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Acute effects of whole-body vibration training on neuromuscular performance and mobility in hypoxia and normoxia in persons with multiple sclerosis: A crossover study

Luis Andreu[a,b], Domingo J. Ramos-Campo[b], Vicente Ávila-Gandía[c], Tomás T. Freitas[d], Linda H. Chung[b,d], Jacobo Á. Rubio-Arias[b,*]

[a] International Chair of Sports Medicine, Catholic University of San Antonio, Murcia, Spain
[b] Sports Science Faculty, Catholic University of Murcia (UCAM), Spain
[c] Department of Exercise Physiology, Catholic University, Murcia, Spain
[d] UCAM Research Center for High Performance Sport, Catholic University, Murcia, Spain

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ABSTRACT

Background: Whole-body vibration training (WBVT) has been used in people with relapsing-remitting multiple sclerosis (pwMS), showing improvements in different neuromuscular and mobility variables. However, the acute effects of this training are still unknown. The acute effects of WBVT on neuromuscular performance, mobility and rating of perceived exertion (RPE) were evaluated in 10 pwMS.

Methods: Maximal voluntary isometric contraction (MVIC), central activation ratio (CAR), electromyography (EMG) of the vastus lateralis during isometric knee extension, Timed Up and Go Test (TUG), walking speed and RPE were assessed before and immediately after a session of WBVT (twelve 60-s bout of vibration; frequency 35 Hz; amplitude 4 mm; 1-min rest intervals) in both hypoxic and normoxic conditions.

Results: EMG 0–100, 0–200 ms and peak EMG resulted in significant differences ($p < 0.05$) between normoxic and hypoxic sessions. The EMG activity tended to decrease in all phases after the hypoxic session, indicating possible influence of hypoxia on neuromuscular performance. No changes were found in CAR, MVIC, TUG and walking speed in both conditions.

Conclusion: Based on our results, as well as those obtained by other studies that have used WBVT with other populations, more studies with a higher sample and lower dose of vibration exposure should be conducted in pwMS.

1. Introduction

Numerous studies have examined the effects of resistance training in persons with MS (pwMS) to help alleviate the symptomology of multiple sclerosis (White and Dressendorfer, 2004; White et al., 2004) and improve muscle strength (Dodd et al., 2011; Filipi et al., 2011; White and Dressendorfer, 2004; White et al., 2004) and physical function (Dodd et al., 2011; White and Dressendorfer, 2004; White et al., 2004). However, whole-body vibration training (WBVT) may be an alternative approach in obtaining physiological benefits (Bautmans et al., 2005; Cochrane et al., 2008) while minimizing symptomatic fatigue. WBVT causes rapid muscle contraction and relaxation due to the mechanical multidimensional oscillations of the vibratory platform (Lohman et al., 2007). This vibratory stimulus is effective in modulating the Ia-afferent motoneuron synaptic transmission via presynaptic inhibition (Hong et al., 2011). Previous studies have shown that mechanical vibrations stimulate the muscle-tendon complex and induce the tonic vibration reflex that increases α-motor neuron activation, thereby enhancing force production in healthy people (Cardinale and Bosco, 2003; Cochrane et al., 2010).

Benefits of short and long-term WBVT in pwMS have shown improvement in muscle strength, functional capacity, resistance, coordination and balance (Castillo-Bueno et al., 2016; Kang et al., 2016), as well as overall physical function (Hilgers et al., 2013). In addition, lower ratings of perceived exertion (RPE) during and after a WBVT session compared to other types of resistance training of similar intensities were observed (Perchthaler et al., 2015). Thus, the observed low RPE in WBVT may be ideal for pwMS, whose main limitation when

* Corresponding author at: UCAM Universidad Católica San Antonio de Murcia, Campus de los Jerónimos, Nº 135 Guadalupe, Murcia 30107, Spain.
E-mail address: jararias@ucam.edu (J.Á. Rubio-Arias).

