Electromyographic response during whole-body vibrations of different frequencies with progressive external loads

INEFC Barcelona. Laboratorio de Biomecánica
(España)

Gerard Moras | Julio Tous | César Juan Muñoz | Josep María Padullés | Lisímaco Vallejo
gmoras@gencat.net | juliotf@blanquerna.url.es

Abstract

The purpose of this study was to analyze if exposure to whole-body vibrations (WBV) of different frequencies with none or additional loads from 20 to 50 kg promotes changes in EMGrms activity of the quadriceps and gastrocnemious muscles. Sixteen male subjects with previous experience in strength training volunteered to participate. Subjects received the treatment while standing on a vibration platform with knees bent at 100º. Normalised EMGrms was recorded in vastus medialis (VM), vastus lateralis (VL), rectus femoris (RF) and gastrocnemious medialis (GM) for 10 secs in the following twenty five conditions: no-vibration (NV), 30, 35, 40 and 50 Hz with body weight or with four different external loads (20, 30, 40 and 50 kg) over the shoulders. In all conditions, average normalised EMGrms from VM was significantly higher than in the NV condition. The same behaviour was observed in VL except in the 50 Hz with 20 kg condition. In RF only six conditions with 40 and 50 Hz were not significantly different compared with the NV condition. However, GM presented a different behaviour and only seven out of twenty four conditions were significantly different compared with the NV condition. The highest EMGrms was found at 30 Hz but no significant differences were found between the different frequencies employed. In all muscles except from GM and in all conditions with or without vibrations, a significant linear relationship was found between external load increments and EMGrms (%) signal increments These results suggest the use of EMGrms to monitor the optimal vibration frequency.

Keywords: EMG. Whole-body vibration. Frequency. Load.

http://www.efdeportes.com/ Revista Digital - Buenos Aires - Año 10 - N° 93 - Febrero de 2006

Introduction

Vibrations are present in many situations of everyday life. In fact, every material vibrates at its own natural frequency (Warman et al., 2002). Sources of vibrations can be found in a wide range of transportation devices or working tools (Troup 1978; Randall et al. 1997; Kumar et al. 1999; Cederlund et al. 2001; de Oliveira et al. 2001; Chen et al. 2003). Furthermore, in many sport activities significant vibration load occurs, such as inline-skating (Thompson and Belanger 2002), surfing, skiing, horse riding or off-road biking (Mester et al. 1999).

Literature into the effects of whole-body vibrations (WBV) in human being cover a broad range of topics and different responses has been reported ranging from beneficial to dangerous. Extensive research has been conducted in occupational medicine or ergonomics where WBV are mainly avoided (Bovenzi et al 1991; Bovenzi and Hulshof 1999; Lings and Leboeuf-Y 1999). On the other hand, in the last decade several controled studies suggest the possitive effects of WBV in strength and/or power development (Issurin et al 1994; Torvinen et al 2002; Delecluse et al 2003; Russo et al 2003; Ronnestad, 2004; Roelants et al 2004), flexibility (Issurin et al 1994), body balance (Verschueren et al. 2004; Bruyere et al 2005) and bone mass (Rubin et al 2004; Verschueren et al 2004; Ward et al 2004). However, other controled studies has not found significant improvements in strength and power (deRuiter et al 2003), balance (Torvinen et al 2002) or bone mass (Russo et al 2003; Torvinen et al 2003). This controversy could be explained by the wide range of parameters utilized (frequency, amplitude, direction or duration of vibration loads). Thus, it is difficult to reach definitive conclusions about the chronic effects of whole-body vibrations on humans (Warman et al 2002).

Muscle activity while exposed to vibration could be monitored recording root mean square electromyographical (EMGrms) signal. Several studies has reported a significant increase in EMGrms signal of different lower body muscles after WBV exposure compared with the same position without vibration (Cardinale and Lim, 2003; Delecluse et al., 2003; Verschueren et al., 2004; Berschin and Sommer, 2004). These changes have been suggested to be due to an increase in neuromuscular activity. It is well known that sustained vibration applied to a muscle or tendon can stimulate muscle spindles and elicit a tonic vibration reflex (TVR) primarily via Ia monosynaptic and polisynaptic pathways (De Gail et al, 1966; Desmedt and Godaux, 1978; Mao et al, 1990; Romaiguere et al, 1991; Martin and Park, 1997). However, it is important to separate research utilising the direct application of a vibration signal at the surface of the muscle/tendon unit or through WBV. Moreover, specific WBV frequencies seem to produce higher EMGrms signal than others. In this way, Cardinale and Lim (2003) have found that 30 Hz vibration frequency provokes a significant higher response than 40 Hz and the latter compared to 50 Hz.

