Journal of Kinesiology and Wellness
A Publication of the Western Society for Kinesiology and Wellness
Volume 9, Number 1, Pages 18-28, 2020
ISSN# 2332-4503

EFFECTS OF PARTIAL BODY WEIGHT SUPPORT ON DUAL-TASK WALKING IN OLDER ADULTS WITH MULTIPLE SCLEROSIS

Gioella N. Chaparro[1]*, Robert W. Motl[2], and Manuel E. Hernandez[1]
[1]Department of Kinesiology and Community Health, University of Illinois at Urbana-Champaign
[2]Department of Physical Therapy, University of Alabama at Birmingham

Submitted February 2020; Accepted in final form June 2020

Chaparro GN, et al. Individuals with multiple sclerosis (MS) experience gait impairments, particularly while dual-tasking, that contribute to an increased risk of falls. Because falls negatively impact participation and quality of life, it is essential to examine how to improve dual-tasking gait. However, no studies, to date, have examined how gait variability is affected by partial body weight support (PBWS) while dual-tasking in older adults with MS. This study examined how PBWS can affect dual-tasking gait variability in older adults with MS and age-matched healthy older adults (HOA). Twenty individuals from each group underwent a dual-tasking paradigm under PBWS and no body weight support (NBWS) while recording gait variability measures. Under PBWS, older adults with MS exhibited significantly greater decreases in gait variability measurements (i.e. smaller coefficient of variation for step width and stride time) when compared with HOA and NBWS. These study findings suggest that PBWS can assist with dual-tasking gait variability and may serve as a therapeutic tool for clinicians and rehabilitation specialists for improving dual-task ability and potentially decreasing fall risk. This study was the first to investigate the effects of dual-tasking under PBWS on gait variability measures in older adults with MS and age-matched controls.

Key Words: gait, dual-task, older adults, multiple sclerosis

INTRODUCTION

Walking (Kalron, 2017) and cognitive impairments (Amato et al., 2006) are common, co-occurring manifestations of multiple sclerosis (MS). These deficiencies in MS can manifest an increased difficulty with dual-tasking (e.g., walking and talking) (Allali et al., 2014; D'Esposito et al., 1996; Hamilton et al., 2009) as demonstrated by gait impairments (Learmonth et al., 2014; Leon et al., 2015; Montero-Odasso et al., 2012; Moon et al., 2015; Sosnoff et al., 2011; Wajda & Sosnoff, 2015) (decreases in stride length, gait speed, and single support time and increases in step width, double support time, and stride time). These gait impairments have been further associated with an increased risk of falls (Leon et al., 2015; Wajda & Sosnoff, 2015). One study reported that higher gait variability was associated with a higher risk of falls in individuals with MS (Allali et al., 2016). Within a three to six-month elapsed period, 50% of individuals with MS self-reported a fall that caused an injury (Finlayson et al., 2006), and individuals have expressed a loss of mobility and falls as a considerable personal concern (Finlayson, 2004). Older adults are the fastest growing segment of the MS population who experience the combined effects of aging and MS on outcomes such as walking and cognition (Sanai et al., 2016). Thus, because of the rate of fall occurrence and the negative impact on participation and quality of life, it is essential to examine approaches to decrease the dual-tasking gait impairments, particularly in older adults with MS. While research has reported improvements in dual-task walking parameters after dual-task training interventions in individuals with MS (Monjezi et al., 2017; Peruzzi, 2016, 2017), it remains unknown if gait while dual-tasking can be improved specifically in older adults with MS. Thus, it is required for research to examine how to improve dual-tasking gait parameters in older adults with MS.

Partial body weight support (PBWS) training traditionally used for gait rehabilitative purposes involves suspending an individual/participant by a mounted harness over a treadmill. Under these conditions, a percentage of the individual's weight is relieved which allows for stability and balance to be manipulated while walking. The application of PBWS has demonstrated various benefits, including improving gait parameters (e.g., gait speed, step length, and swing time symmetry) (Field-Fote, 2001; Miyai et al., 2000; Ribeiro et al., 2013; Ullah et al., 2017) and balance (Visintin et al., 1998), fostering walking confidence (Hesse et al., 1997), maintaining attentional capacity (Chaparro et al., 2017), and decreasing energy costs (Danielson & Sunnerhagen, 2000; Visintin & Barbeau, 1989). Improvements in gait under PBWS have been reported in clinical populations such as Parkinson's (Miyai et al., 2000), spinal cord injury (Field-Fote, 2001), and stroke (Hesse et al., 1997; Visintin et al., 1998; Ullah et al., 2017). These notable benefits associated with PBWS can lead to presumptions that PBWS can ease the walking demands, increase the walking self-efficacy, preserve attentional demands, and decrease the physical demands that are required for walking. Thus, it can be postulated that dual-tasking gait performance in older adults with MS may improve under PBWS, which merits further examination. Unfortunately, there is no research to date that has examined if PBWS influences gait parameters during dual-task walking in older adults with MS when compared with age and gender-matched controls.

As the ability to dual-task decreases, the gait impairments and risk of falls increase in HOA (healthy older adults) (Faulkner et al., 2007; Lundin-Olsson et al., 1997; Springer et al., 2006) and older adults with MS (Allali et al., 2016; Leone et al., 2015; Wajda & Sosnoff, 2015). Thus, it is essential to examine if PBWS can serve as a therapeutic tool for improving dual-tasking gait performance in older adults with MS. To date, research has examined the effects of short-term PBWS interventions (i.e. up to 4 weeks) on gait parameters in individuals with Parkinson's disease (Miyai et al., 2000), yet it is unknown if a one-time use of dual-task walking under PBWS would affect the gait variability in older adults with and without MS. By examining the one-time use of PBWS, this study can evaluate the feasibility for future studies to incorporate dual-tasking PBWS interventions for older adults with MS.

