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Research article

The effect of whole-body vibration frequency and amplitude on the myoelectric activity of vastus medialis and vastus lateralis

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Abstract

The aim of this study was to evaluate the efficiency of training protocols for whole body vibration (WBV) training through the modulation of the frequency and amplitude of vibration. Despite the large number of studies regarding effects of such training, there is still lack of knowledge regarding optimum training protocols. The study analyzed the influence of whole-body vibration parameters (i.e., the frequency and amplitude) on the myoelectric activity of vastus lateralis and vastus medialis in 29 females with the use of electromyography (EMG). The first and second of the eight consecutive trials were performed without vibrations; the remaining six trials were performed in a randomized order on a platform vibrating at different amplitude (2mm and 4mm) and frequency (20 Hz, 40 Hz and 60 Hz) combinations. The results revealed significantly higher EMG amplitude of both muscles during the vibration as compared with the non-vibrated trials (trial 1 and 2). Furthermore, the EMG activity significantly increased both with the amplitude and frequency, being the highest when the frequency and amplitude of reached 60 Hz and 4 mm, respectively. The study aims to determine the optimal vibration parameters in the aspect of purposeful stimulation of chosen leg muscles. Based on the results of the presented investigation, sports trainers and physiotherapists may be able to optimize training programs involving vibration platforms.

Key words: EMG, vibration training, whole body vibration (WBV), muscle activity.

Introduction

Whole body vibration (WBV) devices have been primarily designed for professional athletes in order to increase strength capabilities of muscles (Cardinale and Bosco, 2003). It was also used in space programs as a way of preventing bone density and muscle tissue loss (Rittweger and Felsenberg, 2004). However, nowadays there are easy to find them in all major fitness and wellness centers. Existence of several hundred peer-reviewed published papers and the fact that the number of conducted research studies is growing every year could be an implicit evidence of great popularity of WBV training. Muscle strength and power increase, improved bone density, heightened secretion of hormones associated with exercises, falls prevention are only some of the effects of WBV reported in the literature (Bosco et al., 1999; 2000; Cardinale and Rittweger, 2006; Cormie et al., 2006; Jordan, 2005; Kawanabe et al., 2007; Paradisis and Zacharogiannis, 2007; Rittweger, 2001; 2002; Rubin et al., 2004; Wilcock et al., 2009; Verschueren et al., 2004). WBV can be also successfully used for warm up purposes (Kelly et al., 2010). However there are also a large number of reports showing no benefits or negative influence of vibration trainings (de Ruiter et al., 2003; Rittweger et al., 2000; Torvinen et al., 2002).

Whole-body vibration training can also stimulate the neuromuscular system (Bosco et al., 1999; Issurin and Tenenbaum, 1999). The physiological response of muscles exposed to vibration is a reflex contraction known as „tonic vibration reflex” (TVR) (Eklund and Hagbarth, 1966). The underlying mechanism involves the stimulation of the neuromuscular spindles by rapid and transient muscle stretching, which boosts the feedback of the myelinated Ia fibers (Eklund and Hagbarth, 1966; Eklund, 1973). Stimuli generated in the annulospiral endings are conveyed directly to the alpha motoneurons in the anterior horns of the spinal cord by the thick, fast-conducting myelinated fibers. Mechanical vibrations activate muscle's Ia endings that stimulate the alpha motoneurons and the muscle contracts, while, at the same time, the motoneurons of the antagonists are reciprocally inhibited (Eklund and Hagbarth, 1966). There are numerous reports that indicate positive training effects of vibration on human body performance (Bosco et al., 1999; 2000; Cardinale and Rittweger, 2006; Wilcock et al., 2009). Conversely, note that some studies have not proved the positive effects of vibration training on neuromuscular performance (Jackson and Turner, 2003; Kouzaki et al., 2000; Rittweger et al., 2000).

Most of the commercially available vibration platforms can modulate the acting frequency and amplitude. The literature reports ranges in vibration frequency from 15 to 60 Hz and the ranges in amplitude from 2 to 10 mm (Cardinale and Wakeling, 2005). However, the selective effects of different vibration-amplitude parameters are not clearly understood. Wide variety of frequencies, amplitudes and durations of exposure are used in different studies but, inevitably, not all of them were tested within the same protocols. Rittweger and co-workers (2000) compared exercise and cardiovascular data to progressive bicycle ergometry until exhaustion. Vibration training was performed in two vibration sessions, with a frequency of 26 Hz and amplitude of 1.05 cm on a ground plate, in combination with squatting plus additional load (40% of body weight). Kawanabe and co-workers (2007) investigated the effects of two month whole body vibration exercise on walking ability in the elderly. WBV exercise

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was performed on a platform at a frequency of 12-20 Hz for the duration of 4 minutes, once every week. Bosco and co-workers (1999) used a local vibration in order to evaluate its influence on the mechanical properties of arm flexors. The treatment consisted of five repetitions lasting 1 minute each of mechanical vibration with the frequency of 30 Hz and amplitude 6 mm. Vibration was applied during arm flexion in isometric conditions with one minute rest between them. Therefore, one could speculate that the inconsistency of research outcomes could be partly attributed to the inconsistency of the applied vibration parameters.