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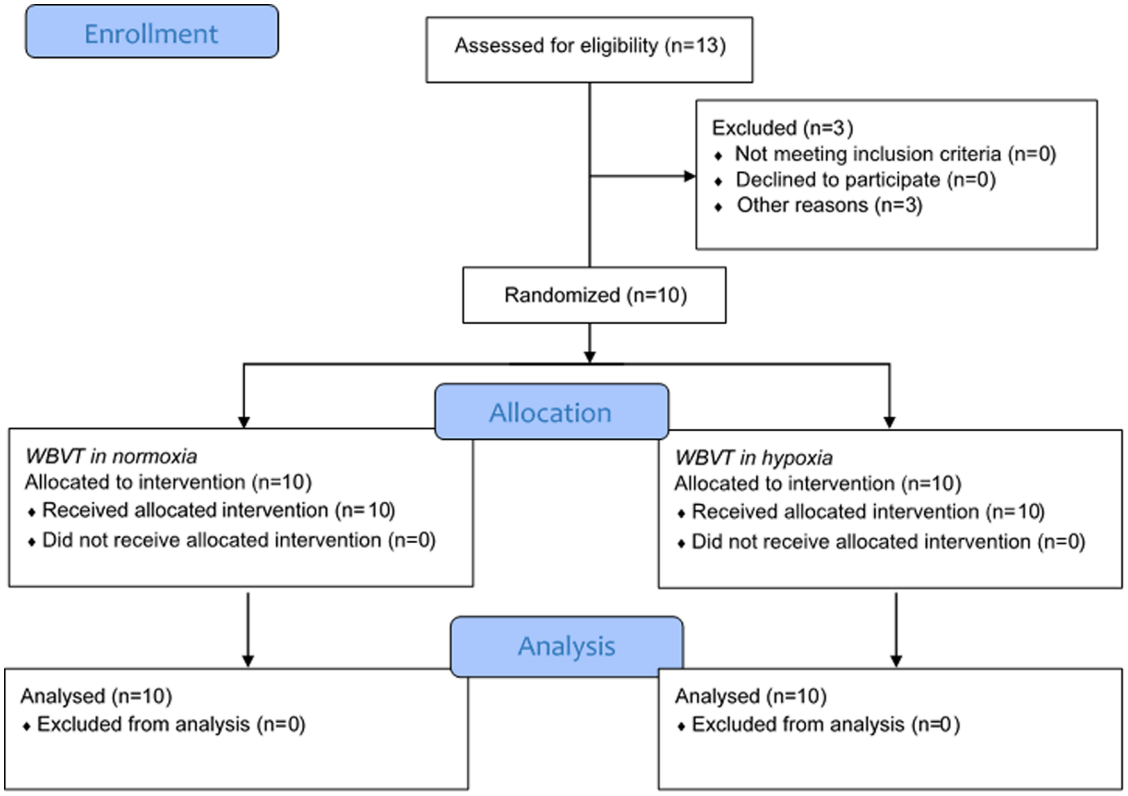

Fig. 1. Flow diagram of the progress of the crossover study.

Table 1
Participant characteristics.

Characteristics	Mean ± SD (n = 10)
General characteristics	
Age (yrs)	44.4 ± 7.7
Sex (men:women)	3:7
EDSS	2.5 ± 1.3
Weight (kg)	65.2 ± 11.1
Height (cm)	164.3 ± 8.9
Lean mass (kg)	44.7 ± 7.7
Fat mass (kg)	18.0 ± 8.2
BMI ($kg{\cdot}m^{-2}$)	24.1 ± 4.0

EDSS = expanded disability status scale; BMI = body mass index.

Table 2
Baseline measures of variables.

Descriptive *Condition*	Mean ± SD Hypoxia	Normoxia
CAR (%)	91.50 ± 3.30	90.00 ± 4.88
MVIC_Right (N·m)	342.00 ± 120.00	345.00 ± 92.30
MVIC_Left (N·m)	306.00 ± 107.00	327.00 ± 105.00
Time-To-MVIC_Right (s)	2.36 ± 0.99	2.59 ± 0.70
Time-To-MVIC_Left (s)	1.63 ± 0.91	2.43 ± 1.09
EMG_0-30 (μV)	131.00 ± 84.20	168.00 ± 153.00
EMG_0-50 (μV)	131.00 ± 88.00	167.00 ± 153.00
EMG_0-100 (μV)	131.00 ± 95.30	174.00 ± 164.00
EMG_0-200 (μV)	126.00 ± 85.30	179.00 ± 175.00
EMG_Peak (μV)	211.00 ± 205.00	325.00 ± 369.00
EMG_Time-To-Peak (s)	2.39 ± 1.47	2.34 ± 1.13
Walking speed ($m.s^{-1}$)	1.67 ± 0.64	1.74 ± 0.60
RPE	8.40 ± 2.95	9.20 ± 2.30
TUG (s)	8.15 ± 3.17	8.20 ± 3.58
Saturation Hb (%)	92.50 ± 0.58	98.17 ± 1.17

CAR = central activation ratio; MVIC = maximal voluntary isometric contraction; EMG = surface electromyography; RPE = rate of perceived exertion; TUG = timed up and go test.

exercising is symptomatic fatigue (Amatya et al., 2019). However, acute effects of WBVT on neuromuscular performance remain unclear in the MS population.

