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Original Article

The effects of Pilates training combined with whole-body vibration on balance and mobility in people with multiple sclerosis: A single-blind randomized controlled clinical trial

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ABSTRACT

Objectives: This study aims to investigate the effects of Pilates training combined with whole-body vibration (WBV) on balance, functional mobility, core muscle endurance and power, lower extremity strength, upper extremity performance, and fatigue in people with multiple sclerosis.

Patients and methods: This randomized controlled trial was conducted between December 2023 and September 2024. Thirty-four participants (9 males, 25 females; mean age: 36.7±12.2 years; range, 20 to 65 years) were included in the study and randomized into two groups: Pilates-WBV (n=17) and Pilates (n=17). The Pilates-WBV group received both Pilates and WBV training, while the Pilates group received only Pilates training. Both groups received training twice a week for six weeks. The primary outcomes included posturography, the Activities-Specific Balance Confidence Scale, core muscle endurance and power tests, the five times sit-to-stand test, the timed up-and-go test, and the 6-min walk test. The secondary outcomes included the nine-hole peg test, the Fatigue Severity Scale, and the Fatigue Impact Scale. Assessments were conducted at baseline and after intervention.

Results: Both groups showed significant improvements in single-leg stance stability, limits of stability, balance confidence, core muscle endurance and power, functional mobility, upper extremity performance, and fatigue ($p<0.05$). Double-leg stance stability and walking distance improved only in the Pilates-WBV group ($p<0.05$). The Pilates-WBV group also showed greater improvements in trunk flexor endurance and core power (modified push-up test) compared to the Pilates group.

Conclusion: Pilates training combined with WBV improved core stability, walking endurance, and physical performance more than Pilates training alone in people with multiple sclerosis.

Keywords: Balance, mobility, multiple sclerosis, pilates, vibration.

Postural instability is a common clinical symptom in people with multiple sclerosis (pwMS) and affects activities of daily living.[1] Reduced postural stability is a predisposing factor that increases the risk of falls in this population.[2]

Regular exercise plays an important role in maintaining postural stability and independent mobility in pwMS.[1] Exercise also suppresses neuroinflammation, promotes neuronal survival, and facilitates neuroplasticity.[3] Core-based exercise training, such as Pilates, is widely used in multiple sclerosis rehabilitation to improve balance and gait.[4,5]

Whole-body vibration (WBV) is another approach used to improve motor function, balance, and gait.[6] The exact physiological pathways through which WBV improves balance remain unclear; its primary effect is believed to stem from activation of the tonic

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vibration reflex.[6] When vibration stimulates the muscle spindle, group Ia afferent fibers activate alpha motor neurons through monosynaptic connections, leading to tonic reflexive contractions.[7] Whole-body vibration has been shown to enhance balance-related activities by improving both motor and sensory performance in patients with neurologic disorders.[8,9] In these studies, it is stated that postural control can be improved with WBV by facilitating both the receptors related to the vibration sense and the muscle spindle.

Since multiple sclerosis involves both motor and sensory impairments, it is thought that including interventions into exercise routines that facilitate somatosensory and motor reflex pathways may provide additional benefits. Therefore, this study aimed to investigate the effects of Pilates training combined with WBV on balance, mobility, lower extremity muscle strength, and core muscle power and endurance in pwMS, as well as the effects on upper extremity performance and fatigue.

