Acute and Chronic Effects of Whole-Body Vibration on Balance, Postural Stability, and Mobility in Women With Multiple Sclerosis

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Abstract

The acute and chronic effects of whole-body vibration (WBV) on balance, postural stability, and mobility were evaluated in 21 women with relapsing-remitting multiple sclerosis (MS) randomly assigned to control (n = 9) or experimental (n = 12) groups. To assess acute responses, outcome variables were assessed before and immediately after a session of WBV (five 30-second bouts of vibration; frequency 30 Hz; amplitude 3 mm; 1-minute rest intervals) during their first visit (week 1) using field (Timed-Up and Go; 500-m walk; Berg Balance Scale) and laboratory tests (NeuroCom Balance Master and EquiTest System—Sensory Organization Test, Adaptation Test, Limits of Stability, Modified Clinical Test for Sensory Integration of Balance, Unilateral Stance, Tandem Walk, Step/Quick Turn). Acute responses were also measured after their fifth visit for only the Adaptation and Sensory Organization tests. For the chronic responses, participants were exposed to the WBV protocol once a week, for a total of 5 weeks, and then at week 5, were reassessed with the Adaptation and the Sensory Organization tests. Neither acute nor chronic exposure to the WBV protocols used in this study resulted in significant improvements ($P > .05$) in balance, postural stability, or mobility as assessed by either field or laboratory tests. However, based on promising results from other studies that have used WBV with other clinical populations, either alone or in conjunction with exercise, additional studies that increase the dose of vibration exposure, both acutely and chronically, should be conducted in patients with MS.

Introduction

Multiple sclerosis (MS) is a chronic, inflammatory, and neuro-degenerative disease of the central nervous system, which is characterized by immune-mediated inflammation with secondary demyelination and potential axonal loss.[1] The most prevalent symptoms of MS include fatigue, weakness, hypertonia, incoordination, balance and gait dysfunction, and vision and sensory impairments.[2] Reductions in muscular strength, power, and endurance are also commonly observed and can result in a reduced ability to perform activities of daily living.[3] Muscle performance deficits are thought to be due to incomplete motor unit recruitment and decreased motor unit discharge as well as changes in muscle fibers consistent with disuse atrophy.[4] Ataxia and balance disorders are very incapacitating problems in patients with MS, are multifactorial in origin, and include

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weakness, spasticity, proprioceptive loss, and cerebellar dysfunction.

Traditional resistance and aerobic exercise protocols have been shown to effectively diminish functional impairments in MS[5-7]; however, reductions in motor control associated with MS may limit the feasibility of traditional resistance exercise in patients with MS. Therefore, alternative interventions, such as whole-body vibration (WBV), are being examined as potential modalities for moderating MS symptoms.

The WBV protocols typically require the participant to stand or sit on a vibration platform while receiving a mechanical stimulus imparted by the device. Although the precise mechanisms explaining improved neuromuscular performance following WBV remain unclear, it has been suggested that the mechanical stimuli imparted through the body stimulate the endings of muscle spindles, leading to an activation of alpha motor neurons to facilitate muscle contractions.[8] Therefore, WBV application has become increasingly popular as both prophylactic and therapeutic interventions to enhance muscular performance in both healthy young individuals, elderly[9-11] and clinical populations.[12] Additionally, compared to resistance exercise, WBV may serve as a safer alternative for augmenting neuromuscular performance in patients with MS displaying impaired motor control.

The evaluation of WBV as a potential therapeutic intervention for MS was first explored by Schuhfried et al[13] who observed significant improvements in mobility (Timed-Up and Go [TUG] performance) and postural stability lasting 1 week after an acute exposure of WBV (5 bouts of vibration at 2.0-4.4 Hz frequency, 3 mm amplitude, with 1-minute rest periods between exposures). Thereafter, several additional investigations have been conducted with contradictory results on the efficacy of WBV.[14-16] Claerbout et al[17] performed a 3-week, 10-session study that had patients perform exercises while standing on a vibration platform (vertical vibrations with a 1.6 mm amplitude, 30-40 Hz frequency) and observed significant improvements in muscular strength but no changes were detected in functional performance outcomes, whereas Broekmans et al[18] conducted a 20-week study (5 sessions every 2 weeks) that involved patients performing static and dynamic squats and lunges on a vibration platform (25-45 Hz, 2.5 mm amplitude) and observed no changes in lower extremity strength or functional performance in patients with MS. Cumulatively, regarding measures of functional performance, some WBV interventions have reported no changes,[17-19] while other studies have reported significant improvements.[20,21] Based on the variations in vibration protocols (durations, frequencies, amplitudes, etc) and the conflicting results, this warrants further examination regarding the effectiveness of WBV for improving functional status in MS populations. Furthermore, to our knowledge, no previous investigations have explored the influence of WBV on postural control, balance measures, or mobility in MS populations. Evidence from previous literature documenting improvements in balance and postural control following WBV in paralleling neurological disorders such as cerebral palsy, Parkinson disease, and stroke,[22-24] supports the examination of WBV on balance, postural control, and mobility in MS populations. Kantele et al[15] highlighted that the results indicating possible benefits of WBV training to patients with MS are limited by methodological issues, which include confounding factors such as additional exercises performed in combination with WBV. Therefore, the purpose of this investigation was to examine the acute and chronic effects of WBV exposure on balance, postural control, and mobility in women with MS following 5 weeks of once-weekly WBV training. To the best of our knowledge, this will be the first study to investigate both the acute and chronic effects of WBV in patients with MS. We hypothesized that a 5-week WBV training would induce positive functional adaptations in patients with MS.

Methods

Participants

Twenty-one women aged from 18 to 64 years (46.6 [9.6] years; 1.6 [0.1] m; 72.6 [15.5] kg) diagnosed with relapsing-remitting MS, not using any assistive devices, and not involved in any resistance or endurance training programs, volunteered to participate in the current study. All participants were previously diagnosed with MS by a board-certified neurologist according to the McDonald criteria.[25]

Study Design

This study investigated the effects of acute (prior to and following a single bout of WBV at week 1 and week 5 of the intervention) and chronic (1 bout of WBV each week for 5 weeks) WBV exposure on balance, mobility, and postural control in women diagnosed with MS (Figure 1). Participants were randomly assigned by using an online number generator (www.random.org) to either an intervention (WBV: n = 12) or a control (CON: n = 9) group. During visit 1 (week 1), study procedures were explained to the participants and written informed consent for participation was completed. The baseline measurements for all the outcome variables were then assessed for all participants in the following order: Sensory Organization Test (SOT), Adaptation Test (ADP), Limits of Stability (LOS), Modified Clinical Test for Sensory Integration of Balance (mCT-SIB), Unilateral Stance (US), Tandem Walk (TW), Step/Quick Turn (SQT), TUG, 500-m walk, and Berg Balance Scale (BBS). This order of assessment was maintained throughout the study. Participants in the WBV group were then exposed to a session of WBV and reassessed immediately after the bout of WBV (first acute session). During visits 2, 3, and 4 (weeks 2, 3, and 4), participants were exposed to the WBV protocol, but no pre- or postvibration assessments were carried out. At visit 5 (week 5), participants were submitted to another bout of WBV exposure and as in visit 1 and were assessed for all outcome variables prior to and following the WBV exposure. All testing during the entire study was done by the same investigator.
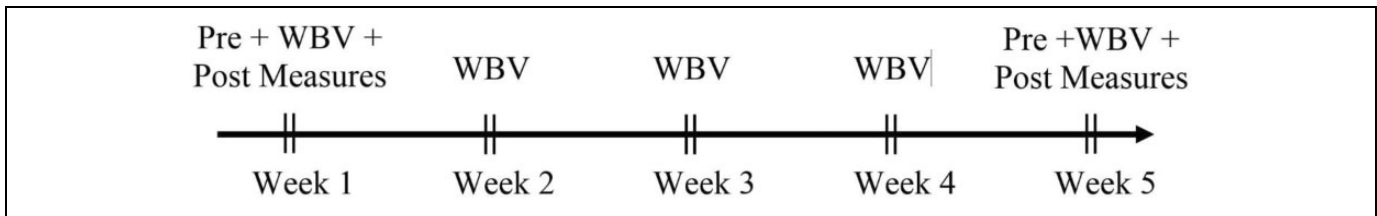
Figure 1. Scheme of the study design.