Another alternative to enhance strength using lower intensity levels is exercising under hypoxic conditions. Hypoxia training has shown chronic improvements in strength and muscle size (Ramos-Campo et al., 2018a), as well as aerobic and anaerobic capacity (Ramos-Campo et al., 2018b). Scott et al. (2017) found higher muscle activation during a moderate-load resistance exercise under hypoxic compared to normoxic conditions in young adults, suggesting improvements in neuromuscular performance with hypoxia. Training in hypoxia has shown to improve physical function, such as the Timed Up and Go Test (TUG), walking speed and dynamic balance in patients with incomplete spinal cord injury (Navarrete-Opazo et al., 2017). Girard et al. (2017) affirmed that the hypoxic condition, by itself, can be used as a tool to increase the training load, which may be advantageous for pwMS (i.e., working at lower intensities in hypoxia). However, no studies have analyzed the hypoxic effects with WBVT. Additionally, no studies have used hypoxia in pwMS during resistance training or WBVT. Thus, understanding the acute effects of WBVT under normoxic and hypoxic condition on neuromuscular function in pwMS may be useful in better ameliorating the symptomology of MS.

Therefore, to our knowledge, little is known regarding the acute physiological benefits, particularly central and peripheral neural activation of the muscle, following a single session of WBVT in pwMS. Moreover, the effects of hypoxia during an exercise session of WBVT on neuromuscular performance in general, as well as pwMS, has not been investigated.

The main objectives were to: (1) examine the acute effect of WBVT on neuromuscular performance in pwMS and (2) compare these effects between normoxia and hypoxia. We hypothesized that (1) WBVT would decrease maximal voluntary contraction, central activation ratio, walking speed and TUG in pwMS and (2) WBVT in hypoxia would

Table 3
Comparison of pre-post effect on primary outcomes.

Primary Outcomes	Pre (Mean ± SD)	Post (Mean ± SD)	Δ ± ΔSD	*t*	*p*	Effect Size	95% CI for Cohen's d Lower	Upper
CAR (%)								
Hyp	91.46 ± 3.29	92.54 ± 4.18	0.01 ± 0.04	−0.77	0.464	−0.257	−0.914	0.416
Norm	90.04 ± 4.88	89.09 ± 8.26	−0.01 ± 0.09	0.36	0.727	0.120	−0.539	0.773
MVIC_Right (Nm)								
Hyp	341.50 ± 120.26	349.10 ± 99.76	0.04 ± 0.14	−0.461	0.656	−0.146	−0.765	0.482
Norm	345.40 ± 92.30	350.70 ± 84.29	0.02 ± 0.08	−0.557	0.591	−0.176	−0.796	0.453
MVIC_Left (Nm)								
Hyp	305.70 ± 106.80	306.00 ± 115.20	−0.01 ± 0.10	−0.033	0.974	−0.011	−0.630	0.610
Norm	327.20 ± 104.65	322.30 ± 95.90	−0.01 ± 0.09	0.511	0.621	0.162	−0.467	0.781
TimeToMVIC Right (s)								
Hyp	2.35 ± 0.99	2.25 ± 0.90	0.05 ± 0.45	0.326	0.752	0.103	−0.521	0.722
Norm	2.59 ± 0.70	2.50 ± 1.03	−0.03 ± 0.30	0.356	0.730	0.113	−0.512	0.732
TimeToMVIC Left (s)								
Hyp	1.63 ± 0.92	2.19 ± 0.73	0.83 ± 1.36	−1.340	0.213	−0.424	−1.062	0.236
Norm	2.42 ± 1.09	2.24 ± 0.90	0.03 ± 0.37	0.643	0.536	0.203	−0.429	0.825
EMG_0–30 (μV)								
Hyp	131.30 ± 84.22	110.20 ± 74.14	−0.17 ± 0.18	2.087	0.067	0.660	−0.043	1.334
Norm	167.90 ± 153.40	197.30 ± 190.50	0.12 ± 0.41	−1.641	0.135	−0.519	−1.170	0.157
EMG_0–50 (μV)								
Hyp	131.00 ± 88.04	110.60 ± 73.60	−0.15 ± 0.18	1.939	0.084	0.613	−0.080	1.279
Norm	167.40 ± 153.30	198.60 ± 194.70	0.12 ± 0.37	−1.698	0.124	−0.537	1.191	0.142
EMG_0–100 (μV)								
Hyp	130.60 ± 95.32	110.90 ± 71.92	−0.13 ± 0.17	1.617	0.140	0.511	−0.163	1.161
Norm	173.70 ± 164.10	201.30 ± 199.00	0.12 ± 0.28	−1.559	0.153	−0.493	−1.140	0.178
EMG_0–200 (μV)								
Hyp	125.50 ± 85.35	113.90 ± 73.39	−0.90 ± 0.14	1.346	0.211	0.426	−0.234	1.064
Norm	179.20 ± 174.40	194.00 ± 175.30	0.15 ± 0.26	−1.654	0.132	−0.523	−1.175	0.153
EMG_Peak (μV)								
Hyp	210.90 ± 205.30	193.20 ± 175.90	−0.07 ± 0.12	1.618	0.140	0.512	−0.163	1.162
Norm	324.80 ± 369.50	387.00 ± 474.80	0.13 ± 0.21	−1.682	0.127	−0.532	−1.185	0.146
EMG_TimeToPeak (s)								
Hyp	2.38 ± 1.47	1.21 ± 1.47	−0.15 ± 1.45	1.685	0.126	0.533	−0.145	1.186
Norm	2.33 ± 1.31	2.73 ± 1.50	0.24 ± 0.69	−1.181	0.268	−0.373	−1.007	0.279

