ORIGINAL ARTICLE

Effects of 4 weeks whole body vibration on electromechanical delay, rate of force development, and presynaptic inhibition.

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Abstract

Long-term functional changes after whole-body vibration (WBV) training have been attributed to adaptations in the neuromuscular system. The present study examined the effect of four weeks of WBV training on muscle function outcome variables [rate of force development (RFD), electromechanical delay (EMD)], and spinal control mechanisms (pre-synaptic inhibition). Forty young individuals with no history of lower leg injuries were randomly assigned to an experimental or control group. The experimental group received WBV training (three bouts of two minutes, three times a week) for four weeks. During each of the training sessions, the subjects stood on the vibration platform with the knees slightly flexed. The control group performed periods of standing in the same position as the experimental subjects. After four weeks of WBV training, the experimental (WBV) group demonstrated a significant improvement in electromechanical delay (EMD). The results also showed a significant group × test interaction for RFD and intrinsic pre-synaptic inhibition (IPI) over the course of the study. Enhanced neuromuscular activation (EMD and RFD) and increased spinal reflex gain followed by 4 weeks of WBV training indicate that WBV training might be used not only for athletes engaged in sports that require explosive type of muscular activation, but also for the elderly individual who need to exert a rapid rise in muscle force in injury related situations.

Keywords: whole body vibration, neurological adaptation, rate of force development, electromechanical delay, pre-synaptic inhibition, H-reflex

Introduction

Whole-body vibration (WBV) has received a great deal of attention due to reports of enhanced physical performance (Delecluse et al 2003; Roelants et al 2004). The performance variables reported to be improved after acute WBV are muscle strength, power, rate of force development (RFD), and electromechanical delay (EMD) (Rittweger et al 2003; Cochrane et al 2010, Hopkins et al 2008a). Chronic vibration studies also have shown increases in similar neuromuscular

variables such as muscle strength, power, and balance (Cardinale and Bosco 2003; Torvinen et al 2003).

Researchers suggested that these improved performance variables following WBV training result from neuromuscular adaptations resulting in enhanced neuromuscular activation (Bosco et al 1999; Delecluse et al 2003; Nordlund and Thorstensson 2007). Among the performance variables, RFD, described as the slope in the force time curve and EMD, the time lag between muscle activation and the muscle's force production, have been considered to be functionally important variables for not only explosive type of muscle action in sports performance but also for quick neuromuscular activation in injury related situations. Investigation of these particular neuromuscular variables is warranted as the improvements in these neuromuscular variables have been considered to be linked to adaptations in the neural control of the muscle, which has been suggested as the primary mechanism of WBV training (Lindford et al 2006). Despite this purported mechanism for change identified in the previous studies, the exact mechanisms eliciting these positive responses are still not clearly known since most of the previous WBV studies primarily examined the efficacy of WBV training on neuromuscular outcome variables instead of intrinsic neurological mechanisms. Therefore it is imperative to focus on the intrinsic mechanism related variables to clearly understand what drives such positive changes.

Recently, several authors considered possible adaptations in the spinal level control as one of the responsible mechanisms for WBV induced improvements (Armstrong et al 2009; McBride et al 2010; De Gail et al 1996; Hopkins et al 2008b). In an attempt to understand this connection, researchers examined the efficacy of WBV on H-reflex, however current studies suggests that reflex activity following acute whole body vibration either is not changed or is decreased (Armstrong et al 2009; McBride et al 2010; de Gail et al 1996; Hopkins et al 2008b). Although the investigation of vibration effect on net motorneuron excitability by examining H-reflex seems to be warranted, the modulation of that excitability by examining pre-synaptic inhibition in the spinal reflex system may provide better insights regarding the connection of spinal mechanism to the changes in neuromuscular outcome variables caused by WBV training.

