J Musculoskelet Neuronal Interact 2014; 14(3):303-310

Hylonome

Original Article

A comparison of different vibration exercise techniques on neuromuscular performance

M.T. García-Gutiérrez[1], M.R. Rhea[2], P.J. Marín[1]

[1]Laboratory of Physiology, European University Miguel de Cervantes, Valladolid, Spain;
[2]Human Movement Program, A. T. Still University, Mesa, AZ

Abstract

The first purpose of this study was to determine the effects of whole-body vibration (WBV) exercise during an isometric handgrip exercise. The second purpose was to evaluate whether more than one vibratory focus would evoke an increase in the effects evoked by only one vibratory focus. The present study investigated whether WBV exposure during 10 repetitions of a handgrip dynamometer while standing on a WBV platform. Twenty-eight recreationally active university students completed 3 different test conditions, in random order: 1) grip dynamometer exercise with superimposed WBV and contralateral arm vibration (WBV+AV); 2) superimposed arm vibration only (AV); 3) grip dynamometer exercise without vibration (Control). The hand grip strength was slightly higher in the WBV condition as compared to the Control and AV conditions (1.1% and 3.6%, $p>0.05$, respectively). A main effect of the EMGrms of extensor digitorum muscle (ED) was observed indicating that the WBV+AV condition produced a lower co-activation of ED during a flexor digital task than the Control and AV ($p<0.05$) conditions. The application of WBV+AV may acutely increase muscle coordination and decreases the coactivation of ED. Furthermore, the muscle EMGrms showed increases in activation near the vibratory focus in both upper- and lower-body.

Keywords: Electromyography, Power, WBV, Hand Grip

Introduction

Vibration training has been investigated throughout the last decade as an alternative or complement method to traditional resistance programs for fitness improvements. Vibratory stimuli can be applied directly to the muscle belly[1] or the tendon muscle[2,3]; indirectly applied by gripping a vibration system[4], dumbbell[5], bar[6] or pulley system[7], or whole body vibration (WBV), in which the stimuli enters via the feet while standing on a vibration platform[8]. WBV has been the most studied method of vibration training. The principle reason for using WBV in muscle training is the strength and power improvements that people can get in a short period of time[9,10]. Numerous investigators have studied the effects that the vibratory platform exposure produces on the lower body. It has been shown to result in improvements in jump height[11], sprint performance[12]; metabolic[13] and hormonal[14] changes, and neuromuscular performance, both acute[8] and chronic[15].

The observed strength improvements, in the first few weeks of a training program, have been attributed to neural performance aspects, because changes in the morphology, architecture, and size of muscle tissue occur at a later stage[16,17]. Electromyography (EMG) activity increases in parallel with the levels of force used for training and reaches maximum with loads near maximal voluntary contraction[16]. Vibration training increases EMG activity on lower body[18-20] as well as on upper body muscles[3,21].

Previous studies have been found significant effects of vibration exposure on upper body muscular activity. Bosco et al.[21] found a significant increase in average electromyography (EMG) activity during upper body vibration and a significant increase in mechanical power during dynamic elbow flexion. Mischi and Cardinale[22] concluded that isometric elbow flexion and extension with superimposed vibration stimulation increasing the activation and coactivation of the biceps and triceps. However, there exist a large number of published articles related to the use of WBV to increase power and strength on

The authors have no conflict of interest.

Corresponding author: Pedro J. Marín, PhD., Laboratory of Physiology. European University Miguel de Cervantes, C/ Padre Julio Chevalier 2, 47012 Valladolid, Spain
E-mail: pjmarin@uemc.es

Edited by: J. Rittweger
Accepted 16 August 2014

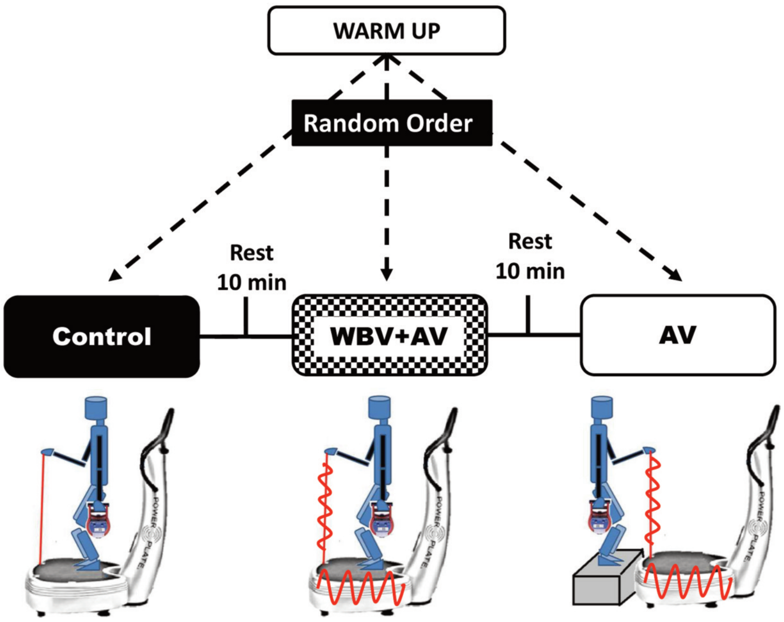

Figure 1. Experiment setup.

