Neuromuscular Activity During Whole-Body Vibration of Different Amplitudes and Footwear Conditions: Implications for Prescription of Vibratory Stimulation

Pedro J. Marín,[1,2] Derek Bunker,[1] Matthew R. Rhea,[1] and Fernando N. Ayllón[2]

[1]*A.T. Still University, Mesa, Arizona; and* [2]*European University of Madrid, Madrid, Spain*

Abstract

Marín, PJ, Bunker, D, Rhea, MR, and Ayllón, FN. Neuromuscular activity during whole-body vibration of different amplitudes and footwear conditions: implications for prescription of vibratory stimulation. *J Strength Cond Res* 23(8): 2311–2316, 2009—This study investigated the magnitude of whole-body vibration (WBV) at 30 Hz induced in surface electromyography root-mean-square (EMGrms) signals of different amplitudes and footwear conditions of unloaded isometric half squat (100°). For this purpose, 10 healthy and active males (age 28.7 ± 4.6 yr; height 180 ± 5.9 cm; and weight 90 ± 13.4 kg) volunteered to participate in this study. Subjects were exposed to the WBV treatment using a vibration platform (FreeMotion Fitness iTonic). The subjects were exposed randomly to 4 different treatments of WBV: with shoes 2 mm amplitude, without shoes 2 mm, with shoes 4 mm, and without shoes 4 mm. The EMGrms signals were recorded from the vastus lateralis and the gastrocnemius medialis muscle during the different conditions. The WBV treatments resulted in a significantly higher ($p \leq 0.05$) EMGrms compared with unloaded isometric half squat (without WBV). The WBV treatment that induced the highest EMGrms signals of the vastus lateralis was during the amplitude of 4 mm without shoes (+62.7%; $p < 0.01$), whereas 4 mm with shoes induced the highest EMGrms signals of the gastrocnemius medialis (+142.7%; $p < 0.01$). These data suggest that wearing shoes does alter the neuromuscular response to WBV stimuli, and exercise professionals should consider such differences when using WBV to target neuromuscular activation of such muscle groups. In this study, the magnitude of the WBV effect was clearly higher with the amplitude 4 mm versus 2 mm for the vastus lateralis muscle and gastrocnemius medialis muscle. The vastus lateralis showed the greatest activity without shoes and at amplitude of 4 mm. The maximal activation for the gastrocnemius medialis was measured with shoes at 4 mm.

Key Words electromyography, vibrations, shoes, squat

Introduction

Whole-body vibration (WBV) exercise has been used among healthy people, athletes, as well as in spinal cord injury patients (3,4,6,21,26). Mechanical vibrations applied to the muscle or tendon stimulates sensory receptors, and activation of muscle spindles facilitates the activations of alpha-motoneurons, leading to tonic vibration reflex (9,14). Studies on vibration have shown transient increases in muscle power output (4), strength enhancement (10), an increase in speed (23), and volume of blood flow (17,27).

These effects, however, are strongly dependent on the type and duration of vibration parameters (16,22). Whole-body vibration is applied through a vibration platform that evokes a mechanical oscillation that can be defined by frequency and amplitude (19). The frequency is measured in the unit of hertz (Hz; cycles/s) that shows oscillations ranging from 15 to 60 Hz (7). Peak to peak amplitude or displacement is defined as the difference between the maximum and the minimum value of periodic oscillation, and on the other hand, amplitude is defined as half the difference between the maximum and the minimum value of the oscillation (11). Amplitude is currently marked ranging from 1 to 15 mm (7). The frequencies have been analyzed using electromyography root mean square (EMGrms) of the vastus lateralis with different frequencies (30, 40, and 50 Hz), showing that the highest EMGrms is found at 30 Hz, suggesting this frequency as the one eliciting the highest response in vastus lateralis muscle during WBV in the half-squat position (6). Other authors have analyzed leg muscle activity during WBV training at 35 Hz on high squat (HS), low squat (LS), and 1-legged squat (OL). The results showed significantly higher activity in OL compared with HS and LS (25). So far, only

Address correspondence to Pedro J. Marín, PedroJM80@hotmail.com; Pjmarin@uemc.es

23(8)/2311–2316

Journal of Strength and Conditioning Research

a recent study has reported basic EMG recordings during WBV vibration at different amplitudes 2 mm versus 4 mm on the vastus lateralis, the biceps femoris, the biceps brachii, and the triceps brachii. This study showed the greatest increase in EMG activity was elicited by 4 mm amplitude (15).