Pre-synaptic inhibition refers to the modulation of the Ia afferent impulses by the action of GABAergic interneurons (Rudomin and Schmidt 1999). This modulation can act through a variety of mechanisms. Recently two different pre-synaptic inhibition protocols have been used to assess the spinal level control. One of the most commonly studied is classical or extrinsic pre-synaptic inhibition (EPI). EPI acts mainly by the activation of GABAergic interneurons causing a reduction in the size and number of Ia afferent impulses by affecting transmitter release of sensory fibers, which subsequently reduces excitability of the motor neuron pool (Rudomin 2009). Additionally, modulation of the Ia afferent impulses can be affected by its own reflex activation history, termed intrinsic pre-synaptic inhibition (IPI). IPI occurs when two action potentials travel down the axon with minimal separation, and this frequent reflex activation decreases reflex amplitude by Ca++ and K+ changes resulting in an alteration of output of the motorneuron (Sefton et al 2007). Investigating these two types of pre-synaptic inhibition mechanism will help better understand the underlying neurological mechanisms for WBV training. The purpose of the study was to investigate the training effect of a four week WBV program on two measures of outcome variables (EMD and RFD) as well as the its effect on pre-synaptic inhibition (EPI and IPI).

Methods

A total of 40 subjects (24.27 yrs ± 5.97) were recruited to participate in this study. Twenty men and 20 women with no history of lower leg injury (specifically ankle or knee joint) were recruited through flyers posted on a university campus. All subjects provided written consent after being fully informed of the nature of the study. Subjects were sex stratified and assigned to one of the treatment groups (WBV or No-WBV).

The WBV group performed vibration training over a period of four weeks (three times per week) for a total of 12 training sessions. Subjects in the WBV group stood, with knees flexed to approximately 20º, on the vibration platform (TurboSonic™ Seoul, Republic of Korea). The experimental parameters for TurboSonic WBV device were set at a frequency of 20 Hz and 5 mm amplitude during each of the three two-minute periods. Each training session lasted 10 minutes. The No-WBV group performed the same static semi squatting position on the floor.

The difference between the WBV group and the No-WBV group was that the WBV group performed the standing position on the vibration machine and No-WBV group performed on the floor. In addition, subjects in the No-WBV group performed the same standing position three times a week and both groups were asked to not to make any changes in their activity level during the study period.

All subjects (WBV and No-WBV) were scheduled to complete their 3 data collection sessions (Pre, Mid, Post) (Table 1). Each testing session involved neuromuscular testing for all subjects and a bout of vibration exposure for the subjects in the vibration group.

Pre- Test	2 Weeks of WBV training	Mid-Test	2 Weeks of WBV training	Post-test

Table 1 Testing / Training Schedule

The outcome measures assessed were: 1) EMD, 2) RFD, 3) extrinsic pre-synaptic inhibition (EPI), and intrinsic pre-synaptic inhibition (IPI). All testing procedures were performed on the dominant leg.

For all subjects, isometric torque measurements were performed on the dominant ankle using an isokinetic dynamometer (Biodex System 3 Pro, Biodex Medical Systems Shirley, NY). The subjects sat on the testing chair of the dynamometer and the leg was secured with body straps (Figure 1), with the hip and the knee joints flexed at 100 degrees. Measurements of RFD and EMD were obtained during plantar flexion. All subjects were instructed to "plantar flex the ankle as hard and as fast as possible". Three trials were performed with one minute rest between each trial.

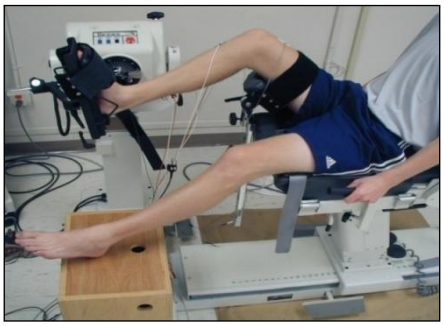

Figure 1 – RFD and EMD testing position

Force signal and the EMG signals from the soleus muscle were sampled at 2000 Hz. The raw unfiltered signals were analog-to-digital converted (Acqknowledge Software v.3.9.1, Biopac Systems, Inc. Goleta, California, USA) and stored on a PC. During the later process of analysis, the force signals were filtered with a fourth-order Butterworth filter with a 50 Hz cutoff. The EMG signal was rectified. Muscle activation onset was determined by the cumulative sum technique as adapted by Scholz and Millford (1995). Briefly, this technique creates an iterative running (i.e. cumulative) sum of individual EMG values. The running sum is then subtracted from the average EMG activation of the entire trial and therefore increases in negative size until the muscle starts to contract; onset of muscle contraction is subsequently determined from the point where the running sum reaches a local minimum. EMD was then determined as the difference between the onset for torque and muscle contraction (Zhou et al 1995).