lower body muscular performance. Lamont et al.[10] found a significant augment to strength in an isometric squat test after resistance training was supplemented with WBV. Also, some studies have found significant effects on neuromuscular performance after a unilateral leg exposure to WBV on the contralateral leg not being stimulated[23]. This suggests definite central nervous system stimulation via WBV applications.

Only a few studies have investigated the effect of WBV on upper limbs, usually involving dynamic exercises[24]. A major reason for this lack of research is the attenuated vibration stimulus that reaches the upper limbs due to the distance between the vibration exposure (platform) and the upper body muscles. The soft tissue properties of the human body, combined with the muscular actions employed by the brain to control vibration exposure, results in less vibration stimulus reaching the upper body when standing on a vibration platform. Having said that, Marin et al.[25] found a significant increase in the number of maximal repetitions until exhaustion during a bicep curl set with WBV exposure. Another study found similar results during an elbow extension set with WBV until exhaustion[26]. To our knowledge, no previous studies have measured the effects of vibration stimuli via the feet on neuromuscular performance of upper limb muscles during an isometric exercise. Therefore, the current study sought to examine whether the use of WBV would improve performance on an isometric task in the upper body. Thus, the first purpose of this study was to determine the effects of WBV during an isometric hand-grip exercise. The second purpose was to evaluate whether more than one vibratory focus would evoke an increase in the effects evoked by only one vibratory focus. First, it was hypothesized that: i) vibration stimulus would provide an additional stimulus for neuromuscular system, increasing the isometric performance of the upper body, ii) more vibratory stimulus through both the arms and feet would evoke more effects than vibratory stimulus solely in the arms.

Methods

Experimental design

The present study investigated whether WBV exposure during 10 repetitions of a handgrip dynamometer while standing on a WBV platform under 3 different conditions, in random order, would benefit muscle performance (Figure 1). Three different conditions were performed: 1) grip dynamometer exercise with superimposed WBV and contralateral arm vibration (WBV+AV); 2) superimposed arm vibration only (AV); 3) grip dynamometer exercise without vibration (Control). Statistical analysis was conducted to evaluate for differences between the conditions.

Participants

Twenty-eight active male students participated in this study. The participants' mean (±*SD*) age, height and body mass were 22±1.6 years, 178.7±6.8 cm and 74.6±9 kg, respectively. The participants were physically active, but none were engaged in a systematic exercise program for at least 2 months before the data collection. All participants were experienced with isometric exercises and training to muscular failure. Exclusion criteria were diabetes, epilepsy, gallstones, kidney stones, cardiovascular diseases, joint implants, recent thrombosis, and musculoskeletal problems. For the purpose of testing, the participants' dominant arm was defined by their preference for writting. Participants were informed of the procedures and potential risks associated with participation in the study, and they provided written informed consent. One week before the testing sessions, participants attended two familiarization sessions. The research project was conducted according to the Declaration of Helsinki and was approved by the University Review Board for use of Human Subjects.

Treatment protocol

Participants performed three sets on the vibration platform in random order, so that each subject was exposed to the three conditions (WBV+AV, AV, Control). The experimental protocol began with electrode placement, followed by a standardized warm-up consisting on 2 min slow jog, 5 dynamic warm-up exercises, 10 reps of each exercise, (pull-backs, butt kicks, knee to chest, squats, and lateral lunges), and 5 maximal hand-grip repetitions. Ten maximal hand-grip repetitions were performed using a hand-grip dynamometer (Grip Strength Dynamometer T.K.K.5401; Takei Scientific Instruments Co., Ltd, Niigata, Japan) in each set. Ten minutes rest was given between each set. Each repetition had an approximate duration of 2 seconds followed by 2 seconds of rest.