The outcome of different frequency-amplitude combinations can be assessed by means of electromyography (EMG) that records the myoelectric activity. Several studies have revealed an increased myoelectric activity of active muscles when exposed to vibration (Bosco et al., 1999; Cardinale and Lim, 2003; Roelants et al., 2006; Torvinen et al., 2002). Bosco and co-workers (1999) showed that vibrations at the frequency of 30 Hz and amplitude of 6 mm, applied locally to the biceps brachii muscle, doubled the muscle's myoelectric activity during elbow flexion. However, there are limited numbers of studies reporting effects of combined vibration parameters (i.e., both the amplitude and frequency). There is no accordance among results of existing studies. The study conducted by Cardinale and Lim (2003) showed decreased EMG amplitude along with the rise in the frequency. Due to the potential importance of the discussed phenomenon and observed inconsistencies in the literature, the study was performed where the effects of different amplitudes and frequencies of the whole body vibration were evaluated. It is hypothesized that the highest myoelectric activity would be obtained at the highest possible combination of amplitude and frequency. Cardinale and Lim (2003) report that vibrations compared with isometric conditions produce higher myoelectric activity, therefore it is likely to enhance the effect of interventions aimed to improve the efficiency of the neuromuscular system. The aim of this study was to indicate the optimal choice of vibration training parameters; therefore the expected findings could be of considerable importance for the routine of sports training and various therapeutic procedures.

Methods

Participants

Twenty-nine female students from the Academy of Physical Education in Katowice volunteered to participate in the experiment. Their average age, height and weight were respectively (mean ± SD): 21.8 ± 1.2 years, 1.67 ± 0.06 m, 58 ± 1.2 kg. They reported no physical, skeletal or neurological disorders and none of them was an active athlete. An informed consent was obtained from each subject prior to their participation in the experiment. All employed methods, plan and scope of the experiment were accepted by the Institutional Review Board of the Academy of Physical Education in Katowice.

Procedures

The experimental procedure consisted of 8 trials, during which EMG recordings were performed. Each trial lasted 30 seconds. Based of the experiences of the previous studies (de Ruiter et al., 2003; Martin and Park, 1997) there was 2 minutes break between trials. Additionally, during the pilot study subjects subjectively reported that it was enough for recovery. There was one trial (T1) for recording the background EMG activity in relaxed position (laying supine). In order to induce an initial muscles' activity during the following seven trials subjects assumed the same position, which was standing with their knees and hips joints flexed to 90° while their arms were stretched horizontally in front of them. Thus, one could observe an additional muscles activity caused by the vibration which superimposed muscle activity triggered by the assumed position. Another reason of the chosen position was subjects' safety. Knees' semi flexion prevent from transmission of vibrations to the head (Cardinale and Wakeling, 2005). Trials in standing position were performed either without (T2) or with (T3-T8) vibration. In order to show wide range of possible muscle reactions, specific combinations of amplitude and frequency, available with the used platform, were applied. They were the following: 2 mm/20 Hz (T3), 2 mm/40 Hz (T4), 2 mm/60 Hz (T5), 4 mm/20 Hz (T6), 4 mm/40 Hz (T7), 4 mm/60 Hz (T8). Due to the fact that vibration below 20 Hz applied to the human body brings about mechanical resonance which could be harmful for the internal organs, lower frequencies were not applied (Mester et al., 2006). The order of trials was fully randomized. The training was conducted with the use of Fitvibe 600 platform (Gymna Uniphy, NV). The platform produced vertical vibrations with a possible choice of two different amplitudes (2 mm, 4 mm) and three different frequencies (20 Hz, 40 Hz and 60 Hz) from the range between 20-60 Hz.