One factor to be considered is the wearing of athletic footwear during platform-based WBV. Athletic shoes absorb part of the vertical impact during physical activity (2,18,20,24). Studies have shown that the use of athletic shoes induced significant improvement of strength, countermovement jump, and flexibility (5,13). Other studies in which subjects did not wear athletic shoes during WBV training induced a significant increase of the neuromuscular activation of the vastus lateralis, the biceps femoris, the gastrocnemius, and the tibialis anterior (1), as well as the tendency of an increase in salivary concentration of cortisol after WBV (12).

This study investigated the magnitude of increased EMGrms during WBV at 30 Hz during different conditions of unloaded isometric half squat: with and without athletic shoes with 2 mm amplitude and with and without athletic shoes with 4 mm amplitude.

Methods

Experimental Approach to the Problem

To address the question put forward in the introduction, this study analyzed the vastus lateralis and gastrocnemius medialis activity during WBV training at 30 Hz while subjects performed 4 standard unloaded isometric exercises (independent variables). With and without athletic shoes with 2 mm amplitude and with and without athletic shoes with 4 mm amplitude were recorded through use of surface EMGrms (dependent variable). For comparison, muscle activation during unloaded isometric half squat without WBV (control) was recorded.

Subjects

Ten healthy, active males (age 28.7 ± 4.6 yr; height 180 ± 5.9 cm; and weight 90 ± 13.4 kg) volunteered to participate in this study. The footwear that was worn during the study included running shoes (3), basketball shoes (2), and tennis shoes (4). Exclusion criteria included history of several musculoskeletal problems, epilepsy, or acute hernia. Full advice was given to the subjects regarding the possible risk and discomfort that might be involved, and the subjects gave their written informed consent. The study was approved by the University's Human Ethics Committee according to the Declaration of Helsinki.

EMG Analysis

The surface EMGrms signals (Noraxon Myosystem 1200, Scottsdale, AZ, USA) from the vastus lateralis and the gastrocnemius medialis muscle of the right leg were recorded bipolarly by disposable 20-mm disc electrodes (Ag/AgCl). Before electrode placement, the skin was shaved and cleansed with alcohol. The electrodes were fixed lengthwise over the middle of the muscle belly with an interelectrode distance of 25 mm. The pre-amplified EMGrms signals were amplified (×1,000), bandpass filtered (15 Hz–10 kHz), and sampled at 2.000 Hz for off-line analysis. A ground electrode was placed over the perone tuberosity. Electromyography cables were fastened to prevent the cables from swinging and for movement artifact.

Treatment Protocol

Subsequent to the positioning of the electrodes, the experimental session started with a standardized warm-up consisting of 5 minutes of cycling on an ergometer without resistance. Subjects were exposed to the vertical sinusoidal WBV treatment (WBV) using a vibration platform (Free-Motion Fitness iTonic, Colorado Springs, CO, USA). The