The isometric semi-squat exercise required participants to stand with feet shoulder-width apart, with 30° knee flexion (considering 0° as the anatomical position) on the vibration platform (Figure 1). Subject placement was measured by a goniometer. When the isometric bicep curl was added to isometric semi-squat participants held the Power Plate hand straps (used to transfer vibration to the upper body) with elbow flexion at 90º. Participants were asked to maximally contract their biceps using the hand straps at the same time as the hand-grip. Joint angles were carefully monitored during each repetition with verbal feedback provided by a trained researcher. During all conditions, participants wore the same athletic shoes to standardize the vibration stimulus across conditions.

Vibration equipment

The vibration stimulus was applied via a commercial platform (Pro5 Power plate, Power Plate International Ltd., London, UK). The acceleration of the vertical sinusoidal oscillations (z-axis) was measured using a uni-axial accelerometer in accordance with ISO2954 (Vibration meter VT-6360, Hong Kong, China). Vibration platform settings included a frequency of 50 Hz with the peak-to-peak displacement of 2.51 mm (High). Measured accelerations were 100.6±0.24 $m \cdot s^{-2}$ (at 50 Hz).

Surface electromyographic activity (EMG)

Muscle activity of long flexor radial digitorum (FR), extensor digitorum (ED), contralateral biceps brachii (BB) and gastrocnemius medialis (GM) was measured using EMG[21,27,28]. Prior to electrode placement, the area was shaved and cleaned with isopropyl alcohol to reduce skin impedance. The electrodes were placed over the midbelly of the muscle parallel to the direction of the fibres according to recommendations by the SENIAM project (Surface ElectroMyo-Graphy for the Non-Invasive Assessment of Muscles)[29]. The double differential technique was used to detect myoelectric raw signals. The surface electrodes were connected to a 16-bit AD converter (TrigoTMWireless System, Delsys Inc., Boston, MA, USA). Raw EMG signals were pre-amplified close to the electrodes (signal bandwidth of 20-450 Hz), sampled at 4000 Hz, and stored on a laptop. EMG data analysis was performed using computer software (Delsys EMGworks Analysis 4.0. Delsys Inc. Boston, Massachusetts, USA). The EMG data were averaged by root mean square (rms) in order to obtain averaged amplitude of the EMG signal, and the maximum value of each repetition was selected. Moreover, in order to obtain average frequency the signal was averaged by median frequency (MDF). EMG was registered during the 10 repetitions of each isometric set.

Statistical analysis

Data were analyzed using PASW/SPSS Statistics 20 (SPSS Inc, Chicago, IL) and significance level was set at $P \leq 0.05$. Values are presented as means ± standard error (SE). All the measures were normally distributed, as determined by the Kolmogorov-Smirnov test. Sphericity was tested by the Greenhouse-Geisser method. Dependent variables were evaluated with a 1-way repeated measures analysis of variance (ANOVA). Where significant F-values were achieved, pairwise comparisons were performed using the Boferroni post hoc procedure. Effect size statistic, η^2, was analyzed to determine the magnitude of the effect independent of sample size.

Results

Hand grip isometric force

Hand grip force was slightly higher in the WBV condition as compared to the Control and AV conditions (1.1% and 3.6%, respectively), however, no significant condition effect was observed ($p>0.05$; $\eta^2=0.048$) (Figure 2a). The maximal isometric force during the 10th repetition was significantly lower than the 6th repetition ($p<0.001$; $\eta^2=0.739$) in all three of the different conditions (Figure 2b). A significant interaction effect of condition and repetition ($p=0.047$; $\eta^2=0.057$) was observed on the 8th repetition between WBV+AV and AV, with the greatest values measured in the WBV+AV condition (Figure 2b).

Muscle activity Extensor and Flexor digitalis

A main effect of the ED EMGrms was observed indicating that the WBV+AV condition produced a lower co-activation of extensor digital during a flexor digital task than the Control and AV ($p<0.05$; $\eta^2=0.111$) conditions. There was no significant difference in the enhanced EMGrms ED between the Control and AV conditions (Figure 2c). Table 1 (ED) and Table 2 (FD) show the summary of the repetition effect as well as the main effects analyzed with the ANOVAs for the dependent variables in each of the 3 different conditions.

Muscle activity Biceps brachii and Gastrocnemius medialis

The EMGrms measured in the biceps brachii muscle during the WBV and AV conditions were significantly higher ($p<0.05$; $\eta^2=0.078$) than the Control (Figure 3a). A similar effect was