However, in our best knowledge, there are not any studies concerning the effects of different external loads and frequencies on EMGrms response. In fact, WBV protocols widely used in sport training or fitness facilities usually include the combination of different external loads and frequencies. Only Rittweger et al (2002) have investigated the effects of different frequencies and amplitudes of vibration with different external loads on oxygen uptake. Results showed an increase of VO_2 proportional to the frequency increase (18, 26 or 34 Hz). Each vibration cycle evoked an oxygen consumption of approximately 2.5 Ml 2 kg-1 with 5 mm amplitude. Furthermore, VO_2 increased more than proportionally with amplitudes from 2,5 to 7,5 mm. With an additional load of 40% of the lean body mass attached to the waist, oxygen uptake likewise increased significantly. A further increase was observed when the load was applied to the shoulders.

The purpose of this study was to analyze normalised EMGrms responses in the vastus medialis and lateralis, rectus femoris and gastrocnemius medialis while standing on a platform vibrating at different frequencies (30, 35, 40 and 50 Hz) with own body weight or applying different external loads (20, 30, 40 and 50 kg).

Methods

Subjects

Sixteen male subjects with previous experience in weight training but not necessarely in WBV training, volunteered to participate in the study after giving their informed consent. Subjects were well trained and usually perform weight training at least twice a week. The mean (SD) age, weight, height and half-squat 1RM were: 23 (2.1) years, 74.4 (6.5) kg, 172.4 (5.3) cm and 163 (37.7) kg respectively.

EMG analysis

Online EMGrms data was collected using the Musclelab 4000e (Ergotest Technology; Langesund, Norway) recording and acquisition system, employing the accompanying 7.16 software version on a laptop computer. This device converts the amplified EMG raw signal to an average root mean square signal (100 Hz, sampling of converted signal) via its built-in hardware circuit network.

The signals of vastus lateralis and medialis, rectus femoris and gastrocnemius medialis were recorded with bipolar surface electrodes (Blue Sensor, Medicotest, Olstykke, Denmark) fixed longitudinally to the muscle belly in the dominant leg. Skin was shaved (if necessary) and cleaned with an alcohol wrap until ruborization following Cram and Kasman (1998) guidelines. First, subjects performed two maximal voluntary isometric contractions (MVC) over 5 seconds on the platform with 100º knee flexion while holding two nylon straps (see figure 1). In case data differed more than 10% between trials a third trial was allowed. Both arbitrary (mV) and normalised (%) data were recorded.

Figure 1. Normalization procedure of EMGrms signal performed over the vibration platform.

Vibration procedure

Before exposure to vibration subjects performed a 3 min warm-up on an ergometer (70 RPM and 75 W).

Subjects were exposed to a vertical sinusoidal vibration with a Power PlateÒ platform. Vibration amplitude was held constant at 4mm. While mantaining the squat position (with 100º flexion) during ten seconds, EMGrms was recorded in the twenty-five following conditions: no-vibration, vibration at 30, 35, 40 and 50 Hz with no external load or with 20, 30, 40 and 50 kg added. External resistance was accomplished by use of an Olympic barbell that was placed behind the neck and over the shoulders. To avoid fatigue enough recovery was allowed between conditions. To minimize fatigue-related effects, the order in which all vibration conditions were presented was randomized. Body position was monitored using a linear encoder attached to the hip.

Data analysis

The EMGrms signal was recorded over 10 sec in each condition. In case any artifact was present in the signal the condition was repeated again.

Statistical analyses

A repeated-measures ANOVA with contrasts was used to compare the average EMGrms of different muscles in all twenty-five conditions. The level of statistical significance was set at p£0.05.

Results

After comparing each condition with or without vibration treatment the first provoked a higher normalised EMGrms activity of the three quadriceps muscles studied. This higher response was statistically significant in all cases except in rectus femoris (between NV and 40, 50 Hz with body weight (BW), 20 and 30 kg conditions) and vastus lateralis (between NV and 50 Hz with 20 kg condition). On the other hand, GM presents a different behaviour and significant differences were only found in the following conditions: between NV and 30 Hz with BW; NV and 35 Hz with 50 kg; NV and 40 Hz with 20, 30, 40 and 50 kg and between NV and 50 Hz with 50 kg. Table 1 and figures 2 to 5 shows average EMGrms (%) and SD from the selected muscle portions.