Note: CAR = central activation ratio; MVIC = maximal voluntary isometric contraction; EMG = surface electromyography; Hyp = hypoxia; Norm = normoxia.

Table 4
Comparison of pre-post effect on secondary outcomes.

Secondary outcomes	Pre (mean ± SD)	Post (mean ± SD)	Δ ± ΔSD	t	p	Effect Size	95% CI for Cohen's d Lower	Upper
TUG (s)								
Hyp	8.15 ± 3.17	8.05 ± 3.42	−0.02 ± 0.04	1.064	0.315	0.337	−0.311	0.966
Norm	8.20 ± 3.58	8.10 ± 3.70	−0.02 ± 0.05	0.737	0.480	0.233	−0.402	0.856
Walking speed (m/s)								
Hyp	1.67 ± 0.64	1.63 ± 0.69	−0.04 ± 0.09	1.307	0.223	0.413	−0.245	1.051
Norm	1.74 ± 0.60	1.75 ± 0.66	−0.01 ± 0.09	−0.107	0.917	−0.034	−0.653	0.587
RPE_Pre-4								
Hyp	8.40 ± 2.95	9.60 ± 2.17	0.20 ± 0.23	−2.714	0.024*	−0.858	−1.574	−0.109
Norm	9.20 ± 2.30	10.70 ± 1.89	0.20 ± 0.210	−3.143	0.012*	0.994	−1.774	−0.209
RPE_Pre-8								
Hyp	8.40 ± 2.95	10.20 ± 2.10	0.28 ± 0.29	−3.250	0.01*	−1.028	−1.787	−0.234
Norm	9.20 ± 2.30	10.60 ± 1.90	0.20 ± 0.26	−2.264	0.05*	−0.716	−1.401	−0.576
RPE_Pre-Post								
Hyp	8.40 ± 2.95	10.70 ± 2.26	0.34 ± 0.32	−3.535	0.006*	−1.118	−1.902	−0.298
Norm	9.20 ± 2.30	11.80 ± 2.30	0.35 ± 0.39	−3.284	0.009*	−1.039	−1.800	−0.242

Note: TUG = Timed Up and Go Test; RPE = Rating of Perceived Exertion; Hyp = Hypoxia; Norm = Normoxia.
* = Significant changes $p \leq 0.05$.

further diminish the aforementioned variables due to the greater stimulus on the neuromuscular component.

2. Methods

2.1. Design

All training and testing sessions were completed in the UCAM Research Center for High Performance Sports (Murcia, Spain). The present study used a cross-over design with blocked randomization (i.e., subjects signed to either a WBVT session under normoxic ($WVBT_{norm}$; FiO_2 = 20,9%) or hypoxic ($WBVT_{hyp}$; FiO_2 = 15%) condition. In visit 1, subjects were familiarized with all testing procedures and the different vibration frequency and amplitudes used for the training session. Subjects returned one week later for visit 2 at the same time of day to perform the first session of WBVT either in normoxia or hypoxia. Visit 3 occurred after one week of rest where participants repeated the same WBVT protocol with a second baseline assessment but under the condition that was not performed previously. For the hypoxia visit, a normobaric chamber (CAT 430, Colorado Altitude Training, USA) with

Table 5
Comparison between hypoxia and normoxia and EDSS effect on primary outcomes.

