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Original Research

Acute Effects of Whole Body Vibration on Rate of Force Development and Electromechanical Delay.

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KEY WORDS

Whole body vibration
Neurological adaptation
Rate of force development
Electromechanical delay
EMG

ABSTRACT

Background: The ability to generate rapid and powerful muscle contractions within a short period of time is an important factor for both enhancing sports performance and preventing injuries. Recently, whole-body vibration (WBV) has been introduced as a novel training method designed to produce neuromuscular improvement similar to that of power and strength training. However, to date there are only limited data on the acute effects of WBV on the neuromuscular system. Furthermore, there is little understanding about the responsiveness of the neuromuscular system to acute exposure WBV.

Research question: The present study examined the effect of acute WBV training on the rate of force development (RFD) and electromechanical delay (EMD) in the soleus muscle.

Type of study: Randomized controlled study.

Methods: Forty young individuals with no leg injuries were randomly assigned to an experimental or control group. The experimental group received acute WBV (3 bouts of 2 minutes). The control group adopted the same position (squat position) on the vibration platform for an equal time but received no vibration.

Results: The experimental (WBV) group demonstrated a significant group × time interaction for the rate of force development (RFD) and electromechanical delay (EMD) representing 15.6% (from 274Nm/sec to 323 Nm/sec) and 16% (from 23.42 ms to 19.3 ms) improvement.

Conclusions: It appears that acute WBV enhances RFD and EMD of the soleus muscle in young healthy subjects.
Key words: whole body vibration, neurological adaptation, rate of force development, electromechanical delay, EMG.

INTRODUCTION

Rate of force development (RFD) represents the ability to rapidly contract muscle and is closely related to an enhanced early neural activation of the trained muscle. Electromechanical delay (EMD), another important neuromuscular related variable, is the delay between the onset of electromyography (EMG) and the onset of mechanical response of the muscle. Increases in RFD and/or decreases in EMD can have important functional consequences as these allow greater and faster levels of muscle contraction for better sports performance and active stabilization of joints in injury-related situations.

Previous studies have shown that RFD and EMD can be improved by neuromuscular training designed to promote neural adaptation in the muscle (Gruber and Gollhofer 2004; Linford et al 2006). For example Gruber and Gollhofer (2004) reported that a 4-week sensorimotor training program had a significant impact on the rate of force development specifically in the early phase of muscle contraction. And Linford et al. (2006) showed that a 6-week neuromuscular training program significantly decreased electromechanical delay of the peroneus longus muscle in healthy subjects.

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Recently, whole body vibration (WBV) training has become increasingly used in sports training and injury treatment settings as an efficient neuromuscular training tool. Some authors suggest WBV exercises can acutely enhance strength and power capabilities in untrained as well as trained individuals (Schuhfried et al 2005). For example, acute application of WBV applied for a total of 10 minutes was shown to increase leg extensor muscle power and countermovement jump height in elite athletes (Bosco et al 2009). Additionally WBV has been used in patients with neuromuscular deficit. A recent study by Tihanyi, Horvath and Fazekas (2007) with stroke patients showed 1 minute WBV treatment improved the patients' isometric and eccentric knee extension torque (Tihanyi, Horvath and Fazekas 2007).

Several mechanisms for these acute effects of WBV training have been suggested, including neural adaptation related to increased muscle activation caused by increased excitability input from muscle spindles exposed to a vibration (Abercromby et al 2007). It has been hypothesized that the enhanced muscle power observed following acute vibration occurs via potentiation of the neuromuscular system whereby stimulation of muscle spindles (Ia afferents) results in reflex activation of motoneurones with increased spatial recruitment (Komi 2000; Romaiguere, Vedel and Pagni 1993). It has been also suggested that the increased level of neural drive following WBV training is closely related to increased muscle stiffness, which is known to contribute to shortening EMD (Komi 2000; Romaiguere, Vedel and Pagni 1993).

Based on the theoretical mechanism of WBV proposed by researchers, it is likely that increased neural drive and muscle stiffness induced by WBV would reduce the rate of muscle shortening and therefore reduce the amount of time necessary to produce force or tension. However, to date it is not clear how such a short exposure to WBV can acutely enhance the rate of force development and electromechanical delay. The purpose of the present study was to investigate the acute effects of WBV on RFD and EMD of the soleus muscle in healthy subjects.