With BW the highest EMGrms (%) activity was found at 30 Hz in all muscles. VM and VL present the highest difference between NV and all vibration conditions with 30 Hz and BW (+47% and +87% respectively) but RF with 30 Hz and 20 kg (+66%) and GM with 30 Hz and 30 kg. However, when increasing the load (30, 40 and 50 kg) RF and VM present a higher activity with higher frequencies (35 Hz with 30 and 40 kg and 40 Hz with 50 Kg in RF; and 35 Hz with 30 kg and 40 Hz with 40 and 50 kg in VM) however, these differences are not significant. Only two of the contrasts between different frequencies are significant: with 30 Hz and 20 kgs condition, RF presents significant higher activity in comparison with 50 Hz and 20 kg condition; with 40 Hz and 40 kg condition, VM presents significant higher activity than 50 Hz and 40 kg condition.

In all three quadriceps muscle portions and all vibration frequencies studied a significant linear relationship was observed between EMGrms (%) activity and load increases. However, this was not the case for GM which presents a heterogeneous response.

	EMGrms (%)	**NV (1)**	**30Hz (2)**	**35Hz (3)**	**40Hz (4)**	**50Hz (5)**	*=$p<0.05$ **=$p<0.01$ ***=$p<0.001$
Vastus lateralis (VM)	BW **(a)**	41.1(14.1)	60.7(15.4)	57.9(21.1)	57.7(19.5)	54.8(17.0)	1-2,4,5***1-3**
	20Kg **(b)**	50.3(19.1)	72.8(25.4)	66.5(20.5)	63.2(20.8)	58.5(14.6)	1-2,**1-3,4***
	30Kg **(c)**	53.7(17.2)	69.3(11.7)	73.2(24.6)	72.0(27.0)	69.5(24.6)	1-2***1-3,5**1-4*
	40Kg **(d)**	56.5(16.3)	74.4(18.8)	75.0(22.4)	78.8(25.6)	72.0(26.5)	1-2***1-3,4**1-5*4-5*
	50Kg **(e)**	60.4(15.3)	83.1(20.8)	82.9(23.3)	89.0(33.6)	81.6(26.3)	1-2,3,4,5***
		a-b*a-c*** a-d***a-e*** b-e*	a-c*a-d* a-e*** c-e**	a-b***a-c*** a-d***a-e*** b-d**b-e*** d-e**	a-c**a-d*** a-e***b-d** b-e***c-e* d-e**	a-c**a-d** a-e***b-e*** c-e***d-e**	
Vastus medialis (VL)	BW **(a)**	37.5(11.8)	70.4(26.5)	61.1(22.0)	56.3(19.6)	51.6(16.8)	1-2,4,5***1-3**
	20Kg **(b)**	48.6(17.1)	76.4(25.7)	66.7(20.1)	65.7(21.4)	59.6(18.1)	1-2,3**1-4,5***
	30Kg **(c)**	54.5(18.8)	82.4(27.7)	73.5(20.1)	72.4(23.6)	70.8(31.9)	1-2,3,4**1-5*
	40Kg **(d)**	58.6(23.3)	89.3(39.7)	80.3(30.0)	84.0(38.3)	74.0(34.2)	1-2,3**1-4***1-5*
	50Kg **(e)**	67.4(25.7)	98.6(47.2)	86.7(28.6)	96.9(43.7)	83.8(31.9)	1-2,3,5**1-4***
		a-b*a-c*** a-d**a-e*** b-c***b-d** b-e***c-e*	ns	a-d* a-e** b-d*b-e***	a-b*a-c** a-d**a-e** b-e*d-e*	a-c*a-d*a-e* d-e**c-e** b-e**	
Rectus femoris (RF)	BW **(a)**	47.9(23.2)	66.4(24.5)	62.2(26.7)	63.2(31.3)	63.9(33.7)	1-2,3***
	20Kg **(b)**	54.7(30.7)	90.9(46.6)	89.6(37.9)	69.3(36.6)	65.8(27.2)	1-2***1-3**2-5*
	30Kg **(c)**	63.4(32.9)	93.1(38.6)	100.4(41.7)	85.0(43.5)	77.7(39.1)	1-2,3***
	40Kg **(d)**	60.8(28.7)	98.8(44.3)	106.5(55.0)	100.7(50.7)	90.5(50.1)	1-2***1-3,4,5*
	50Kg **(e)**	84.5(42.7)	118.1(55.0)	115.1(47.4)	119.5(57.5)	106.7(49.4)	1-2,3***1-4**1-5*
		a-d**a-e* b-e*c-e*	a-b*a-c* a-d**a-e** c-e*	a-b*a-c*** a-d*a-e** b-e*	a-e**b-e*	a-e*b-e*	
Gastrocnemius medialis (GM)	BW **(a)**	52.8(14.4)	69.2(22.4)	65.2(20.1)	66.0(17.6)	62.5(18.8)	1-2*
	20Kg **(b)**	55.7(17.0)	63.3(18.1)	65.3(18.3)	64.7(16.4)	66.0(17.8)	1-4*
	30Kg **(c)**	51.8(15.0)	65.8(18.4)	62.4(18.4)	70.2(24.4)	61.6(19.1)	1-4*
	40Kg **(d)**	52.0(14.5)	72.3.(35.4)	72.2(35.4)	76.7(29.1)	71.0(24.6)	1-4*
	50Kg **(e)**	52.5(13.9)	73.3(25.5)	70.0(25.5)	72.4(23.2)	67.4(20.1)	1-3,4,5*
		ns	ns	ns	ns	ns	

