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## A comparison of training intensity between whole-body vibration and conventional squat exercise

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### ABSTRACT

The aim of this study was to investigate surface electromyographic activity (sEMG) and rate of perceived exertion (RPE) during semi-squat exercise on vibration platform compared with semi-squat exercise performed on a Smith machine. Twenty-three recreationally active students (15 males and 8 females) were exposed to six different loads in one of both exercise modes: vibration or Smith machine. The subject performed a squat in six experimental conditions; the load differed per experimental condition. For each subject the exercise mode ( $n = 2$ ) and the different loads per mode ( $n = 6$ ) were assigned in a random order to check the influence of vibration magnitude (acceleration:  $\text{m s}^{-2}$ ) as well as weight (kg) on sEMG and RPE. Two-way ANOVA for RPE, lumbar and lower-body sEMG revealed a significant weight main effect ( $P < 0.01$ ) and a significant acceleration main effect ( $P < 0.01$ ). The results from this study demonstrate that the training stimulus resulting from an isometric semi-squat exercise on a vibration platform (acceleration: from 12 to 89  $\text{m s}^{-2}$ ) is similar to the training stimulus of an isometric semi-squat exercise on Smith machine (weight: from 20 to 70 kg) according to lower-body sEMG and RPE. However, the impact of semi-squat on vibration platform exercise for lumbar muscle is relatively small compared with semi-squat on Smith machine.

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### 1. Introduction

The squat is one of the most popular exercises to develop muscle strength of the lower limbs. The squat exercise can be performed in unloaded conditions, but to guarantee an optimal training intensity, squatting is mostly executed with an additional load by means of free weights, cable machine, Smith machine, vibration platform, etc. The variation in training stimulus during squat exercise that was performed in different conditions or on specific devices has been studied by several authors (McCurdy et al., 2010; Roelants et al., 2006; Schwanbeck et al., 2009). Anderson and Behm (2005) compared surface electromyographic activity (sEMG) of the soleus, vastus lateralis, biceps femoris, abdominal stabilizers, upper lumbar erector spinae, and lumbosacral erector spinae muscles during squat exercises using free weights and the Smith machine. They found that sEMG of the trunk musculature was the highest ( $P < 0.05$ ) during the free weight

squat; however, sEMG of the vastus lateralis was the highest during the Smith machine squats.

Recently, there has been a growing interest in the training effects of squat exercise executed on a vibrating platform. This method is called 'whole-body vibration' (WBV) and is considered to be beneficial in training (Delecluse et al., 2003; Marin and Rhea, 2010a,b; Petit et al., 2010) and rehabilitation (Bogaerts et al., 2009; Machado et al., 2010; Totosty de Zepetnek et al., 2009). Earlier research indicated that direct mechanical vibrations applied to the muscle belly elicit reflex muscle contractions, resulting into a 'tonic vibration reflex' (TVR), mediated by mono- and poly-synaptic pathways (Gillies et al., 1971a,b; Kossev et al., 2001). Muscle spindle Ia reflexes have been indicated as the major determinant of this vibration-induced neuromuscular activation leading to the TVR (Burke and Gandevia, 1995). In contrast to these direct vibrations, WBV-exercise consists mainly of squat exercises performed on a vibration platform that evokes a mechanical oscillation. The up- and downward acceleration of the platform depends on the amplitude (mm) and the frequency (Hz) of the oscillation. The training stimulus during WBV is determined by the magnitude of the acceleration (Marin and Rhea, 2010a,b; Petit et al., 2010). Considering the numerous possible combinations of amplitude and frequency

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with the current technology, there is a need for scientific studies that analyze the responses during vibration exercise to elicit adequate responses and to achieve optimal training effects.

One study analyzed differences in leg muscle activity within a variation of squat exercises performed on a vibrating platform (Roelants et al., 2006). The authors concluded that WBV (frequency of 35 Hz and amplitude of 2.5 mm) resulted in an activation of the different leg muscles to a magnitude that varied between 12.6% and 82.4% of maximal voluntary contraction.