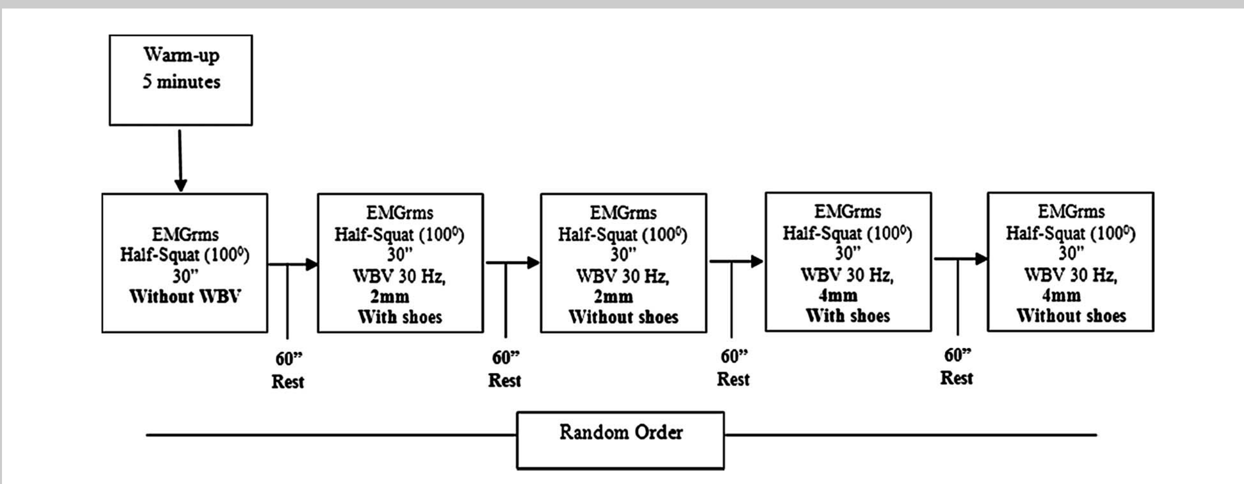

Figure 1. Study design.

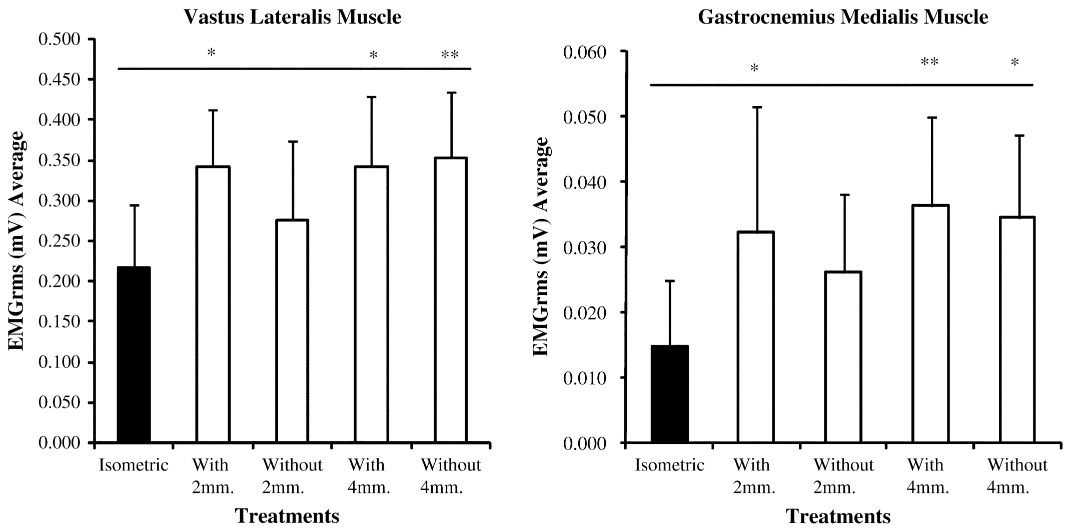

Figure 2. Mean ± *SE* of EMGrms activity of vastus lateralis muscle (left) and gastrocnemius medialis muscle (right) at different half-squat conditions, without WBV (Isometric), and with WBV: 2 mm amplitude with shoes (With 2 mm.), 2 mm amplitude without shoes (Without 2 mm.), 4 mm amplitude with shoes (With 4 mm.), and 4 mm amplitude without shoes (Without 4 mm.). ($n = 10$). Significant difference from baseline value ** = $p < 0.01$; * = $p \leq 0.05$.

frequency used was maintained at 30 Hz throughout all conditions, and the amplitudes used were 2 and 4 mm. The subjects were exposed to 4 different WBV conditions: 1) with shoes 2 mm, 2) without shoes 2 mm, 3) with shoes 4 mm, and 4) without shoes 4 mm. Each vibration treatment was for 30 seconds, with 60 seconds of rest allowed between each WBV treatment. The sequence of the conditions was randomly applied to avoid any sequential affect. The subjects were asked to stand in half-squat position on the vibration platform (100°) as indicated in previous studies (4–6). The EMGrms signal was collected from the vastus lateralis and the gastrocnemius medialis during the 30-second duration of the testing position. A total of 5 sets lasting 30 seconds each were performed with 60 seconds of rest between sets allowed.