For pre-synaptic inhibition testing, subjects were tested lying prone on a padded table with the ankle positioned at 90º. Subjects remained in this same position for both pre-synaptic inhibition-testing procedures. To elicit and record muscle responses and stimulation intensity, an EMG channel with surface electrodes (MP 100, BIOPAC Systems Inc., Santa Barbara, California, USA) and a stimulating circuit (s88, Grass Instruments) were used (Figure 2). Throughout the testing, EMG recordings of the soleus and tibialis anterior muscles were the same for EPI and IPI testing procedures.

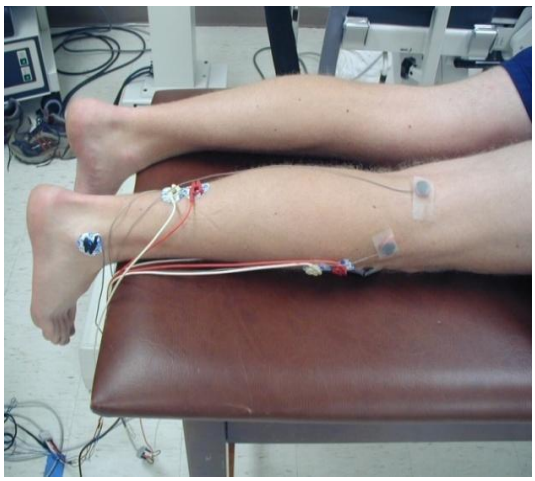

Figure 2 – Electrodes placement for Spinal Reflex Testing

For EPI testing, the stimulating intensity for the tibial nerve was set up to elicit the reflex of the soleus muscle 100 ms before the stimulating intensity for the common peroneal nerve was triggered to elicit the reflex of the tibialis anterior muscle. For the IPI testing, the standardized H-reflex stimulating intensity was set up with 80 ms delay between the first and second stimulation.
For the assessment of EPI, conditioned (15 trials) and unconditioned (15 trials) H-reflexes were measured. At least 10 seconds passed between each of the stimulation pairs (Figure 3).

Figure 3 – Modulation of the soleus H-reflexes from extrinsic pre-synaptic inhibition (EPI) protocol. A: Unconditioned S1(tibial nerve) stimulus producing an H-reflex (2.10 mV). B: Conditioned S2 (common peroneal nerve) stimulus 100 ms prior to tibial nerve stimulation producing depressed H-reflex (0.270 volts). For the paired reflex depression protocol, conditioned S2 stimulus was tibial nerve stimulation. The degree of depression (% depression) of the second H-reflex produced relative to the first H-reflex was compared.

2 (Group) x 3 (Test) repeated measures ANOVA was used to analyze the data. All statistical analyses were performed using the SPSS 15 software (SPSS, Inc., Chicago, IL). Alpha was set at 0.05.

Results

Subjects who received the WBV were similar to controls at baseline for all dependent measures: EMD, RFD, EPI, and IPI. The values of all outcome measures are reported as mean ± standard deviation (SD) (Table 2).

	No- WBV (n=20)			**WBV (n=20)**		
	Pre	Mid	Post	Pre	Mid	Post
EMD (ms)	21.25 ± 7.63	20.13 ± 6.20	20.92 ± 5.06	23.42 ± 7.54	20.62 ± 8.39	15.14 ± 7.13
RFD (Nm/sec)	318.41 ± 145.42	322.73 ± 142.03	321.58 ± 129.49	274.13 ± 137.77	320.41 ± 136.35	401.71 ± 176.64
EPI (%)	75.13 ± 30.64	74.07 ± 32.38	73.48 ± 33.67	83.82 ± 22.78	88.87 ± 21.84	83.53 ± 24.05
IPI (%)	21.25 ± 7.63	20.13 ± 6.20	20.92 ± 5.06	23.42 ± 7.54	20.62 ± 8.39	15.14 ± 7.13

Table 2: The mean and standard deviation of the neuromuscular parameters

The 2 × 3 ANOVA showed a significant group × test interaction (p=0.001) for EMD**.** The evaluation of the interaction revealed significant differences between the means of the testing times in the WBV group (p=0.005) but not in the No-WBV group (Figure 4).