Research findings indicate that squat exercises, performed on a vibrating platform, increase the strength of the leg extensors to a similar extent as can be realized by means of conventional resistance exercise at moderate intensity (Delecluse et al., 2003). However to develop a structured training methodology by means of progressive loading through WBV, we need to understand how the magnitude of acceleration ( $\text{m s}^{-2}$ ) impacts on muscle activation and to compare this with the training stimulus of squat exercise through traditional loading (kg). To the best of our knowledge, no study has compared neuromuscular effect of vibration exercise versus conventional resistance exercise at different loads. The aim of this study was to investigate muscle activation and rate of perceived exertion (RPE) during semi-squat exercise on vibration platform compared with semi-squat exercise performed on a Smith machine.

## 2. Methods

### 2.1. Subjects

Twenty-three recreationally active students (15 males and 8 females). The subjects' mean ( $\pm$ SD) age, height, and weight were  $24.3 \pm 2.3$  years;  $174.5 \pm 8.3$  cm; and  $69.9 \pm 8.1$  kg, respectively. Exclusion criteria were diabetes, epilepsy, gallstones, kidney stones, cardiovascular diseases, joint implants, recent thrombosis, as well as any musculoskeletal problems that could affect performance. Prior to data collection subjects were informed of the requirements associated with participation and provided written informed consent. Moreover, subjects were not allowed to change their sleeping, eating, or drinking habits throughout the duration of their participation to the study. The research project was conducted according to the Declaration of Helsinki and it was approved by the University Review Board for research involving human subjects.

### 2.2. Exercise protocol

Each participant attended two laboratory test sessions. Initially, the skin of the subject was prepared and sEMG electrodes were placed. Before testing, all subjects performed a standardized warm-up, consisting of a 5-min walking at  $6 \text{ km h}^{-1}$ . After that, subjects were exposed to six different loads in one of both exercise modes: vibration (Fitvibe, GymnaUniphy NV, Bilzen, Belgium) or Smith machine (Nautilus NT 1800; Nautilus, Inc., Vancouver, WA, USA). In the vibration mode the training load is quantified by means of the acceleration of the platform ( $\text{m s}^{-2}$ ). On the Smith machine the different loads are determined by the weight (kg) that rests on the subject's shoulders. The subject performed a squat in six experimental conditions; the load differed per experimental condition. For each subject the exercise mode ( $n = 2$ ) and the different loads per mode ( $n = 6$ ) were assigned in a random order to check the influence of vibration magnitude (acceleration:  $\text{m s}^{-2}$ ) as well as weight (kg) on sEMG and RPE. Load of each experimental condition is presented in Table 1. Each experimental condition lasted 15s, with 60s of rest between each condition. The vibration and weight exercises were performed with the subjects standing with their feet, separated to shoulder-width, on the vibration platform or on the floor, respectively. The knee angle was pre-set at  $30^\circ$

**Table 1**

Parameters for each exercise mode.

Vibration exercise			Weight exercise
Frequency (Hz)	Amplitude	Acceleration ( $\text{m s}^{-2}$ )	Weight (kg)
25	Low	12.5	20
35	Low	20.2	30
45	Low	30.9	40
25	High	36.3	50
35	High	60.1	60
45	High	88.4	70

High amplitude (3.1 mm [peak to peak]); low amplitude (1.0 mm [peak to peak]).

flexion. All subjects were asked to wear athletic shoes. All exercises were performed with a bar resting across the upper trapezius muscle. In the case of vibration exercise, an unloaded bar was used to maintain the same position during both exercises modes.

The vertical component of the acceleration of vibration platform was measured by means of an accelerometer in accordance with ISO2954, (Vibration meter, VT-6360, Hong Kong, China).

### 2.3. Surface electromyographic activity (sEMG)

Muscle activity of the vastus medialis (VM), vastus lateralis (VL), biceps femoris long head (BF), medial gastrocnemius (MG), and lumbar paravertebral (LP) muscles were measured using sEMG. One set (two measuring electrodes and a reference electrode) of surface electrodes (Ag/AgCl, Skintact, Austria) was placed longitudinally to the muscle fibers direction approximately half-way from the motor point area to the distal part of the muscle. An inter-electrode distance of 2 cm was maintained. The reference electrode was placed in a neutral area away from the measuring electrodes. Before electrode placement, the area was cleaned with isopropyl alcohol, shaved and abraded in order to reduce skin impedance until it was lower than  $5 \text{ k}\Omega$  (De Luca, 1997).