Electromyography root mean squares were recorded for 5 seconds before starting the vibration treatment to verify the absence of residual muscle activity. All treatments were applied in random order in both the no WBV (control) and with WBV conditions. The subjects then performed the isometric half squat in the following conditions: no WBV, 2 mm with shoes, 2 mm without shoes, 4 mm with shoes,

Table 1. Mean ± *SE* of electromyography root-mean-square (EMGrms) activity of vastus lateralis (VL) muscle and gastrocnemius medialis (GM) muscle at different half-squat conditions, without whole-body vibration (WBV; isometric), and with WBV: 2 mm amplitude with shoes (with 2 mm), 2 mm amplitude without shoes (without 2 mm), 4 mm amplitude with shoes (with 4 mm), and 4 mm amplitude without shoes (without 4 mm) ($n = 10$).

	VL average		GM average	
	EMGrms (mV)	Effect size (*d*)	EMGrms (mV)	Effect size (*d*)
Isometric	0.217 ± 0.078		0.015 ± 0.01	
With 2 mm	0.341 ± 0.071	1.59	0.032 ± 0.019*	1.70
Without 2 mm	0.276 ± 0.097	0.76	0.026 ± 0.012	1.10
With 4 mm	0.342 ± 0.086*	1.60	0.036 ± 0.014†	2.10
Without 4 mm	0.353 ± 0.081†	1.74	0.035 ± 0.013*	2

Significant difference from baseline value (without WBV, isometric); *$p \leq 0.05$; †$p < 0.01$. Effect size (*d*) difference from baseline value (without WBV, isometric).

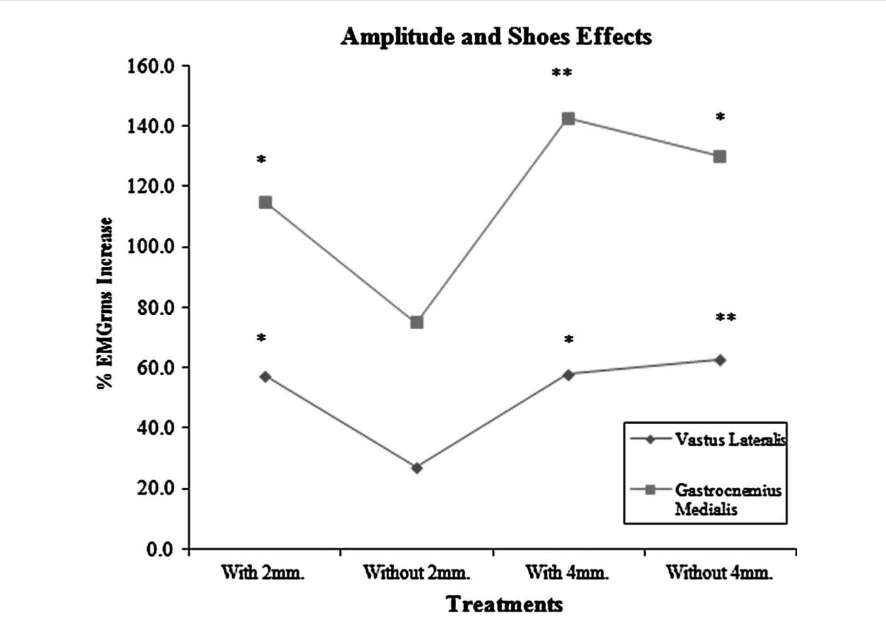

Figure 3. Percent increase above baseline (half-squat without WBV) EMGrms during 2 mm amplitude with shoes (With 2 mm), 2 mm amplitude without shoes (Without 2 mm), 4 mm amplitude with shoes (With 4 mm), and 4 mm amplitude without shoes (Without 4 mm) conditions. ($n = 10$) ** = $p < 0.01$; * = $p \leq 0.05$.

and 4 mm without shoes vibration amplitude (Figure 1). The EMGrms value compared with the equivalent baseline (no WBV) half-squat conditions, normalization relative to maximal voluntary contractions, was unnecessary as indicated in previous studies (1,6). All subjects familiarized themselves with the different treatments before testing.

Statistical Analyses

All analyses were performed using a specialized statistical software package (StatistiXL, Statistical Power, Broadway-Nedlands, Australia) for MS Excel, Version 1.8. Average EMGrms values for the vastus lateralis and the gastrocnemius medialis were considered for analysis. Before statistical analysis, data were found to be normally distributed (Shapiro-Wilk test), and therefore the analysis was carried out using parametric statistical tests. To analyze differences in EMGrms between treatments, a repeated-measures analysis of variance was computed to identify significant differences for the dependent variable. Significant F values were followed by a Tukey post hoc test to determine the exact sites of statistical significance. The level of significance was set at $p \leq 0.05$. Effect sizes were analyzed to determine the magnitude of an effect independent of sample size. Coheńs effect sizes (d) were measured by the formula:

Coheńs $d = M_2 - M_1/\sigma$

Small effect sizes are considered $d \leq 0.2$, *moderate* effect sizes are $0.2 < d < 0.8$, and *large* effects sizes are $d \geq 0.8$ (8).