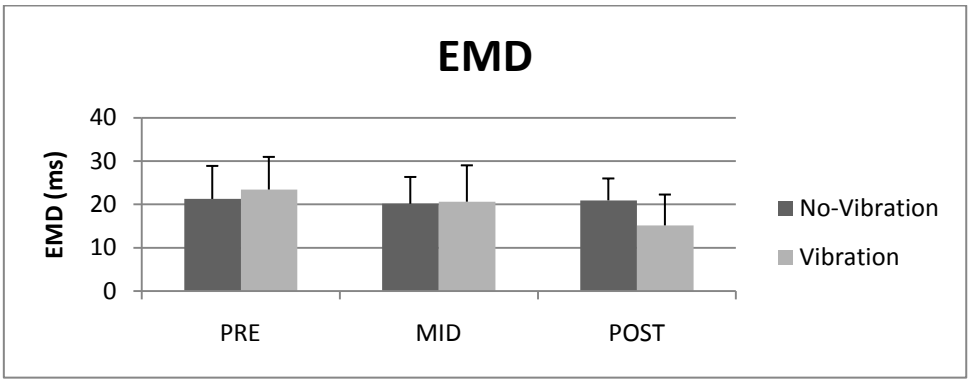

Figure 4 – Mean and standard deviation (SD) of the EMD before (pre), after 2 weeks (mid), and after 4 weeks (post) in the WBV group and the No-WBV group. There is a significant interaction effect (group × test) at p<.05. Post-test values are significantly higher than pre-test and mid-test values (p=0.05).

The 2 × 3 ANOVA showed a significant group × test interaction for RFD (p=0.001). However, the evaluation of the interaction revealed no significant differences between the means in the WBV group and the No-WBV group at any level of the testing sessions (pre, mid, post) (Figure 5). After 4 weeks of WBV, RFD from pre-test to post-test increased by about 32% (from 274Nm/sec to 401 Nm/sec) in the vibration treatment group.

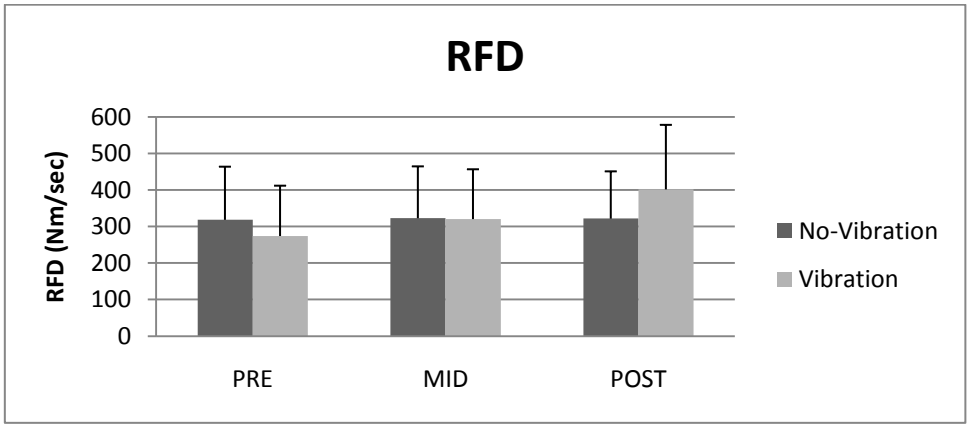

Figure 5 – Mean and standard deviation (SD) of the RFD before (pre), after 2 weeks (mid), and after 4 weeks (post) in the WBV group and the No-WBV group. In WBV group, there is a 15% increase from pre-test to mid-test and 17% increase from mid-test to post-test. Even though there is a significant interaction effect (group × test) at p<.05, Post-test values are not statistically different from pre-test and mid-test values at p<.05.

The 2 × 3 ANOVA for EPI showed no significant Group × Test interaction (p=0.348) and no significant test effect (p=0.220) (Figure 6).