The current study examined if gait performance in HOA and older adults with MS are influenced while dual-tasking with an acute or single application of PBWS. Based on previous research that has established various benefits associated with walking under PBWS (as discussed above), it was hypothesized that individuals with MS would demonstrate improvements in gait performance as exhibited through lower gait variability measures while dual-tasking under PBWS when compared to no body weight support (NBWS) conditions. In addition, due to greater motor performance impairments observed in individuals with MS when compared to age-matched controls (Martin et al., 2006; Sosnoff et al., 2012), it was hypothesized that individuals with MS would benefit more from the use of PBWS and thus exhibit greater improvements in dual-tasking gait performance when compared to the age and gender-matched controls (i.e., HOA).

METHODS

Participants

Twenty individuals with MS (mean age of 61.1 ± 6.9, 15 females) and HOA (mean age of 61.2 ± 5.9 years, 15 females) were recruited from the surrounding community to participate in the study. Subjects were included in the study if they: had no lower limb injury in the past 6 months, medical conditions, cognitive dysfunction, or neurological disorders other than MS, had normal or corrected to normal vision, were right-side dominance, and over 45 years of age. All participants with MS were relapse-free 30 days prior to testing and had mild to moderate disability (EDSS range of 1-6), as evaluated by the Kurtzke Expanded Disability Status Scale (EDSS) (Kurtzke, 1983). The EDSS was evaluated through a neurological examination that was administered by a Neurostatus-certified examiner. Overall eligibility to participate in the study was established through a health screening and a score above 18 on the Telephone Interview for Cognitive Status (TICS-M) (Welsh et al., 1993). Higher education was assessed by measuring the number of years of education after high school. Body mass index (BMI) was calculated using weight (kg), as measured from the treadmill's force plate, and height (m), using a wall-mounted measuring tape. Demographic measures consisted of: age, sex, EDSS, higher education, height, weight, and BMI. All participants were informed about the study and signed informed consent forms approved by a university-based institutional review board before data collection.

Dual-task Paradigm

Participants performed the dual-task paradigm under two different walking conditions: one with NBWS and the other with PBWS. The amount of body weight support provided for each participant was defined at 30% body weight (Lindquist et al., 2007). This amount of body weight support was based off of previous research demonstrating improvements in walking parameters under 30% body weight support (Barela et al., 2019; de Oliveira et al., 2018; Lindquist et al., 2007; Luo et al., 2016). The conditions included: walking (W) and walking and talking (WT). During the WT condition, participants were asked to recite alternating letters of the alphabet (Verghese et al., 2002). Thus, there were four total trials: NBWS-W, NBWS-WT, PBWS-W, and PBWS-WT. Each trial consisted of a 30 second warm-up period to reach a comfortable self-paced speed, followed by a 30 second period of walking at a comfortable walking speed used for testing, and a 15 second period to decelerate (total trial time = 75 seconds). While the order of conditions (i.e. W and WT) was counterbalanced, the order of body weight support conditions was not; NBWS conditions were always done before the PBWS conditions.

Gait Variability

A three-meter self-paced treadmill (C-Mill, Motekforce Link, Culemborg, The Netherlands) was utilized for all walking conditions. For safety purposes, all participants wore a harness during all walking conditions (see Figure 1). Raw data such as gait events (i.e., heel strikes and toe offs) were recorded by the CueFors 2 software. Gait variability measurements included the coefficient of variance (%) for stride time and step width (COV-ST and COV-SW, respectively). These parameters were selected because of their relevance in detecting gait difficulties in individuals with MS (Moon et al., 2015; Socie et al., 2013).

Because of the unique self-paced feature of the C-Mill, participants were given instruction and training on the ability for the treadmill to adjust to their comfortable speed before testing began. In addition, participants were given training to get accustomed to the body weight support before the testing conditions began. Training consisted of the participant: receiving instruction of the treadmill functions, practicing the self-paced functionality, and walking with the body-weight support.

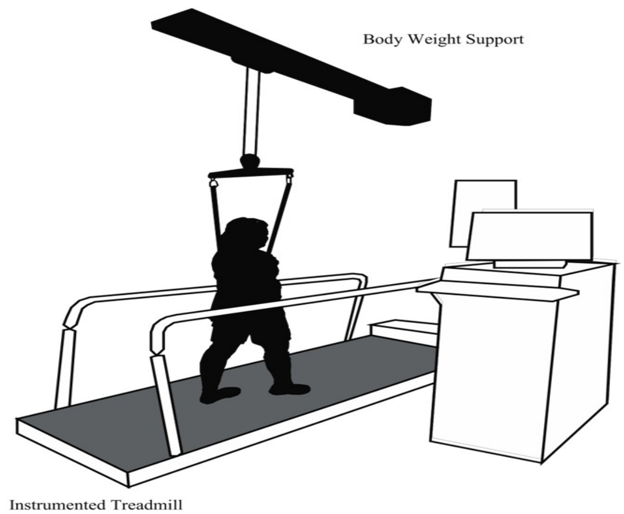

Figure 1. Experimental set up.