Methods

A total of 40 individuals (20 males, 20 females, mean age = 24.27 ±5.97 yrs) with no history of lower leg injury were recruited through flyers posted on a university campus. Informed consent was obtained from each subject prior to participation in accordance with the university's Institutional Review Board. Subjects were sex stratified and randomly assigned to either of the treatment (WBV) or control (No-WBV) group.

Subjects in the WBV group stood, with knees flexed to approximately 20º, on the vibration platform (TurboSonic™ Seoul, Republic of Korea) (Figure 1). The experimental parameters for the WBV device were a frequency of 20 Hz and 5 mm amplitude during each of three 2-minute periods. Each training session lasted 10 min. The No-WBV group performed the same static semi-squatting position on the floor.

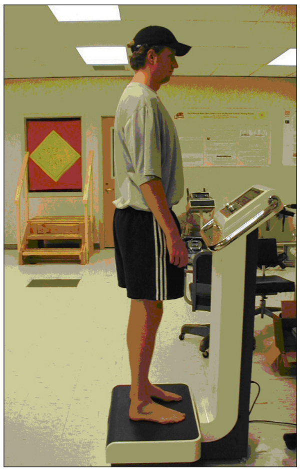

Figure 1 - Vibration Treatment

All subjects (WBV and No-WBV) were tested before and after a set of vibration exposures on the testing days. The outcome measures were: 1) the rate of force development, 2) electromechanical delay. Both measurements were recorded in the soleus muscle. Outcome measures were calculated from the same trials. And all testing procedures were performed on the dominant leg.

For all subjects, RFD and EMD were obtained 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 2), while the hip and the knee joints are flexed at 100 degree. All subjects were instructed to "plantar flex the ankle as hard and as fast as possible" for the testing. Three trials were performed with 1-minute rest between each trial.

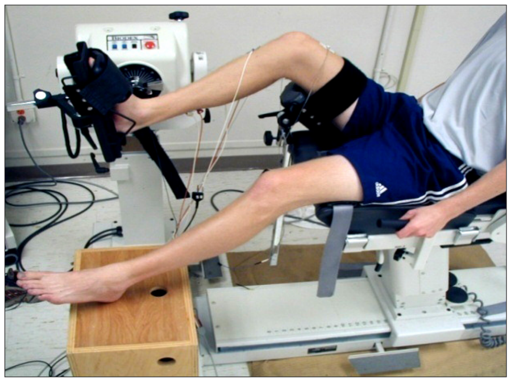

Figure 2 – RFD and EMD testing position

The force signal and the EMG signals were synchronously sampled at 2000 Hz. The raw unfiltered signals were analog-to-digital converted (Acqknowledge Software v.3.9.1, Biopac Systems, Goleta, CA) and stored on a PC. During the later process of analysis, the force signals and EMD were digitally high-pass filtered by using a fourth-order, zero lag Butterworth filter with a 50 Hz cutoff. Onset of force and EMG was determined by the cumulative sum technique (cholz and Millford 1995). Maximal RFD was calculated from the individual maximal isometric force development record. RFDmax was defined as the maximal slope of the force time curve (Δforce/Δtime) (Aagaard et al 2002). EMD was defined as the time interval between the onset of EMG and the onset of the force applied to the footplate (Muraoka et al 2004; Zhou et al 1996).
All statistical analyses were performed using the SPSS 15 software (SPSS, Inc., Chicago, IL). Initially a 1-way ANOVA was applied to the baseline data to determine if differences between the groups (WBV, No-WBV) existed. Next, a 2 x 2 (group by test) mixed design ANOVA was applied to the RFD and EMD data. Descriptive data are reported as mean ± standard deviation (SD).