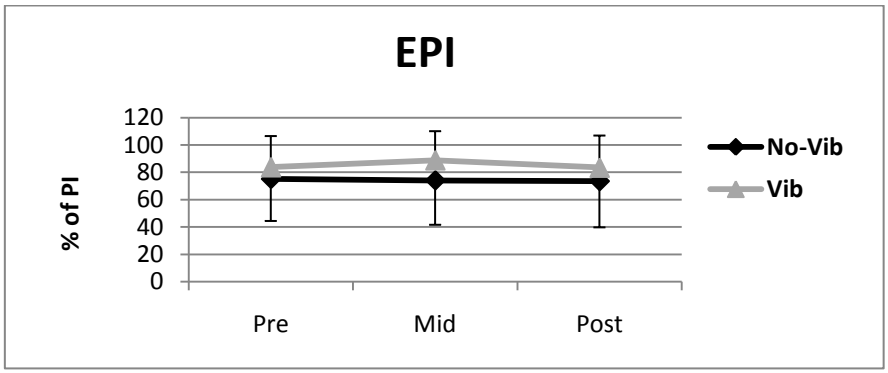

Figure 6 — Mean and standard deviation (SD) of the EPI before (pre), after 2 weeks (mid), and after 4 weeks (post) in the WBV group and the No-WBV group. There is a no significant interaction effect (group × test) at P<.05. There is no significant difference in the means between groups at any of the testing sessions (pre, mid, post-test)

The 2 × 3 ANOVA showed a significant group × test interaction for IPI (p=0.001). However, the evaluation of the interaction revealed no significant differences between the means in the WBV group and the No-WBV group (p=0.052). After four weeks of vibration training, IPI decreased by about 37% (from 71.9% to 45.7%) in the WBV group (Figure 7).

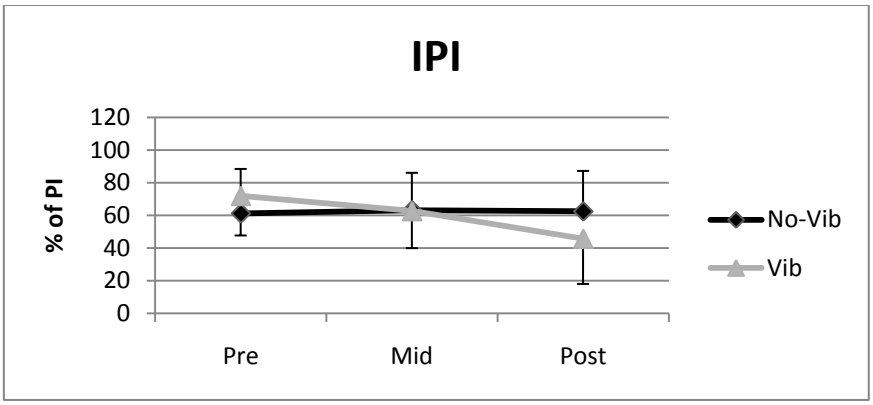

Figure 7 — Mean and standard deviation (SD) of the IPI before (pre), after 2 weeks (mid), and after 4 weeks (post) in the WBV group and the No-WBV group. There is a significant interaction effect (group × test) at P<.05. However, no significant differences were shown between post-test values and either pre and mid-test values.

Discussion

The main finding of our study is that four weeks of WBV training significantly shortened EMD. Our results also showed statistically non-significant changes in rate of force development (RFD), however, RFD increased by 32% in the vibration group and remained unchanged in the control group. EMD includes the time courses of the propagation of action potential on the muscle

membrane, the excitation-contraction coupling processes, and the stretching of the series elastic components (SEC) by the contractile component (Cavanagh and Komi 1979). The predominant component of EMD is the time required to lengthen the elastic components of the musculotendinous structures (Zhou et al 1995). Therefore, changes in EMD are primarily attributed to changes in the stiffness of the SEC of muscle (Granata et al 2000). Concerning the possible connection between muscle stiffness and WBV, it has been reported that when muscles are vibrated, muscle spindle sensitivity and muscle stiffness increase to dampen the vibration (Cardinale and Bosco 2003). Activation of joint mechanoreceptors and stimulation of the gamma efferents sensitize the muscle spindles and is known to result in increases in muscle stiffness (Johansson 1991). In this respect, we believe that the semi squatting position held during WBV might have contributed to the increased level of pre-activation of the soleus muscle and resulted in increased muscle stiffness and decreased EMD.

Although the extent of change in RFD was not statistically significant, the observed changes in RFD for the WBV group are arguably practically significant. Previous WBV studies suggest that vibration affects the ability to generate high firing rates in high-threshold motor units (Bongiovanni et al 1990) and the recruitment thresholds of the motor units during WBV are expected to be lower compared with voluntary contractions, probably resulting in a more rapid activation (Romaiguere et al 1993). It is possible, therefore, that the increase in RFD was attainable by the recruitment of high threshold motor units after WBV training.