Primary outcomes	ANCOVA interactions (F, p, ES η^2)					
	Conditioning Effect			EDSS Effect		
	F	p	ES η^2	F	p	ES η^2
CAR						
Hyp-Norm	0.584	0.457	0.034	1.396	0.256	0.082
MVIC_Right						
Hyp-Norm	0.151	0.702	0.009	0.039	0.845	0.002
MVIC_Left						
Hyp-Norm	0.008	0.930	0.000	0.870	0.364	0.049
Time-To-MVIC_Right						
Hyp-Norm	0.183	0.674	0.010	0.466	0.504	0.026
Time-To-MVIC_Left						
Hyp-Norm	3.850	0.066	0.169	1.920	0.184	0.084
EMG_0-30						
Hyp-Norm	3.597	0.075	0.170	0.579	0.457	0.027
EMG_0-50						
Hyp-Norm	3.728	0.070	0.174	0.752	0.398	0.035
EMG_0-100						
Hyp-Norm	5.330	0.034*	0.224	1.500	0.237	0.063
EMG_0-200						
Hyp-Norm	6.049	0.025*	0.252	0.966	0.339	0.040
EMG_Peak						
Hyp-Norm	6.652	0.02*	0.277	0.377	0.547	0.016
EMG_Time-To-Peak						
Hyp-Norm	0.408	0.531	0.019	3.764	0.069	0.178

Note: CAR = central activation ratio; MVIC = maximal voluntary isometric contraction; EMG = surface electromyography; Hyp = hypoxia; Norm = Normoxia; EDSS = expanded disability status scale.
* $p < 0.05$ differences between hypoxia and normoxia condition.

Table 6
Comparison between hypoxia and normoxia and EDSS effect on secondary outcomes.

Secondary Outcomes	ANCOVA interactions (F, p, ES η^2)					
	Conditioning Effect			EDSS Effect		
	F	p	ES η^2	F	p	ES η^2
TUG						
Hyp-Norm	0.123	0.730	0.007	0.281	0.603	0.016
Walking speed (m/s)						
Hyp-Norm	0.583	0.456	0.033	0.097	0.760	0.005
RPE_Pre-4						
Hyp-Norm	0.001	0.973	0.000	0.076	0.787	0.004
RPE_Pre-8						
Hyp-Norm	0.491	0.493	0.027	0.569	0.461	0.031
RPE_Pre-Post						
Hyp-Norm	0.001	0.973	0.000	0.342	0.566	0.020

Note: TUG = timed up and go test; RPE = rate of perceived exertion; Hyp = hypoxia; Norm = normoxia; EDSS = expanded disability status scale.

reduced oxygen content to 15% via a generator (CAT-12, Colorado Altitude Training, USA) was used. The trial design followed Consort guidelines for randomized clinical trials. The trial was approved by the Catholic University of Murcia's Science Ethics Committee and was in accordance with the Declaration of Helsinki. This study was registered in ClinicalTrials.gov (identifier: NCT03856801: available from website).

2.2. Participants

Thirteen pwMS (male: 39%, age: 42,3 ± 9,6years, height: 164,2 ± 8,5 cm, body mass: 67,3 ± 12,7 kg, body mass index: 29,6 ± 5,6 $kg.m^{-2}$) were recruited from the local MS association. Participants were diagnosed with relapsing-remitting MS, not using any assistive devices, and not involved in any resistance or endurance training programs. All participants were previously diagnosed with MS by a board-certified neurologist according to the McDonald criteria (Thompson et al., 2018). Participants were included if he/she: (1) had mild or moderate disability with clinical mild spastic-ataxic gait disorder, and (2) was in the stable phase of the disease. The exclusion criteria were: (1) Expanded Disability Status Scale (EDSS) < 6, (2) relapse within the preceding 12 months, (3) corticosteroid treatment within the last 2 months before inclusion, and (4) involved in a training program in the prior two months. All participants provided a written and signed informed consent before starting the study.