Data Analysis

Spatiotemporal data used to calculate the gait variability measures were exported from the CueFors 2 software to MATLAB R2014a (The Mathworks, Inc.). Custom MATLAB scripts were used for processing data and exporting to R. R, version 3.1.1, was used to run the statistical analysis with the significance level set at .05. Independent t-tests were run to analyze cohort differences in the demographic measures. A x^2 test was used to examine gender differences between the groups. To test our primary hypothesis, a linear mixed-model was used to examine differences between cohort (MS and HOA), task (W and WT), and body weight support (BWS) (NBWS and PBWS) for COV-SW and COV-ST, separately. Random intercepts were included: by-subject, by-BWS, and by-task. The necessary tests were run to test for normality and outliers. The rankit transformation was used to meet the assumptions necessary for the linear mixed-model for COV-ST. To control for multiple comparisons in the linear mixed models, post-hoc t-tests were carried out using Hochberg's step-up method.

RESULTS

Participants reported There were no significant group differences in any of the demographic measures (p >.05, Table 1).

Table 1. Demographic data of participants.

Variable	HOA (n=20)	MS (n=20)	p-value
Age (yr)	61.2 (5.9)	61.0 (6.9)	0.94
Sex (#, % female)	15, 75%	15, 75%	1
Height (m)	1.7 (0.08)	1.7 (0.09)	0.34
Weight (kg)	76.2 (19.2)	74.9 (24.5)	0.85
BMI (%)	26.1 (6.1)	26.3 (7.4)	0.92
Higher education (yr)	5.2 (3.2)	5.8 (8.3)	0.77
EDSS (0-10)		4.25 (2.62) ɫ	

Mean (SD) and results from independent t test and Chi-squared test. ɫ Median (IQR). *Abbreviations: HOA= Healthy older adults; MS= Older adults with multiple sclerosis; BMI= Body mass index; EDSS= Expanded Disability Status Scale*

For findings on COV-SW: 1) A significant BWS effect (95% CI= -2.16 to 5.63, p <. 0001) indicated that all individuals demonstrated a significant decrease in step width variability under PBWS when compared to NBWS conditions 2) A significant two-way interaction between BWS and cohort (95% CI= 0.82 to 11.95, p =.008) indicated that older adults with MS demonstrated greater decreases in step width variability during PBWS conditions when compared to HOA. For findings on COV-ST: 1) A significant task effect (95% CI= -0.97 to -0.09, p =.05) indicated that all individuals demonstrated an increase in stride time variability when going from single-task walking to dual-task walking 2) A significant two-way interaction between BWS and task (95% CI= 0 to 1.24, p =.02) indicated that all individuals demonstrated lower stride time variability during single-task walking under PBWS when compared to dual-task walking under NBWS 3) A significant two-way interaction between BWS and cohort (95% CI= -0.07 to 0.71, p =.04) indicated that older adults with MS demonstrated greater decreases in stride time variability during PBWS conditions when compared to HOA. See Table 2-3 and Figure 2 for illustration of these findings.

Table 2. Summary of coefficient of variance variables.

	W-NBWS		WT-NBWS		W-PBWS		WT-PBWS	
COV Variable	**HOA**	**MS**	**HOA**	**MS**	**HOA**	**MS**	**HOA**	**MS**
SW	15.47 (5.65)	20.89 (10.47)	15.93 (5.64)	22.44 (13.84)	12.86 (4.71)	14.44 (5.07)*	14.38 (10.27)	14.87 (6.3)
ST	3.38 (2.38)	5.25 (5.8)	2.90 (1.31)	5.59 (5.82)	2.75 (1.61)	3.10 (2.09)*	4.40 (4.51)	4.71 (4.28)

Mean (SD) of COV variables. *Significant decreases when compared to HOA.
Abbreviations: W-NBWS= Walking with no body weight support; WT-NBWS= Walking and talking with no body weight support; W-PBWS= Walking under partial body weight support; WT-PBWS= Walking and talking under partial body weight support; COV= Coefficient of variance; HOA= Healthy older adults; MS= Older adults with multiple sclerosis; SW= Step width; ST= Stride time

Table 3. Results of linear mixed effect models.

	β	SE	p-value
(A) COV-SW			
BWS	1.73	1.99	< .0001 ***
Task	-1.01	2.04	0.43
Cohort	0.12	2.68	0.11
BWS * Task	0.55	2.83	0.82
BWS * Cohort	6.39	2.84	0.008 **
Task * Cohort	0.90	2.88	0.96
BWS * Task * Cohort	-1.99	3.40	0.62
(B) COV-ST (Rank-it transformation)			
BWS	-0.43	0.22	0.30
Task	-0.53	0.23	0.05 *
Cohort	0.02	0.31	0.22
BWS * Task	0.62	0.31	0.02 *
BWS * Cohort	0.55	0.31	0.04 *
Task * Cohort	0.08	0.32	0.98
BWS * Task * Cohort	-0.17	0.44	0.70

Linear mixed effect models with BWS (NBWS and PBWS), Task (W and WT), and Cohort (MS and HOA) as the main effects and COV-SW (panel A) and COV-ST (panel B) as the dependent variables. Data are reported as estimates, standard error, and p-value. Positive values for the estimate indicate that the measure is larger under NBWS, for MS, or for W, respectively.
Abbreviations: SE= standard error; COV-SW= Coefficient of variance of step width; BWS= Body weight support; NBWS= No body weight support; MS= Multiple Sclerosis; COV-ST= Coefficient of variance of stride time; PBWS= Partial body weight support; W= Walking task; WT= Walking and talking task; HOA= Healthy older adults