Figure 4. EMGrms activity by subject of vastus lateralis muscle (VL) and gastrocnemius medialis muscle (GM) at different half-squat conditions, without WBV (Isometric), and with WBV: 2 mm amplitude with shoes (With 2 mm.), 2 mm amplitude without shoes (Without 2 mm.), 4 mm amplitude with shoes (With 4 mm.), and 4 mm amplitude without shoes (Without 4 mm.). ($n = 10$).

Results

Vastus Lateralis Muscle

The EMGrms activity was higher with the WBV conditions compared with half squat without WBV ($p < 0.01$). Figure 2 and Table 1 represent the muscle activity of the vastus lateralis during different treatments: isometric (no WBV), 2 mm with shoes, 2 mm without shoes, 4 mm with shoes, and 4 mm without shoes vibration amplitude. Contrast analyses clarified a significant ($p < 0.01$) WBV-induced increase in EMGrms activity during the 4 mm without shoes amplitude (+62.7%) and a significant ($p \leq 0.05$) WBV-induced increase during the 4 mm with shoes WBV (+57.8%). A significant ($p \leq 0.05$) WBV-induced increase occurred during the 2 mm with shoes WBV (+57.3%) compared with no WBV (Figures 3 and 4). The WBV effect 2 mm without shoes was not significantly different; nevertheless, this treatment was of *moderate* effect sizes ($d = 0.76$) (Table 1). On the other hand, no significant difference resulted when the WBV conditions were compared with each other.

Gastrocnemius Medialis Muscle

The EMGrms activity of gastrocnemius medialis was higher in the WBV conditions compared with half squat without WBV ($p < 0.01$) (Figure 2 and Table 1). Contrast analyses clarified a significant ($p < 0.01$) WBV-induced increase in EMGrms activity 4 mm without shoes amplitude (+130%) and a significant ($p \leq 0.05$) WBV-induced increase in 4 mm with shoes WBV (+142.7%) and also a significant ($p \leq 0.05$) WBV-induced increase in 2 mm with shoes WBV (+114.9%) (Figure 3 and Figure 4). The WBV effect during the 2 mm without shoes was not significantly different; nevertheless, it had a *large* effect size ($d = 1.10$) (Table 1). No significant difference was noted when the WBV conditions were compared with each other.

Discussion

This is the first study that analyzes the effect of wearing athletic shoes to different amplitudes (2 and 4 mm) on the WBV-induced increase in EMGrms activity of the leg muscles during an unloaded isometric half squat. In this study, the magnitude of the WBV effect was clearly higher with the amplitude 4 mm versus 2 mm for the vastus lateralis muscle and gastrocnemius medialis muscle, such as also reported Hazell et al. (15). When analyzing the EMGrms of the vastus lateralis, wearing shoes showed no conclusive changes with the different amplitudes of 2 versus 4 mm (+57.3% vs. + 57.8%, respectively). Without shoes, there were greater changes, depending on the amplitude, 2 versus 4 mm (+27.2% vs. + 62.7%, respectively). The vastus lateralis showed the greatest activity without shoes and at amplitude of 4 mm. Thus, if high activation of the vastus lateralis is wanted, then the training process needs to be performed without shoes and at an amplitude of 4 mm. The gastrocnemius medialis responded to different amplitudes while wearing shoes at 2 versus 4 mm (+114.9% vs. +142.7%, respectively) and without shoes as well (+74.8% vs. +130%, respectively). The maximal activation for the gastrocnemius medialis was measured with shoes at an amplitude of 4 mm.

Cardinale and Lim (6) reported an increase of 34% in the vastus lateralis muscle EMGrms when subjects (professional women volleyball players) stood in an half squat (100°) on a platform vibrating at 30 Hz with a peak to peak amplitude of 10 mm (amplitude or displace = 5 mm). This increase is lower compared with a WBV-induced increase in the vastus lateralis muscle activity of 62.7% with 30 Hz and 4 mm amplitude without shoes in the present study. It is reasonable to accept that this difference in the vibration effect may be caused by the differences of subjects (professional women volleyball players vs. active males) or the different conditions (shoes vs. without shoes).