Study Procedures

Whole-body vibration. Whole-body vibration was applied using a vibration platform (PowerPlate; Next Generation, Northbrook, Illinois) at a frequency of 30 Hz and a fixed low amplitude set at 3 mm (approximately 2.2 g acceleration). Each participant in the WBV group was exposed to 5 bouts of vibration that lasted 30 seconds each and with a rest interval of 1 minute between bouts. Participants were asked to stand barefoot on the platform with feet shoulder width apart and to adopt a squat position, which required a slight flexion of the hip, knee, and ankle joints. Participants were instructed to hold on to the supportive bars that are part of the vibration platform, which would also vibrate whenever the platform was turned on, so that the upper body would also receive the vibration stimulus. Participants in the CON group did not receive any vibration stimuli, but they were required to stand on the platform in the same squat position and for the same amount of time as the participants in the WBV group. All assessments were performed immediately post vibration exposure with an average 3-minute period from the WBV exposure to the first measurement for both acute and chronic effects.

Field Tests

Timed-Up and Go test. The TUG test was used to measure mobility. Participants were asked to raise up from sitting in a chair to a standing position and to walk a distance of 10 m, turn around, walk back to the chair, and sit down again with their backs flush to the back of the chair and with arms resting on the arm rests. The time for participants to complete the task was measured in seconds with a stopwatch. The best, or lowest time from 3 trials, was used in the analyses.

The 500-m walk. The 500-m walk was used to assess mobility by measuring the time, in minutes, to walk 500 m. A 62.5 m straight line was traced on the floor and participants were asked to walk as fast as possible through the length of the line 8 times. The timing started as participants initiated the walk and ended as soon as they finished the eighth lap and only one trial was performed.

Berg Balance Scale. The BBS was used to measure balance.[26] The scale consists of 14 tasks with a 5-point scale, ranging from 0 to 4, with 0 indicating the lowest and 4 the highest level of function. The highest possible score is 56 and the scale includes both balance and mobility tasks. Each participant was asked to perform all the 14 tasks to the best of their ability. The 14 tasks

included: (1) sit to standing, (2) standing unsupported, (3) sitting unsupported, (4) stand to sitting, (5) transfers, (6) standing with eyes closed (EC), (7) standing with feet together, (8) reaching forward with outstretched arms, (9) retrieving an object from the floor, (10) turning to look behind, (11) turning 360°, (12) placing alternate feet on a stool, (13) standing with one foot in front, and (14) standing on one foot. The tester recorded the appropriate score for each test based on each participant's performance. There was only one trial of each measure and the combined score out of 56 was used in the analyses.

Laboratory Tests

Sensory Organization Test. The SOT was performed using a NeuroCom Balance Master (NeuroCom International Inc, Clackamas, OR) and the EquiTest System (v8.0). This test measures the participants' ability to make effective use of visual, vestibular, and proprioceptive information to maintain balance. It provides an equilibrium score (ES%) that reflects the amount of sway in both anterior and posterior directions. Higher scores indicate greater stability and less sway. The support surface that participants stood on and/or the visual surroundings moved or swayed in response to a participants' sway during the test (sway-referenced). There were 6 different testing conditions for the SOT: (1) normal vision (eyes open [EO]) with fixed floor; (2) EC with fixed floor; (3) EO, fixed surroundings and floor sways; (4) EC, fixed surroundings and floor sways; (5) EO, surroundings sway and fixed floor; and (6) EO, both surroundings and floor sways. Before testing, participants were strapped into a harness that was attached to a support beam and positioned on the fixed platform in proper alignment according to the computer screen to ensure that their center of gravity was in the center of the screen. Participants were asked to stand as still and stable as possible during each test and each testing condition was measured 3 times with the highest, or best score used in the analyses.

Adaptation Test. The ADP was performed using a NeuroCom Balance Master and the EquiTest System to analyze the motor system's ability to adapt to platform movements that caused the ankles to rotate resulting in the participants toes to go up or down, without causing displacement of the participant's center of gravity. This test provided a nondimensional sway energy score (SES) that quantified how well participants were able to minimize anteroposterior platform rotations, based on the velocity and acceleration of the center of pressure. Participants were

exposed to a series of 5 consecutive rotations for each cycle of toes up or toes down and the lowest, or best score was used in the analyses. A smaller SES would represent a greater ability to react more efficiently. Participants were asked to keep their EO and to look straight ahead while standing upright as steady as possible. A computer screen located in front of the participants displayed foot placement and indicated when trial sessions were over. Participants were instructed to maintain their balance during a disruptive somatosensory input caused by unexpected changes in the orientation of the support surface. This test provides information regarding standing and walking on uneven surfaces.

Limits of Stability. The LOS test was performed on the NeuroCom Balance Master and EquiTest System with participants secured in the harness to assess the ability to voluntarily sway to different points in space and to maintain that position. The parameter examined was directional control, or the amount of movement in the intended direction toward the target compared to the amount of extraneous movement away from the target and expressed as a percentage. The higher the percentage score (closest to 100%), the greater the directional control. There were 8 trials for this test: (1) forward, (2) forward-right, (3) right, (4) backward-right, (5) backward, (6) backward-left, (7) left, and (8) forward left, and each trial lasted 8 seconds. While strapped into the harness, participants began with their actual center of gravity being observed on the computer screen in front of them, and as their center of gravity shifted, the cursor which represented them also moved on the computer screen. The goal was to lean accurately and quickly in order for the cursor to coincide with one of the 8 targets (trials) on the screen and to maintain that position for 8 seconds before returning to the neutral starting position and await the next trial. Only one trial of each condition was performed and the percentage score obtained from each condition was used in the analyses. This test could provide information concerning adaptation abnormalities that could occur with lower limb biomechanical and/or vestibular system and central nervous system problems affecting balance.

Modified Clinical Test for Sensory Integration of Balance. The mCT-SIB was conducted on the NeuroCom Balance Master's 5 ft (1.5 m) long, flat dual force plate to assess stability or postural sway velocity (°/s) on hard or soft surfaces with EO or EC. There were 4 testing conditions, each lasting 10 seconds. The first 2 conditions took place on a hard surface with EO and EC and the last 2 conditions were on a foam surface with EO and EC. Participants were instructed to keep their EO or EC and look straight ahead while standing in an upright position remaining as still as possible. In all conditions, a low score indicated less sway and more stability, whereas a high score indicated more sway and less stability. There were 3 trials of each condition performed and the best or lowest score from each condition was used in the analyses. In order to project good balance, an individual must hold their center of gravity near the center of their base of support. This test attempts to identify abnormalities in the sensory system contributions to

postural control by distinguishing between normal, abnormal, and severely abnormal individuals.

Unilateral Stance. The US test was assessed on the same NeuroCom Balance Master flat force plate that was used for the mCT-SIB. The US test was measured with participants standing on the force plate using only one foot and postural stability was quantified by assessing postural sway velocity (°/s), with greater sway velocities indicating greater instability. There were 3 trials (10 seconds each) in each of the 4 testing conditions: (1) balancing on the right foot with EO or (2) EC and (3) balancing on the left foot with EO or (4) EC. The best, or lowest score for each condition, was used in the analyses.

Tandem Walk. The TW test was used to analyze gait and balance (gait speed measured in cm/s and end point sway velocity measured in ° /s) as participants walked heel-to-toe along the flat force plate of the NeuroCom Balance Master. While standing on one end of the force plate with heel-to-toe touching, the participants were instructed to stand as steady as possible until they heard the word "go." They were then asked to walk as fast and safely as possible, heel-to-toe, to the other end of the force plate and remain steady. Once finished, they returned the starting point on the opposite side of the force plate and repeated the test 2 additional times. The best, or highest speed and the best, or lowest sway velocity scores were used in the analyses. Low sway velocities are good and provide some information of neck, trunk, and hip extensor strength.

Step/Quick Turn. This test was used to measure balance (mean turn sway in degrees) as participants pivoted 180° after taking 2 steps forward and then returning back to the starting position on the NeuroCom long force plate. This test consisted of 3 trials with the right foot leading and 3 trials with the left foot leading and the best, or lowest, scores were used in the analyses. The test started with the participants standing in the upright position at the end of the force platform. Once the test started, the participants quickly took 2 steps forward beginning with either the left or the right foot and then pivoted, either turning to the left or right, and returned to the starting position and remained steady for 5 seconds. This test provides information regarding possible somatosensory loss, trunk and lower extremity weaknesses, vestibular deficiencies, or asymmetrical lower extremities.

Statistical Analysis

Acute responses (pre vs post) to WBV at week 1 (TUG, 500-m walk, BBS, SOT, ADP, LOS, mCT-SIB, US, TW, and SQT) and week 5 (SOT and ADP) were analyzed with a 2-way repeated-measures analysis of variance (ANOVA) (group [control and WBV] × time [pre and post]). To evaluate the chronic effects of WBV, percentage change scores from the acute sessions at week 1 and week 5 (SOT and ADP) were analyzed with a 2-way repeated-measures ANOVA (group [control and WBV] × time [week 1 and week 5]). Chronic effects of WBV

Table 1. Acute Effects of WBV Exposure on Timed-Up and Go, 500-m Walk, Berg Balance Scale, and Sensory Organization Tests at Week 1.