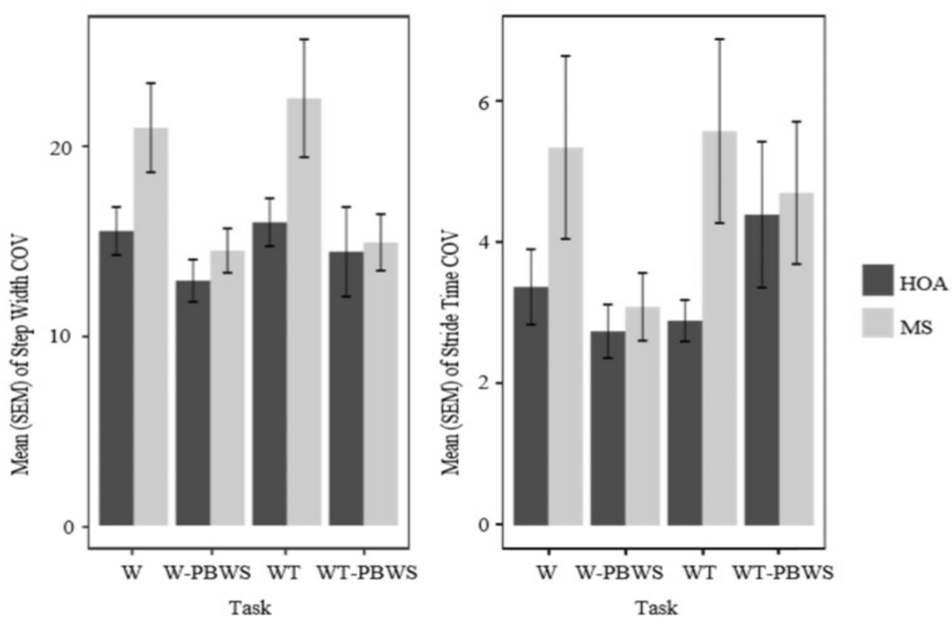

Figure 2. Results of step with and strike time. Coefficient of variance (COV) for step width (SW) and stride time (ST) in healthy older adults (HOA) and older adults with multiple sclerosis (MS) while walking (W), walking under partial body weight support (W-PBWS), walking and talking (WT), and walking and talking under partial body weight support (WT-PBWS).

DISCUSSION

The objective of this study was to examine how the one-time use of PBWS could affect gait performance in older adults with and without MS while dual-task walking. This study builds upon prior work examining the benefits of PBWS (Chaparro et al., 2017; Danielsson & Sunnerhagen, 2000; Field-Fote, 2001; Hesse et al., 1997; Miyai et al., 2000; Ribeiro et al., 2013; Ullah et al., 2017; Visintin & Barbeau, 1989; Visintin et al., 1998) and work examining how to improve dual-task gait performance in older adults with MS (Monjezi et al., 2017; Peruzzi, 2016, 2017). To our knowledge, this was the first study to examine the effects of the one-time use of PBWS on dual-task gait performance (as measured by gait variability measures) in older adults with and without MS. Our findings indicate that while older adults with MS exhibited greater decreases (i.e., improvements) in gait variability under PBWS when compared to NBWS, all participants exhibited decreases in gait variability under PBWS. Together, these results suggest that older adults with and without MS can benefit from PBWS while dual-tasking as demonstrated by improvements in gait performance. Thus, study findings highlight the importance for implementing PWBS for older adults, but especially for older adults with MS.

Consistent with our hypothesis, while HOA did improve their gait performance (i.e., lower COV-ST and COV-SW) under PBWS when compared to NBWS, the older adults with MS exhibited greater improvements under PBWS. As can be seen in Figure 2 (both COV-SW and COV-ST), while cohort differences exist under NBWS (for both single and dual-task walking conditions), those differences disappear under PBWS conditions. Thus, the study findings indicate that the older adults with MS exhibited greater improvements in gait variability under PBWS which allowed them to exhibit similar behavior as that of the healthy control. This is an indication that older adults with MS benefitted more from PBWS conditions than HOA. While research has established that individuals with MS experience lower extremity muscle weakness which can negatively impact gait (Kalron et al., 2011; Sandroff et al., 2013; Yahia et al., 2011), perhaps the use of PBWS in this study assists with decreasing the physical load/demands for MS, overpowers the effects of lower extremity weakness, and leads to gait improvements. On the other hand, the larger COV-SW and COV-ST seen in MS under NBWS is similar to findings in individuals with fibromyalgia (Heredia-Jimenez et al., 2016) and mild cognitive impairment (Boripuntakul et al., 2014) who demonstrated higher COV-SW when compared to a healthy control group, suggesting that symptoms of pain or mild cognitive impairment in older adults with MS may contribute to increased gait variability. Along with COV-SW, COV-ST has also been negatively correlated with balance confidence (Nagano et al., 2014; Schinkel-Ivy et al., 2016). Together, these results indicate that gait variability changes could be sensitive to changes in physical and psychological function in older adults with MS, and that the use of PBWS in older adults with MS can indeed serve as a therapeutic tool for improving gait parameters while dual-tasking.