However, Roelants et al. (25) found a greater increase compared with our data. Roelants et al. reported WBV-induced increase in the vastus lateralis and the gastrocnemius medialis muscle activity of 92.5% and 301%, respectively. Both sets of data are higher than the present study, 92.5% versus 62.7% for vastus lateralis and 301% versus 142.7% for gastrocnemius medialis. These differences may be a result of different knee angles selected in the study design (100° vs. 125°) and in differences in vibration frequency (30 vs. 35 Hz).

Nonetheless, Abercromby et al. (1), using the same frequency and amplitude as in the present study, reported data similar to ours, WBV-induced increases in vastus lateralis and gastrocnemius medialis muscle activity of 77% and 132%, respectively. Nevertheless, in all these studies, a high increase in EMGrms activity during WBV has been shown.

On the other hand, the vibration effect was clearly dependent on the distance between the muscle and the vibration platform, as also reported in several studies (1,25). For example, with an amplitude of 4 mm while wearing shoes, the relative WBV induced in EMGrms activity of gastrocnemius medialis muscle was clearly higher (142.7%) when compared with vastus lateralis muscle (57.8%). In addition, the gastrocnemius medialis has shown to have more variation for amplitude and footwear changes than the vastus lateralis.

The mechanism by which athletic shoes alter the response to WBV is somewhat speculative. One theory involves a potential change in the amplitude and frequency of the actual vibration when the stimulus is absorbed by the sole of the shoe. If the sole is very pliable, more dampening of the vibration would be expected, and a different amplitude of movement would be transferred to the body. In addition, especially with running shoes, shoe soles increase the surface area of the foot that is in contact with the platform surface. This increase may enhance the amount of vibration transferred into the body and thus alter the optimal frequency and amplitude needed to elicit the greatest muscle activity. Such mechanisms would require greater research to confirm or reject. In addition, further studies are required to analyze the acute and chronic affects of different WBV amplitudes, frequencies, and conditions in different individuals (e.g., high vs. low performance).

Practical Applications

To increase the activation of the vastus lateralis and the gastrocnemius medialis, it is proposed that the trainer/therapist have the individual in training begin the use of the WBV platform while in an unloaded, isometric half squat. For progression in training, the individual can begin using the WBV training at the 2 mm without wearing athletic footwear. The next step in the progression would be to keep the WBV setting at a 2 mm while wearing footwear. The final step in this training progression is to set the WBV stimulus at 4 mm while having the individual alternate from wearing shoes to removing the footwear. This approach would present variation in stimulus. However, if an individual has a foot condition (e.g., over-pronation, orthotics, etc.), then it is proposed that correct athletic footwear is worn while in the half squat position on the WBV platform.