PATIENTS AND METHODS

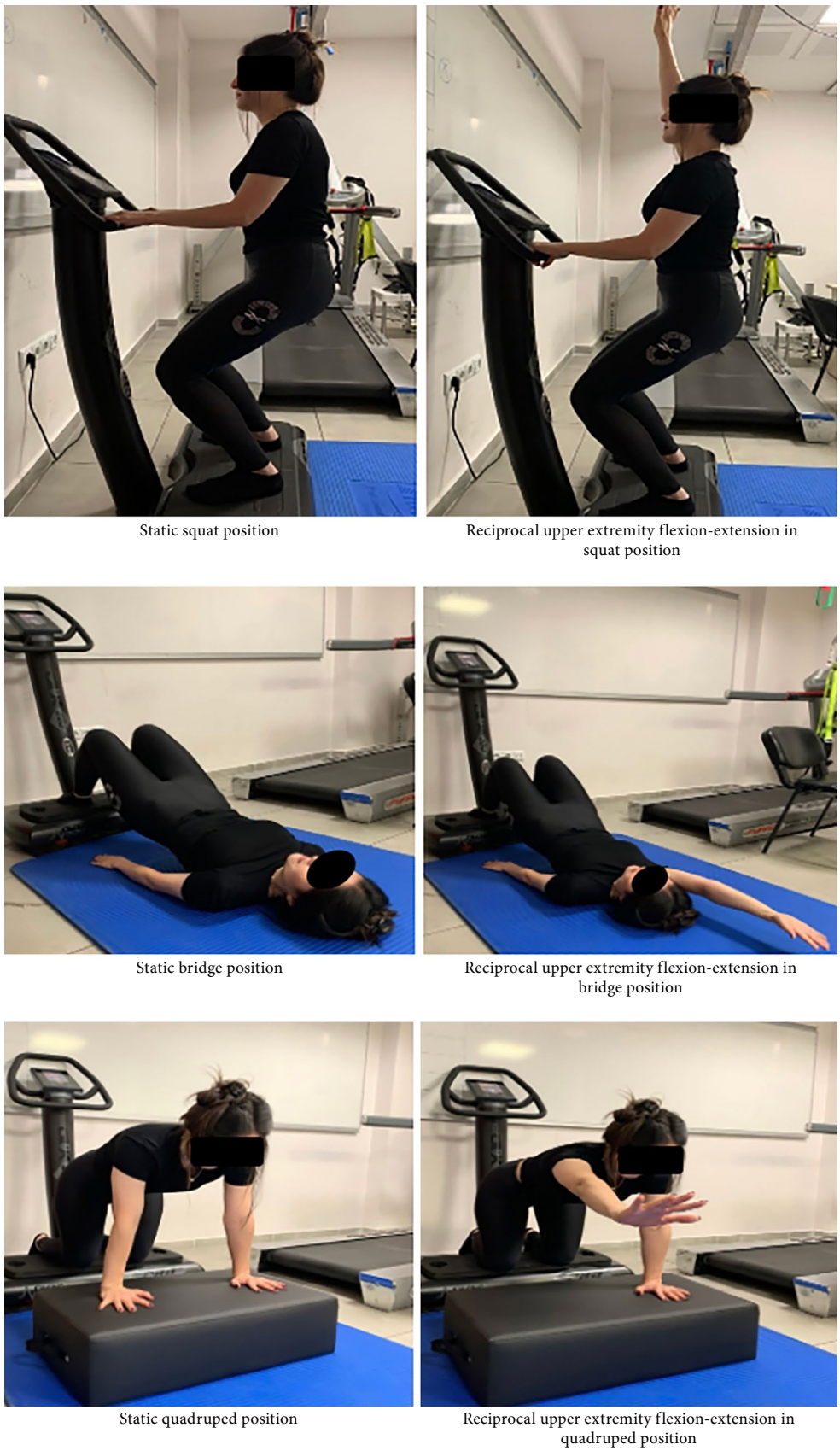
This single-blind, parallel-group, randomized controlled trial was conducted with 34 participants (9 males, 25 females; mean age: 36.7±12.2 years; range, 20 to 65 years) at the Faculty of Health Sciences, Gazi University, Department of Neurological Physiotherapy and Rehabilitation, between December 2023 and September 2024. The inclusion criteria were a definite diagnosis of multiple sclerosis by a neurologist, an Expanded Disability Status Scale (EDSS) score between 0 and 5, age between 18 and 65 years, and no relapses in the last three months. The exclusion criteria included pregnancy, having an endoprosthesis or electronic implant, having a cardiovascular, pulmonary, or orthopedic disease, any immune-related disease (e.g., infection or cancer), and any additional neurological disease other than multiple sclerosis. Written informed consent was obtained from all participants. The study protocol was approved by the Gazi University Ethics Committee (Date: 26.12.2023, No: 2023-1602). The study was retrospectively registered at ClinicalTrials.gov (NCT06829680). The study was conducted in accordance with the principles of the Declaration of Helsinki.

The participants were randomly assigned in a 1:1 ratio to the Pilates-WBV group or the Pilates group. The allocation was achieved using a computer-generated randomization sequence with blocks of four (http://www.randomizer.org). The randomization was carried out by a researcher who was not involved in the assessments. All participants were evaluated by the rater who was blinded to group allocation at baseline and seven weeks.

The Pilates-WBV group received Pilates training combined with WBV, while the Pilates group received only Pilates training. Both groups trained twice a week for six weeks. In the Pilates-WBV group, each session included a 10-min rest period between the Pilates and WBV trainings. All sessions were carried out by a physiotherapist with Pilates certification and experience in neurological physiotherapy.

The Pilates training sessions lasted approximately 60 min. After the baseline assessments, all participants attended an educational session on the basic principles of Pilates training. This session was not part of the six-week training program. The Pilates training sessions included 18 exercises performed in supine, side-lying, prone, and standing positions. Each session began with roll down (two repetitions) and segmental extremity movements with centering (10 repetitions) in the warm-up phase. The main phase exercises consisted of one leg stretch, double leg stretch, one leg circle, heels together toes apart, shoulder bridge, the hundreds, chest lift, criss cross, clam, side bend, arm opening, cobra, breast stroke, swimming, modified push-up, plank, leg pull prone, and squat. In this phase, the exercises were performed for 10 repetitions in the first the weeks and 20 repetitions in the last three weeks.[10] Resistance bands and balls were used to enhance the difficulty of the exercises. Each session ended with single knee to chest, double knee to chest, camel stretch, cat stretch, lying trunk rotation, and relaxation exercises in the cool-down phase, with each exercise performed once.

The WBV machine used in the study was the DKN XG10 PRO (DKN Technology, Hamme, Belgium). The vibration parameters were set as follows: frequency, 20 Hz; amplitude, 2-3 mm; duration, 30-60 sec; and rest period, 60 sec.[11] Initially, the duration was 30 sec, and it was increased by 15 sec every two weeks. During the first two weeks, participants maintained static squat, shoulder bridge, and quadruped positions on the vibration platform. During the last four weeks, reciprocal upper extremity flexion and extension movements were added while maintaining these positions (Figure 1). Each position was repeated three times.