Electromyography

The recordings of the myoelectric activity were performed by means of POCKET EMG (BTS, Italy) which is a portable unit for collecting and transmitting data wirelessly to the computer. The sampling frequency of 1000 Hz was used. Preamplifiers placed next to the measuring electrode allowed to rule out the influence of likely movements of the wires on the measurement. Bipolar surface EMG electrodes (Al/AgCl, discs of 10 mm diameter) were placed on the bellies of the vastus lateralis (VL) muscle and the vastus medialis (VM) muscle of the right leg in accordance with SENIAM recommendations (Hermens et al., 1999). An inter-electrode centre-to-centre distance of 20 mm was used to limit the pick-up area. The reference electrode was placed at the lateral ankle. Before the electrodes were attached, subjects' skin was cleaned of dead epidermis with abrasive paste and then defatted.

After the acquisition, the raw data was further processed by means of the SMART Analyzer software (BTS, Italy). There were the following steps undertaken in the process of EMG signal analysis: filtering with bandpass filter (4th order Butterworth filter of 20-400 Hz); the root mean square method (RMS) (Soderberg and Knutson, 2000) was used with moving time window (100ms) for whole 30 seconds trial. The mean value of RMS (RMSemg) in static conditions, in which the trials were conducted, indicates the level of constant mean electrical activity of the selected muscle group. The signal's mean value (RMSemg) was used for further analysis. Signal sensitivity, as well as the amplification was kept constant, thus ensuring measurement range within ±5 mV.

Statistical analyses

Prior to all calculations the standard descriptive statistics were performed. A one-way within-subjects multivariate analysis of variance (MANOVA) with repeated measures was used to compare the myoelectric activity of VM and VL during vibration and non-vibration trials. A two-way within-subjects multivariate analysis of variance (MANOVA) with repeated measures with factors (amplitude (2) and frequency (3)) was used to analyze the effect of different amplitudes and frequencies of vibration training. The Bonferroni's post hoc analyses were used for further comparisons within the testing conditions. The level of significance was set at $p < 0.05$.

Results

Non-vibration and vibration conditions

A repeated measures one-way MANOVA was conducted to compare the effects of vibration (trial T3-T8) to non-vibration condition (T1) as well as comparison between non-vibration conditions T1 and T2, elicited in myoelectric activity of VL and VM muscles. The differences between trial T1 and all other trials (T2-T8) were statistically significant in all cases in VL and VM ($p < 0.001$). Another repeated measures one-way MANOVA was conducted to compare the effects of vibration (trial T3-T8) to non-vibration condition (T2), elicited in myoelectric activity of VL and VM muscles. The effect was statistically significant in VL (Wilks' Lambda = 0.31; F(6, 23) = 8.49, $p < 0.001$). Post hoc comparisons indicated that the mean RMSemg of VL muscle (M = 110.28μV, SD = 35.93μV) in T2 was significantly different in all cases except for T3 (M = 124.05μV, SD = 36.93μV), where the amplitude and frequency was the smallest. Similar finding was observed from VM muscle. Specifically, the data revealed Wilks' Lambda = 0.39 (F(6,23) = 5.89, $p < 0.001$). The post-hoc suggested that the only case with no significant differences between mean level of RMSemg of T2 (M = 108.20μV, SD = 36.01μV) was observed when the amplitude and frequency of vibration was the smallest (i.e., T3) (M = 125.55μV, SD = 44.7μV).

The effect of different frequency and amplitude on myoelectric activity

The repeated measures MANOVA applied to compare the effect of different amplitudes and frequencies of vibration on VL RMSemg revealed the main effect of amplitude (Wilks' Lambda = 0.719; F(1,28) = 10.92, p = 0.002). The main effect of frequency was also observed (Wilks' Lambda = 0.359; F = (2,27) = 24.08, $p < 0.001$) but not the amplitude*frequency interaction. Post hoc analysis suggested statistically significant differences among most of the conditions except between T4 and T5, and T7 and T6. This indicates that certain combinations of amplitude and frequency produce similar effects in muscle activity (Figure 1).

A significant main effect of amplitude (Wilks' Lambda = 0.692; F(1,28) = 12.44, p = 0.001) and frequency (Wilks' Lambda = 0.579; F(2,27) = 9.77, $p < 0.001$), but not their interaction was found for VM RMSemg. Bonferoni's post hoc comparisons suggest statistically significant differences among all conditions except for the following combinations of trials: T4 and T5, T4 and T6, T6 and T7, T6 and T8 (see Figure 1).

These findings generally suggest that the highest RMSemg in both muscles was achieved when the amplitude and frequency were the highest, as well as that that particular combinations of amplitude and frequencies could cause similar effects in mean RMSemg values.