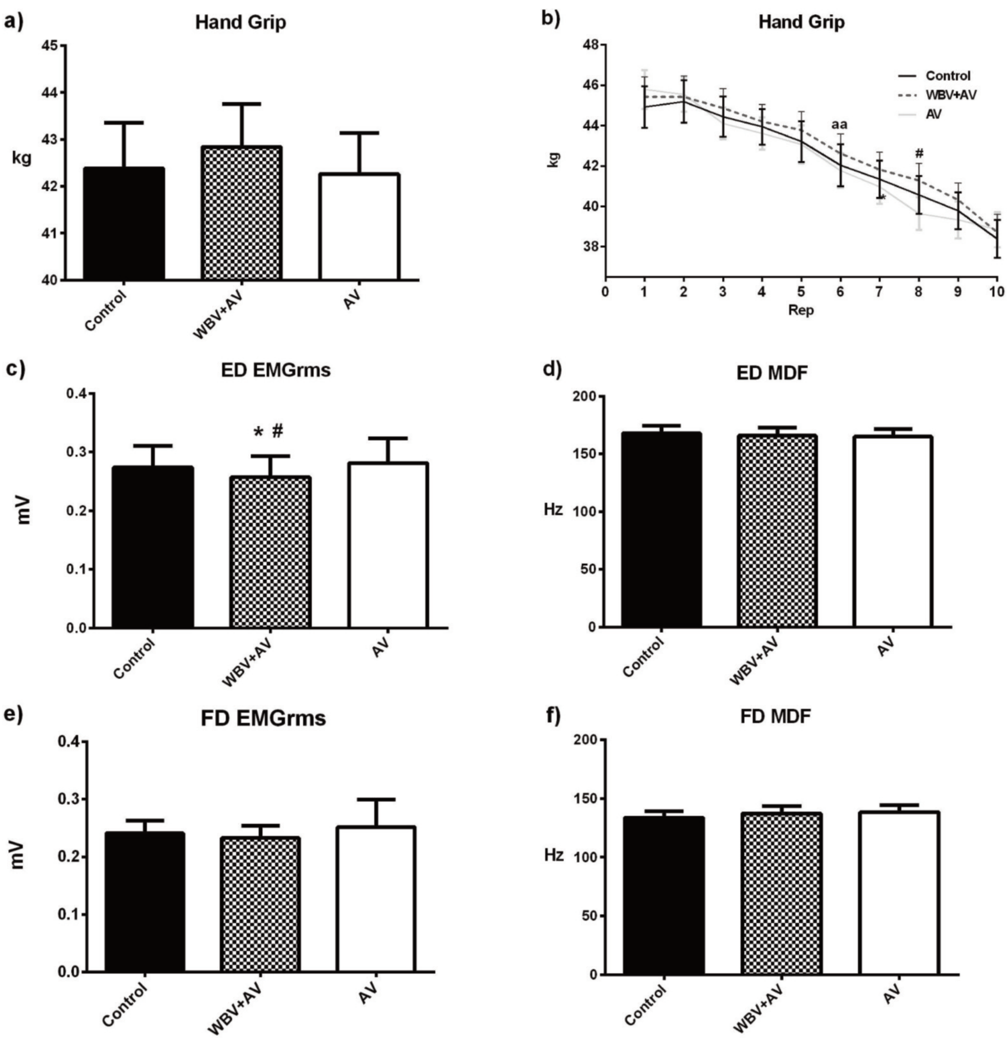

Figure 2. Hand grip strength and EMG results. WBV+AV, Whole body vibration and arm vibration; AV, arm vibration; ED, extensor digitalis; FD, flexor digitalis; EMGrms root mean square MDF, median frequency. [aa]Significant drop from 6 repeat in the three conditions (p<0.001). *Difference from Control condition (p<0.05). [#]Difference from AV condition (p<0.05).

	Extensor Digitorum Muscle					
	EMGrms (mV)			MDF (Hz)		
	Control	WBV+AV	AV	Control	WBV+AV	AV
Rep 1**	0.278±0.179	0.271±0.192	0.298±0.217	181.1±7.4	182.8±7.5	179.9±5.7
Rep 2[##]	0.273±0.195	0.264±0.209	0.287±0.233	175.2±6.9	172.1±7.1	168.6±6.3
Rep 3	0.283±0.200	0.265±0.201	0.263±0.227	170.0±6.6	174.5±7.5	162.3±6.1
Rep 4	0.273±0.211	0.246±0.200	0.289±0.242	172.1±6.3	162.8±6.7	162.9±6.5
Rep 5	0.295±0.220	0.251±0.195	0.286±0.236	163.8±6.7	165.1±6.6	163.9±6.8
Rep 6	0.272±0.207	0.247±0.195	0.286±0.228	167.3±6.5	162.5±6.3	159.9±7.4
Rep 7	0.286±0.225	0.246±0.183	0.273±0.237	164.0±6.1	160.9±6.5	160.3±6.1
Rep 8	0.255±0.191	0.241±0.165	0.258±0.215	163.1±6.1	160.8±6.8	163.1±6.2
Rep 9	0.256±0.179	0.238±0.186	0.264±0.214	160.8±6.4	158.3±7.6	167.9±6.2
Rep 10	0.253±0.165	0.236±0.179	0.279±0.209	163.1±6.3	158.8±7.6	162.5±6.1

*** MDF statistical difference from Rep. 5-10 (p<0.001); [##] MDF statistical difference from Rep. 8-10 (p<0.01).*

Table 1. Root-mean square (EMGrms) and median frequency (MDF) of extensor digitorum muscle from dominant hand; during the 3 conditions, 10 repetitions each condition.

