

Effect of whole body vibration in energy expenditure and perceived exertion during intense squat exercise

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Purpose: The purpose of this study was to investigate the effect of whole body vibration in oxygen uptake during intense squatting exercise with an added weight and whole body vibration compared with the same exercise without vibration. **Methods:** Nine male subjects performed three trials of dynamic squatting with an additional load of 50% of their body weight during 3 min. One trial without vibration, one trial with the frequency of 40 Hz and amplitude of 2 mm and one trial with the frequency of 40 Hz and amplitude of 4 mm. **Results:** The results showed no difference between the three experimental trials in relative and absolute oxygen uptake. However, the metabolic power and energy expended in whole body vibration (2 mm) were significantly different from exercise without vibration. The data analysis also showed a significant difference in rating of perceived exertion with whole body vibration (4 mm) compared with the exercise without vibration. Results showed that the addition of vibration stimulus has an increase in the energy expenditure particularly with 40 Hz and 2 mm amplitude, suggesting that the high metabolic power during heavy resistance training could be increased by the addition of vibration stimulation. **Conclusions:** Involuntary contractions generated by the vibration can be used by coaches to increase the intensity of heavy resistance training or to increase the energy expended during the workouts if the goal is a decrease of body mass.

Key words: whole body vibration, energy expended, intense squat exercise, rating of perceived exertion

1. Introduction

Whole body vibration (WBV) is a neuromuscular training method used to improve muscular strength, body balance and bone mineral density. WBV induces muscle contraction, it has been suggested that the effect of WBV in muscle is elicited via reflex muscle activation. This neuromuscular response is named tonic vibration reflex (e.g., [18]).

Many studies have been performed to understand the acute and chronic responses of WBV exercise (e.g., [9], [20]). One of the reasons of using vibration stimulus during training is to increase the muscular activity and energy expended. Most previous studies have concluded that WBV exercise has a moderate effect in cardiovascular capacity [6], [14], [24], but we noted that the results can be affected by different factors and make them inconsistent. These factors

could be, for example: (1) the frequency of the vibrations, (2) the amplitude of vibration, (3) the type of exercise (static or dynamic, duration, intensity), and (4) the type of platform used (vertical vs. rotational) (see [7]).

The energy consumption can be controlled by increasing the vibration frequency and amplitude and also by the addition of an added weight [22]. Thus, there appears a linear relationship between the frequency of the vibration and the oxygen uptake (each vibration cycle requires oxygen of $2.5 \mu\text{LO}_2/\text{kg}$). However, the influence of the amplitude of vibration seems to be non-linear and more pronounced by increasing the muscular responses and also more pronounced at the frequency of 30 Hz compared with 40 Hz and 50 Hz [5]. In another study, Hazell et al. [13] found that the 35, 40 and 45 Hz vibration frequency \times 4 mm amplitude are the optimal parameters for increasing muscular responses.

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Received: May 9th, 2014

Accepted for publication: July 11th, 2014

Regarding the effect of exercise types, Rittweger et al. [21] reported that under various conditions such as standing and squat exercise with and without extra loading, oxygen uptake increased by 4.5 mlO₂/min/kg at specific vibration (frequency (*f*): 26 Hz, amplitude (*A*): 5mm). However, the addition of WBV to static semi-squat does not appear to have a significant effect in cardiovascular stress [14]. Cochrane et al. [6] compared the physiological effect of acute WBV during exercise of leg press in seated position with different relative body mass of 0, 20 and 40% (with and without vibration). These authors found a significant increase in VO₂ uptake of 1.2 mlO₂/min/kg but this increase may be an insufficient stimulus to improve cardiovascular fitness. Furthermore, Abercromby et al. [1] demonstrated that neuromuscular responses in extensor muscles during static squatting are greater than during dynamic squatting.

One of the reasons for the contradictory results in the WBV studies is the use of different types of platform. Two types of platform are involved: rotational vibration or vertical vibration. Indeed, Abercromby et al. [1], [2] have indicated that the type of vibration devices could affect the neuromuscular and biodynamic responses. No study has been conducted about the difference in metabolic responses between the two vibration platform types. Most studies that have found an effect of the WBV on the metabolic demands have been performed on platforms generating oscillation vibration stimulation. The platform generating vertical vibrations allow different experimental conditions compared to the oscillating platform. For example, this first platform with synchronous vibration allows a higher frequency stimulation and lower amplitude than oscillating platform (35–45 vs. 26–30 Hz and 2–4 vs. 6–10 mm, respectively).