Furthermore, as seen in Figure 2, all individuals (regardless of condition (i.e., MS or HOA)) exhibited lower COV-SW during PBWS conditions when compared to NBWS. Thus, the use of PBWS acted as a tool to improve step width variability. This is consistent with findings from Dragunas et al. (2016) where healthy young individuals exhibited a decrease in COV-SW while walking with body weight support. A larger COV-SW has been related to impaired balance (Nagano et al., 2014) and thus able to identify fallers (Svoboda et al., 2017). Thus, the smaller COV-SW under PBWS found in this study, indicates that individuals had better balance under PBWS when compared to NBWS conditions. Together, these results indicate that the one-time use of PBWS can exhibit positive effects on gait symmetry variables in HOA and older adults with MS and thus improve the ability to dual-task. It is important to note, that though this study did not examine the effects of PBWS on the risk of falls, the gait behavior observed under PBWS can be a reflection of a lower risk of falls in older adults with MS.

Consistent with the literature, when compared to single-task walking, all individuals (regardless of group (i.e., MS or HOA)) exhibited a larger stride time variability while dual-task walking (see Figure 2). Increases in stride time variability has been exhibited while dual-tasking in healthy older adults (Dubost et al., 2006) and older adults with dementia (Ijmker & Lamoth, 2012). This increase in variability during a dual-task has been found to be attributed to a cognitive task requiring attention (Dubost et al., 2006) or levels of executive function (Ijmker & Lamoth, 2012). Thus, the larger stride time variability exhibited by the participants in the present study can also be attributed to the cognitive task required to perform while walking or level of executive function. However, given the focus of the paper on whether gait performance in HOA and older adults with MS are influenced while dual-tasking with an acute or single application of PBWS, the effects of PBWS on measures of the cognitive performance or level of cognition were not explicitly examined in this paper. Nonetheless, the increase in stride time variability while dual-tasking can be explained by the shared attentional capacity that leads to a decrease in gait automaticity (Nutt et al., 1993).

As expected, when compared to the single-task walking under PBWS, COV-ST was higher for all individuals (regardless of group (i.e., MS or HOA)) during dual-task walking under NBWS (see Figure 2). Similarly, for individuals with MS, it has been found that they exhibit greater gait variability measures while dual-tasking when compared to single task walking and healthy controls (Hamilton et al., 2009). This increase in COV-ST can be partly attributed to the addition of the cognitive task which can decrease the amount of attention allocated towards walking performance and thus cause an increase in COV-ST. Meanwhile, because this study examined the effects of the one-time use of PBWS on gait variability, perhaps these findings are due to the initial destabilizing effect caused by PBWS. Thus, these findings require further exploration into the possible effects of longer training periods using PBWS.

Contradictory to our study findings, Kyvelidou et al. (2008) discovered that when compared to younger adults and low levels of body weight support, older adults demonstrated greater joint kinematic variability while walking with higher amounts of body weight support. While they attribute their findings to the need of altering proprioceptive information due to the decrease of gravitational stimulation under PBWS, this study can attribute the opposing findings to the increase in the ease of walking demands and decrease in the physical demands that are required for walking under PBWS. While research has demonstrated improvements in gait while dual-task walking after different dual-task training interventions such as balance and cognitive dual-tasks (Monjezi et al., 2017) and virtual reality treadmill training (Peruzzi, 2016, 2017), the population examined were individuals with MS in middle adulthood (i.e., ages 30-40) and the gait parameters measured included gait speed, stride length, and hip range of motion. Thus, the present study findings contribute to the literature by demonstrating improvements in gait variability in older adults with MS while dual-task walking under a one-time use of PBWS.

Because this study examined individuals with low levels of disability severity (median EDSS score of 4.25) that had no significant mobility impairments present, these findings cannot be generalized for individuals with MS with higher disability levels with marked mobility impairments. Thus, future research should examine the possible benefits of PBWS for individuals with higher disability severity levels. Furthermore, given that the gait variability improvements observed under PBWS were not tested for permanence, further work should examine the long-term effects of PWBS on gait variability in older adults with MS. While this study examined the effects on gait symmetry variables, future studies should examine dynamic postural control variables to provide greater sensitivity in identifying the benefits of PBWS on balance and gait. Lastly, because the order of BWS conditions was fixed (i.e., NBWS conditions before PBWS conditions), the authors acknowledge that the changes exhibited in the present study can be a result from a practice effect. Thus, future research should incorporate randomized BWS conditions into their methods.

CONCLUSION

This study was the first to examine the effects of the one-time use of PBWS on the dual-tasking gait variability of older adults with MS and compare it to age and gender matched controls. Findings exhibited that PBWS can indeed improve gait performance while dual-tasking which, though not examined in this study, can reflect a decrease in the risk of falls. For a clinical population such as older adults with MS, it was effectively demonstrated that PBWS can be implemented for improving dual-tasking gait parameters. It has been discovered that PBWS has the ability to improve gait parameters while dual-tasking in older adults with MS. With further work examining the long-term benefits of PBWS on gait variability, PBWS may be recommended by clinicians in order to improve the dual-tasking ability and increase quality of life in HOA and older adults with MS. In addition, the benefits observed after the one-time use of PBWS can highlight the feasibility for researchers to incorporate dual-tasking interventions under PBWS for these populations.

ACKNOWLEDGEMENT
We would like to thank the participants in this study and the research staff in the Mobility and Fall Prevention Research Laboratory for their assistance.

FUNDING
No funding declared to complete this research.