	Flexor Digitorum Muscle					
	EMGrms (mV)			MDF (Hz)		
	Control	WBV+AV	AV	Control	WBV+AV	AV
Rep 1**	0.213±0.017	0.211±0.018	0.233±0.027	151.0±4.8	154.5±7.5	157.9±7.0
Rep 2##	0.241±0.022	0.227±0.019	0.250±0.025	146.3±5.6	143.7±5.9	148.0±6.0
Rep 3	0.243±0.021	0.233±0.020	0.247±0.022	140.0±4.6	147.9±6.3	144.7±5.7
Rep 4	0.251±0.024	0.226±0.018	0.256±0.026	139.6±7.1	140.1±6.1	138.5±5.7
Rep 5	0.244±0.023	0.245±0.024	0.255±0.027	131.7±4.7	132.7±5.4	136.0±6.8
Rep 6	0.246±0.022	0.233±0.021	0.263±0.029	128.2±4.9	131.4±6.2	137.6±5.4
Rep 7	0.248±0.022	0.242±0.019	0.277±0.029	131.7±5.5	137.7±7.9	133.2±5.5
Rep 8	0.247±0.025	0.242±0.023	0.242±0.026	122.6±5.1	128.9±6.6	128.7±6.4
Rep 9	0.244±0.023	0.236±0.022	0.262±0.029	122.1±5.0	124.4±6.4	131.6±6.6
Rep 10	0.229±0.023	0.230±0.023	0.236±0.024	124.3±5.6	131.5±7.2	128.4±6.4

*** MDF statistical difference from Rep. 2-10 (p<0.001); ## MDF statistical difference from Rep. 9.*

Table 2. Root-mean square (EMGrms) and median frequency (MDF) of flexor digitorum muscle from dominant hand; during the 3 conditions, 10 repetitions each condition.

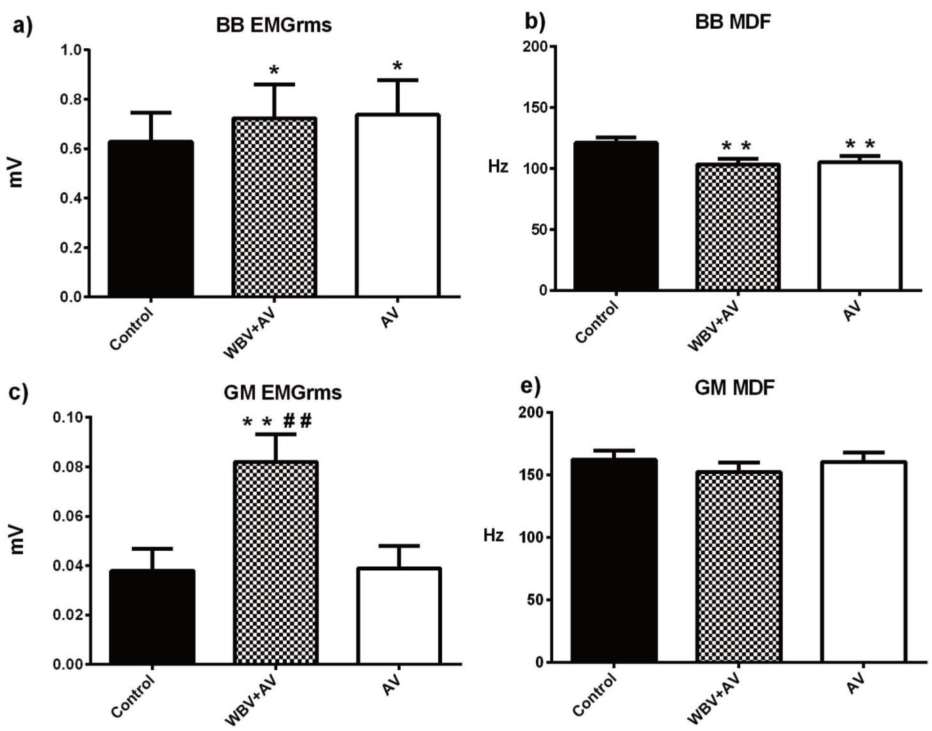

Figure 3. EMG from muscles near vibratory focus. WBV+AV, Whole body vibration and arm vibration; AV, arm vibration; BB, biceps brachii; GM, gastrocnmeius medialis; EMGrms root mean square MDF, median frequency. *Diffencies from Control condition, (p<0.05). **Difference from Control condition (p<0.001). ##Difference from Control and AV, respectively (p<0.001).