The surface electrodes were connected to a 14-bit AD converter (ME6000 Biomonitor, Mega Electronics, Kuopio, Finland). Raw EMG signals were pre-amplified close to the electrodes (gain of 375, in the bandwidth of 8–500 Hz) and sampled at 2000 Hz before being stored in a memory card (compact flash memory, 256 MB). On the basis of the frequency analysis, a band width of  $\pm 0.8 \text{ Hz}$  around each harmonic was excluded from the root-mean-square calculation (Abercromby et al., 2007). sEMG data analysis was performed across the use of specific software (MegaWin V 2.21, Mega Electronics, Kuopio, Finland). The middle 10 s of the exercise (from 2.5 s to 12.5 s) were chosen for data analysis. sEMG raw data was averaged by root mean square in order to obtain averaged amplitude of the sEMG signal. The sEMG values were compared with equivalent baseline during unloaded squatting (no vibration and no weight), normalization relative to maximal voluntary contractions was unnecessary (Abercromby et al., 2007; Marín et al., 2009). Lower-body sEMG were calculated as the mean sEMG of VM, VL, BF, and MG.

### 2.4. Rating of perceived exertion (RPE)

The OMNI-RES perceived exertion scale was verbally anchored (Robertson et al., 2003). OMNI-RES consists of 10 reporting options between 1 (extremely easy) to 10 (extremely hard). One week before the testing session, subjects attended two familiarization sessions, one for vibration exercises and one for weight exercises. Each subject was read a set of scale-specific instructions for the use of the OMNI-RES scale. For vibration exercises, participants were instructed to assign a rating of 1 to any perceptions of exertion that were less than those experienced during the semi-squat position (knee angle at  $30^\circ$  flexion; without vibration) and a rating of 10 was associated with semi-squat position at the maximum vibration

limit of the vibration platform (60 Hz, high amplitude  $3.1 \pm 0.3$  mm [peak to peak]). For weight exercise, participants were instructed according to Robertson et al. (2003).

### 3. Experimental procedure

To investigate the difference in muscle activation and RPE between a semi-squat exercise performed on a vibration platform or on a Smith machine, a randomized, crossover experimental design was used for this study. Each subject participated for four days in this study (two familiarization sessions and two test sessions). To reduce the impact of nocturnal changes on performance, testing of the individual subjects was standardized to approximately the same time of day.

#### 3.1. Statistical analysis

Data were analyzed using SPSS software (Version 15.0 for Windows, Chicago, IL). All data were first examined visually and statistically for normality of distribution. Values are presented as means  $\pm$  standard deviation (SD). Significance level was set at  $P \leq 0.05$ .

A two-way ANOVA (exercise load by exercise mode) was performed to assess significant main effects and interactions on muscular activation lumbar and lower-body sEMG, and the RPE. A Bonferroni post hoc test was used in all pairwise comparisons when a significant result was found.

Agreement between exercise load (weight or acceleration), RPE, lower body and lumbar sEMG was quantified by the Pearson correlation coefficient.

Linear regression analyses were used to study the relationship between lumbar or lower-body sEMG and exercise load (weight or acceleration). The slope of a linear regression line was used to calculate the rate of change in lumbar or lower-body sEMG when exercise load changed.

### 4. Results

Mean values  $\pm$  SD of RPE are given in Table 2 for each load exercise. The results of the two-way ANOVA for RPE revealed a significant exercise load main effect ( $F_{5, 110} = 75.43$ ,  $P < 0.01$ ) and a significant interaction effect ( $F_{5, 110} = 68.21$ ,  $P < 0.01$ ). The results for lumbar and lower-body sEMG are displayed in Fig. 1A and B.