Static squat position

Reciprocal upper extremity flexion-extension in squat position

Static bridge position

Reciprocal upper extremity flexion-extension in bridge position

Static quadruped position

Reciprocal upper extremity flexion-extension in quadruped position

Figure 1. Whole-body vibration training.

Disability status was assessed using the EDSS, a 10-point scale commonly used to assess the functional systems of the central nervous system in pwMS.[12] Disability scores were interpreted as mild (0-3.5), moderate (4.0-6.5), severe (7.0-9.5), and death due to multiple sclerosis (EDSS score=10).

Balance was assessed using the static posturography system (Biodex-Biosway; Biodex Medical Systems Inc., Shirley, NY, USA) and the Activities-Specific Balance Confidence Scale. The postural stability test, the modified Clinical Test of Sensory Interaction on Balance (m-CTSIB), and the limits of stability test were performed using the Biodex-Biosway Portable Balance System (Biodex Medical Systems Inc., Shirley, NY, USA).[13]

Before starting the tests, participants' feet were placed on the Biodex-Biosway platform, and the coordinates were recorded in the system. Each test was performed three times. Postural stability was assessed in double-leg and single-leg stances in the postural stability test. In the limits of stability test, participants were asked to move the center point representing themselves on the screen to randomly illuminated target points as quickly as possible and with minimal deviation.

The m-CTSIB was used to assess sensory integration under conditions in which one or more sensory inputs were disrupted. The test was performed under four conditions: on a firm surface with eyes open, on a firm surface with eyes closed, on a foam surface with eyes open, and on a foam surface with eyes closed. The Activities-Specific Balance Confidence Scale evaluates balance confidence in daily living activities and includes 16 activities related to balance.[14] The total score on this scale is between 0 and 100. Scores close to zero indicate greater balance impairment and a higher risk of falls.

Core endurance was evaluated using the trunk flexor test, side-bridge test, prone bridge test, and modified Biering-Sorensen test.[15] During the endurance tests, participants were instructed to hold their position for as long as possible, and the total duration was recorded. Core power was assessed using the modified push-ups and sit-ups tests, and the number of repetitions completed within 30 sec was recorded.[10,15]

Lower extremity functional muscle strength was assessed using the five times sit-to-stand (5-TSTS) test.[16] Participants were seated in a standard chair with armrests (height of 43 to 45 cm), with their arms crossed on their chests. They were instructed to stand up and sit down five times as quickly as possible. The total time was recorded in seconds.

Functional mobility was evaluated using the timed up-and-go (TUG) test.[17] During the assessment, participants were asked to rise from a seated position, walk 3 m, turn, return to the chair, and sit down again. The total time was recorded.

Functional exercise capacity and walking performance and were assessed using the six-minute walk test (6-MWT).[18] Participants were instructed to walk at the fastest speed they felt safe on a 30 m straight course for 6 min. Blood pressure, heart rate, and perceived fatigue were measured before and after the 6-MWT, and total walking distance was recorded.

Upper extremity performance was assessed using the nine-hole peg test (9-HPT).[19] Participants were asked to place and remove nine pegs one by one as quickly as possible. The test was repeated for both extremities, and the total time was recorded.

Fatigue was assessed using the Fatigue Impact Scale and the Fatigue Severity Scale. The Fatigue Severity Scale evaluates fatigue levels in the last four weeks and includes nine items, with response options ranging from strongly disagree (0) to strongly agree (7).[20] The Fatigue Impact Scale evaluates the impact of fatigue on cognitive, psychosocial, and physical functions in the last four weeks.[21] It consists of 40 questions, and response options range from no problem (0) to extreme problem (4).

Statistical analysis

The sample size was calculated based on the timed up-and-go test scores reported in the study by Broekmans et al.[22] Using G*Power version 3.1 software (Heinrich-Heine Universität Düsseldorf, Düsseldorf, Germany) and an effect size (Cohen's d) of 1.16, a total of 24 participants (12 per group) were required to achieve 80% statistical power at a two-tailed significance level of 0.05. Accounting for a 25% anticipated drop-out rate, the final sample size was set at 30 participants.

Data were analyzed using IBM SPSS version 22.0 software (IBM Corp., Armonk, NY, USA). All randomized participants were included in the analysis (intention-to-treat). To assess the normality of variables, both numerical indicators, including the Shapiro-Wilk test, skewness, kurtosis, and graphical

techniques such as histograms and detrended plots were used. Normally distributed variables were reported as mean and standard deviation, while nonnormally distributed variables were reported as median and interquartile range. Frequencies and percentages were reported for categorical data. Fisher exact test was used to examine between-group differences in categorical variables due to the small sample size. When comparing baseline continuous variables, the independent samples t-test was applied for normally distributed data, whereas the Mann-Whitney U test was used for nonnormally distributed data. To evaluate within-group changes from pre- to postintervention, the paired samples t-test was used for parametric data, and the Wilcoxon signed-rank test was used for nonparametric data. Statistical significance was set at $p<0.05$.