observed with the MDF, with a condition effect observed between the Control condition and the WBV+AV and AV ($p<0.001$; $\eta^2=0.521$) indicating that arm vibration produced a decrease in the frequency of muscle activation in muscles near the application of vibration (Figure 3b). The WBV+AV condition showed a statistical significant increase in the EMGrms of the GM ($p<0.001$; $\eta^2=0.596$) compared with Control and AV, indicating that muscles near the vibratory application experience an increase in the amplitude of muscle activation (Figure 3c). Post hoc comparisons for EMGrms and MDF values during each repetition are presented in Table 3 (BB) and Table 4 (GM).

	Biceps Brachii Muscle					
	EMGrms (mV)			MDF (Hz)		
	Control	**WBV+AV**	**AV**	**Control**	**WBV+AV**	**AV**
Rep 1**	0.613±0.076	0.650±0.090	0.725±0.088	126.7±4.4	114.8±4.9	112.2±5.5
Rep 2	0.640±0.096	0.742±0.116	0.766±0.095	127.4±4.7	104.7±5.1	107.2±5.6
Rep 3	0.687±0.097	0.754±0.108	0.786±0.100	123.9±4.8	103.2±5.1	106.8±5.7
Rep 4	0.625±0.082	0.754±0.104	0.781±0.103	121.2±4.9	104.3±4.3	106.0±5.6
Rep 5	0.604±0.083	0.794±0.113	0.751±0.093	120.6±4.4	100.2±4.1	104.1±5.7
Rep 6##	0.697±0.095	0.724±0.097	0.782±0.103	119.3±4.6	101.5±4.8	101.5±5.1
Rep 7	0.633±0.086	0.722±0.103	0.714±0.092	119.2±4.6	101.7±4.2	103.2±5.2
Rep 8	0.612±0.080	0.727±0.088	0.724±0.082	119.1±4.6	101.3±4.9	103.8±5.0
Rep 9	0.602±0.082	0.681±0.091	0.681±0.087	117.3±5.0	101.1±4.5	102.3±4.8
Rep 10	0.565±0.087	0.688±0.084	0.667±0.093	116.0±3.8	99.7±4.9	104.0±4.6

*** MDF statistical difference from Rep. 5-10 (p<0.001); ##EMGrms statistical difference from Rep. 9 (p<0.001).*

Table 3. Root-mean square (EMGrms) and median frequency (MDF) of biceps brachii muscle from non-dominant hand; during the 3 conditions. 10 repetitions each condition.

	Gastrocnemius Medialis Muscle					
	EMGrms (mV)			MDF (Hz)		
	Control	**WBV+AV**	**AV**	**Control**	**WBV+AV**	**AV**
Rep 1	0.029±0.005	0.070±0.011	0.027±0.005	170.1±7.4	148.5±6.8	161.6±6.7
Rep 2	0.032±0.006	0.078±0.011	0.032±0.006	166.4±7.4	154.1±6.7	161.3±6.3
Rep 3	0.033±0.006	0.076±0.010	0.032±0.006	164.5±8.3	154.1±7.6	163.5±7.3
Rep 4	0.036±0.008	0.078±0.009	0.043±0.009	156.1±6.3	158.6±7.3	163.8±7.0
Rep 5	0.036±0.009	0.081±0.011	0.037±0.008	159.7±7.0	149.1±7.8	157.0±7.1
Rep 6	0.044±0.012	0.078±0.009	0.063±0.023	166.4±8.0	146.8±7.0	156.0±8.1
Rep 7	0.038±0.008	0.088±0.010	0.035±0.007	166.7±7.2	150.6±8.1	156.5±7.1
Rep 8	0.039±0.007	0.092±0.015	0.038±0.009	161.8±7.7	157.9±8.7	163.9±9.6
Rep 9	0.037±0.009	0.091±0.013	0.042±0.008	154.0±7.3	153.8±8.0	162.3±8.6
Rep 10	0.057±0.021	0.092±0.016	0.041±0.008	157.8±8.0	152.0±7.6	160.4±6.8

Table 4. Root-mean square (EMGrms) and median frequency (MDF) of gastrocnemius medialis muscle from dominant hand; during the 3 conditions. 10 repetitions each condition.