Discussion

The present study aimed to analyze the effects of particular vibration parameters on the myoelectric activity of the vastus lateralis and vastus medialis muscle. The frequencies applied were 20 Hz, 40 Hz, 60 Hz, while the amplitudes were 2 mm and 4 mm. It is well-known that in the sports training different values of applied load engage appropriate muscles to a greater or lesser extent. We have assumed that the use of vibration with different combinations of parameters will exert different muscle activity. As expected, the lowest myoelectric activity of the muscles, proving weak excitation of the motor units, was recorded when the subjects were laying relaxed. It is well known that a healthy and relaxed muscle has some constant level of tone known as a residual muscle tension (Davidoff, 1992). In the course of the present study, the tension of the muscles gradually increased at both vibration amplitudes (i.e. 2 mm and 4 mm) following the rise in frequency of vibration. When exposed to vibration, the highest myoelectric activity was recorded when the frequency and amplitude were 60 Hz and 4 mm, respectively. These results are in accordance with the findings of Matthews (1966), which suggest that the level of muscle response to mechanical vibration depends on the applied frequency and the higher frequencies lead to greater muscle activity. In this study the mean value of myoelectric voltage increased with the frequency, independently whether the vibration amplitudes were 2 mm or 4 mm. The higher frequency and amplitude of EMG signal obtained from the bellies of the examined muscles indicate a larger number of simultaneously stimulated motor units, as well as a better synchronization of their stimulation (Cardinale and Erskine, 2008). In contrast to Cardinale and Lim's (2003) report, who studied the effect of whole-body vibration at different frequencies (30 Hz, 40 Hz, 60 Hz) but the same amplitude of 10 mm on the RMSemg activity, this study shows that rise in frequency leads to a statistically significant increase in RMSemg, which is in accordance with previous studies (Matthews, 1966; Roll et al., 1989). However, more recent study by Cardinale and Lim (2003) shows the highest RMSemg when the frequency was the lowest (i.e., 30 Hz), while the lowest RMSemg was at 60 Hz, which may be due to some inhibitory mechanisms caused by mechanoreceptors and skin receptors. Since there are obvious inconsistencies between the results of these reports, the authors in this study aimed to test the hypothesis that higher parameters