2.3. Training procedure

WBVT was performed on the Power Plate Pro5 (Power Plate International, London, UK) in a static squat position (30° knee flexion) (Hilgers et al., 2013). Vibration frequency was set at 35 Hz with a 4 mm peak-to-peak amplitude (Castillo-Bueno et al., 2016). All participants held on to the rail of the vibration unit for safety. The training session consisted of 12 sets of 1 min static squat with 1 min rest between sets. During the resting period, participants stood upright on the platform.

2.4. Testing procedures

Participants performed the testing measurements before and after $WVBT_{norm}$ and $WBVT_{hyp}$ training sessions. A standardized warm-up of 5 min on a cycle ergometer at 75 W and a dynamic stretching routine were performed. The order of the tests was the same for both conditions and each assessment was conducted by the same investigator. The primary outcomes of neuromuscular performance were MVIC, Time-to-MVIC, CAR and EMG amplitudes at time ranges of 0–30 ms, 0–50 ms, 0–100 ms and 0–200 ms, EMG_{peak} and Time-to-EMG_{peak}. The secondary outcomes were RPE, TUG and walking speed.

2.4.1. Neuromuscular testing: MVIC, CAR and surface EMG

Participants sat upright on an isokinetic dynamometer chair (Biodex Medical System, NY) with both right and left legs flexed at 90° and the ankle strapped directly to a customized apparatus that contained a load cell (Model SML500, Interface Scottsdale, AZ, USA). Participants performed 3 MVICs, each lasting for 5 s with 3 min of rest between contractions. To ensure maximal effort, participants were encouraged verbally and at least 2 MVICs had to be within 10% of one another. The highest trial was used for MVIC.

Then, two bipolar 10 × 15 cm stimulating electrodes were placed over the proximal and distal portions of the quadriceps of the right leg and secured with a Velcro wrap. Signal 6.0 software (CED, Cambridge, England) was used to control the stimulating characteristics: 100 Hz, 50 pulses, length 0.009 s and interval 0.01 s. The intensity of the stimulus was set at 40–50% of MVIC. The electrical stimulator (Digitimer DS7A, England; 400 Vmax, 2000 ms) and the EMG receiver were synchronized using a CED Micro3 1401 Data Acquisition Unit (Cambridge, England).

Afterwards, EMG electrodes (Ambu Blue Sensor SP, Ambu A/S, Denmark) were placed over the vastus lateralis following SENIAM Guidelines (Hermens et al., 1998). Then, wireless DTS EMG sensors (2.4 × 3.4 × 1.4 cm; Noraxon EMG TeleMyo DTS Desk receiver, Scottsdale, AZ, USA) were connected to the EMG electrodes and taped to the skin. Noraxon MR 3.6.20 software (Noraxon, Scottsdale, AZ, USA) was used to record force and EMG activity simultaneously. Participants performed an MVIC with a superimposed 100 Hz train when maximal force was steady. This sequence was repeated 2 times. Peak MVIC and, peak force obtained by superimposed stimulation were determined. The CAR was calculated as follows: (Kent-Braun, 1999).

$$CAR = \frac{MVIC}{MVIC + \text{superimposed train}} \cdot 100$$

A decrement in CAR was associated with central fatigue mechanisms (Kent-Braun, 1999).

2.4.2. TUG

TUG was performed before and after both $WBVT_{hyp}$ and $WBVT_{norm}$ sessions to assess functional mobility. When indicated, participants stood up from a seated position, walked three meters, turned around, walked back, and sat down again as quickly as possible (Podsiadlo and Richardson, 1991). The same armchair and footwear were used for all tests. The fastest time of two trials was used for analysis.

2.4.3. Walking speed

Participants walked 10 m, marked with taped lines, as quickly as possible without running twice with 1 min of rest between each trial. Verbal encouragement was given to the participants. Walking time was recorded between 6 and 10 m with two photocells (Witty, Microgate, Italy) (Estes et al., 2018), and walking speed was calculated. The fastest walking speed was used for analysis.

2.4.4. Variables measured during the session

Participants were instructed and familiarized on how to use the RPE scale in Visit 1. RPE was assessed before, during (after sets 4 and 8) and after the training session using the Borg Scale (Borg, 1982). Participants were asked "How was your workout?" and were presented with the scale. Arterial oxygen saturation was measured before, after set 6 and immediately after the training session using a finger pulseoximetry (Onyx-Nonin Medical Inc, Model 9500 Finger Pulse Oximeter, USA).