Discussion

The main finding of the present study was that the vibration platform initiates a decrease in the coactivation of the extensors during one set of repeated hand grip performance while maintaining the maximal voluntary contraction. In contrast, MVC is not affected by WBV+AV or AV. To the best of our knowledge, this is the first study to assess the effects of WBV on upper limbs. Moreover, previous studies have reported effects of WBV during a dynamic[21,26] set of bicep curls[25] and elbow extension[26]. Those findings demonstrated that vibration exposure improves muscle coordination, decreasing the activation of the antagonist muscle without a decrease in the activation of the agonist muscle. In contrast to Mischi and Cardinale[22], in which it was concluded that vibration exposure increased the activation and coactivation of the triceps brachii and biceps brachii during an isometric elbow extension, the present results show a decrease in coactivation of the extensor digital while activation of the digital flexor is maintained during a set of 10 repetitions of isometric hand grip.

Cardinale and Lim[19] noted that the EMG signal of the vastus lateralis reached higher activity during WBV than no vibration application in an isometric muscular performance. Also Ronnestad[11,30] found the same effects during dynamic lower body performance. The present study found higher muscle activity during isometric upper body performance in the biceps brachii and gastrocnemius.

It has been suggested that vibration may result in greater muscle fatigue because it may increase neuromuscular performance earlier in an exercise[31]. In contrast found no increase in neuromuscular performance earlier in an exercise[3]. That study found an increase in EMGrms of biceps brachii in the vibration conditions, AV and WBV+AV, respectively.

Wirth et al.[32] found an increase in muscle activation due to WBV during static trunk muscle exercises; depending on two factors, namely on the distance from the corresponding muscle to the vibration platform, and on how much the exercise position challenges body balance. In relation to that finding, the current study found an increase on muscle activity, in the biceps brachial and gastrocnemio medialis, muscles with a close proximity to the current application of both AV and WBV+AV.

This study shows no effect on hand grip mean strength with any vibration condition. However, there was an effect on the number of repetitions and the WBV+AV application increased hand grip strength in relation to the AV condition. Some studies have observed no variation in hand grip force with vibration exposure[5,33,34].

Conclusion

In conclusion, the results of this study suggest that the application of WBV+AV acutely increases muscle coordination and decreases the coactivation of digital extensors muscle without any decrease in hand grip strength. Furthermore, the muscle EMG showed increases in activation near the vibratory focus in both upper- and lower-body.

Acknowledgements

The authors thank the participants for their excellent cooperation.

References

1. Jackson SW, Turner DL. Prolonged muscle vibration reduces maximal voluntary knee extension performance in both the ipsilateral and the contralateral limb in man. Eur J Appl Physiol 2003;88:380-6.
2. Luo J, McNamara BP, Moran K. A portable vibrator for muscle performance enhancement by means of direct muscle tendon stimulation. Med Eng Phys 2005;27:513-22.
3. Moran K, McNamara B, Luo J. Effect of vibration training in maximal effort (70% 1RM) dynamic bicep curls. Med Sci Sports Exerc 2007;39:526-33.
4. Humphries B, Warman G, Purton J, Doyle TL, Dugan E. The Influence of Vibration on Muscle Activation and Rate of Force Development during Maximal Isometric Contractions. J Sports Sci Med 2004;3:16-22.
5. Cochrane DJ, Hawke EJ. Effects of acute upper-body vibration on strength and power variables in climbers. J Strength Cond Res 2007;21:527-31.
6. Poston B, Holcomb WR, Guadagnoli MA, Linn LL. The acute effects of mechanical vibration on power output in the bench press. J Strength Cond Res 2007;21:199-203.
7. Issurin VB, Liebermann DG, Tenenbaum G. Effect of vibratory stimulation training on maximal force and flexibility. J Sports Sci 1994;12:561-6.
8. Mileva KN, Naleem AA, Biswas SK, Marwood S, Bowtell JL. Acute effects of a vibration-like stimulus during knee extension exercise. Med Sci Sports Exerc 2006; 38:1317-28.
9. Adams JB, Edwards D, Serravite DH, et al. Optimal frequency, displacement, duration, and recovery patterns to maximize power output following acute whole-body vibration. J Strength Cond Res 2009;23:237-45.
10. Lamont HS, Cramer JT, Bemben DA, Shehab RL, Anderson MA, Bemben MG. Effects of 6 weeks of periodized squat training with or without whole-body vibration on short-term adaptations in jump performance within recreationally resistance trained men. J Strength Cond Res 2008;22:1882-93.
11. Ronnestad BR. Acute effects of various whole-body vibration frequencies on lower-body power in trained and untrained subjects. J Strength Cond Res 2009;23:1309-15.
12. Delecluse C, Roelants M, Diels R, Koninckx E, Verschueren S. Effects of whole body vibration training on muscle strength and sprint performance in sprint-trained athletes. Int J Sports Med 2005;26:662-8.
13. Rittweger J, Beller G, Felsenberg D. Acute physiological effects of exhaustive whole-body vibration exercise in man. Clin Physiol 2000;20:134-42.
14. Bosco C, Colli R, Bonomi R, von Duvillard SP, Viru A. Monitoring strength training: neuromuscular and hormonal profile. Med Sci Sports Exerc 2000;32:202-8.
15. Verschueren SM, Roelants M, Delecluse C, Swinnen S, Vanderschueren D, Boonen S. Effect of 6-month whole body vibration training on hip density, muscle strength, and postural control in postmenopausal women: a randomized controlled pilot study. J Bone Miner Res 2004; 19:352-9.
16. Preatoni E, Colombo A, Verga M, et al. The effects of whole-body vibration in isolation or combined with strength training in female athletes. J Strength Cond Res 2012;26:2495-506.
17. Goodwill AM, Kidgell DJ. The effects of whole-body vibration on the cross-transfer of strength. ScientificWorldJournal 2012;2012:504837.
18. Abercromby AF, Amonette WE, Layne CS, McFarlin BK, Hinman MR, Paloski WH. Variation in neuromuscular responses during acute whole-body vibration exercise. Med Sci Sports Exerc 2007;39:1642-50.
19. Cardinale M, Lim J. Electromyography activity of vastus lateralis muscle during whole-body vibrations of different frequencies. J Strength Cond Res 2003;17:621-4.
20. Hazell TJ, Jakobi JM, Kenno KA. The effects of whole-body vibration on upper- and lower-body EMG during static and dynamic contractions. Appl Physiol Nutr Metab 2007;32:1156-63.
21. Bosco C, Cardinale M, Tsarpela O. Influence of vibration on mechanical power and electromyogram activity in human arm flexor muscles. Eur J Appl Physiol Occup Physiol 1999;79:306-11.