Table 1. Normalised EMGrms activity of each muscle portion in no-vibration (NV) condition or exposed to different vibrations frequencies with own body weight (BW) or different external loads.

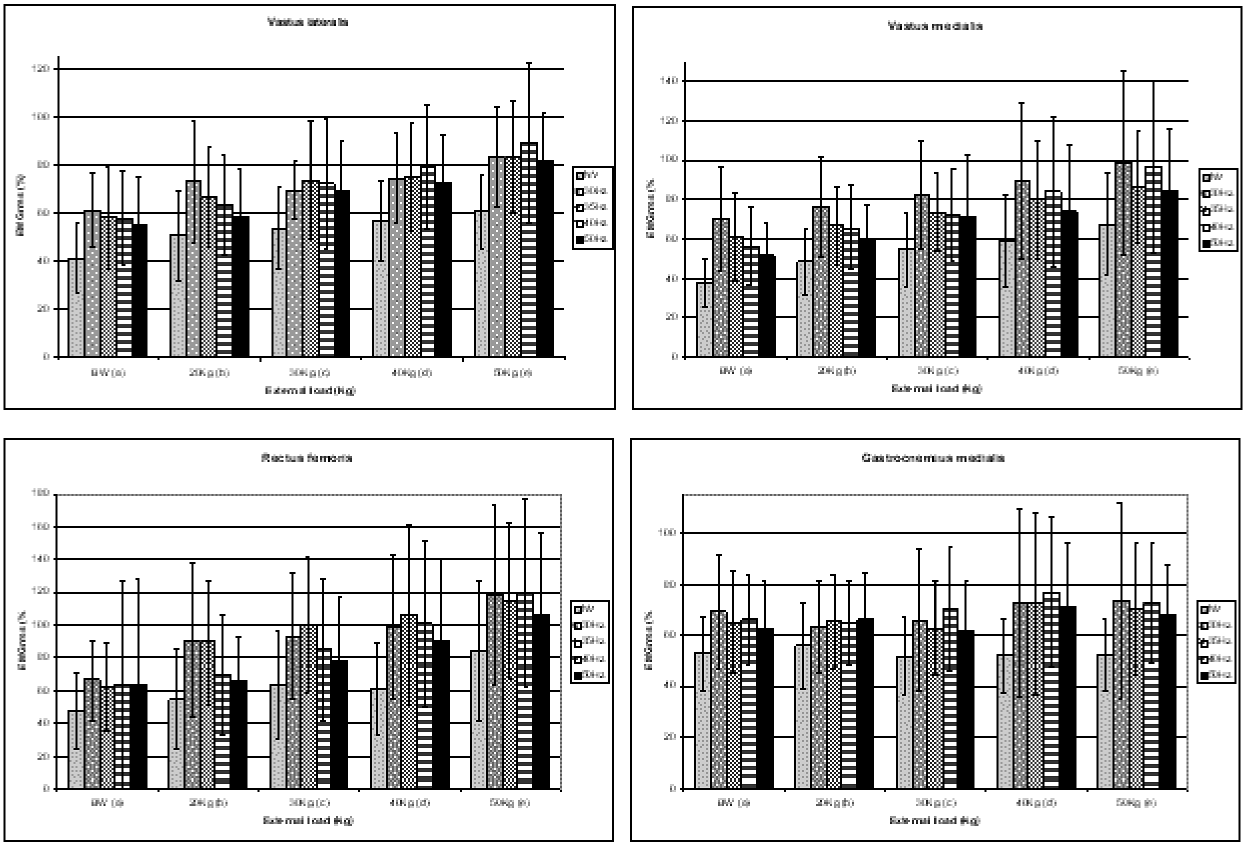

Figure 2. Normalised EMGrms activity of vastus lateralis, vastus medialis, rectus femoris and gastrocnemius medialis in no-vibration (NV) condition or exposed to different vibrations frequencies with own body weight (BW) or different external loads (see significant differences in table 1).