Tables 3 and 4 display the correlation coefficients between the independent variables corresponding to weight and vibration exercises, respectively. A strong positive relationship was elicited between the training load (weight or acceleration) on the one hand and the muscle activation (lumbar sEMG, lower-body sEMG) and RPE on the other hand ( $P \leq 0.01$ ). All correlation coefficients were higher than 0.70.

Lower-body sEMG (Fig. 2A) and lumbar sEMG (Fig. 2B) were modeled as a linear function of training load (weight or acceleration). The statistical significance ( $P < 0.01$ ) of the linear regression parameters was noted. The regression line (Fig. 2A) between lower-body sEMG and training load for weight (or acceleration) conditions has an intercept of 8.18 kg ( $-4.55 \text{ m s}^{-2}$ ), and a slope of 0.35 (0.42). The regression line (Fig. 2B) between lumbar sEMG and exercise load for weight (or acceleration) conditions has an intercept of 17.89 kg ( $-4.07 \text{ m s}^{-2}$ ), and a slope of 0.20 (0.94), respectively.

Linear regressions between lower body and lumbar sEMG is displayed in Fig. 3 for both exercise modes.

### 5. Discussion

To the best of our knowledge, this is the first study that analyzed muscle activation and rate of perceived exertion during squat

**Table 2**

Rating of perceived exertion (RPE) at each experimental condition.

	RPE	
	Mean	SD
<i>Weight (kg)</i>		
20	1.5 $\pm$ 0.8	
30	2.7 $\pm$ 1.1 <sup>*</sup>	
40	4.0 $\pm$ 1.7 <sup>*</sup>	
50	4.8 $\pm$ 2.1 <sup>*,#</sup>	
60	5.3 $\pm$ 2.2 <sup>*,#</sup>	
70	6.2 $\pm$ 2.3 <sup>*,#,&amp;</sup>	
<i>Acceleration (m s<sup>-2</sup>)</i>		
12.5	1.5 $\pm$ 1.1	
20.2	2.4 $\pm$ 1.6 <sup>*</sup>	
30.9	3.3 $\pm$ 1.8 <sup>*</sup>	
36.3	3.8 $\pm$ 1.6 <sup>*,#</sup>	
60.1	5.5 $\pm$ 1.9 <sup>*,#,&amp;,*</sup>	
88.4	6.4 $\pm$ 1.9 <sup>*,#,&amp;,*</sup>	

<sup>\*</sup>  $P < 0.01$  significantly different for 20 kg weight exercise or 12.5 m s<sup>-2</sup> vibration exercise.

<sup>#</sup>  $P < 0.01$  significantly different for 30 kg weight exercise or 20.2 m s<sup>-2</sup> vibration exercise.

<sup>&</sup>  $P < 0.01$  significantly different for 40 kg weight exercise or 30.9 m s<sup>-2</sup> vibration exercise.