22. Mischi M, Cardinale M. The effects of a 28-Hz vibration on arm muscle activity during isometric exercise. Med Sci Sports Exerc 2009;41:645-53.
23. Marin PJ, Hazell TJ, Garcia-Gutierrez MT, Cochrane DJ. Acute unilateral leg vibration exercise improves contralateral neuromuscular performance. J Musculoskelet Neuronal Interact 2014;14:58-67.
24. Marin PJ, Herrero AJ, Milton JG, Hazell TJ, Garcia-Lopez D. Whole-body vibration applied during upper body exercise improves performance. J Strength Cond Res 2013;27:1807-12.
25. Marín PJ, Herrero AJ, Zarzosa F, Rhea MR, García-López D. Vertical whole-body vibrations improve the total volume of a biceps curl set to failure. European Journal of Sport Science 2010;10:385-90.
26. Marin PJ, Herrero AJ, Sainz N, Rhea MR, Garcia-Lopez D. Effects of different magnitudes of whole-body vibration on arm muscular performance. J Strength Cond Res 2010;24:2506-11.
27. Perchthaler D, Horstmann T, Grau S. Variations in neuromuscular activity of thigh muscles during whole-body vibration in consideration of different biomechanical variables. J Sports Sci Med 2013;12:439-46.
28. Marin PJ, Bunker D, Rhea MR, Ayllon FN. Neuromuscular activity during whole-body vibration of different amplitudes and footwear conditions: implications for prescription of vibratory stimulation. J Strength Cond Res 2009;23:2311-6.
29. Hermens HJ, Freriks B, Disselhorst-Klug C, Rau G. Development of recommendations for SEMG sensors and sensor placement procedures. J Electromyogr Kinesiol 2000;10:361-74.
30. Ronnestad BR. Acute effects of various whole body vibration frequencies on 1RM in trained and untrained subjects. J Strength Cond Res 2009;23:2068-72.
31. Luo J, McNamara B, Moran K. The use of vibration training to enhance muscle strength and power. Sports Med 2005;35:23-41.
32. Wirth B, Zurfluh S, Muller R. Acute effects of whole-body vibration on trunk muscles in young healthy adults. J Electromyogr Kinesiol 2011;21:450-7.
33. Gomez AL, Volek JS, Rubin MR, et al. Physiological and functional effects of acute low-frequency hand-arm vibration. J Strength Cond Res 2003;17:686-93.
34. Cochrane DJ, Stannard SR. Acute whole body vibration training increases vertical jump and flexibility performance in elite female field hockey players. Br J Sports Med 2005;39:860-5.