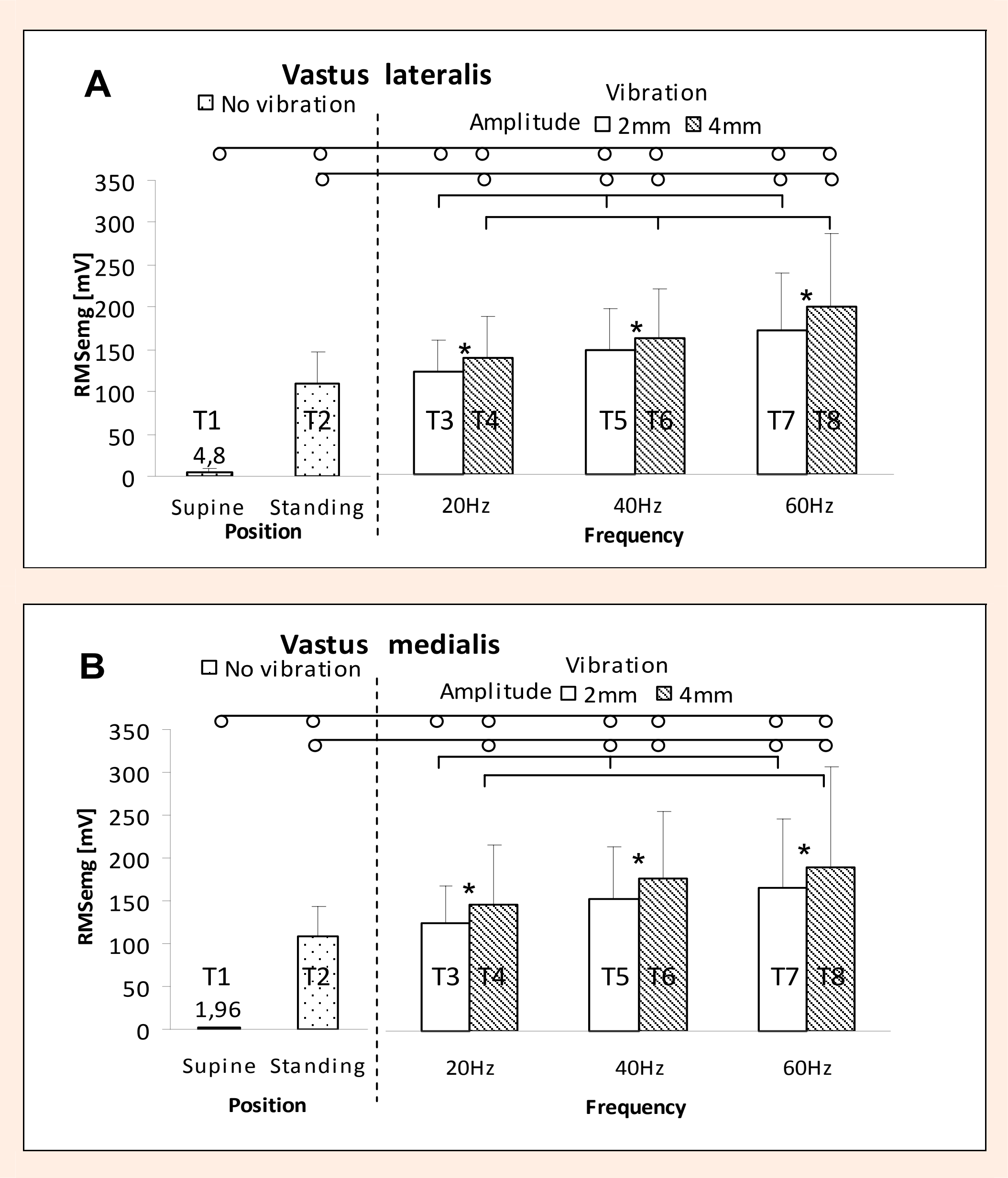

Figure 1. Mean and SD RMSemg values of (A) – vastus lateralis; (B) – vastus medialis for trails without vibration (T1 and T2) and combinations of frequencies and amplitudes: 2 mm/20 Hz (T3), 2 mm/40 Hz (T4), 2 mm/60 Hz (T5), 4 mm/20 Hz (T6), 4 mm/40 Hz (T7), 4 mm/60 Hz (T8). * indicate statistically significant differences between 2 mm and 4 mm amplitude of vibration at the same frequency ($p < 0.05$), horizontal bars with vertical dashes indicate statistically significant differences between frequencies at the same amplitude of vibration ($p < 0.05$), horizontal bars with circles indicate statistically significant differences between T1 and T2 (no vibration) and all trials with vibration (T3-T8) ($p < 0.05$).

of vibration determine increased neuromuscular response.

The same vibration frequency at different amplitudes (i.e., 2 mm and 4 mm) resulted in significantly higher myoelectric muscle activity at 4 mm. As it was mentioned in the Introduction, increased activity of tensed muscles during the vibration training is likely to be related to the appearance of the stretch reflex (Eklund and Hagbarth, 1966; Eklund, 1973). The increased signal of RMSemg, which was obtained while the higher amplitude of vibration at the same frequency was applied, may be associated with faster and bigger stretching of the muscle. The increase of muscle activity with increasing frequency of vibration at the same amplitude may be associated with higher rates of stretching. As shown in the present study, certain frequency/amplitude combinations of mechanical vibrations could cause the same level of myoelectric muscle activity. This finding suggests that despite relatively large differences across subjects, the response to the applied combination of frequency and amplitude could be relatively independent. Therefore, professionals should choose high frequencies and amplitudes during vibration training instead of using parameters that might have no effect at all. Since the other studies reported mostly the influence of the only vibration parameter (frequency or amplitude), this study concentrates on a wider scope of vibration training (i.e. the interaction of both parameters). It would be important to find out how certain vibration training programs influence the actual performance, however this was not the object of this study and is planned to be examined in the follow up research.

Conclusion

Vibration training is a part of athletes training, biological regeneration, and activities of the fitness centers. One of the factors ensuring effective vibration training is a set of optimal vibration parameters. The observed findings suggest that myoelectric activity increases both with the amplitude and frequency (being the strongest at the frequency of 60 Hz and the 4 mm amplitude). Therefore, high frequencies and amplitudes might be recommended for trainers, fitness instructors and physiotherapists to improve the effectiveness of their training and rehabilitation programs involving vibration platforms. However, in order to avoid the use of high frequencies which are sometimes unpleasant for certain individuals, practitioners should modulate the vibration characteristics by combining lower frequencies with higher amplitudes and, based on our finding, still expect the same outcome of the applied training. It should be also noted that certain combinations of relatively low amplitude and frequency of vibration could have no effects at all. This way, based on results of this study, practitioners will be able to optimize applied trainings which should result in the effects of vibration training.

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Key points

- The observed vibration effect significantly increases both with the amplitude and frequency.
- Certain frequency/amplitude combinations of mechanical vibrations cause the same level of myoelectric muscle activity.

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