Effect size was also estimated in the study. In the paired samples t-test, the within-group effect size was estimated using Hedges' g index (dg), which is based on Cohen's d.[23] This index estimates effect size by reducing the bias associated with small sample sizes (n<20).[24] Hedges' g values were interpreted as large (dg ≥0.8), moderate (0.5≤ dg <0.8), and small (0.0≤ dg <0.5).[25]

In the Wilcoxon test, the rank-based effect size (r) was used to assess the magnitude of within-group differences. For the Mann-Whitney U test, between-group differences were evaluated using the rank-biserial correlation (rrb). Nonparametric effect sizes were interpreted as large (r, rrb ≥0.5), moderate (0.3≤ r, rrb <0.5), and small (0.1≤ r, rrb <0.3).[25]

RESULTS

A total of 84 pwMS were evaluated for eligibility, and 34 were included and analyzed. The CONSORT (Consolidated Standards of Reporting Trials) flow

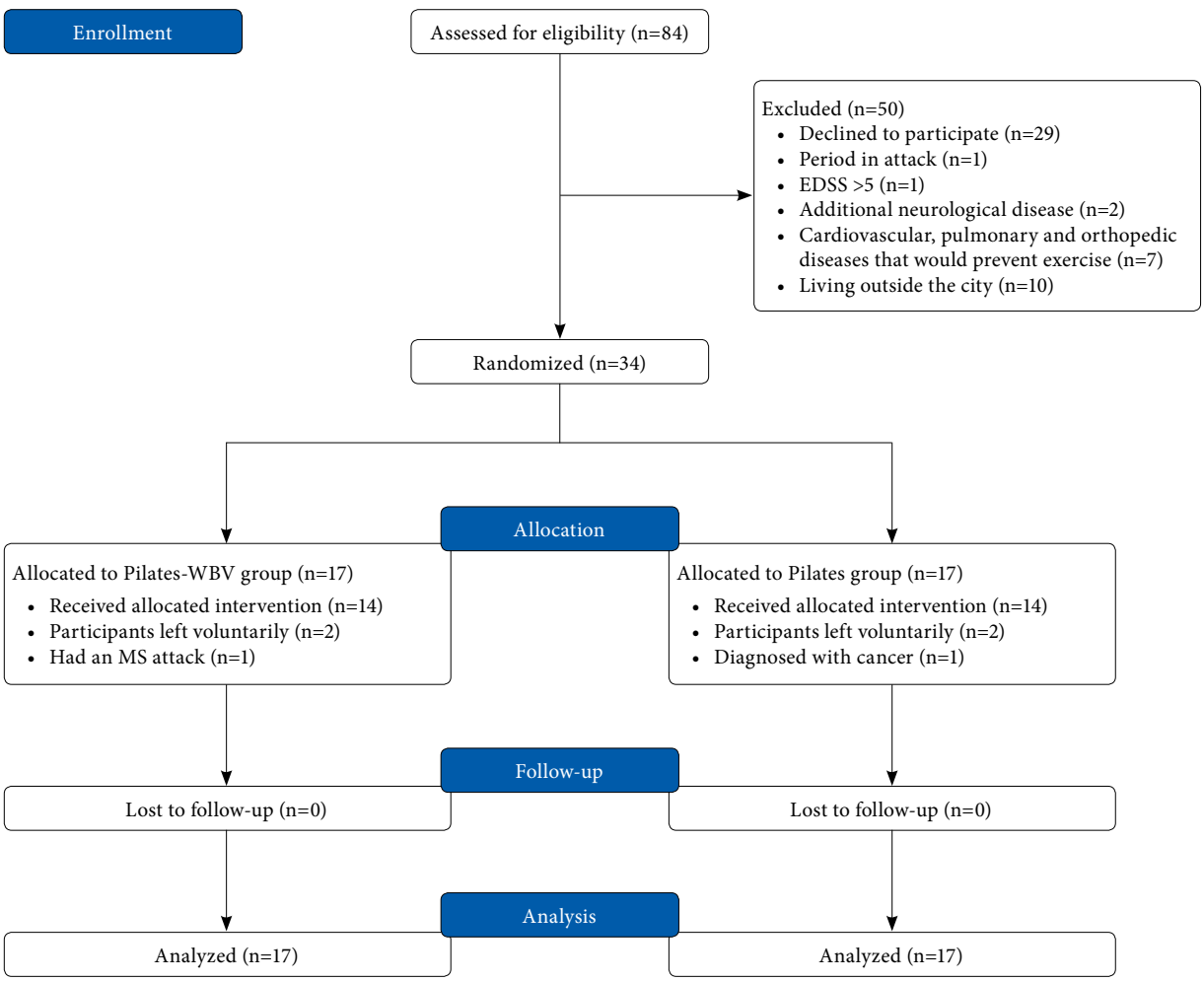


Figure 2. The CONSORT flow diagram illustrating the participants in the study.
EDSS: Expanded disability status scale; WBV: Whole-body vibration.

diagram according of the study is presented in Figure 2. No adverse effect was reported during the Pilates training with WBV or Pilates training sessions.

There were no statistically significant differences in demographic and clinical characteristics between the Pilates-WBV and Pilates groups (p>0.05; Table 1). All baseline measurements were similar between the groups (p>0.05; data not presented in tables).