Variable	Exp.	N	Pre	Post	Group	Time	Group × Time
TUG test (seconds)	WBV	12	7.78 (1.67)	8.29 (1.84)	$P = .735$	$P = .219$	$P = .421$
	CON	9	8.25 (1.67)	8.36 (2.23)	$\eta_p^2 = .06$	$\eta_p^2 = .08$	$\eta_p^2 = .03$
500-m walk (minutes)	WBV	12	5.78 (1.64)	5.34 (1.33)	$P = .535$	$P = .566$	$P = .118$
	CON	9	5.10 (0.91)	5.31 (1.31)	$\eta_p^2 = .02$	$\eta_p^2 = .02$	$\eta_p^2 = .12$
BBS	WBV	12	53.42 (3.18)	53.50 (3.17)	$P = .894$	$P = .400$	$P = .400$
	CON	9	53.67 (3.94)	53.67 (3.94)	$\eta_p^2 < .01$	$\eta_p^2 = .04$	$\eta_p^2 = .04$
SOT EO (%)	WBV	12	91.83 (6.48)	92.50 (6.16)	$P = .409$	$P = .599$	$P = .792$
	CON	9	93.89 (3.55)	94.11 (3.14)	$\eta_p^2 = .04$	$\eta_p^2 = .02$	$\eta_p^2 < .01$
SOT EC (%)	WBV	12	87.75 (9.87)	88.00 (12.30)	$P = .727$	$P = .558$	$P = .408$
	CON	9	90.00 (6.34)	88.56 (4.98)	$\eta_p^2 < .01$	$\eta_p^2 = .02$	$\eta_p^2 = .04$
SOT FL EO (%)	WBV	11	79.73 (9.23)	84.55 (6.30)	$P = .792$	$P = .439$	$P = .353$
	CON	9	81.44 (7.81)	81.00 (14.56)	$\eta_p^2 < .01$	$\eta_p^2 = .03$	$\eta_p^2 = .05$
SOT FL EC (%)	WBV	11	64.55 (9.47)	66.72 (9.51)	$P = .478$	$P = .206$	$P = .818$
	CON	8	61.00 (12.13)	64.13 (12.67)	$\eta_p^2 = .03$	$\eta_p^2 = .92$	$\eta_p^2 < .01$
SOT SUR (%)	WBV	12	87.25 (14.89)	88.25 (7.42)	$P = .577$	$P = .377$	$P = .697$
	CON	9	88.67 (8.25)	91.22 (3.27)	$\eta_p^2 = .02$	$\eta_p^2 = .04$	$\eta_p^2 = .01$
SOT SUR-FL (%)	WBV	12	66.33 (16.42)	66.75 (12.82)	$P = .634$	$P = .887$	$P = .730$
	CON	8	64.00 (14.70)	63.00 (13.31)	$\eta_p^2 = .01$	$\eta_p^2 < .01$	$\eta_p^2 < .01$

Abbreviations: TUG, Timed-Up and Go—lower scores indicate greater mobility; 500-m walk—lower scores indicate greater mobility; BBS, Berg Balance Scale—higher scores indicate greater level of function; SOT, Sensory Organization Test—higher scores indicate greater stability; SUR, surroundings sway; FL, floor sways; SUR-FL, both floor and surroundings sway; EO, eyes open; EC, eyes closed; WBV, whole-body vibration.

(SOT and ADP) were also evaluated with a complete model that involved a 2-way repeated-measures ANOVA (group [control and WBV] × time [pre-week 1, post-week 1, pre-week 5, and post-week 5]). The level of significance was set as $P < .05$ and all statistical analyses were carried out using IBM SPSS (v23, IBM, Illinois). Data are presented as means (standard deviation).

Results

Acute Responses

Regarding responses to a single bout of WBV at week 1, no significant main effects for time ($P > .05$) or group ($P > .05$), nor significant group × time interactions ($P > .05$), were observed for the TUG test, 500-m walk test, BBS, or for any of the 6 conditions of the SOT (Table 1).

For the ADP at week 1, there were significant main effects for group ($P = .049$) and time ($P = .003$) but no significant group × time interaction for the toes up testing condition. The CON group had significantly lower or better scores than the WBV group across both time points, and postscores were significantly lower or better than prescores for both groups. For the toes down condition, there were no significant main effects for group ($P > .05$) or time ($P > .05$) and no significant group × time interaction ($P > .05$; Table 2). Similarly, there were no significant main effects for group ($P > .05$) or time ($P > .05$) and no significant group × time interaction ($P > .05$) for the 8 testing conditions of the LOS test (Table 2) at week 1.

Table 3 presents the results for the mCT-SIB and the US test at week 1. There were no significant main effects for group (P

$> .05$) or time ($P > .05$) and no significant group × time interaction ($P > .05$) for any of the 8 testing conditions for the mCT-SIB. Similarly, there were no significant main effects for group ($P > .05$) or time ($P > .05$) and no significant group × time interaction ($P > .05$) for any of the US conditions observed at week 1.

Results for the TW test and SQT at week 1 are displayed in Table 4. There were no significant main effects for group or time ($P > .05$) and no significant group × time interaction ($P > .05$) for the end point sway velocity (°/s) parameter for the TW test. For the speed parameter of the TW test, there was no significant main effect for group ($P > .05$) and no significant group × time interaction ($P > .05$), but there was a significant main effect for time ($P = .003$), with postmeasures being significantly greater than premeasures. Table 4 also illustrates the results for the 2 parameters of the SQT. There were no significant main effects for group ($P > .05$) or time ($P > .05$) and no significant group × time interaction ($P > .05$) for either the right or left turn sway parameters of the 2 parameters of the SQT at week 1 (Figure 1).

The acute effects of WBV for the ADP and SOT at week 5 are presented in Table 5. Similar to week 1, a significant main effect for time ($P = .003$) was observed for the toes up condition, with premeasures across both groups being significantly greater than postmeasures; however, no significant main effects for group ($P > .05$) or significant group × time interaction ($P > .05$) were observed for the same condition. For the toes down condition, there were no significant main effects for group ($P > .05$) or time ($P > .05$) and no significant group × time interaction ($P > .05$). There were significant main effects for time with EO, fixed floor condition ($P = .002$), as well as

Table 2. Acute Effects of WBV Exposure on the Adaptation and Limits of Stability Tests at Week 1.

Variable	Exp.	n	Pre	Post	Group	Time	Group × Time
ADP TU (SES)	WBV	12	66.50 (22.49)[a,b]	58.50 (14.97)[b]	$P = .049$	$P = .003$	$P = .935$
	CON	9	51.63 (10.41)[a]	44.00 (7.98)	$\eta_p^2 = .20$	$\eta_p^2 = .40$	$\eta_p^2 < .01$
ADP TD (SES)	WBV	12	49.25 (15.67)	46.75 (10.83)	$P = .167$	$P = .299$	$P = .798$
	CON	9	43.22 (13.54)	39.11 (10.27)	$\eta_p^2 = .01$	$\eta_p^2 = .06$	$\eta_p^2 < .01$
LOS-R (%)	WBV	11	81.64 (6.83)	83.09 (4.74)	$P = .150$	$P = .144$	$P = .486$
	CON	9	73.33 (13.96)	77.33 (16.61)	$\eta_p^2 = .11$	$\eta_p^2 = .12$	$\eta_p^2 = .03$
LOS-L (%)	WBV	11	81.55 (6.24)	80.82 (5.98)	$P = .689$	$P = .350$	$P = .583$
	CON	8	83.75 (9.21)	81.00 (8.67)	$\eta_p^2 = .01$	$\eta_p^2 = .05$	$\eta_p^2 = .02$
LOS-F (%)	WBV	12	79.00 (25.16)	81.17 (11.78)	$P = .473$	$P = .112$	$P = .279$
	CON	9	69.67 (19.07)	80.56 (8.73)	$\eta_p^2 = .03$	$\eta_p^2 = .13$	$\eta_p^2 = .06$
LOS-FL (%)	WBV	12	76.50 (11.23)	77.00 (13.90)	$P = .486$	$P = .826$	$P = .933$
	CON	8	72.13 (17.26)	73.25 (18.26)	$\eta_p^2 = .03$	$\eta_p^2 < .01$	$\eta_p^2 < .01$
LOS-FR (%)	WBV	12	77.83 (15.04)	82.00 (6.88)	$P = .622$	$P = .157$	$P = .939$
	CON	8	75.75 (11.93)	79.50 (11.01)	$\eta_p^2 = .01$	$\eta_p^2 = .11$	$\eta_p^2 < .01$
LOS-B (%)	WBV	8	69.88 (13.87)	71.50 (10.86)	$P = .185$	$P = .217$	$P = .139$
	CON	7	69.57 (93.38)	52.86 (28.92)	$\eta_p^2 = .13$	$\eta_p^2 = .12$	$\eta_p^2 = .16$
LOS-BR (%)	WBV	11	65.27 (14.65)	63.45 (19.64)	$P = .087$	$P = .555$	$P = .373$
	CON	6	48.17 (19.61)	57.00 (12.81)	$\eta_p^2 = .18$	$\eta_p^2 = .02$	$\eta_p^2 = .05$
LOS-BL (%)	WBV	11	54.64 (17.39)	60.18 (15.89)	$P = .395$	$P = .309$	$P = .968$
	CON	7	48.57 (23.90)	54.57 (14.47)	$\eta_p^2 = .05$	$\eta_p^2 = .06$	$\eta_p^2 < .01$