REFERENCES

Allali, G., Laidet, M., Assal, F., Armand, S., & Lalive, P. H. (2014). Walking while talking in patients with multiple sclerosis: The impact of specific cognitive loads. *Neurophysiologie Clinique, 44*(1), 87-93. doi: 10.1016/j.neucli.2013.10.136

Allali, G., Laidet, M., Herrmann, F. R., Armand, S., Elsworth-Edelsten, C., Assal, F., & Lalive, P. H. (2016). Gait variability in multiple sclerosis: A better falls predictor than EDSS in patients with low disability. Journal of Neural Transmission, 123(4), 447-450. doi: 10.1007/s00702-016-1511-z

Amato, M. P., Zipoli, V., & Portaccia, E. (2006) Multiple sclerosis-related cognitive changes: A review of cross-sectional and longitudinal studies. Journal of Neurological Sciences, 245(1-2), 41-46. doi: 10.1177/1747493018778713

Barela, A. M. F., Gama, G. L., Russo-Junior, D.V., Celestino, M. L., & Barela, J. A. (2019). Gait alterations during walking with partial body weight supported on a treadmill and over the ground. *Scientific Reports, 9*(1), 8139. doi: 10.1038/s41598-019-44652-y

Boripuntakul, S., Lord, S. R., Brodie, M. A., Smith, S. T., Methapatara, P., Wongpakaran, N., & Sungkarat, S. (2014). Spatial variability during gait initiation while dual tasking is increased in individuals with mild cognitive impairment. *Journal of Nutrition, Health, and Aging, 18*(3), 307-312. doi: 10.1007/s12603-013-0390-3

Chaparro, G., Balto, J. M., Sandroff, B. M., Holtzer, R., Izzetoglu, M, Motl, R. W., & Hernandez, M. E. (2017). Frontal brain activation changes due to dual-tasking under partial body weight support conditions in older adults with multiple sclerosis. *Journal of Neuroengineering and Rehabilitation, 14*(1), 65. doi: 10.1186/s12984-017-0280-8.

D'Esposito, M., Onishi, K., Thompson, H., Robinson, K., Armstrong, C., & Murray, G. (1996). Working memory impairments in multiple sclerosis: Evidence from a dual-task paradigm. *Neuropsychology, 10*(1), 51-56. http://dx.doi.org/10.1037/0894-4105.10.1.51

Danielsson, A., & Sunnerhagen, K. S. (2000). Oxygen consumption during treadmill walking with and without body weight support in patients with hemiparesis after stroke and in healthy subjects. *Archives of Physical Medicine and Rehabilitation, 81*(7), 953-957. doi: 10.1053/apmr.2000.6283

de Oliveira, L. A. S., Martins, C. P., Horsczaruk, C. H. R., da Silva, D. C. L., Vasconcellos, L. F., Lopes, A. J., Mainenti, M. R. M., & Rodrigues, E. C. (2018). Partial body weight-supported treadmill training in spinocerebellar ataxia. *Rehabilitation Research and Practice, 2018*, 7172686. doi: 10.1155/2018/7172686

Dragunas, A. C., & Gordon, K. E. (2016). Body weight support impacts lateral stability during treadmill walking. *Journal of Biomechanics, 49*(13), 2662-2668. doi: 10.1016/j.jbiomech.2016.05.026

Dubost, V., Kressig, R. W., Gonthier, R., Herrmann, F. R., Aminian, K., Najafi, B., & Beauchet, O. (2006). Relationships between dual-task related changes in stride velocity and stride time variability in healthy older adults. *Human Movement Science, 25*(3), 372-382. doi: 10.1016/j.humov.2006.03.004

Faulkner, K. A., Redfern, M. S., Cauley, J. A., Landsittel, D. P., Studenski, S. A., Rosano, C., Simonsick, E. M., Harris, T. B., Shorr, R. I., Ayonayon, H. N., Newman, A. B., & Health, Aging, and Body Composition Study. (2007) Multitasking: Association between poorer performance and a history of recurrent falls. *Journal of the American Geriatrics Society, 55*(4), 570-576. doi: 10.1111/j.1532-5415.2007.01147.x

Field-Fote, E. C. (2001). Combined use of body weight support, functional electric stimulation, and treadmill training to improve walking ability in individuals with chronic incomplete spinal cord injury. *Archives of Physical Medicine and Rehabilitation, 82*(6), 818–824. doi: 10.1053/apmr.2001.23752

Finlayson, M. (2004). Concerns about the future among older adults with multiple sclerosis. *American Journal of Occupational Therapy, 58*(1), 54-63. doi: 10.5014/ajot.58.1.54

Finlayson, M. L., Peterson, E. W., & Cho, C. C. (2006). Risk factors for falling among people aged 45 to 90 years with multiple sclerosis. *Archives of Physical Medicine and Rehabilitation, 87*(9), 1274-1279. doi: 10.1016/j.apmr.2006.06.002

Hamilton, F., Rochester, L., Paul, L., Rafferty, D., O'Leary, C. P., & Evans, J. J. (2009). Walking and talking: an investigation of cognitive-motor dual tasking in multiple sclerosis. *Multiple Sclerosis, 15*(10), 1215-1227. doi: 10.1177/1352458509106712

Heredia-Jimenez, J., Orantes-Gonzalez, E., & Soto-Hermoso, V. M. (2016) Variability of gait, bilateral coordination, and asymmetry in women with fibromyalgia. *Gait & Posture,* 45, 41-44. doi: 10.1016/j.gaitpost.2016.01.008