Table 2 and Table 3 show the comparison of pre- and postintervention performances within groups. Following the interventions, single-leg

TABLE 1
Demographic and clinical characteristics of the participants

	Pilates-WBV (n=17)			Pilates (n=17)			
	n	%	Mean±SD	n	%	Mean±SD	*p*
Age (year)			40.1±12.8			33.2±11.0	0.105
Sex							1
Female	13	76.5		12	70.6		
Male	4	23.5		5	23.4		
BMI (kg/m^2)			23.68±4.62			23.42±3.71	0.859
Dominant hand							1
Left	0	0		1	5.9		
Right	17	100		16	94.1		
Disease duration (year)			10.08±9.58			7.85±8.68	0.482
Clinical type of MS							
Relapsing-remitting (RRMS)	15	88.2		12	70.6		
Primary progressive (PPMS)	1	5.9		0	0		
Secondary progressive (SPMS)	1	5.9		5	29.4		
Progressive-relapsing (PRMS)	0	0		0	0		
EDSS ambulation score			2.05±1.02			2.08±1.14	0.938
EDSS ambulation scores							
0	1	5.9		0	0		
1	2	11.8		4	23.5		
1.5	3	17.6		5	29.4		
2	6	35.3		3	17.6		
2.5	1	5.9		0	0		
3	2	11.8		3	17.6		
4	2	11.8		1	5.9		
5	0	0		1	5.9		
Medications							
Dimethyl fumarate	5	29.4		4	23.5		
Fingolimod	3	17.6		3	17.6		
Cladribine	0	0		2	11.8		
Teriflunomide	3	17.6		3	17.6		
Interferon beta-1a	1	5.9		0	0		
Glatiramer acetate	1	5.9		0	0		
Ocrelizumab	0	0		2	11.8		
Peginterferon beta-1a	3	17.6		0	0		
No medication us	1	5.9		3	17.6		

WBV: Whole body vibration; SD: Standard deviation; BMI: Body mass index; MS: Multiple sclerosis; EDSS: Expanded disability status scale. A p-value of <0.05 was considered statistically significant.

TABLE 2
Comparison of pre- and post-intervention performances in the Pilates-WBV group (n=17)

	Pre-intervention			Post-intervention						
	Mean±SD	Median	IQR	Mean±SD	Median	IQR	Z	*p*	r	d_g
Balance										
PST (score)										
Both feet		0.30	0.20-0.45		0.20	0.10-0.25	−2.268	**0.023***	−0.55	
Right foot		0.80	0.60-1.15		0.60	0.50-0.70	−2.222	**0.026***	−0.54	
Left foot		0.90	0.70-2.10		0.65	0.60-0.85	−2.468	**0.014***	−0.60	
LOS (score)	55.82±13.51			66.17±9.94				**0.008***		0.70
m-CTSIB (score)										
Eyes open, firm surface		0.46	0.37-0.76		0.43	0.33-0.63	−1.060	0.289	−0.26	
Eyes closed, firm surface		0.95	0.45-1.61		0.75	0.55-2.17	−0.497	0.619	−0.12	
Eyes open, foam surface		0.73	0.58-1.05		0.68	0.55-0.73	−1.760	0.078	−0.43	
Eyes closed, foam surface		2.09	1.64-2.42		1.97	1.61-2.27	−0.331	0.740	−0.08	
ABC (%)		86.87	74.68-93.12		98.75	96.56-99.68	−3.520	**<0.001***	−0.85	
Core endurance (seconds)										
Side bridge (Left)		14	4.75-21.92		35.25	31-40.91	−3.480	**0.001***	−0.84	
Side bridge (Right)	17.64±14.96			43.67±21.34				**<0.001***		1.30
Modified Biering-Sorensen		45.13	17.12-53.58		73.45	66.53-109.20	−3.527	**<0.001***	−0.85	
Trunk flexor test		19.75	3.71-36		86.36	70.03-163.24	−3.621	**<0.001***	−0.87	
Prone bridge		31.87	15.52-50.36		93.42	72.50-126.70	−3.622	**<0.001***	−0.87	
Core power (Repetition/30s)										
Sit-ups		6	0-15		17	11-22.50	−3.353	**0.001***	−0.81	
Modified push-ups test	9.70±6.23			21.82±5.58				**<0.001***		1.97
Lower extremity muscle strength, functional mobility, and walking performance										
5-TSTS (s)		11.06	9.09-13.56		7.76	7.39-8.20	−3.527	**<0.001***	−0.85	
TUG (s)		6.29	5.81-7.53		5.56	5.10-5.74	−3.337	**0.001***	−0.80	
6-MWT (m)	548.34±106.02			615.52±66.82				**0.006***		0.73
Upper extremity performance										
9-HPT- Left hand (s)		21.69	20.02-27.51		18.99	18.28-20.62	−3.053	**0.002***	−0.74	
9-HPT- Right hand (s)		20.98	18.70-29.49		17.94	16.56-19.29	−3.622	**<0.001***	−0.87	
Fatigue										
FSS (score)		4.88	3.66-5.61		2.22	1.49-2.94	−3.622	**<0.001***	−0.87	
FIS (score)		29	19.50-51.50		2	0-9	−3.574	**<0.001***	−0.86	

WBV: Whole body vibration; SD: Standard deviation; IQR: Interquartile range; PST: Postural stability test; LOS: Limits of stability; m-CTSIB: Modified clinical test of sensory interaction in balance; ABC: Activities-specific balance confidence scale; 5-TSTS: 5 Times sit-to-stand test; TUG: Timed up and go test; 6-MWT: Six-minute walk test; 9-HPT: Nine-hole peg test; FSS: Fatigue severity scale; FIS: Fatigue impact scale; Z: Z value. Effect size is given by r and Hedges's d (dg). *significantly changed from baseline ($p<0.05$).