Abbreviations: WBV, whole-body vibration; CON, control; ADP, Adaptation Test—lower scores indicate greater balance; TU, toes Up; TD, toes down; SES, sway energy score; LOS, Limits of Stability test—higher scores indicate greater directional control; LOS-R, Limits of Stability right; LOS-L, Limits of Stability left; LOS-F, Limits of Stability forward; LOS-FL, Limits of Stability forward-left; LOS-FR, Limits of Stability forward-right; LOS-B, Limits of Stability backward; LOS-BR, Limits of Stability backward-right; LOS-BL, Limits of Stability backward–left.
[a]Significantly different from post ($P < .05$).
[b]Significantly greater than CON ($P < .05$).

Table 3. Acute Effects of WBV Exposure on the Modified Clinical Test for Sensory Integration of Balance and the Unilateral Stance Test at Week 1.

Variable	Exp.	N	Pre	Post	Group	Time	Group × Time
Firm—EO (°/s)	WBV	12	0.25 (0.23)	0.26 (0.21)	$P = .587$	$P = .356$	$P = .577$
	CON	9	0.19 (0.15)	0.22 (0.20)	$\eta_p^2 = .02$	$\eta_p^2 = .05$	$\eta_p^2 = .02$
Firm—EC (°/s)	WBV	12	0.31 (0.23)	0.34 (0.25)	$P = .515$	$P = .838$	$P = .314$
	CON	9	0.27 (0.28)	0.24 (0.22)	$\eta_p^2 = .02$	$\eta_p^2 < .01$	$\eta_p^2 = .05$
Foam—EO (°/s)	WBV	12	0.86 (0.36)	0.89 (0.28)	$P = .338$	$P = .320$	$P = .169$
	CON	9	0.83 (0.58)	0.63 (0.20)	$\eta_p^2 = .05$	$\eta_p^2 = .05$	$\eta_p^2 = .01$
Foam—EC (°/s)	WBV	12	1.43 (0.70)	1.32 (0.45)	$P = .218$	$P = .411$	$P = .973$
	CON	9	1.16 (0.57)	1.06 (0.40)	$\eta_p^2 = .08$	$\eta_p^2 = .04$	$\eta_p^2 < .01$
US—RL: EO (°/s)	WBV	12	0.93 (0.49)	0.78 (0.38)	$P = .275$	$P = .250$	$P = .376$
	CON	9	2.06 (3.76)	0.93 (0.42)	$\eta_p^2 = .06$	$\eta_p^2 = .07$	$\eta_p^2 = .04$
US—RL: EC (°/s)	WBV	12	3.79 (4.96)	2.86 (4.29)	$P = .474$	$P = .875$	$P = .134$
	CON	9	1.58 (1.11)	2.72 (3.69)	$\eta_p^2 = .02$	$\eta_p^2 < .01$	$\eta_p^2 = .11$
US—LL: EO (°/s)	WBV	12	2.15 (3.23)	0.98 (0.53)	$P = .870$	$P = .110$	$P = .865$
	CON	9	2.19 (3.70)	1.23 (1.01)	$\eta_p^2 < .01$	$\eta_p^2 = .13$	$\eta_p^2 < .01$
US—LL: EC (°/s)	WBV	12	2.23 (3.17)	3.72 (5.00)	$P = .938$	$P = .130$	$P = .771$
	CON	9	2.60 (3.57)	3.62 (4.76)	$\eta_p^2 < .01$	$\eta_p^2 = .12$	$\eta_p^2 < .01$

Abbreviations: WBV, whole-body vibration; CON, control; mCT-SIB, Modified Clinical Test for Sensory Integration of Balance tests—lower scores indicate greater stability; US, Unilateral Stance—lower scores indicate greater stability; EO, eyes open; EC, eyes closed; LL, left leg; RL, right leg.

for the EO, surroundings sway and fixed floor condition ($P = .009$), indicating that postequilibrium scores decreased from prescores across both conditions. There were no significant main effects for group ($P > .05$) or time ($P > .05$) or group × time interactions ($P > .05$) for the remaining 4 conditions of the SOT.

Table 4. Acute Effects of WBV Exposure on Tandem Walk and Step/Quick Turn Tests at Week 1.

Variable	Exp.	N	Pre	Post	Group	Time	Group × Time
TW: sway velocity (°/s)	WBV	12	3.46 (1.20)	3.43 (1.01)	$P = .921$	$P = .386$	$P = .309$
	CON	9	3.19 (0.69)	3.80 (1.84)	$\eta_p^2 = .01$	$\eta_p^2 = .04$	$\eta_p^2 = .05$
TW: speed (cm/s)	WBV	12	18.78 (6.67)	26.08 (10.81)[a]	$P = .277$	$P = .003$	$P = .973$
	CON	9	22.97 (11.93)	30.41 (10.44)[a]	$\eta_p^2 = .06$	$\eta_p^2 = .37$	$\eta_p^2 = .01$
SQT: right (°)	WBV	12	21.25 (14.15)	20.33 (12.11)	$P = .865$	$P = .656$	$P = .267$
	CON	9	18.89 (9.11)	21.02 (7.10)	$\eta_p^2 < .01$	$\eta_p^2 = .01$	$\eta_p^2 = .06$
SQT: left (°)	WBV	12	23.83 (15.21)	20.37 (14.08)	$P = .423$	$P = .318$	$P = .705$
	CON	9	19.18 (6.16)	17.60 (4.63)	$\eta_p^2 = .03$	$\eta_p^2 = .05$	$\eta_p^2 < .01$

Abbreviations: WBV, whole-body vibration; CON, control; TW, Tandem Walk—lower scores indicate greater mobility; SQT, Step/Quick Turn—lower scores indicate greater mobility.
[a]Post significantly larger than pre (P < .05).

Table 5. Acute Effects of WBV Exposure on the ADP and SOT at Week 5.

Variable	Exp.	N	Pre	Post	Group	Time	Group × Time
ADP TU (SES)	WBV	12	48.75 (11.73)[a]	46.42 (11.15)	$P = .635$	$P = .016$	$P = .242$
	CON	9	48.00 (15.57)[a]	41.79 (14.93)	$\eta_p^2 = .01$	$\eta_p^2 = .27$	$\eta_p^2 = .07$
ADP TD (SES)	WBV	12	45.50 (9.32)	43.25 (9.37)	$P = .304$	$P = .314$	$P = .948$
	CON	9	41.67 (12.41)	39.11 (9.27)	$\eta_p^2 = .06$	$\eta_p^2 = .05$	$\eta_p^2 < .01$
SOT EO (%)	WBV	12	93.67 (2.46)[a]	87.75 (10.70)	$P = .764$	$P = .002$	$P = .859$
	CON	9	94.78 (2.59)[a]	88.22 (8.34)	$\eta_p^2 < .01$	$\eta_p^2 = .40$	$\eta_p^2 < .01$
SOT EC (%)	WBV	12	89.75 (6.30)	89.33 (6.91)	$P = .859$	$P = .986$	$P = .591$
	CON	9	89.78 (5.67)	90.22 (4.66)	$\eta_p^2 < .01$	$\eta_p^2 < .01$	$\eta_p^2 = .02$
SOT FL EO (%)	WBV	11	77.73 (6.47)	67.27 (11.41)	$P = .441$	$P = .301$	$P = .387$
	CON	8	67.13 (7.75)	66.63 (14.89)	$\eta_p^2 = .04$	$\eta_p^2 = .06$	$\eta_p^2 = .04$
SOT FL EC (%)	WBV	12	71.83 (8.94)	68.00 (12.08)	$P = .983$	$P = .122$	$P = .881$
	CON	8	72.13 (10.32)	67.50 (16.79)	$\eta_p^2 < .01$	$\eta_p^2 = .13$	$\eta_p^2 < .01$
SOT SUR (%)	WBV	12	88.00 (7.63)[a]	83.42 (9.14)	$P = .991$	$P = .009$	$P = .509$
	CON	9	89.33 (6.46)[a]	82.00 (13.50)	$\eta_p^2 < .01$	$\eta_p^2 = .31$	$\eta_p^2 = .23$
SOT SUR-FL (%)	WBV	12	92.58 (4.78)	89.08 (30.66)	$P = .373$	$P = .118$	$P = .281$
	CON	8	94.13 (3.60)	76.00 (23.00)	$\eta_p^2 = .04$	$\eta_p^2 = .13$	$\eta_p^2 = .06$