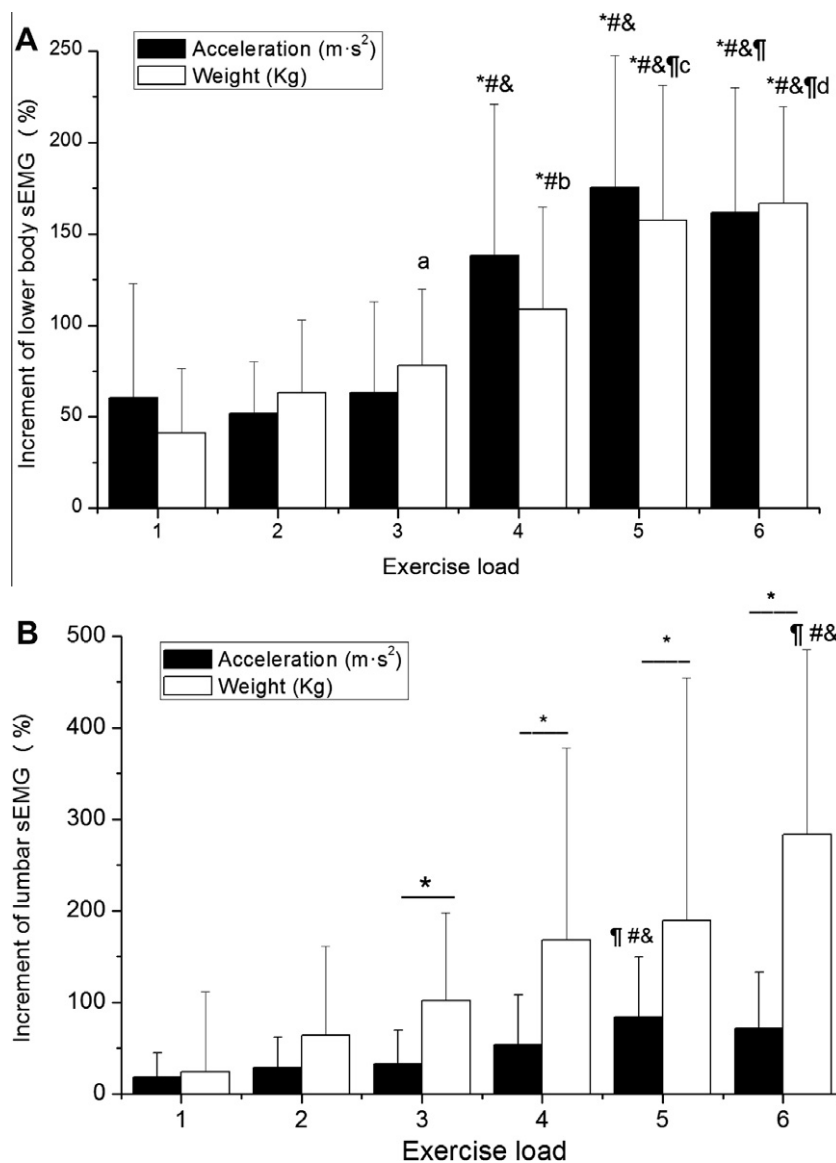
<sup>\*</sup>  $P < 0.01$  significantly different for 50 kg weight exercise or 36.3 m s<sup>-2</sup> vibration exercise.

exercise on vibration platform (acceleration; m s<sup>-2</sup>) compared with Smith machine (weight; kg). The primary finding of the present study is that an increase of acceleration by 1 m s<sup>-2</sup> applied by the vibration platform results in increases of lower-body sEMG (mean sEMG of VM, VL, BF and MG) of 0.42%, and 1 kg of additional weight on the Smith machine increases lower-body sEMG on average by 0.36%. In other words, the training loads on the Smith machine and vertical vibration platform are proportionally related to each other with a ratio of 1/0.86. This means that in this group of recreationally active students the lower-body sEMG during a semi-squat on a vibration platform with an acceleration of 60 m s<sup>-2</sup> almost equals the lower-body sEMG during a semi-squat on a Smith machine with 70 kg load.

A direct relationship between the intensity of exercise by weights and the percentage of maximal sEMG has been previously established (Adams et al., 1992; Clark et al., 2002). The results of this study confirm that the magnitude of vibrations (acceleration) has a clear positive correlation on lower body and lumbar muscle activation, as previously reported by Hazell et al. (2007).

Schwanbeck et al. (2009) have reported a 43% higher muscle activation during the free weight squat compared to the Smith machine squat. Activation of the knee extensors and flexors and ankle plantar flexors were higher during free weight squat, whereas activation of the trunk stabilizers was similar across the two exercises. However, prior to this investigation, no study had attempted to compare between lumbar muscle activity during a semi-squat on a vibration platform and on a Smith machine. The data from this investigation indicate that there are remarkable differences in lumbar muscle activity between both exercise modes at similar lower-body sEMG (Fig. 3). The data in Fig. 3 clearly indicate that a squat work-out that activates the lower body to the same extent on a vibration platform and on a Smith machine results in much lower activation the lumbar muscle using in the vibration condition.