Hesse, S., Helm, B., Krajnik, J., Gregoric, M., &

Mauritz, K. H. (1997). Treadmill training with partial body weight support: Influence of body weight release on the gait of hemiparetic patients. *Neurorehabilitation and Neural Repair, 11*, 15-20. doi.org/10.1177/154596839701100103

Ijmker, T., & Lamoth, C. J. (2012). Gait and cognition: The relationship between gait stability and variability with executive function in persons with and without dementia. *Gait &Posture, 35*(1), 126-130. doi: 10.1016/j.gaitpost.2011.08.022

Kalron, A. (2017). Association between gait variability, falls and mobility in people with multiple sclerosis: A specific observation on the EDSS 4.0-4.5 level. *NeuroRehabilitation, 40*(4), 579-585. doi: 10.3233/NRE-171445

Kalron, A., Achiron, A., & Dvir, Z. (2011). Muscular and gait abnormalities in persons with early onset multiple sclerosis. *Journal of Neurologic Physical Therapy, 35*(4), 164-169. doi: 10.1097/NPT.0b013e31823801f4

Kurtzke, J. F. (1983). Rating neurologic impairment in multiple sclerosis: An expanded disability status scale (EDSS). *Neurology, 33*(11), 1444-1452. doi: 10.1212/wnl.33.11.1444

Kyvelidou, A., Kurz, M. J., Ehlers, J.L., & Stergiou, N.

(2008). Aging and partial body weight support affects gait variability. *Journal of Neuroengineering and Rehabilitation, 5*(22), doi: 10.1186/1743-0003-5-22

Learmonth, Y. C., Sandroff, B. M., Pilutti, L. A., Klaren, R. E., Ensari, I., Riskin, B. J., Holtzer R., & Motl, R. W. (2014). Cognitive motor interference during walking in multiple sclerosis using an alternate-letter alphabet task. *Archives of Physical Medicine and Rehabilitation, 95*(8), 1498-1503. doi: 10.1016/j.apmr.2014.03.007

Leone, C., Patti, F., & Feys, P. (2015). Measuring the cost of cognitive-motor dual tasking during walking in multiple sclerosis. *Multiple Sclerosis, 21*(2), 123–131. doi: 10.1177/1352458514547408

Lindquist, A. R., Prado, C. L., Barros, R. M., Mattioli, R., da Costa, P. H., & Salvini, T. F. (2007). Gait training combining partial body-weight support, a treadmill, and functional electrical stimulation: Effects on poststroke gait. *Physical Therapy, 87*, 1144-1154. doi: 10.2522/ptj.20050384

Lundin-Olsson, L., Nyberg, L., & Gustafson, Y. (1997). "Stops walking when talking" as a predictor of falls in elderly people. *Lancet, 349*(9052), 617. doi: 10.1016/S0140-6736(97)24009-2

Luo, Y., Shen, W., Jiang, Z., & Sha, J. (2016). Treadmill training with partial body-weight support after anterior cruciate ligament reconstruction: A randomized controlled trial. *Journal of Physical Therapy Science, 28*(12), 3325-3329. doi: 10.1589/jpts.28.3325

Martin, C. L., Phillips, B. A., Kilpatrick, T. J., Butzkueven, H., Tubridy, N., McDonald, E., & Galea, M. P. (2006). Gait and balance impairment in early multiple sclerosis in the absence of clinical disability. *Multiple Sclerosis, 12*(5), 620-628. doi: 10.1177/1352458506070658

Miyai, I., Fujimoto, Y., Ueda, Y., Yamamoto, H., Nozaki, S., Saito, T., & Kang, J. (2000). Treadmill training with body weight support: Its effect on Parkinson's disease. *Archives of Physical Medicine and Rehabilitation, 81*(7), 849–852. doi: 10.1053/apmr.2000.4439

Monjezi, S., Negahban, H., Tajali, S., Yadollahpour, N., & Majdinasab, N. (2017). Effects of dual-task balance training on postural performance in patients with multiple sclerosis. *Clinical Rehabilitation, 31*(2), 234-241. doi: 10.1177/0269215516639735

Montero-Odasso, M., Muir, S. W., & Speechley, M. (2012). Dual task complexity affects gait in people with mild cognitive impairment: The interplay between gait variability, dual tasking, and risk of falls. *Archives of Physical Medicine and Rehabilitation, 93*(2), 293-299. doi: 10.1016/j.apmr.2011.08.026

Moon, Y., Wadja, D. A., Motl, R. W., & Sosnoff, J. J. (2015). Stride-time variability and fall risk in persons with multiple sclerosis. *Multiple Sclerosis International, 2015*, 964790. doi: 10.1155/2015/964790

Nagano, H., James, L., Sparrow, W. A., & Begg, R. K. (2014). Effects of walking-induced fatigue on gait function and tripping risks in older adults. *Journal of Neuroengineering and Rehabilitation, 11*, 155. doi: 10.1186/1743-0003-11-155

Nutt, J. G., Marsden, C. D., & Thompson, P. D. (1993). Human walking and higher-level gait disorders, particularly in the elderly. *Neurology, 43*(2), 268-279. doi: 10.1212/wnl.43.2.268

Peruzzi, A., Cereatti, A., Della Croce, U., & Mirelman, A. (2016). Effects of a virtual reality treadmill training on gait of subjects with multiple sclerosis: A pilot study. *Multiple Sclerosis and Related Disorders, 5*, 91-96. doi: 10.1016/j.msard.2015.11.002