Abbreviations: WBV, whole-body vibration; CON, control; ADP, Adaptation Test—lower scores indicate greater balance; TU, toes up; TD, toes down; SES, sway energy score; SOT, Sensory Organization Test—higher scores indicate greater stability; EO, eyes open; EC, eyes closed; SUR, surroundings sway; FL, floor sways; SUR-FL, both floor and surroundings sway.
[a]Significantly different from post (P < .05).

Chronic Responses

Figure 2 presents the percentage changes in the SESs from pre- to postvibration for weeks 1 and 5 for the ADP. No significant main effects for group ($P > .05$) or time ($P > .05$) nor significant group × time interactions ($P > .05$) were observed for the ADP with toes up (Figure 2A) or toes down (Figure 2B).

The percentage changes from pre- to postvibration at weeks 1 and 5 in the equilibrium scores measured in the 6 conditions of the SOT are illustrated in Figure 3. No significant main effects for group ($P > .05$) or time ($P > .05$) nor significant group × time interactions ($P > .05$) were observed for the following SOT testing conditions: EC fixed floor (Figure 3B), EC fixed surroundings and floor sways (Figure 3D), and EO, both surroundings and floor sways (Figure 3F). Although there were no significant main effects for group ($P > .05$) or no significant group × time interactions ($P > .05$) for the remaining variables, there were significant main effects for time ($P < .05$) for the EO, fixed floor condition (Figure 3A), the EO, fixed surroundings and floor sways condition (Figure 3C), and for the EO, surroundings sway and fixed floor condition (Figure 3E). For all these 3 conditions, significant reductions in the percentage changes for the equilibrium score were observed at visit 5 compared to visit 1, indicating a poorer performance in maintaining stability.

Table 6 displays the acute (previbration to postvibration) and chronic changes (from weeks 1 to 5) for both the ADP and SOT using the full model (group [2] and time points [4]). Although no significant main effects for group ($P > .05$) or time ($P > .05$) nor no significant group × time interactions ($P > .05$) were observed for the toes down condition of the ADP, a significant main effect for time main ($P < .05$) was observed
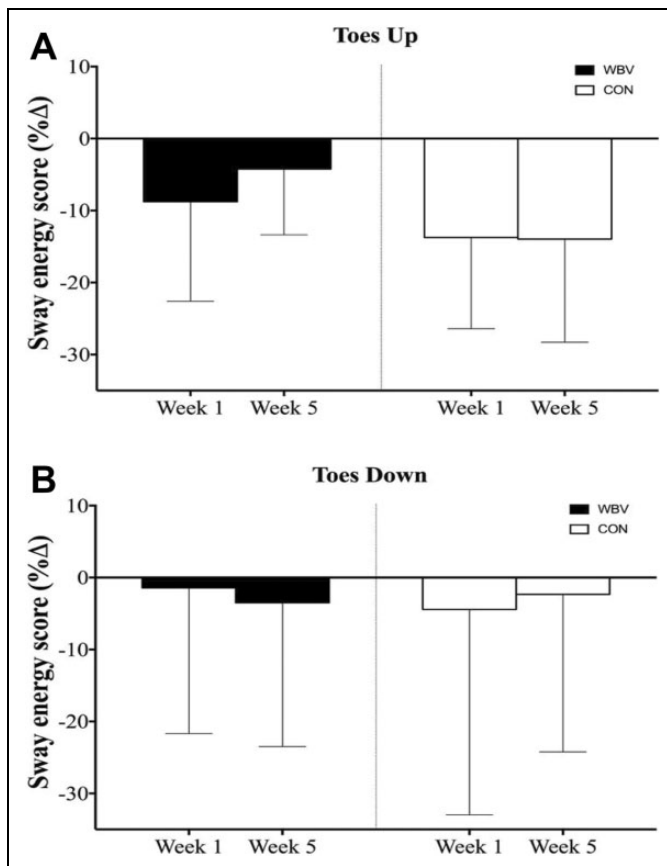
Figure 2. Chronic effects of WBV exposure on the sway energy scores of the ADP (lower scores indicate greater stability). ADP indicates Adaptation Test; WBV, whole-body vibration; CON, control condition.

for the toes up condition, where all time points were significantly lower compared to previbration exposure measures at week 1 indicating a greater ability to react more efficiently to minimize anterior–posterior platform rotations. For the EC and fixed floor condition of the SOT, there were no significant main effects for group ($P > .05$) or time ($P > .05$) and no significant group × time interaction ($P > .05$).

Although no significant main effects for group ($P > .05$) or no significant group × time interactions were detected for the other 5 conditions of the SOT, there were significant main effects for time ($P < .05$) for each of these 5 conditions. For the EO, fixed floor condition, postvibration percentage equilibrium scores at week 5 were significantly lower ($P < .05$) or poorer than scores at pre- and post-week 1 and pre-week 5. For the EO, fixed surroundings and floor sways condition, postvibration percentage equilibrium scores at week 5 were significantly lower ($P < .05$) or poorer than scores at pre- and post-week 1, but not different from previbration week 5 and previbration week 5 scores which were significantly lower ($P < .05$) than previbration week 1 scores. Scores for previbration week 5 were significantly greater or better ($P < .05$) than scores at previbration week 1 but not different from postvibration scores week 1 or week 5 for the EC, fixed surroundings and floor sways condition. Scores postvibration week 5 were significantly ($P < .05$) lower or poorer

than postvibration scores at week 1, and finally previbration scores at week 5 were significantly ($P < .05$) greater than both pre- and postvibration score week 1 for the EO, both surroundings and floor sway condition.

Discussion

This study investigated the acute and chronic effects of WBV exposure on balance, postural control, and mobility in women with MS. To the best of our knowledge, this is the first study to examine the acute effects of WBV in women with MS; however, a limited number of studies have investigated the chronic effects of WBV training on balance in patients with MS with conflicting results. The main findings of the current investigation were that neither acute nor chronic WBV exposure once a week for 5 weeks improved balance, postural control, or mobility in women with MS.

Acute Responses

Essentially, there were no significant main effects for group and time nor significant group × time interactions for any of the outcome variables at week 1 with only 3 exceptions. There was a significant group effect for the ADP, toes up condition ($P = .049$), with the CON group had significantly lower or better scores than the WBV group across both time points. There also were 2 significant main effects for time, the first being for the ADP, toes up condition ($P = .003$), which found postscores significantly lower or better than prescores for both groups and for the TW test, speed score ($P = .003$) which decreased from pre- to postvibration.

At week 5, acute responses were only assessed by the ADP and SOT and results were similar to the findings at week 1, with no significant main effects for group and no significant group × time interactions. There were 3 variables (1 ADP variable and 2 SOT variables) that had significant main effects for time (toes up condition of the ADP, $P = .016$, and EO with fixed floor, $P = .002$, and EC with surroundings sway and fixed floor, $P = .0090$, conditions for the SOT).

As mentioned earlier, there was only one previous study that assessed acute responses to WBV in patients with MS, and our mobility results (acute responses at week 1) are similar to those reported by Schuhfried,[13] who also found no significant differences between a WBV and a passive CON group for the TUG test, measured 15 minutes following an acute bout of WBV.