At the moment, the mechanisms by which vibration acutely increases neuromuscular activity are still poorly understood. There are a few theories on how vibration stimuli can have effect on the neuromuscular system (Luo et al., 2005), such as a stimulation of Ia-afferents via spindle, resulting in facilitating homonymous  $\alpha$ -motor neurons, and the possible effects of vibration on the thixotropic properties of skeletal muscle and muscles spindles (Proske et al., 1993). Mechanical vibration of muscle induces a reflex,



**Fig. 1.** Surface electromyography (sEMG) activity at each experimental condition. \* $P < 0.01$  significantly different for 20 kg weight exercise or  $12.5 \text{ m}\cdot\text{s}^{-2}$  vibration exercise. # $P < 0.01$  significantly different for 30 kg weight exercise or  $20.2 \text{ m}\cdot\text{s}^{-2}$  vibration exercise. & $P < 0.01$  significantly different for 40 kg weight exercise or  $30.9 \text{ m}\cdot\text{s}^{-2}$  vibration exercise. ¶ $P < 0.01$  significantly different for 50 kg weight exercise or  $36.3 \text{ m}\cdot\text{s}^{-2}$  vibration exercise. <sup>a</sup> $P < 0.05$  significantly different for  $36.3 \text{ m}\cdot\text{s}^{-2}$ . <sup>b</sup> $P < 0.05$  significantly different for  $60.1 \text{ m}\cdot\text{s}^{-2}$ . <sup>c</sup> $P < 0.05$  significantly different for  $88.4 \text{ m}\cdot\text{s}^{-2}$ . <sup>d</sup> $P < 0.05$  significantly different for  $88.4 \text{ m}\cdot\text{s}^{-2}$ . A: lower-body sEMG; B: lumbar sEMG.

**Table 3**

Pearson correlation coefficients among independent variables. Analyses were performed on data pooled from all weight conditions imposed. Rating of perceived exertion (RPE) and surface electromyography (sEMG) activity.

	RPE	Increment of lumbar sEMG (%)	Increment of lower body sEMG (%)
Weight	0.97*	0.97*	0.96*
RPE		0.93*	0.89*
Increment of lumbar sEMG (%)			0.92*

\*  $P < 0.01$ .

**Table 4**

Pearson correlation coefficients among independent variables. Analyses were performed on data pooled from all vibration conditions imposed. Rating of perceived exertion (RPE) and surface electromyography (sEMG) activity.

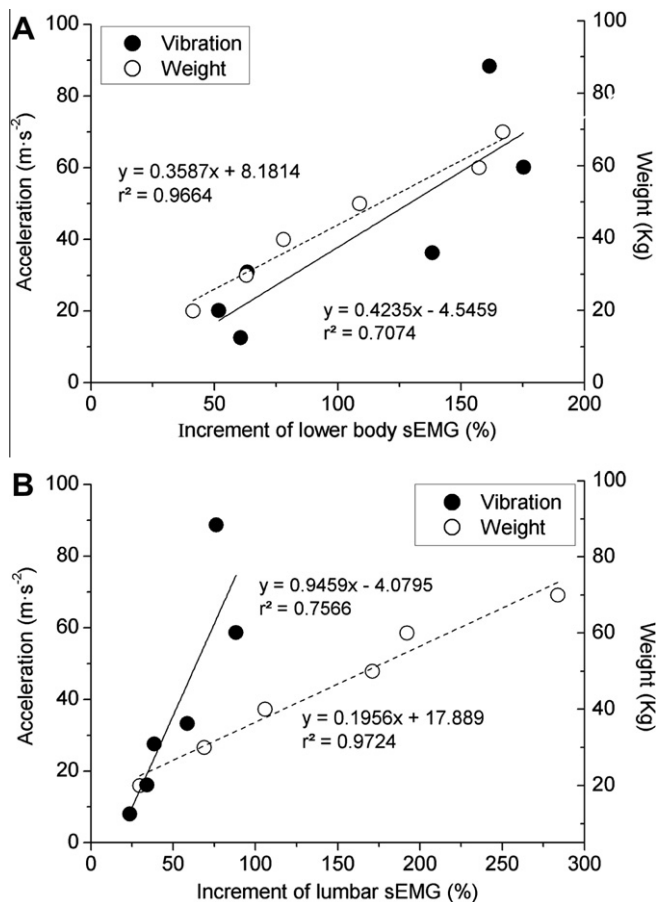
	RPE	Increment of lumbar sEMG (%)	Increment of lower-body sEMG (%)
Acceleration	0.95*	0.75*	0.70*
RPE		0.87*	0.79*
Increment of lumbar sEMG (%)			0.93*

\*  $P < 0.01$ .