The effects of vertical vibrations on the metabolic responses of WBV exercise are not clear and can be contradictory to most of the studies involving the oscillating platform. Also, the most intense exercises tested in the previous studies are relatively low and do not correspond to the intensity used by the trained subjects [14], [21], [22]. Thus, the aim of this study is to explore and analyze the metabolic and perceptible responses of trained subjects during dynamic squat at relatively high intensity performed with vertical vibration stimulation using different amplitude of stimulation. We hypothesized that under vibration stimulation, squat exercise performed in high intensity condition creates higher rating of perceived exertion and energy expended compared to the stimulation without vibration. We hypothesized also that a variation of amplitude of vibration during the squat exer-

cise performed in high intensity condition creates higher energy expended. The results of this current study could be used by researchers or coaches to optimize the choice of vibration stimulation characteristics when the trained subjects performed dynamic squat training.

2. Materials and methods

2.1. Subjects

Nine subjects participated in the present study (age 24 ± 3 years, height 1.82 ± 0.07 m, mass 74 ± 8 kg), before inclusion it was verified that the participants had no contraindications to WBV according to the manufacturer's recommendations (i.e., cardiovascular diseases, epilepsy, acute inflammations, joint problems, back problems, migraine, recent operative wounds, recent thrombosis, kidney stones, or gallstones). All subjects were students of the faculty of sport. Prior to testing and after having received full explanation concerning the nature and purpose of our study, the subjects gave written informed consent. These studies have been approved by the ethics committee of the local institute and have been conducted in accordance with the classical ethical guidelines. All subjects have never practiced whole body vibration training but practiced regularly resistance training between 4–6 hours and 2–3 times per week.

2.2. Experimental procedures

The gas exchanges were measured by assessing the oxygen uptake (VO₂, l/min), carbon dioxide rejection (VCO₂, l/min), ventilation (VE, l/min) and heart rate (HR, bpm). The subjects were fitted with a face mask connected to a portable ergospirometric device (Oxycon Mobile, Jaeger, Wurzburg, Germany) which was calibrated before every test session according to the manufacturer's specifications. Respiratory exchange ratio (RER) values have been computed. The metabolic power was determined as described in Faria et al. [11] from Brouwer's equation: metabolic power (J/s) = $[3.869 \times \text{VO}_2 + 1.195 \times \text{CO}_2] \times (4.186/60) \times 1000$. From these values, the energy expended (kJ) was computed for the different experimental conditions. The VO₂ uptake for each vibration cycle was computed from the VO₂ and the frequency of vibration stimulation: VO₂/kg/(60 × frequency). The HR

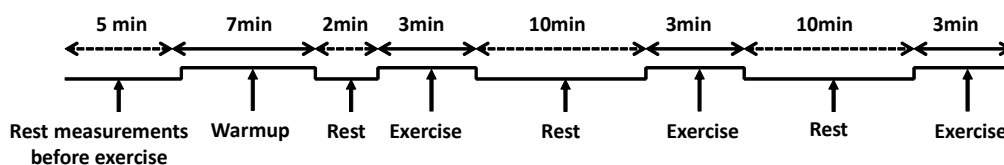


Fig. 1. Experimental protocol



Fig. 2. Experimental Protocol

values were expressed in absolute values (bpm) and in relative values to the empirical theoretical maximal values determined from the following relation: maximal value of HR (bpm) = $220 - \text{age of the subject (year)}$ [16]. The intensity of the exercises was also quantified in number of the Metabolic Equivalent of Task (MET) [3].

Before the beginning of the exercise the physiological values were measured in the seated position on a chair over a period of 5 min. This data is used in the computation of a resting metabolic rate and thus one MET. After these measurements, a standardized warm up of 7 min was performed (Fig. 1).

The squatting exercise with extra weight was performed standing on a vibrating platform (FitVib 600, Germany), this device delivers synchronized vertical sinusoidal vibrations with range of frequencies between 20 and 60 Hz and two amplitudes (2 and 4 mm).

Subjects performed the squats with a knee angle of 90° , determined by manual goniometer and fixed by adjustable benchmark placed behind subjects' legs in order to limit and to control the amplitude movement during the squat. The subjects bent their knee until their buttocks touched the mark (Fig. 2).