Our findings also indicated that acute exposure to WBV did not improve balance or postural stability. Although there are no studies in patients with MS for these outcomes, studies in patients with stroke reported improvements in ambulation and postural control after acute exposure to WBV. Chan et al[27] exposed patients with stroke to two, 10-minute periods of vibration (vertical vibrations at 12 Hz and 4 mm amplitude) and reported decreases in ankle spasticity and increased ambulatory capacity. van Nes et al[24] used 4 vibration bouts of 45 seconds each separated by 1-minute rest periods (30 Hz
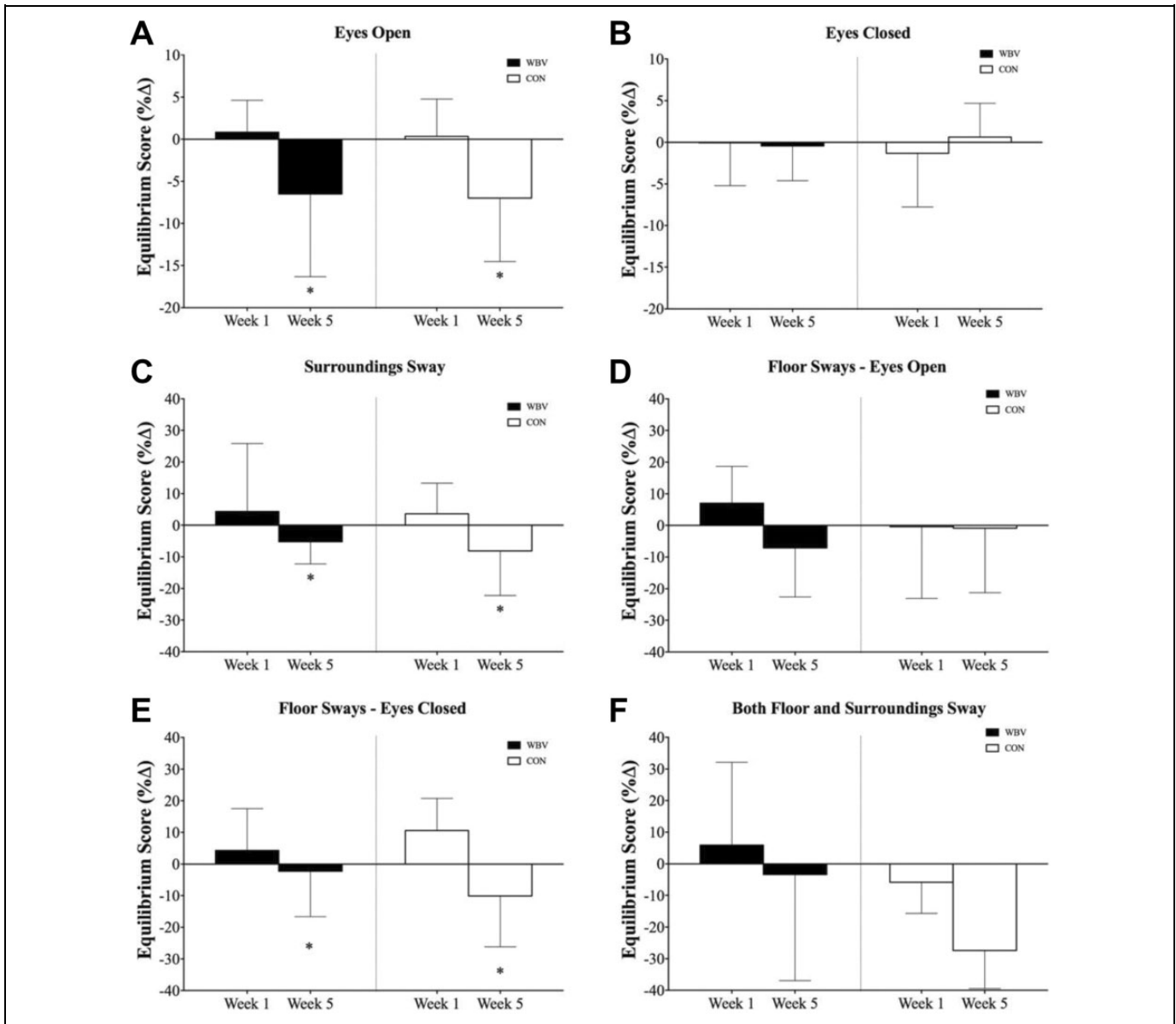
Figure 3. Chronic effects of WBV exposure on SOT scores (higher scores indicate greater stability). *Significantly different from week 1 (P < .05). SOT indicates Sensory Organization Test; WBV, whole-body vibration; CON, control condition.

and 3 mm amplitude) and reported promising results for improving proprioceptive control of posture in patients with stroke. Our protocol (five, 30-second bouts of vibration, 30 Hz and 2-4 mm amplitude, 1-minute rest intervals between bouts) was very similar to the van Nes et al's[24] protocol but substantially lower in amplitude compared to the Chan et al's[27] study.

Chronic Responses

As mentioned earlier, only the ADP and SOT were used to examine the chronic effects of WBV after 5 weeks of vibration exposure. Exposure to the chronic use of WBV (once a week for 5 weeks) did not improve balance or postural control

for any of the assessment variables. These results are consistent with the previous literature that also examined WBV in patients with MS. Alguacil Diego et al[28] used the SOT to assess the impact of 5 consecutive days of WBV exposure on participants' postural control. Similar to our findings, the authors observed that 5 days of WBV (5 bouts of 1-minute exposures separated by 1-minute rest periods at a frequency of 6 Hz and 3 mm amplitude) did not improve postural control in patients with MS.

It is possible that more bouts of WBV are needed in order to elicit significant improvements in balance and postural control in individuals with MS. In this regard, Wolfsegger[14] submitted 18 patients with MS to 3 weeks of WBV training performed 3 times per week instead of 1, as in the current investigation.

Table 6. Chronic Effects of WBV Exposure on the ADP and SOT.

Variable	Exp.	n	Week 1		Week 5		Group	Time	Group × Time
			Pre	Post	Pre	Post			
ADP TU (SES)	WBV	12	66.5 (22.49)	58.50 (14.97)[a]	48.75 (11.73)[a]	46.42 (11.15)[a]	$P = .068$ $\eta_p^2 = .17$	$P < .001$ $\eta_p^2 = .53$	$P = .089$ $\eta_p^2 = .11$
	CON	8	51.63 (10.41)	44.00 (7.98)[a]	44.50 (12.94)[a]	37.13 (42.70)[a]			
ADP TD (SES)	WBV	12	49.25 (15.66)	46.75 (10.83)	45.50 (9.32)	43.25 (9.37)	$P = .201$ $\eta_p^2 = .08$	$P = .245$ $\eta_p^2 = .07$	$P = .857$ $\eta_p^2 = .01$
	CON	9	43.22 (13.54)	39.11 (10.28)	41.67 (12.42)	39.11 (9.27)			
SOT EO (%)	WBV	12	91.83 (6.48)	92.5 (6.17)	93.67 (2.46)	87.50 (10.70)[a,b,c]	$P = .577$ $\eta_p^2 = .02$	$P < .001$ $\eta_p^2 = .35$	$P = .929$ $\eta_p^2 < .01$
	CON		93.89 (3.55)	94.11 (3.14)	94.78 (2.59)	88.22 (8.35)[a,b,c]			
SOT EC (%)	WBV	12	87.75 (8.87)	88.00 (12.30)	89.75 (6.30)	89.33 (6.91)	$P = .755$ $\eta_p^2 < .01$	$P = .688$ $\eta_p^2 = .03$	$P = .891$ $\eta_p^2 = .01$
	CON	9	90.00 (6.34)	88.56 (4.98)	89.78 (5.67)	89.78 (5.67)			
SOT FL EO (%)	WBV	11	79.83 (9.23)	84.55 (6.30)	72.73 (6.47)[a]	67.27 (11.41)[a,b]	$P = .519$ $\eta_p^2 = .03$	$P < .001$ $\eta_p^2 = .43$	$P = .661$ $\eta_p^2 = .04$
	CON	8	82.12 (8.06)	81.00 (15.57)	67.13 (7.75)[a]	66.63 (14.89)[a,b]			
SOT FL EC (%)	WBV	11	64.55 (9.47)	66.73 (9.51)	72.55 (9.02)[a]	70.23 (9.61)	$P = .722$ $\eta_p^2 < .01$	$P = .012$ $\eta_p^2 = .20$	$P = .748$ $\eta_p^2 = .03$
	CON	7	61.86 (9.14)	67.86 (7.56)	72.71 (11.00)[a]	66.14 (17.66)			
SOT SUR (%)	WBV	12	87.25 (14.89)	88.25 (7.42)	88.00 (7.63)	83.42 (9.14)[b]	$P = .762$ $\eta_p^2 < .01$	$P = .003$ $\eta_p^2 = .21$	$P = .729$ $\eta_p^2 = .02$
	CON	9	88.67 (8.25)	91.22 (3.27)	89.33 (6.46)	82.00 (13.50)[b]			
SOT SUR-FL (%)	WBV	12	66.33 (16.43)	66.75 (12.82)	92.58 (4.78)[a,b]	89.08 (30.66)	$P = .242$ $\eta_p^2 = .08$	$P < .001$ $\eta_p^2 = .43$	$P = .153$ $\eta_p^2 = .10$
	CON	7	66.29 (14.26)	62.29 (14.21)	94.86 (3.18)[a,b]	69.00 (12.64)			

Abbreviations: WBV, whole-body vibration; CON, control; ADP, Adaptation Test—lower scores indicate greater balance; TU, toes up; TD, toes down; SES, sway energy score; SOT, Sensory Organization Test—higher scores indicate greater stability; EO, eyes open; EC, eyes closed; SUR, surroundings sway; FL, floor sways; SUR-FL, both floor and surroundings sway.
[a]Significantly different from pre at week 1 ($P < .05$).
[b]Significantly different from post at week 1 ($P < .05$).
[c]Significantly different from pre at week 5 ($P < .05$).