TABLE 3
Comparison of pre- and post-intervention performances in the Pilates group (n=17)

	Pre-intervention			Post-intervention						
	Mean±SD	Median	IQR	Mean±SD	Median	IQR	Z	*p*	r	d_g
Balance										
PST (score)										
Both feet		0.30	0.20-0.45		0.30	0.20-0.40	−1.075	0.282	−0.26	
Right foot		1.40	0.50-3.40		0.70	0.40-0.90	−2.630	**0.009***	−0.63	
Left foot		2.20	0.90-4		0.70	0.40-1.35	−3.183	**0.001***	−0.77	
LOS (score)	55.58±13.95			66.64±16.36				**0.002***		0.83
m-CTSIB (score)										
Eyes open, firm surface		0.50	0.32-0.77		0.49	0.28-0.72	−0.024	0.981	−0.00	
Eyes closed, firm surface		1.02	0.49-1.77		1.63	0.56-2.22	−1.344	0.179	−0.32	
Eyes open, foam surface		0.79	0.58-1.08		0.60	0.50-0.68	−2.888	**0.004***	−0.70	
Eyes closed, foam surface		2.32	1.56-2.91		2.03	1.74-2.47	−0.592	0.554	−0.14	
ABC (%)		87.81	56.56-96.25		95.93	87.16-98.74	−2.819	**0.005***	−0.68	
Core endurance (seconds)										
Side bridge (Left)		18.43	3.66-39.45		33.68	24.48-41.57	−2.438	**0.015***	−0.59	
Side bridge (Right)		18	4.37-47.98		37.55	31.38-51.24	−2.533	**0.011***	−0.61	
Modified Biering-Sorensen		47.98	21.15-71.79		77.74	55.19-101	−3.385	**0.001***	−0.82	
Trunk flexor test		30.91	9.12-55.11		68.42	29-105	−3.621	**<0.001***	−0.87	
Prone bridge		40	15-64.87		85.21	56.76-118.59	−2.864	**0.004***	−0.69	
Core power (Repetition/30s)										
Sit-ups		7	5-12.50		15	14-20.50	−3.524	**<0.001***	−0.85	
Modified push-ups test		12	5-16.50		18.50	15.50-21.50	−3.239	**0.001***	−0.78	
Lower extremity muscle strength, functional mobility, and walking performance										
5-TSTS (s)	11.11±2.72			8.10±1.15				**<0.001***		−1.24
TUG (s)		6.52	6.13-6.92		6.15	5.72-6.20	−2.482	**0.013***	−0.60	
6-MWT (m)	546.43±93.57			563.02±91.42				0.258		0.27
Upper extremity performance										
9-HPT- Left hand (s)		22.69	20.77-25.13		19.39	18.40-22.38	−3.051	**0.002***	−0.73	
9-HPT- Right hand (s)		19.77	17.77-23.22		17.67	16.44-19.94	−2.438	**0.015***	−0.59	
Fatigue										
FSS (score)		4.94	2.73-5.60		2.64	1.77-3.60	−3.155	**0.002***	−0.76	
FIS (score)		34.65	19.50-52.50		11.37	1.50-22	−3.624	**<0.001***	−0.87	

SD: Standard deviation; IQR: Interquartile range; PST: Postural stability test; LOS: Limits of stability; m-CTSIB: Modified clinical test of sensory interaction in balance; ABC: Activities-specific balance confidence scale; 5-TSTS: 5 Times sit-to-stand test; TUG: Timed up and go test; 6-MWT: Six-minute walk test; 9-HPT: Nine-hole peg test; FSS: Fatigue severity scale; FIS: Fatigue impact scale; Z: Z value. Effect size is given by r and Hedges's d (dg). *significantly changed from baseline ($p<0.05$).

stance stability (right and left foot), stability limits, and balance confidence improved significantly in both groups ($p<0.05$). However, double-leg standing balance (postural stability test performed with both feet) improved only in the Pilates-WBV group ($p=0.023$). In addition, core endurance and core power showed marked improvements in both groups ($p\leq0.015$). Moreover, the 5-TSTS and the TUG tests improved significantly in both groups ($p\leq0.013$). The Pilates-WBV group also exhibited increased walking distance in the 6-MWT ($p=0.006$), whereas the Pilates group did not ($p=0.258$). Both groups showed improved upper extremity performance (9-HPT for both hands; $p\leq0.015$) and reduced fatigue severity and impact ($p\leq0.002$). Notably, the Pilates group demonstrated a significant improvement in the eyes-open-on-foam condition of the m-CTSIB with a large effect size ($p=0.004$, $r=-0.70$), while the vibration group showed a moderate but nonsignificant trend ($p=0.078$, $r=-0.43$). No significant changes were observed in other the m-CTSIB conditions in either group ($p>0.05$).