Results

The two groups were equivalent at baseline (Table 1). The 2 × 2 ANOVA showed a significant group × test interaction for RFD (p=.003). However, the evaluation of the interaction revealed that the differences between the means in the vibration group and the control group were not statistically significant [pre (p=.329) and post (p=.876)] (Table 2). After acute WBV exposure, RFD increased by about 15.6% (from 274.13 N/sec to 323.03 N/sec) in the WBV group (Figure 3)

	WBV (n=20)	No-WBV (n=20)	
	Pre	Pre	***P***
RFD (N/sec)	274.13 ± 137.77	318.41 ± 145.42	*P=.329*
EMD (ms)	23.42 ± 7.54	21.25 ± 7.63	*P=.371*

Table 1: Comparison of group differences for the baseline values of EMD and RFD

	WBV (n=20)		No-WBV(n=20)	
	Pre	Post	Pre	Post
RFD (Nm/sec)	274.13 ± 137.77	323.02 ± 161.98	318.41 ± 145.42	315.54 ± 137.99
EMD (ms)	23.42 ± 7.54	19.3 ± 8.08	21.25 ± 7.63	21.11 ±6.49

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

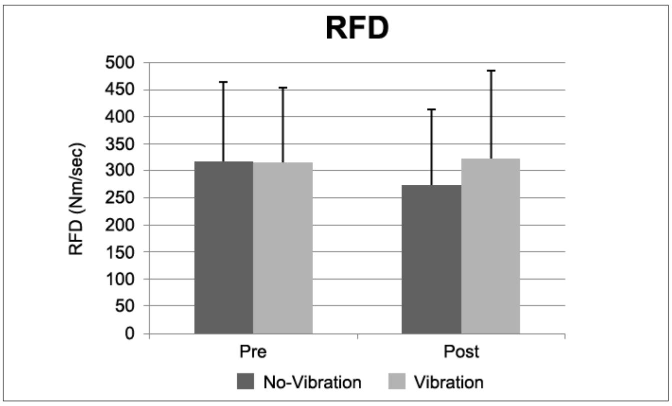

Figure 3: Mean and standard deviation (SD) of the RFD before and after three bouts of 2 minutes WBV training in the WBV group and the No-Vibration group. In WBV group, there is a 15.6% increase between pre and post-test.

The 2 × 2 ANOVA showed a significant group × time interaction for EMD (p=.002). However, the evaluation of the interaction revealed no significant differences between the means in the vibration group and the control group at either testing time [pre (p=.371) and post (p=.438)]. EMD decreased by about 16% (from 23.42 ms to 19.3 ms) in the WBV group (Figure 4).

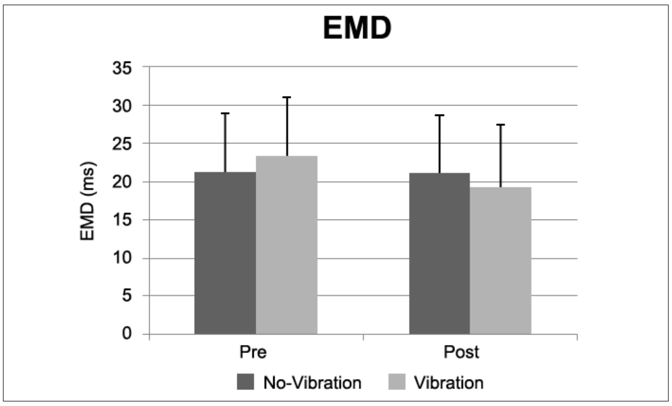

Figure 4: Mean and standard deviation (SD) of the EMD before and after three bouts of 2 minutes WBV training in the WBV group and the No-WBV group. EMD decreased by about 16% (from 23.42 ms to 19.3 ms) in the WBV group.

Discussion

The aim of this study was to examine changes in the neuromuscular properties of soleus muscle in young healthy individuals after three bouts of 2-minutes WBV. To assess neuromuscular function of the soleus, rate of force development (RFD) and electromechanical delay (EMD) were tested. Our results indicated that the WBV protocol used in the present study increased RFD and decreased EMD during isometric contractions; no changes were observed in the control group.

Increased rate of force development (RFD)

The RFD has functional significance in fast and forceful muscle contraction and any increase in RFD is important as it allows reaching a higher level of muscle force in the early phase of muscle contraction (Aagaard et al 2002).