However, as reported in the current study, WBV vibration was not efficient at improving physical function in patients mildly affected with MS. In another study performed over a longer period of time (20 weeks), Broekmans et al[18] investigated patients with MS who performed static and dynamic exercises on a vibration platform (25-45 Hz, 2.5 mm amplitude, 5 training sessions per 2-week cycle) in which the training volume and intensity was progressively increased over time. They did not observe any significant improvements in muscle performance or functional capacity following the 20-week period of WBV training. Although the current study did not assess muscle performance, our results are similar with though from Broekmans et al[18] in terms of no significant chronic changes post-WBV training in patients with MS.

Even though chronic WBV training did not induce any positive adaptations in patients with MS in the current investigation, previous studies have reported different results in other populations. The ability to compare our results with these studies is warranted, considering that patients with MS display many physical limitations that are similar to those observed in the elderly patients and in patients with stroke. Considering this, Bruyere et al[29] demonstrated significant improvements in balance and mobility in nursing home residents exposed to 6 bouts of WBV training. The training protocol involved 3 visits per week for 6 weeks with a protocol of 4 bouts of 1-minute vibrations separated by 90 seconds of rest at a frequency of 10 Hz and 3 mm amplitude for the first and third bouts and a frequency of 26 Hz and 7 mm amplitude for the second and fourth bouts. However, these results may differ from our study due to the fact that the study by Bruyere et al[29] used multiple visits over 6 weeks and much larger amplitudes than most other studies and their vibration protocol was in combination with physical therapy. In another study, Torvinen et al[30] submitted 66 young participants to a 4-month WBV training period in which they performed light exercises during different bouts of WBV, 3 to 5 times per week. During the first 2 weeks of the study, the duration of the vibration was 2 minutes, at a frequency of 25 Hz for the first minute and 30 Hz for the second minute. Then, over the next month and a half, the duration of the vibration was 3 minutes at frequencies of 25 Hz/60 s, 30 Hz/60 s, and 35 Hz/60 s. Finally, for the last 2 months, the length of exposure was 4 minutes, at frequencies of 25 Hz/60 s, 30 Hz/60 s, 35 Hz/60 s, and 40 Hz/60 s. The amplitude of the vertical vibration was 2 mm. Interestingly, even though the WBV training increased muscular power and strength in the participants, there were no changes in balance, similar to our findings. An important point is that the direct effects of WBV in this study cannot be determined given that patients also performed exercise while receiving the vibration stimulus, which also makes it difficult to compare these findings with those from the present study since our participants were exposed to session of WBV without performing any exercises. We also observed a large variability across participants in our study, which indicates that the response to WBV in MS may be affected by the severity of the disease. Therefore, we encourage future studies to test the

effects of WBV in patients with MS at different levels of disability or in more restrictive age groups.

Santos-Filho et al[31] also reported conflicting results based on a variety of studies that were examined in a systematic review of the literature dealing with the possible benefits of WBV in patients with stroke. These authors suggest that the possible reasons for the varied include a variety of WBV exposure times, different clinical characteristics of the patients from the different studies, and the length of time elapsed from the onset of the stroke. In another study on patients with stroke, Pang et al[32] reported that 15 min/d, 3 d/wk for 8 weeks of WBV had no extra beneficial effects on muscular strength or bone turnover rates compared to an exercise-only group, but knee spasticity did improve for the WBV-only group. In this study, patients with stroke performed exercises (weight shifting, squats, lunges, standing on one leg) while receiving 6 bouts of the vibration stimulus that ranged from 20 to 30 Hz, from 0.6 to 0.44 amplitudes, and 1.5 to 2.5 minutes across the length of the study. They concluded that the protocol was safe and feasible but provided no substantial benefits compared to dynamic exercises in patients with stroke with mild-to-moderate motor impairments.

Tihanyi et al[33] examined the effects of a 4-week vibration protocol 3 times per week (6 bouts of vibration at a frequency of 20 Hz and 5 mm amplitude with each bout separated by 1 minute of rest) in patients with stroke. They reported significant improvements in voluntary force production and muscle activation of the quadriceps and concluded that a relatively short-term training program of WBV (4 weeks) at medium frequencies (20 Hz) was as effective as longer duration WBV training programs (more than 2 months) at high frequencies (26-40 Hz).

In contrast to patient with stroke findings, 2 studies in the elderly patients (older than 60 years) reported improved balance and a reduction in the risk of falls following a WBV intervention of 3 months[34] and 18 months.[35] Cheung et al[34] utilized the Galileo 900 to induce the vibration stimulus that was at a frequency of 20 Hz with feet placed at the second position (amplitude between 0 and 5.3 mm). Patients were independent living and received the stimulus 3 min/d, 3 d/wk, for 3 months. They reported significant improvements in stability as indicated by the LOS test and functional reach test. One limitation of this study was that activity levels for the participants outside the training protocol were assessed by self-report. Leung et al[35] also studied independent living participants older than 60 years who stood straight legged on the vibration platform for 20 min/d, 5 d/wk, for 18 months (vertical vibrations at a frequency of 35 Hz, 0.3 g). Significant improvements in reaction time, movement velocity, and maximum excursion of balancing ability were reported along with a significant increase in quadriceps muscle strength. Once again, activity outside the training program was not directly assessed.

The current study is not without limitations. First, only female participants were included; thus, our findings cannot be extended to men with MS. Also our sample sizes for both groups were small with not all patients completing all testing

sessions. Additionally, there was a large age range in our sample (18-64 years of age), which could impact our outcome measures, not only because of normal age-related changes that one might expect in balance, postural control, and mobility but also because of the length of time that each participant has spent with their diagnosis of MS. One problem that we had to address when designing the vibration protocol for this study was the uncertainty of the WBV intervention and safety issues that could have arisen with a group of patients with MS, which could have included exacerbation of their symptoms, increased muscle weakness, or increased fatigue, since there is a paucity of published findings from which to base our protocols on.

We recommend that future studies increase WBV dose such as increasing the exposure times to at least 1 minute and to increase the number of bouts to 5 or 6 during acute sessions and to increase the frequency of sessions per week to either daily sessions or at minimum 3 times per week for at least 6 to 8 weeks to better study the chronic effects of WBV. Additionally, other patient populations that might benefit from WBV exposure should be investigated and these could include patients with stroke and patients with other neurodegenerative diseases, such as Parkinson disease. Finally, we would also suggest that future studies should combine WBV with some sort of resistance exercise to determine whether there may be additive effects of WBV to the benefits of an exercise intervention to enhance positive adaptations.

Based on the findings from this study, we concluded that neither acute nor chronic WBV exposure resulted in significant improvements in balance, postural stability, or mobility in women with MS, but additional studies are needed.

Declaration of Conflicting Interests

Funding

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References

1. Lassmann H. The pathology of multiple sclerosis and its evolution. *Philos Trans R Soc Lond B Biol Sci*. 1999;354(1390): 1635-1640. doi:10.1098/rstb.1999.0508.

2. Love S. Demyelinating diseases. *J Clin Pathol*. 2006;59(11): 1151-1159. doi:10.1136/jcp.2005.031195.

3. Metter EJ, Conwit R, Tobin J, Fozard JL. Age-associated loss of power and strength in the upper extremities in women and men. *J Gerontol A Biol Sci Med Sci*. 1997;52(5):B267-B276. http://www.ncbi.nlm.nih.gov/pubmed/9310077.

4. Erim Z, Beg MF, Burke DT, de Luca CJ. Effects of aging on motor-unit control properties. *J Neurophysiol*. 1999;82(5): 2081-2091. doi:10.1152/jn.1999.82.5.2081.