TABLE 4
Comparison of changes between pre- and post-intervention in the Pilates-WBV and Pilates groups

	Pilates-WBV (n=17)		Pilates (n=17)				
	Median	IQR	Median	IQR	U	p	r_{rb}
PST (score)							
Both feet	−0.10	−0.15-0	0	−0.20-0.05	122.50	0.454	0.15
Right foot	−0.20	−0.52-0.05	−0.10	−1.10-0	137.50	0.812	0.04
Left foot	−0.30	−1.19-0.10	−0.40	−3.10 - −0.05	116.50	0.339	0.19
LOS (score)	5	1.50-20	11	2-18.50	133.50	0.708	0.07
m-CTSIB (score)							
Eyes open, firm surface	−0.05	−0.36-0.16	−0.02	−0.15-0.23	120	0.413	0.16
Eyes closed, firm surface	−0.06	−0.49-0.18	0.16	−0.17-0.83	107	0.205	0.25
Eyes open, foam surface	−0.07	−0.33-0.09	−0.17	−0.35 - −0.06	118.50	0.375	0.17
Eyes closed, foam surface	−0.04	−0.26-0.20	−0.10	−0.49-0.35	136	0.786	0.05
ABC (%)	10.62	5.63-21.87	5.62	0.31-23.12	105	0.182	0.27
Core endurance (seconds)							
Side bridge (Left)	20	8.59-35.25	13.79	1.78-31.84	114	0.306	0.21
Side bridge (Right)	22.5	11.6-40.5	17.25	8.40-29.28	113	0.290	0.21
Modified Biering–Sorensen	43	23.97-67.75	30.41	8.26-41.63	99	0.122	0.31
Trunk flexor test	74.17	48.42-129.86	35	10.28-63.63	74	0.014*	0.48
Prone bridge	71.17	33.74-100.68	35	22.44-78.60	98	0.114	0.32
Core power (Repetition/30s)							
Sit-ups	10	2.50-15	7	1.50-9.50	114.50	0.306	0.21
Modified push-ups test	11	7.50-18	6	1-13.50	78	0.022*	0.46
5-TSTS (s)	−2.74	−5.60 - −1.50	−3.37	−4.95 - −0.51	125	0.518	0.13
TUG (s)	−0.70	−1.97 - −0.43	−0.64	−0.87-0	103	0.160	0.28
6-MWT (m)	40.60	19.70-105.75	16.20	−8.40-55.35	94	0.085	0.34
9-HPT							
Left hand (s)	−2.48	−6.54 - −0.91	−2.93	−4.90 - −1.41	136	0.786	0.05
Right hand (s)	−2.04	−7.83 - −1.68	−1.89	−4.60-0.24	107	0.205	0.25
FSS (score)	−2.44	−3.38 - −1.27	−1.89	−3.22 - −0.29	110	0.245	0.23
FIS (score)	−27	−38 - −15	−23.28	−33 - −11.12	129	0.610	0.10

WBV: Whole body vibration; IQR: Interquartile range; PST: Postural stability test; LOS: Limits of stability; m-CTSIB: Modified clinical test of sensory interaction in balance; ABC: Activities-specific balance confidence scale; 5-TSTS: 5 Times sit-to-stand test; TUG: Timed up and go test; 6-MWT: Six-minute walk test; 9-HPT: Nine-hole peg test; FSS: Fatigue severity scale; FIS: Fatigue impact scale; U: Mann-Whitney U value. Effect size is given by the rank-biserial correlation (rrb). * Significantly changed from baseline ($p<0.05$).

Table 4 shows the comparison of changes between pre- and postintervention in the Pilates-WBV and Pilates groups. The Pilates-WBV group exhibited significantly greater improvements than the Pilates group in the trunk flexor test, a measure of core endurance (p=0.014, rrb=0.48) and core power, as measured by the modified push-ups test (p=0.022, rrb=0.46). In addition, improvements in walking distance in the 6-MWT also favored the Pilates-WBV group, although this difference showed a trend towards significance but did not reach the threshold (p=0.085, rrb=0.34). No other between-group differences were observed (p>0.05; Table 4).

DISCUSSION

The study aimed to investigate the effects of Pilates training combined with WBV on balance, functional mobility, core muscle power and endurance, lower extremity strength, upper extremity performance, and fatigue in pwMS. While both groups showed improvements in balance, the Pilates-WBV group improved in double-leg and single-leg postural stability, whereas the Pilates group improved only in single-leg postural stability. This was the first study to investigate the effects of Pilates training combined with WBV in pwMS. Previous research has investigated the effects of WBV on sensory organization in pwMS.[26,27] Schuhfried et al.[26] showed no improvement in the sensory organization test (SOT) after WBV at 2 to 4.4 Hz for one session in pwMS. Similarly, Alguacil Diego et al.[27] showed that the SOT improved only under the eyes open/fixed surface and eyes open/fixed surface/sway referenced visual surround conditions of the SOT after five consecutive days of WBV training at 6 Hz in pwMS. The main difference between these studies and our study is that in our study, WBV training was combined with a six-week exercise intervention, progressing from static posture to dynamic exercises. Moreover, we employed a higher vibration duration and frequency, which may explain why postural sway in both feet was reduced only in the Pilates-WBV group.

Pilates training alone has been shown to improve balance in pwMS.[4,5,10] Eldemir et al.[10] applied Pilates training-based telerehabilitation three times a week for six weeks in pwMS, resulting in improvements in postural stability limits of stability, and across all m-CTSIB conditions. The main difference between our study and theirs is the frequency of training. Although balance was measured using different methods, this difference is also observed in the studies of Bulguroglu et al.[4] and Gheitasi et al.,[5] suggesting that Pilates training is more effective when applied three times a week.