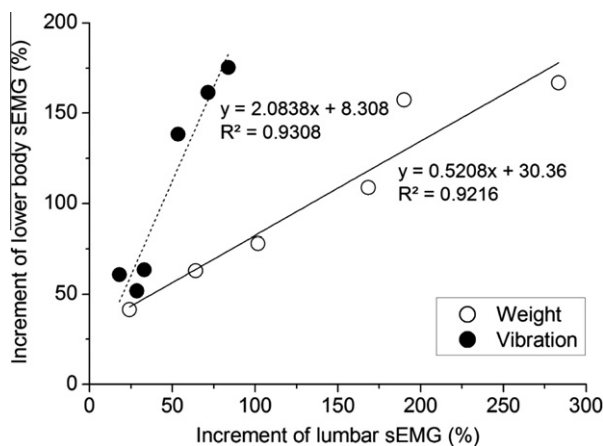
contraction (TVR) (Mileva et al., 2006). However, it has not clearly been demonstrated during WBV. On the other hand, vibration during exercise is thought to result in short-duration, small and rapid changes in the length of the muscle–tendon complex, in a fashion similar to simulated hypergravity. Several authors have demonstrated the RPE to be an effective method of qualifying resistance training (Day et al., 2004; Dishman et al., 1991; Gearhart et al., 2009). Duncan et al. (2006) reported that there were uniform

increases in RPE and sEMG in response to increases in resistance exercise intensity from 30% to 60% to 90% of 1RM during a leg extension exercise. In the same sense, Lagally et al. (2002) indicated that monitoring RPE may be a useful technique for regulating resistance exercise intensity. According to our data, the magnitude of the correlations was very high for correlations between RPE, lower body sEMG and acceleration (Table 3), as well as RPE, lower body sEMG and weight (Table 4). In this sense, the results from this





**Fig. 2.** Linear regression of external load versus surface electromyography activity (sEMG). Analyses were performed on separated data pooled from all two exercise modes imposed (external load of vibration exercises is acceleration (m·s<sup>-2</sup>) (●); external load for weight exercises is kilogram (kg) (○). A: lower-body sEMG; B: lumbar sEMG.



**Fig. 3.** Linear regression of lower body versus lumbar surface electromyography activity (sEMG). Analyses were performed on separated data pooled from all two exercise modes imposed (vibration exercise: ●; weight exercise: ○).

study suggest that using the RPE method after a vibration exercise would allow fitness professionals to assess the intensity levels that correspond to the level of the vibratory program.

In conclusion, the results from this study demonstrate that in young, recreationally active, adults the training stimulus resulting from an isometric semi-squat exercise on a vibration platform (acceleration: from 12 to 89 m·s<sup>-2</sup>) is similar to the training stim-

ulus of an isometric semi-squat exercise on Smith machine (weight: from 20 to 70 kg) according to lower body sEMG and RPE. However, the impact of semi-squat on vibration platform exercise for lumbar muscle is relatively small compared with semi-squat on Smith machine. In addition, this study suggests that RPE method after a WBV exercise would allow the trainer to assess the intensity levels that correspond to the level of the vibratory program in healthy subjects.

These data suggest that for progression in training, exercise professionals can increase the training load by altering several variables, such as weight by means of kg in Smith machine or acceleration as a result of frequency and amplitude on vibration platform. Moreover, the vibration exercise could be a good strategy to train lower body muscles without an overload for lumbar muscle. Data also suggest that RPE method after a WBV exercise would allow trainer/therapist to assess the exercise loads that correspond to the level of the vibratory program in healthy subject.

### Conflict of interest statement

None declared.

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