Discussion

Based on the results obtained, it was posible to verify that WBV at 30 Hz transmitted through a vibration platform in half squat position without any additional load significantly increased the normalised EMGrms activity of all muscle portions studied compared with the nonvibrating condition. To the best of our knowledge this is the first study that collected normalised EMGrms activity during application of a WBV stimulus from a commercially available platform in four lower body muscles.

Despite electromyographic response was highly variable between different subjects, specific vibration frequencies may produce higher normalised EMGrms values than others. This behaviour was expected and in agreement with a previous study (Cardinale and Lim 2003). However, in our study no significant differences were found when comparing 30, 35, 40 and 50 Hz in mainly all conditions. A quadratic relationship was observed between frequency increments and EMGrms signal increments in all muscles. The higher response under specific frequencies may depend on the position to be held. In the selected half squat position significant differences were found in vastus medialis and lateralis activity between no-vibration condition with all frequencies and mainly all external load conditions. However, rectus femoris and gastrocnemius medialis, both biarticular muscles, do not respond in the same way to all frequencies and external load conditions, being the significant differences less frequent in GM. A higher EMGrms response in RF and GM could be likely obtained if selected position during vibration exposure submits the muscle to an active or passive tension. Just by performing, from a half squat position, a slight hip extension, a heel raise or by an activation of these muscles a considerable increase in EMG activity was observed (data not presented).

Cardinale and Lim (2003) in their study, reported the highest EMGrms at 30-Hz (+34% in comparison with NV, $p<0.001$) in VL, revealing significant diferences between all selected frequencies (30, 40 and 50 Hz) but not between 30 and 40 Hz (9%). In this study, also 30 Hz produced the highest response in VL in comparison with NV condition (+47%, $p<0.001$). This higher difference could be related to different equipment (Nemes vs. PowerPlate) or different sample (professional female volleyball players vs. experienced weight-training males) employed in both studies.

When the external load was increased from 20 to 50 kg, there was a slight trend to move the higher EMGrms (%) value to frequencies over 30 Hz. It could be speculated that the addition of external loads of 30, 40 and 50 kg affects the stiffness of the musculoskeletal system and could explain this changes in EMG activity. In fact, Cardinale and Lim (2003) suggest that vibration causes a strong perturbation that is perceived by the central nervous system which modulates the stifness of the stimulated muscle groups. The reflex activity could be responsible for the minimization of vibration over soft tissues as proposed by Wakeling et al (2002). This response may be a complex interaction between mechanical and reflex factors and could not be the same under different external load conditions and different subjects. It could be speculated that, in subjects with higher stiffness, the maximum EMGrms response could be found under higher vibration frequencies, but further studies are needed to clarify this response.

In all conditions a significant linear relationship ($p<0.05$) was observed between external load increments and EMGrms signal increments in all muscles except from GM. This result was expected due to the small contribution of GM in the half-squat exercise. Overall results support the use of external loads to perform exercises over a vibration platform in order to increase the training intensity in well-trained subjects. The maximum load used in this study was 50 kg (about 30% of 1RM in these subjects) provoking the maximum response in all conditions for the three quadriceps muscle portions. In this way, it would be necesary to observe the response under higher external load conditions.

In conclusion, WBV at 30 Hz transmitted through a vibration platform in half squat position without any additional load significantly increased the normalised EMGrms activity of all muscle portions studied compared with the nonvibrating condition of the same position. Furthermore, a highly individual response to vibrations of different frequencies was observed but in most cases, when the external load is light, the highest response is at 30 Hz. However, when the external load is heavier (30 to 50 Kg), RF and VL maximal response slightly shifts, but not significantly, to higher vibrations frequencies (35-40 Hz).

On the other hand, in all muscles except from GM and in all conditions with or without vibrations, a significant linear relationship was found between external load increments and EMGrms (%) signal increments.

Finally, we consider normalised EMGrms as a good method to monitor static training protocols performed over a commercial vibration platform that could be found in many gyms or training centres nowadays. However, further studies are needed to determine the EMG response to WBV while performing dynamic movements in different body positions. Other EMG analysis techniques such as wavelet analysis should be performed to obtain more detailed information of muscle activity patterns.

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