The findings of this study demonstrated that following three bouts of 2 minutes WBV, maximal rate of force development (RFD) increased by about 15.6% (from 274N/sec to 323 N/sec) in the WBV group whereas maximum RFD remained unchanged (318 N/sec to 315 N/sec after 4 weeks of study period) in the control group. In our study, RFD is defined as the slope in the force time curve (Δforce/Δtime). (Gruber and Gollhofer 2004)

It has been documented that the effects of WBV on functional muscular performance is similar to the effects of resistance training (Torvinen et al 2002a; Torvinen et al 2002b) and that the first adaptation mechanism of a skeletal muscle to resistance training is neural (Torvinen et al 2002a; Torvinen et al 2002b). Previous studies suggested that WBV improved power (Bosco et al 2009; Bosco et al 2000) and force generating capacity in lower limbs (Bosco et al 2009; Torvinen et al 2002a; Torvinen et al 2002b). Although changes in RFD after acute WBV in the present study may be due to neural adaptation, to date since there are few data available on the effects of acute WBV on the contractile rate of force development or the exact mechanism by which acute exposure to WBV can enhance neuromuscular activation or muscular performance.

During a whole body vibration, skeletal muscles undergo small changes in muscle length, most likely because mechanical vibration is able to induce a tonic excitatory influence on the muscles (Seidel 1988). It has been shown that vibration elicits tonic vibration reflex (TVR) including activation of muscle spindles, mediation of the neural signals by Ia afferents (Hagbarth et al 1976). TVR is also known to affect the subjects' ability to generate high firing rates in high-threshold motor units (Bongiovanni, Hagbarth and Stjernberg 1976). In addition, it has been demonstrated that the recruitment threshold of the motor units during WBV are expected to be lower compared with voluntary contractions, possibly resulting in a more rapid activation (Romaiguere, Vedel and Pagni 1993; Bongiovanni and Hagbarth 1990). From these findings, we infer that the RFD changes in the present study may be due to the effects of tonic vibration reflex on the recruitment threshold of motor units.

As a contributing factor, the increase in the sensitivity of the stretch reflex is known to be related to the acute enhancement of neuromuscular performance after WBV (Cardinale and Pope 2003). Considering that attenuation of stretch reflex is a common finding after demanding exercise, the maintained or increased stretch reflex amplitude observed after WBV seems most likely due to an enhanced central motor excitability, particularly with respect to the fast twitch fibers and motor units (Rittweger, Mutschelknauss and Felsenberg 2003). Shinohara et al. (2005) demonstrated a significant increase in stretch reflex amplitude and motor unit discharge rate after prolonged muscle vibration, and indicated that the increased stretch reflex depends on the sensitivity of the muscle spindles, which is determined by the level of gamma motor neuron activity (Shinohara et al 2005). Although the stretch reflex was not assessed in the present study, since maximal force is closely related to the RFD, enhancement of stretch reflex can be considered as a possible explanation for the changes in RFD observed in our study.

Among many different physiological factors thought to contribute to the changes in RFD, the spinal adaptation caused by training has been discussed as a possible mechanism for enhancing RFD. Gruber and Golhoffer (2004) suggested that increased frequency, earlier recruitment as well as improved synchronization could be related to an excitatory modulation of the spinal motoneuron pool. Holtermann et al. (2007) reported that the modulation of motor unit recruitment and discharge rate with training involve an enhanced synaptic excitatory input to the motoneuron pool or increased motoneuron excitability (Holtermann et al 2007). It has been suggested that the contributing intrinsic neural mechanism for the improvement in muscle function after WBV training might be due to vibration induced presynaptic inhibition (Romaiguere, Vedel and Pagni 1993; Bongiovanni and Hagbarth 1990; Rittweger, Beller and Felsenburg 2000). This could be another important neural mechanism for the RFD changes in the present study. Capaday and Stein (1987) suggested that the neural modulation of presynaptic inhibition pathways affects the recruitment of motor units for voluntary movements (Capaday and Stein 1987). In addition, Kukulka and Calmann (1981) reported that the enhanced excitatory synaptic input or motoneuron excitability with training causes high-threshold motor units to be recruited earlier in a maximal voluntary contraction (MVC) increasing RFD, whereas recruitment of additional motor units ends before maximal tension (Kukulka and Clamann 1981). From the above findings, we suggest that the change in RFD after acute WBV observed in the present study may have occurred by neural modulation potentially involving alterations in recruitment threshold, stretch reflex, or presynaptic inhibition (Aagaard et al 2002).