5. White LJ, McCoy SC, Castellano V, et al. Resistance training improves strength and functional capacity in persons with multiple sclerosis. *Mult Scler*. 2004;10(6):668-674. doi:10.1191/1352458504ms1088oa.

6. McCullagh R, Fitzgerald AP, Murphy RP, Cooke G. Long-term benefits of exercising on quality of life and fatigue in multiple sclerosis patients with mild disability: a pilot study. *Clin Rehabil*. 2008;22(3):206-214. doi:10.1177/0269215507082283.

7. Rampello A, Franceschini M, Piepoli M, et al. Effect of aerobic training on walking capacity and maximal exercise tolerance in patients with multiple sclerosis: a randomized crossover controlled study. *Phys Ther*. 2007;87(5):545-555. doi:10.2522/ptj.20060085.

8. Burke D, Schiller HH. Discharge pattern of single motor units in the tonic vibration reflex of human triceps surae. *J Neurol Neurosurg Psychiatry*. 1976;39(8):729-741. doi:10.1136/jnnp.39.8.729.

9. Kessler J, Radlinger L, Baur H, Rogan S. Effect of stochastic resonance whole body vibration on functional performance in the frail elderly: a pilot study. *Arch Gerontol Geriatr*. 2014;59(2):305-311. doi:10.1016/j.archger.2014.06.005.

10. Rogan S, Hilfiker R, Herren K, et al. Effects of whole-body vibration on postural control in elderly: a systematic review and meta-analysis. *BMC Geriatr*. 2011;11:72. doi:10.1186/1471-2318-11-72.

11. Rogan S, Hilfiker R, Herren K, Radlinger L, de Bruin ED. Effects of whole-body vibration on postural control in elderly: a systematic review and meta-analysis. *BMC Geriatr*. 2011;11:72. doi:10.1186/1471-2318-11-72.

12. Wunderer K, Schabrun SM, Chipchase LS, Physiotherapy B, App Sc M. Effects of whole body vibration on strength and functional mobility in multiple sclerosis. *Physiother Theory Pract*. 2010;26(6):374-384. doi:10.3109/09593980903147384.

13. Schuhfried O, Mittermaier C, Jovanovic TT, Pieber K, Paternostro-sluga T. Effects of whole-body vibration in patients with multiple sclerosis: a pilot study. *Clin Rehabil*. 2005;19(8):834-842. doi:10.1191/0269215505cr919oa.

14. Wolfsegger T, Assar H, Topakian R. 3-week whole body vibration does not improve gait function in mildly affected multiple sclerosis patients—a randomized controlled trial. *J Neurol Sci*. 2014;347(1-2):119-123. doi:10.1016/j.jns.2014.09.030.

15. Kantele S, Karinkanta S, Sievänen H. Effects of long-term whole-body vibration training on mobility in patients with multiple sclerosis: a meta-analysis of randomized controlled trials. *J Neurol Sci*. 2015;358(1-2):31-37. doi:10.1016/j.jns.2015.09.357.

16. Castillo-Bueno I, Ramos-Campo DJ, Rubio-Arias JA. Effects of whole-body vibration training in patients with multiple sclerosis: a systematic review. *Neurologia*. July 2016. doi:10.1016/j.nrl.2016.04.007.

17. Claerbout M, Gebara B, Ilsbroukx S, et al. Effects of 3 weeks' whole body vibration training on muscle strength and functional mobility in hospitalized persons with multiple sclerosis. *Mult Scler J*. 2012;18(4):498-505. doi:10.1177/1352458511423267.

18. Broekmans T, Roelants M, Alders G, Feys P, Thijs H, Eijnde BO. Exploring the effects of a 20-week whole-body vibration training programme on leg muscle performance and function in persons with multiple sclerosis. *J Rehabil Med*. 2010;42(9):866-872. doi:10.2340/16501977-0609.

19. Uszynski MK, Purtill H, Donnelly A, Coote S. Comparing the effects of whole-body vibration to standard exercise in ambulatory people with multiple sclerosis: a randomised controlled feasibility study. *Clin Rehabil*. 2016;30(7):657-668. doi:10.1177/0269215515595522.

20. Eftekhari E, Mostahfezian M, Etemadifar M, Zafari A. Resistance training and vibration improve muscle strength and functional capacity in female patients with multiple sclerosis. *Asian J Sports Med*. 2012;3(4):279-284. http://www.ncbi.nlm.nih.gov/pubmed/23342227. Accessed March 20, 2018.

21. Hilgers C, Mündermann A, Riehle H, Dettmers C. Effects of whole-body vibration training on physical function in patients with multiple sclerosis. *NeuroRehabilitation*. 2013;32(3):655-663. doi:10.3233/NRE-130888.

22. Turbanski S, Haas CT, Friedrich A, Duisberg P, Schmidtbleicher D. Effects of random whole-body vibration on postural control in Parkinson's disease. *Res Sport Med*. 2005;3(VIII):1.

23. Ebersbach G, Edler D, Kaufhold O, Wissel J. Whole body vibration versus conventional physiotherapy to improve balance and gait in Parkinson's disease. *Arch Phys Med Rehabil*. 2008;89(3):399-403. doi:10.1016/j.apmr.2007.09.031.

24. van Nes IJW, Geurts ACH, Hendricks HT, Duysens J. Short-term effects of whole-body vibration on postural control in unilateral chronic stroke patients. *Am J Phys Med Rehabil*. 2004;83(11):867-873. doi:10.1097/01.PHM.0000140801.23135.09.

25. Polman CH, Reingold SC, Banwell B, et al. Diagnostic criteria for multiple sclerosis: 2010 revisions to the McDonald criteria. *Ann Neurol*. 2011;69(2):292-302. doi:10.1002/ana.22366.

26. Berg K, Wood-Dauphine S, Williams JI, Gayton D. Measuring balance in the elderly: preliminary development of an instrument. *Physiother Canada*. 1989;41(6):304-311. doi:10.3138/ptc.41.6.304.

27. Chan KS, Liu CW, Chen TW, Weng MC, Huang MH, Chen CH. Effects of a single session of whole body vibration on ankle plantarflexion spasticity and gait performance in patients with chronic stroke: a randomized controlled trial. *Clin Rehabil*. 2012;26(12):1087-1095. doi:10.1177/0269215512446314.

28. Alguacil Diego IM, Pedrero Hernández C, Molina Rueda F, Cano de la Cuerda R. Effects of vibrotherapy on postural control, functionality and fatigue in multiple sclerosis patients. A randomised clinical trial. *Neurologia*. 2012;27(3):143-153. doi:10.1016/j.nrl.2011.04.019.

29. Bruyere O, Wuidart MA, Di Palma E, et al. Controlled whole body vibration to decrease fall risk and improve health-related quality of life of nursing home residents. *Arch Phys Med Rehabil*. 2005;86(2):303-307. doi:10.1016/j.apmr.2004.05.019.

30. Torvinen S, Kannus P, Sievänen H, et al. Effect of four-month vertical whole body vibration on performance and balance. *Med Sci Sports Exerc*. 2002;34(9):1523-1528. doi:10.1097/00005768-200209000-00020.

31. Santos-Filho SD, Cameron MH, Bernardo-Filho M. Benefits of whole-body vibration with an oscillating platform for people with multiple sclerosis: a systematic review. *Mult Scler Int*. 2012;2012:1-6. doi:10.1155/2012/274728.

32. Pang MYC, Lau RWK, Yip SP. The effects of whole-body vibration therapy on bone turnover, muscle strength, motor function, and spasticity in chronic stroke: a randomized controlled trial. *Eur J Phys Rehabil Med*. 2013;49(4):439-450. http://www.ncbi.nlm.nih.gov/pubmed/23486302.

33. Tihanyi J, Di Giminiani R, Tihanyi T, Gyulai G, Trzaskoma L, Horváth M. Low resonance frequency vibration affects strength of paretic and non-paretic leg differently in patients with stroke. *Acta Physiol Hung*. 2010;97(2):172-182. doi:10.1556/APhysiol.97.2010.2.3.

34. Cheung WH, Mok HW, Qin L, Sze PC, Lee KM, Leung KS. High-frequency whole-body vibration improves balancing ability in elderly women. *Arch Phys Med Rehabil*. 2007;88(7):852-857. doi:10.1016/j.apmr.2007.03.028.

35. Leung KS, Li CY, Tse YK, et al. Effects of 18-month low-magnitude high-frequency vibration on fall rate and fracture risks in 710 community elderly—a cluster-randomized controlled trial. *Osteoporos Int*. 2014;25(6):1785-1795. doi:10.1007/s00198-014-2693-6.