2.5. Statistical analyses

Data collection, treatment, and analysis were performed using the SPSS for Windows statistical package (version 20.0; SPSS, Inc., Chicago, IL, USA). Descriptive statistics (mean and SD) were calculated. Before using parametric tests, the assumption of normality and homoscedasticity was confirmed with the Shapiro-Wilks test. Student's *t*-test for pair samples was used to test if significant changes occurred in differences between pre and post training for each group separately. Analysis of covariance (ANCOVA) was performed with the EDSS score as a covariate to evaluate the differences between hypoxia and normoxia sessions. For all procedures, a level of $p \leq 0.05$ was set to indicate statistical significance.

3. Results

Although 13 pwMS volunteered to participate in this clinical trial, 3 participants dropped out of the study for different reasons (injury outside of the study intervention and schedule incompatibility). Thus, a total of 10 pwMS completed the study, including all testing assessments (Fig. 1).

All participants had an Expanded Disability Status Scale between 1 and 6 (EDSS: 2.55 ± 1.30). Table 1 shows the participant characteristics.

Baseline measures of neuromuscular and mobility variables are shown in Table 2. During the hypoxic and normoxic sessions, patients showed an oxygen saturation of 92.51 ± 0.52% and 98.10 ± 1.13%, respectively.

No significant pre-post differences were found in CAR in $WBVT_{norm}$ ($t = 0.361$, $p = 0.727$) or $WBVT_{hyp}$ ($t = -0.77$, $p = 0.464$). No significant differences were shown between conditions ($F = 0.584$, $p = 0.457$). There were no significant pre-post differences in MVIC in the right leg in normoxia ($t = -0.557$, $p = 0.591$) and hypoxia ($t = -0.461$, $p = 0.656$) nor in the left leg ($t = 0.511$, $p = 0.621$; $t = -0.033$, $p = 0.974$), respectively. No significant differences were found between conditions in right and left legs ($F = 0.151$, $p = 0.702$; $F = 0.008$, $p = 0.930$). EMG 0-30 and 0-50 V tended to decrease in $WBVT_{hyp}$. See Tables 3 and 4.

A significant increase in EMG 0-100, EMG 0-200 and EMG Peak ($F = 5.33$, $p = 0.034$; $F = 6.049$, $p = 0.025$; $F = 6–652$, $p = 0.02$) were observed in normoxia compared to hypoxia. Table 5 shows the comparison between conditions and EDSS effect for each primary outcome variable.

No pre-post differences were found in TUG and walking speed after $WBVT_{norm}$ ($t = 0.737$, $p = 0.48$; $t = -0.107$, $p = 0.917$) and $WBVT_{hyp}$ ($t = 1.064$, $p = 0.315$; and $t = 1.307$, $p = 0.223$), respectively. No differences were found between conditions in TUG ($f = 0.123$, $p = 0.730$) and walking speed ($F = 0.583$, $p = 0.456$). An increase in RPE was found in both $WBVT_{hyp}$ and $WBVT_{norm}$ ($p = 0.006$ and $p = 0.009$, respectively). Table 6 shows the comparison between conditions and the EDSS effect on secondary outcome variables.

4. Discussion

The main finding of the current study was that acute WBVT exposure (12 sets, 1-min of rest, 35 Hz, 3 mm, squat position) did not produce changes in neuromuscular performance and mobility in pwMS, except for in EMG activity where significant differences were observed between conditions. The EMG activity tended to decrease after a hypoxic session of WBVT.

Cochrane et al. (2010) did not observe changes in Time-to-MVIC after a single bout of WBVT in normoxia (one 5-min bout of vibration; frequency 26 Hz; amplitude 6 mm; static squat position of 40º knee flexion) in athletes. However, they did find changes in other neuromuscular variables, such as Rate of Force Development. The authors suggested that an acute bout of WBVT induces a post-activation potentiation (PAP) of the twitch, indicating that this modality of training can be used as a warm-up. This finding is consistent with our results, since we have also found a slight increase in MVIC, in all moments of the EMG and EMG Peak, as well as a slight decrease in the Time-to-MVIC after a session of normoxia. There are several possible explanations for the results of Cochrane et al. (2010). One possible explanation might be that WBVT increases intramuscular temperature due to muscular activity (Cochrane et al., 2008). In addition, another possible explanation could be the PAP, which can produce an increase in muscle performance due to a greater muscle contractile activity (Sale, 2002). Laudani et al. (2018) investigated the acute effects of WBVT in normoxia on MVIC and CAR in healthy people using a frequency spectrum from 20 to 50 Hz (position: 10º knee joint; bout of 1-min; amplitude: 4 mm). Neither MVC nor CAR changed after WBVT with the different frequency conditions. Jackson et al. (2008) studied the acute effects of WBV session in normoxia with two different frequencies (2 and 26 Hz) on muscle torque in pwMS. No significant pre-post differences was found in isometric torque production or between the different frequencies used (2 and 26 Hz; 30 s of vibration). The lack of changes from these studies may be due to low training dose (30 s to 1 min of vibration).