Although improvements in functional mobility were observed in both the Pilates-WBV and Pilates groups, walking distance and functional exercise capacity improved only in the Pilates-WBV group. Previous research has linked decreased trunk flexor muscle endurance with reduced walking speed in pwMS.[28] In our study, the improvement in trunk flexor endurance was greater in the Pilates-WBV group than in the Pilates group. Thus, the superior walking distance in the Pilates-WBV group may stem from better trunk flexor endurance. Additionally, 6-MWT outcomes are known to correlate with disability severity in multiple sclerosis.[29] Therefore, demonstrating that Pilates training with WBV enhances walking endurance in pwMS is crucial for reducing the negative impact of disease on mobility.

Similar to our study, some studies show that WBV improves mobility in pwMS.[26,27] Schuhfried et al.[26] reported that functional mobility assessed by TUG test, was significantly improved after a single WBV session in pwMS compared to a placebo group. Similarly, Alguacil Diego et al.[27] found that WBV improved functional mobility assessed by TUG test and suggested that this result may be due to improved motor control through proprioceptive system activation. In our study, the increase in walking speed in the Pilates-WBV group may be due to enhanced proprioceptive input from WBV. Given that proprioceptive loss in MS negatively affects balance and mobility,[30] this conclusion appears reasonable. Additionally, the Pilates-WBV group reported improved sensation in their soles after the sessions, indicating increased somatosensory input.

Eftekhari et al.[31] reported that walking speed, assessed by the 10-m walk test, was significantly improved in pwMS who participated in WBV and strength training three times per week for eight weeks compared to a nontraining control group. Similarly, Hilgers et al.[32] found that adding WBV to a standard rehabilitation program (three times per week for three weeks) improved 6-MWT performance compared to standard rehabilitation alone. These findings suggest that WBV enhances physical performance by improving neuromuscular control and coordination.

In this study, it was found that both Pilates-WBV and Pilates training improved core muscle strength

and endurance. This result was expected, since Pilates training aims to improve core stability.[33] However, greater improvements in core strength and endurance were observed in the Pilates-WBV group. This result suggests that WBV provides an additional contribution to core stability. Similarly, Abbasi et al.[11] demonstrated that WBV enhances core muscle strength and endurance in pwMS. While lower extremity functional muscle strength improved in both the Pilates-WBV and Pilates groups, the changes after training were similar between the groups. No additional contribution of WBV to lower extremity muscle strength was observed.

Upper extremity functions are related to core stability in pwMS.[34] The literature states that the effects of exercise methods targeting trunk muscle strength on upper extremity function have not been sufficiently investigated.[35] Previous research showed that Pilates can enhance upper extremity muscle strength in pwMS.[4,10,36] However, among studies investigating trunk training in multiple sclerosis, only a few have included upper extremity performance measures.[37,38] Kara et al.[37] reported that a mat Pilates program twice a week for eight weeks in pwMS improved nondominant hand performance as measured by the 9-HPT. In contrast, Küçük et al.[38] applied a clinical Pilates program twice a week for eight weeks in pwMS and found no significant improvement in upper extremity performance as measured by the 9-HPT.

However, no studies were found investigating the effects of WBV on upper extremity function in multiple sclerosis. Therefore, this study investigated the effects of Pilates with WBV versus Pilates alone on upper extremity function, which is essential for daily activities. The results showed similar improvements in upper extremity performance in both groups. Furthermore, this study provides evidence that interventions aimed at improving core stability can also benefit upper extremity function in pwMS.

Fatigue frequently impairs physical ability and quality of life in pwMS.[39] In this study, it was observed that the severity of fatigue and the effect of fatigue decreased in the Pilates-WBV and Pilates groups with a six-week training program. Although posttraining fatigue improvements were similar between groups, this improvement was regarded as a significant gain for both groups, enhancing participants' perceived energy levels in daily life. Pilates training has been shown to be effective in reducing fatigue severity and the effects of fatigue on daily living activities in pwMS.[4,10,40] Our results on fatigue are in line with the literature. Although WBV was not observed to provide an additional benefit for fatigue, participants reported reduced exercise-induced fatigue and faster recovery with WBV after Pilates training. Alguacil Diego et al.[27] examined the effect of WBV on fatigue in multiple sclerosis and reported no change in fatigue severity after five consecutive days of WBV in pwMS. While this study examined the short-term effects of WBV on fatigue, as in our study, long-term studies are needed to fully understand its impact.

This study had some limitations. First, it included pwMS who had low levels of disability. Therefore, the findings may not apply to all disability levels in pwMS. The second limitation was the lack of long-term follow-up.

In conclusion, Pilates and Pilates-WBV training improved balance, mobility, upper extremity performance, and reduced fatigue. However, the addition of WBV provided further advantages in core stability and walking performance in pwMS. These findings suggest that combining WBV with conventional Pilates programs may improve rehabilitation outcomes in pwMS. Future studies should aim to include participants with different disability levels and investigate the long-term sustainability of these benefits.

Data Sharing Statement: The data that support the findings of this study are available from the corresponding author upon reasonable request.

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