Peruzzi, A., Zarbo, I. R., Cereatti, A., Della Croce, U., & Mirelman, A. (2017). An innovative training program based on virtual reality and treadmill: effects on gait of persons with multiple sclerosis. *Disability and Rehabilitation, 39*(15), 1557-1563. doi: 10.1080/09638288.2016.1224935

Ribeiro, T., Britto, H., Oliveira, D., Silva, E., Galvao, E., & Lindquist, A. (2013). Effects of treadmill training with partial body weight support and the proprioceptive neuromuscular facilitation method on hemiparetic gait: A randomized controlled study. *European Journal of Physical Rehabilitation Medicine, 49*(4), 451-461.

Sanai, S. A., Saini, V., Benedict, R. H., Zivadinov, R., Teter, B. E., Ramanathan, M., & Weinstock-Guttman, B. (2016). Aging and multiple sclerosis. *Multiple Sclerosis, 22*(6), 717-725. doi: 10.1177/1352458516634871

Sandroff, B. M., Sosnoff, J. J., & Motl, R. W. (2013). Physical fitness, walking performance, and gait in multiple sclerosis. *Journal of Neurological Sciences, 328*(1-2), 70-76. doi: 10.1016/j.jns.2013.02.021

Schinkel-Ivy, A., Inness, E. L., & Mansfield, A. (2016). Relationships between fear of falling, balance confidence, and control of balance, gait, and reactive stepping in individuals with sub-acute stroke. *Gait & Posture, 43*, 154-159. doi: 10.1016/j.gaitpost.2015.09.015

Socie, M. J., Motl, R. W., Pula, J. H., Sandroff, B. M., & Sosnoff, J. J. (2013). Gait variability and disability in multiple sclerosis. *Gait & Posture, 38*(1), 51-55. doi: 10.1016/j.gaitpost.2012.10.012

Sosnoff, J. J., Boes, M. K., Sandroff, B. M., Socie, M. J., Pula, J. H., & Motl, R. W. (2011). Walking and thinking in persons with multiple sclerosis who vary in disability. *Archives of Physical Medicine and Rehabilitation, 92*(12), 2028-2033. doi: 10.1016/j.apmr.2011.07.004

Sosnoff, J. J., Sandroff, B. M., & Motl, R. W. (2012). Quantifying gait abnormalities in persons with multiple sclerosis with minimal disability. *Gait & Posture, 36*(1), 154-156. doi: 10.1016/j.gaitpost.2011.11.027

Springer, S., Giladi, N., Peretz, C., Yogev, G., Simon, E. S., & Hausdorff, J. M. (2006). Dual-tasking effects on gait variability: The role of aging, falls, and executive function. *Movement Disorders, 21*(7), 950-957. doi: 10.1002/mds.20848

Svoboda, Z., Bizovska, L., Janura, M., Kubonova, E., Janurova, K., & Vuillerme, N. (2017). Variability of spatial temporal gait parameters and center of pressure displacements during gait in elderly fallers and nonfallers: A 6-month prospective study. *PloS One, 12*(2), e0171997. doi: 10.1371/journal.pone.0171997

Ullah, M. A., Shafi, H., Khan, G. A., Malik, A. N., & Amjad, I. (2017). The effects of gait training with body weight support (BWS) with no body weight support (no-BWS) in stroke patients. *Journal of the Pakistan Medical Association, 67*(7), 1094-1096.

***Address correspondence to:**
Gioella Chaparro, PhD
Division of Kinesiology and Recreation
California State University, Dominguez Hills
1000 E. Victoria Street, SAC 2141
Carson, California 90747
Email: gchaparro@csudh.edu

Verghese, J., Buschke, H., Viola, L., Katz, M., Hall, C., Kuslansky, G., & Lipton, R. (2002). Validity of divided attention tasks in predicting falls in older individuals: A preliminary study. *Journal of the American Geriatrics Society, 50*, 1572-1576. doi: 10.1046/j.1532-5415.2002.50415.x

Visintin, M., & Barbeau, H. (1989). The effects of body weight support on the locomotor pattern of spastic paretic patients. *Canadian Journal of Neurological Sciences, 16*(3), 315-325. doi: 10.1017/s0317167100029152

Visintin, M., Barbeau, H., Korner-Bitensky, N., & Mayo, N. (1998). A new approach to retrain gait in stroke patients through body weight support and treadmill stimulation. *Stroke, 29*(6), 1122-1128. doi: 10.1161/01.str.29.6.1122

Wajda, D. A., & Sosnoff, J. J. (2015). Cognitive-motor interference in multiple sclerosis: A systematic review of evidence, correlates, and consequences. *BioMed Research Institute, 2015*, 720856. doi: 10.1155/2015/720856

Welsh, K. A., Breitner, J. C. S., & Magruder-Habib, K. M. (1993). Detection of dementia in the elderly using telephone screening of cognitive status. *Neuropsychiatry, Neuropsychology and Behavioral Neurology, 6*(2): 103-110.

Yahia, A., Ghroubi, S., Mhiri, C., & Elleuch, M. H. (2011). Relationship between muscular strength, gait and postural parameters in multiple sclerosis. *Annals of Physical Rehabilitation Medicine, 54*(3), 144-155. doi: 10.1016/j.rehab.2011.02.004