Pre-synaptic inhibition has been suggested as a modulatory mechanism responsible for neurological changes seen with WBV. This study is unique in the fact that it utilized two different presynaptic inhibition protocols to assess how WBV affects spinal level control. Our results showed a significant interaction between group and time for the measurement of IPI. It has been documented that the reduced IPI of the H-reflex would represent a decrease in the depression associated with the reflex activation history and would effectively allow spindle afferent feedback to contribute to the neural drive of the muscle (Trimble et al 2000).

Regarding a possible mechanism for an increased RFD by pre-synaptic inhibition, the neural modulation of pre-synaptic inhibition pathway affected by the recruitment of motor units for voluntary movements can be attributed to the results (Gruber and Gollhofer 2004). In addition, the enhanced excitatory synaptic input or motoneuron excitability with training has been shown to cause high-threshold motor units to be recruited earlier in a maximal voluntary contraction (MVC) increasing RFD (Gruber and Gollhofer 2004). These findings can provide supporting evidence for the speculation that the main neural adaptation occurring in supraspinal structures is caused by an enhanced neural drive in descending corticospinal pathways. Based on these findings and mechanisms documented in previous studies, the change in RFD following WBV in our study indicates that WBV may have an effect on RFD. However more studies should investigate the effects of WBV on each of these possible factors for the increased RFD, i.e., potentially involving alterations in motor unit recruitment, motor unit discharge rate, and possibly pre-synaptic mechanism.

In this study, the EPI remained unchanged after four weeks of WBV training but IPI as measured with paired reflex depression of soleus H-reflex decreased by 37% in the WBV group. These findings support the hypothesis that changes seen with WBV may have been due to pre-

synaptic inhibition (Bongiovanni et al 1990; Rittweger et al 2000), and that WBV interacts with the spinal reflex loops, potentially influencing these pathways (Rittweger et al 2000). Theoretically, the preferential activation of Ia afferents by muscle vibration initiates impulses in a polysynaptic excitatory pathway and a pre-synaptic inhibitory pathway (Romaiguere et al 1993). The spinal polysynaptic excitatory pathway evokes the tonic vibration reflex (TVR), whereas the spinal pre-synaptic inhibitory pathway is responsible for the vibration-induced reflex inhibition (Romaiguere et al 1993).

In conclusion, **t**he present study indicates that 4 weeks of WBV has an effect on the neuromuscular properties of soleus muscles and spinal mechanisms. This is demonstrated by a decreased electromechanical delay (EMD), increased rate of force development (RFD) and the pre-synaptic inhibition (IPI) of the soleus muscle. The findings here provide a means of isolating the effect of WBV on the neuromuscular system and perhaps may give important insights about the role of training on human nervous system. Further research is needed to investigate other mechanisms that underlie the physiological responses and adaptation to WBV.

Clinical Implications

The present study basically extends our knowledge of neuromuscular adaptations. Significant decreases in EMD and increases in RFD were observed after only four weeks of WBV training. This improvement was accompanied by decrease in pre-synaptic inhibition of soleus. This impressively is consistent with the theoretical mechanism that has suggests that enhanced neuromuscular activation can be mainly attributed to reduced pre-synaptic inhibition (Zehr and Stein 1999). From the data of the present study, it is suggested that WBV training is selectively beneficial for the explosive type of muscular actions. It is also assumed that facilitation in neuromuscular activation observed in the present study may arise from enhanced spinal reflex contributions. Therefore, it is important for coaches and physiotherapists to notice that WBV induced changes in neuromuscular activation (EMD and RFD) will have important functional implications not only in athletes but also in nonathletic populations. For athletes, rapid muscular activation is of importance not only for better performance but also injury prevention. For the elderly population, the ability to generate rapid muscle contraction may reduce the incidence of falls related to the impaired control of postural balance with increasing age (Gruber et al 2007).

Conclusion

The present study indicates that four weeks of WBV appear to have an effect on the neuromuscular properties of soleus muscles and spinal mechanisms (pre-synaptic inhibition). This is demonstrated by a decreased electromechanical delay in line with a significant group × test interaction for the rate of force development and the pre-synaptic inhibition (IPI) of the soleus muscle. The findings here may provide a means of isolating the effect of WBV on the neuromuscular system and perhaps may give important insights about the role of training on the human nervous system. Further research is needed to investigate other mechanisms that may underlie the physiological responses and adaptation to WBV, and how these responses may occur among individuals with abnormal muscle function or soft-tissue injury.

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