References

1. Abercromby, AF, Amonette, WE, Layne, CS, Mcfarlin, BK, Hinman, MR, and Paloski, WH. Variation in neuromuscular responses during acute whole-body vibration exercise. *Med Sci Sports Exerc* 39: 1642–1650, 2007.
2. Barnes, RA and Smith, PD. The role of footwear in minimizing lower limb injury. *J Sports Sci* 12: 341–353, 1994.
3. Bosco, C, Cardinale, M, and, Tsarpela, O. Influence of vibration on mechanical power and electromyogram activity in human arm flexor muscles. *Eur J Appl Physiol Occup Physiol* 79: 306–311, 1999.
4. Bosco, C, Colli, R, Introini, E, Cardinale, M, Tsarpela, O, Madella, A, Tihanyi, J, and Viru, A. Adaptive responses of human skeletal muscle to vibration exposure. *Clin Physiol* 19: 183–187, 1999.
5. Bosco, C, Iacovelli, M, Tsarpela, O, Cardinale, M, Bonifazi, M, Tihanyi, J, Viru, M, De Lorenzo, A, and Viru, A. Hormonal responses to whole-body vibration in men. *Eur J Appl Physiol* 81: 449–454, 2000.
6. Cardinale, M and Lim, J. Electromyography activity of vastus lateralis muscle during whole-body vibrations of different frequencies. *J Strength Cond Res* 17: 621–624, 2003.
7. Cardinale, M and Wakeling, J. Whole body vibration exercise: are vibrations good for you? *Br J Sports Med* 39: 585–589, 2005.
8. Cohen, J. *Statistical Power Analysis for the Behavioral Sciences* (2nd ed). Hillsdale, NJ: Erlbaum, 1988.
9. De Cuyper, H. The tonic vibration reflex. *Acta Belg Med Phys* 8: 41–46, 1985.
10. Delecluse, C, Roelants, M, and Verschueren, S. Strength increase after whole-body vibration compared with resistance training. *Med Sci Sports Exerc* 35: 1033–1041, 2003.
11. Dimarogonas, A. *Vibration for Engineers* (2nd ed). London: Prentice Hall International, 1996.
12. Erskine, J, Smillie, I, Leiper, J, Ball, D, and Cardinale, M. Neuromuscular and hormonal responses to a single session of whole body vibration exercise in healthy young men. *Clin Physiol Funct Imaging* 27: 242–248, 2007.
13. Fagnani, F, Giombini, A, Di Cesare, A, Pigozzi, F, and Di Salvo, V. The effects of a whole-body vibration program on muscle performance and flexibility in female athletes. *Am J Phys Med Rehabil* 85: 956–962, 2006.
14. Hagbarth, KE and Eklund, G. Tonic vibration reflexes (TVR) in spasticity. *Brain Res* 2: 201–203, 1966.
15. Hazell, TJ, Jakobi, JM, and Kenno, KA. The effects of whole-body vibration on upper- and lower-body EMG during static and dynamic contractions. *Appl Physiol Nutr Metab* 32: 1156–1163, 2007.
16. Issurin, VB and Tenenbaum, G. Acute and residual effects of vibratory stimulation on explosive strength in elite and amateur athletes. *J Sports Sci* 17: 177–182, 1999.
17. Kerschan-Schindl, K, Grampp, S, Henk, C, Resch, H, Preisinger, E, Fialka-Moser, V, and Imhof, H. Whole-body vibration exercise leads to alterations in muscle blood volume. *Clin Physiol* 21: 377–382, 2001.
18. Lake, MJ. Determining the protective function of sports footwear. Ergonomics 43: 1610–1621, 2000.
19. Luo, J, McNamara, B, and Moran, K. The use of vibration training to enhance muscle strength and power. *Sports Med* 35: 23–41, 2005.
20. McPoil, TG. Athletic footwear: design, performance and selection issues. *J Sci Med Sport* 3: 260–267, 2000.
21. Melchiorri, G, Andreoli, A, Padua, E, Sorge, R, and De Lorenzo, A. Use of vibration exercise in spinal cord injury patients who regularly practise sport. *Funct Neurol* 22: 151–154, 2007.
22. Mileva, KN, Naleem, AA, Biswas, SK, Marwood, S, and Bowtell, JL. Acute effects of a vibration-like stimulus during knee extension exercise. *Med Sci Sports Exerc* 38: 1317–1328, 2006.
23. Paradisis, G and Zacharogiannis, E. Effects of whole-body vibration training on sprint running kinematics and explosive strength performance. *J Sports Sci Med* 6: 44–49, 2007.
24. Robbins, S and Waked, E. Balance and vertical impact in sports: role of shoe sole materials. *Arch Phys Med Rehabil* 78: 463–746, 1997.
25. Roelants, M, Verschueren, SM, Delecluse, C, Levin, O, and Stijnen, V. Whole-body-vibration-induced increase in leg muscle activity during different squat exercises. *J Strength Cond Res* 20: 124–129, 2006.
26. Torvinen, S, Kannus, P, Sievänen, H, Järvinen, TA, Pasanen, M, Kontulainen, S, Nenonen, A, Järvinen, TL, Paakkala, T, Järvinen, M, and Vuori, I. Effect of 8-month vertical whole body vibration on bone, muscle performance, and body balance: a randomized controlled study. *J Bone Miner Res* 18: 876–884, 2003.
27. Yamada, E, Kusaka, T, Miyamoto, K, Tanaka, S, Morita, S, Tanaka, S, Tsuji, S, Mori, S, Norimatsu, H, and Itoh, S. Vastus lateralis oxygenation and blood volume measured by near-infrared spectroscopy during whole body vibration. *Clin Physiol Funct Imaging* 25: 203–208, 2005.