Although the present study did not include the measures of acute change in presynaptic inhibition after WBV training, it has been suggested that the contributing intrinsic neural mechanism for the improvement in muscle function after WBV training might be due to vibration induced presynaptic inhibition (Romaiguere, Vedel and Pagni 1993; Bongiovanni and Hagbarth 1990; Rittweger, Beller and Felsenburg 2000). Furthermore, the neural modulation of presynaptic inhibition pathways is known to affect the recruitment of motor units for voluntary movements (Capaday and stein 1987). Further research is needed to test the hypothesis that WBV exercise interacts with spinal reflex loops and possibly influences these pathways, and examine how this spinal mechanism is related to the improvement in muscle function caused by WBV.

A shortened electromechanical delay with WBV

In this study electromechanical delay was defined as the lag time between the beginning of the soleus muscle activation and the beginning of the plantar flexion torque.

To identify possible explanations for the changes observed in the present study, it is important to isolate factors that influence EMD including the maximal voluntary contraction force, rate of force development, muscle fiber types, muscle spindle sensitivity and stiffness of series elastic components (SEC) of the muscle.

Regarding the change in EMD observed in the study, there are several possible mechanisms that may explain how acute WBV can increase the sensitivity of muscle spindles and muscle stiffness. The primary endings of muscle spindles are more sensitive to vibration than are the secondary endings and golgi tendon organs. Vibration is perceived not only by neuromuscular spindles, but also by the skin, the joints, and secondary endings (Torvinen et al 2002a; Torvinen et al 2002b). Consequently, during application of WBV these sensory structures likely facilitate the gamma system and enhance the sensitivity of the primary endings of the muscle spindles (Cardinale and Bosco 2003). It has been shown that the tonic vibration reflex induces a sensitization of the muscle spindles and increases facilitation of the reflex action on the motoneuron pool (Romaiguere, Vedel and Pagni 1993).

Cardinale and Bosco (2003) reported that when muscles are vibrated, muscle spindle sensitivity and muscle stiffness increase to dampen the vibration. WBV causes fast joint rotation and muscle stretching which is likely to increase muscle stiffness through activation of both alpha and gamma sensory motoneuron (Shinohara et al 2005). To better understand the mechanism of WBV on muscle stiffness, the response of musculotendinous units to WBV has been examined (Nigg and Wakening 1985). Nigg and Wakening (1985) demonstrated that impact forces during running produce vibration, which are transmitted to the body at a frequency between 10 and 20 Hz. The study found that the soft tissues of the lower limbs damp the vibrations coming from heel contact, changing their stiffness. The adjustment of the stiffness of the lower limbs is not only based on the sensory receptors in muscles, but also in the joints, ligaments, and in the skin (Nigg and Wakening 1985). This mechanism called "muscle tuning," may be the adaptive response to the acute application of WBV, resulting in the changes in EMD.

Another factor that may have contributed to the EMD changes in the present study is based on the mechanism that the vibration effect would be larger in the posture in which the receptor-bearing muscle is more preactivated. Roelants et al. (2006) have noted that elongated muscles or an increased muscle length or increased degree of preactivation seemed to be most affected by vibration (Roelants et al 2006). In addition, Burke et al. (1976) suggested that even a small increase in preactivation may lead to increased muscle spindle sensitivity because of alpha-gamma co-activation which is known to increase the muscle stiffness (Burke et al 1976). The findings of this study showed a substantial decrease in electromechanical delay after acute WBV. However, as no studies have yet investigated the effects of acute WBV on EMD of the soleus muscle in healthy subjects, the exact mechanism responsible for this change remains unknown. Future studies should investigate how EMD is affected by the physiological factors suggested to contribute to the changes in electromechanical response of the muscle (muscle stiffness, muscle spindle sensitivity, muscle fiber types, muscle length, muscle preactivation, etc.).

Conclusion

The present study clarifies the impact of whole body vibration training on neuromuscular adaptation. Acute treatment with whole body vibration (WBV) so far has been shown to elicit adaptive changes primarily in the muscle function. The present study indicated that acute WBV positively influences the speed of neuromuscular activation, which can be beneficial for the explosive type of muscular activation. Further research is needed to investigate the parameters of vibration exercise duration, frequency, amplitude, and load that are optimum to evoke enhanced neuromuscular function in various populations including young adults, athletes, elderly subjects and clinical patients.

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