily represent the official views of the Eunice Kennedy Shriver National Institutes of Child Health and Human Development or the National Institutes of Health. In addition we would like to thank our research participants and the many DPT students in the physical therapy programs at Samuel Merritt University and the University of California San Francisco / San Francisco State University who helped with this study.

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Figure 1. Comparison between participants with multiple sclerosis (MS) and healthy controls (HS), with and without strategically placed weights, walking at “fast as possible” velocities, in centimeters per second (cm/sec).

Table 1

Demographic and clinical characteristics of study population

Variable	Participants with MS (n=20)	Healthy Controls (n= 20)	T-test P value
Age in years, mean (SD), range	49.4 (13.4), 24–68	48.3 (11.1), 29–69	0.394
Years since diagnosis, mean (SD)	12.8 (8.2)	-	-
EDSS score equivalent, mean (SD), range	4.1 (1.6), 2–6	-	-
Number of falls in last 12 months, mean (SD), range	2.0 (3.4), 0–15	0.2 (0.4), 0–1	0.005
Height, mean (SD) cm	166.2 (6.0)	166.1 (6.5)	0.475
Weight, mean (SD) kg	73.2 (15.7)	73.3 (13.1)	0.487
% body weight BBTW, mean (SD),range	1.0 (0.4), 0.5–1.6 %	0.7 (0.2), 0.4–1.2%	0.003
Type of MS (number of people)			
Primary Progressive (PP)	1	-	-
Secondary Progressive (SP)	4	-	-
Relapsing Remitting (RR)	11	-	-
Unknown (UN)	4	-	-

MS = Multiple Sclerosis; SD = Standard deviation; EDSS = Expanded Disability Status Scale; cm = centimeters; kg = kilograms; BBTW = Balance-based torso-weighting

Table 2

Gait parameters obtained with GAITRite system

Group, Speed	Variable	Without weights Mean (SD, Range)	With Weights Mean (SD, Range)	P-value within group	P-value MS to HS matched	P-value MS to HS fast
MS fast	Velocity (cm/s)	160.8 (41.1, 76–232)	167.7 (39.5, 82–234)	.002		
	Cadence (steps/min)	141.0 (21.6, 92–173)	145.1 (20.8, 99–180)	.007		
	Single Support (%GC)	40.2 (2.1, 35–44)	40.7 (2.2, 34–44)	.014		
	Double Support (%GC)	19.2 (4.3, 11–30)	18.3 (4.2, 12–30)	.004		
	Step Length (cm)	67.6 (10.5, 48–85)	68.7 (9.4, 49–85)	.059		
	Support Base, Step Width (cm)	11.6 (3.8, 2–20)	11.1 (3.2, 7–20)	.150		
HS matched	Velocity (cm/s)	159.4 (40.0, 80–227)	166.7 (40.1, 83–233)	.002	.449	
	Cadence (steps/min)	132.6 (25.1, 81–193)	136.7 (25.5, 83–200)	.005	.055	
	Single Support (%GC)	40.3 (1.5, 36–43)	40.9 (1.4, 37–43)	.001	.330	
	Double Support (%GC)	19.0 (3.1, 15–27)	18.1 (3.1, 14–26)	.001	.398	
	Step Length (cm)	71.3 (7.3, 59–85)	72.6 (7.3, 60–85)	.009	.028	
	Support Base, Step Width (cm)	10.0 (2.7, 3–15)	9.2 (2.4, 3–13)	.001	.006	
HS fast	Velocity (cm/s)	213.5 (35.4, 158–292)	219.2 (34.7, 166–277)	.012		.000
	Cadence (steps/min)	165.7 (23.6, 127–207)	169.8 (25.8, 138–224)	.015		.000
	Single Support (%GC)	42.3 (1.7, 40–47)	42.6 (1.7, 41–47)	.120		.000
	Double Support (%GC)	14.3 (3.9, 4–18)	13.8 (3.5, 6–17)	.134		.000
	Step Length (cm)	77.3 (6.4, 65–88)	77.7 (5.6, 68–85)	.321		.000
	Support Base, Step Width (cm)	10.3 (2.0, 6–14)	9.3 (2.5, 3–13)	.014		.008

MS = Participants with Multiple Sclerosis; HS = Healthy Controls; SD = standard deviation; cm = centimeters; cm/s = centimeters/second; min = minute; %GC = percent gait cycle

Table 3
Comparing Fast and Self-Selected Gait Parameters Obtained with GAITRite Technology

	Fast Gait			Self-Selected Gait		
	Current Study Mean (SD, Range)			Givon et al (2009)	Sosnoff et al (2011)	
EDSS mean (SD, Range)	MS (n=20)	HS (n=20)	MS (n=81)	HS (n=25)	MS (n=13)	
	4.1 (1.6, 2-6)	-	2.8 (0.3, 0-5.5)	-	Median 6.0 (IQR 1.7, 4-6)	
Age, years, mean (SD)	49.4 (13.4)	48.3 (11.0)	36.2 (4.5)	34.2 (2.2)	51.5 (11.3)	
Velocity (cm/s)	160.7 (41.1)	213.5 (35.4)	85.5 (3.0)	138.6 (4.1)	79.43 (45.8)	
Cadence (Steps/min)	141.0 (21.6)	165.7 (23.6)	94.4 (2.1)	115.2 (1.8)	92.9 (22.3)	
Single Support (%GC)	40.2 (2.1)	42.3 (1.7)	L 36.7 (0.8) R 37.3 (1.0)	L 37.7 (0.4) R 38.5 (0.4)	L 31.2 (5.0) R 30.4 (5.6)	
Double Support (%GC)	19.2 (4.3)	14.3 (3.9)	L 24.9 (0.7) R 24.6 (0.7)	L 23.6 (0.8) R 23.9 (0.8)	L 39.2 (9.7) R 39.1 (9.8)	
Step Length (cm)	67.6 (10.5)	77.3 (6.4)	L 44.6 (1.0) R 46.0 (1.1)	L 72.1 (1.7) R 72.2 (1.7)	L 48.6 (22.1) R 49.6 (18.4)	
Support Base, Step width (cm)	11.6 (3.8)	10.3 (2.0)	L 11.6 (0.5) R 11.6 (0.5)	L 9.1 (0.6) R 9.6 (0.6)	L 14.5 (6.4) R 14.6 (6.5)	

* In the current study, values for single support, double support, step length, and support base reflect the average across the two legs.

MS = Participants with Multiple Sclerosis; HS = Healthy Controls; SD = Standard deviation; EDSS = Expanded Disability Status Scale; BBTW = balance-based torso-weighting; cm = centimeters; cm/s = centimeters/second; %GC = percent gait cycle; IQR = inter-quartile range.