Interestingly, in older women with sarcopenia, Miller et al. (2018) demonstrated improvements in jump height and strength with intermittent WBVT (six 60-s exposures with 60-s rest intervals) compared with continuous WBVT (one six-minute exposure). These results support the idea that intermittent WBVT may have a greater capacity to stimulate PAP than continuous WBVT. The improvements of neuromuscular performance after a bout of WBVT in normoxia is supported by previous research in healthy population (Cochrane and Stannard, 2005; Torvinen et al., 2002).

However, the improvement of neuromuscular performance in a population with neuromuscular diseases after a bout of WBVT is unclear (Freitas et al., 2018). The findings from the current study could be due to the inability of muscle spindles of persons with MS to adapt to the stimulus vibration and react to the tonic reflex. The decrease in EMG activity during an isometric contraction after the WBVT session in hypoxia shows an interesting use of hypoxia training as a training load with a capacity to alter the neuromuscular component in force production, as it indicates a greater recruitment of muscle fibers of the vastus lateralis during a hypoxic session, according to Scott et al. (2017). During the normoxic session, there was a slight

increase in the MVIC in the right knee extensors, EMG and EMG Peak and a slight decrease in the Time-to-MVIC in both legs, suggesting that WBVT in normal conditions can be performed as a warm-up to pre-activate the neuromuscular response (i.e., PAP).

In a recent study, Freitas et al. (2018) did not observe changes in balance, postural stability or mobility after a session of WBVT (five 30-s bouts of vibration; frequency 30 Hz; amplitude 3 mm; 1-min rest intervals) in pwMS. However, Miller et al. (2018) observed improvements in TUG Test in older women with sarcopenia following intermittent, and not continuous, WBVT. This indicates that intermittent WBVT has greater potential for improvement mobility than continuous WBVT. Along these lines, Dickin et al. (2013) found increases in walking speed after an acute session of WBVT in adults with cerebral palsy, which is likely explained by the improvement in range of motion at the knee and ankle. However, Salmon et al. (2012) did not observe changes in TUG after WBVT session (ten 60-s of vibration with 60-s rest periods; frequency 35 Hz; amplitude 4–6 mm; knees slightly flexed) in people with knee osteoarthritis. Therefore, the results related to mobility in different populations are inconsistent, which may be because of the different types of health predicaments. Regardless, more research is needed to understand the acute and chronic effects of WBVT on daily life activities. In the current study, no significant pre-post differences were found in the neuromuscular variables, which could contribute to the lack of differences in the mobility measures. However, significant increases in RPE during and after sessions were found in both hypoxic and normoxic conditions. RPE increases from the beginning of the session, without reaching to very high values, suggesting that the participants exerted effort during the WBVT session and supports WBVT as a valid training load.

This study provides a preliminary understanding of the acute effects of a WBVT session under both normoxic and hypoxic conditions on neuromuscular performance in pwMS, which is essential for designing long-term training programs using WBVT in this population. One limitation of this study was the small sample size. In addition, more studies are needed to examine the effects of vibration exposure using lower dosage. Training under hypoxic condition in pwMS is a field that needs further study for its potential benefits.

Based on the findings from this study, we conclude that acute WBVT in hypoxia and normoxia resulted in no significant changes in mobility and neuromuscular performance in persons with MS, with the exception of EMG activity during maximal voluntary isometric contraction, which decreased after WBVT in hypoxia. Thus, there were no observed negative effects of using WBVT and hypoxia in persons with MS.

5. Conclusions

The importance of this study is to understand the acute physiological changes that occur with Whole-body Vibration Training (WBVT) in persons with MS, from which a better methodological approach can be designed for chronic WBVT in this population. Furthermore, it also highlights that WBVT minimizes symptomatic fatigue during physical effort in persons with MS. The researchers of this study, knowledgeable in the area of hypoxia and exercise training, believe that hypoxia may serve to potentiate the effects of training (Girard et al., 2017) on strength with minimal training duration. Thus, hypoxic training in persons with MS may be a good alternative in improving strength and physical function without needing a high exercise load.

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Declaration of Competing Interest

None.

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