The subjects performed three trials of the squatting exercise with extra-weight (corresponding to 50% of the body weight) each with a 3 minute total duration time: one trial without vibration (NOVIB), one trial with a vibration (frequency: 40 Hz, amplitude: 2 mm,

VIB2) and the last trial with vibration by increasing the amplitude (frequency: 40 Hz, amplitude: 4 mm, VIB4). A rate movement execution was imposed on the participants, each squat repetition requires 3 seconds, and then a total of 60 repetitions were performed during each experimental session. These three sessions were performed in random order, taking 10 minutes of passive recovery between each set sitting on a chair (Fig. 1). Gas exchanges were measured continuously with the mobile Oxycon system. The following data were recorded during 3 min of exercise: VO_2 , VCO_2 and HR. Immediately after the end of each trial, subject indicated rating of perceived exertion (RPE) by choosing a score in 6–20 points Borg's scale. Before starting the exercise, it was explained to the subjects that there are no good or bad scores and they were asked to answer as honestly as possible.

2.3. Data analysis

Statistic analysis was performed with Statview software (PC version 4.55). Variables were tested for normal distribution with the Shapiro–Wilk test and for homogeneity of variances with Bartlett's F test. Whenever data showed normal distribution, differences between groups were checked by repeated measured ANOVA test and the post-hoc LSD's Fisher

test was applied for multiple comparisons. If variables did not show normal distribution, the nonparametric Wilcoxon or Friedman tests were applied. According to Rittweger [21] we have performed a regression analysis (Spearman's correlation) between the VO_2 with and without vibration stimulation. Significance was assumed if $p \leq 0.05$.

3. Results

The physiological values in rest condition before the exercises are shown in Table 1. The statistical analysis revealed no differences for absolute VO_2 (ml/min) and for relative VO_2 (ml/min/kg) between NOVIB, VIB2 and VIB 4 conditions (Table 2). Repeated measured ANOVA test showed that RER in VIB2 and VIB4 were significantly higher (+17%) compared with NOVIB.

Table 1. Data during resting metabolism in sitting position before exercises

	Resting metabolism
Heart Rate (beats \cdot min ⁻¹)	73 \pm 14
VO_2 (ml \cdot min ⁻¹ \cdot kg ⁻¹)	4.8 \pm 1
VO_2 (ml \cdot min ⁻¹)	348 \pm 68
VCO_2 (ml \cdot min ⁻¹)	305 \pm 64

The results showed that the energy expenditure (kJ) and metabolic power (J/s) in VIB2 (139 \pm 30 kJ and 774 \pm 169 J/s, respectively) were significantly different from NOVIB (129 \pm 24 and kJ 715 \pm 133 J/s, respectively).

HR in VIB4 (159 \pm 21 bpm) has a tendency to be different ($p = 0.054$) compared with NOVIB (153

\pm 18 bpm). The intensity of exercise was estimated at 78% and 80% of theoretical HR max for NOVIB and VIB sessions, respectively.

The data analysis showed a significant difference in RPE in squat with extra weight in VIB4 (17 \pm 2) in comparison with squat exercise in NOVIB (14 \pm 2) and no difference was found between VIB4 and VIB2 (Table 2).

Our results (Fig. 3) have shown a significant correlation ($p < 0.01$) between the VO_2 during exercise with and without vibration stimulation.

4. Discussion

The aim of this study was to compare the effect of vibration combined with loaded squat exercise with high level intensity on the energy expended and RPE.

The main result has shown that the metabolic power (J/s) and the energy expended (kJ) were higher in VIB2 compared with NOVIB and VIB4 (Table 2). However, the additional vibration stimulations at 40 Hz frequency with 2 and 4 mm amplitude do not have a significant effect on absolute and relative VO_2 uptake. In the current study, relative VO_2 were 27 \pm 5, 29 \pm 6 and 28 \pm 4 ml O_2 /min/kg for NOVIB, VIB2 and VIB4, respectively at the rate of 3 s (up + down) with 50% body mass extra weight. This intensity corresponded at 5.6 to 6 METS. The maximal HR represented 78% and 80% theoretical maximal HR for NOVIB and VIB, respectively. These results indicate that the exercises were performed at relatively high intensity. Contrary to the present study, Rittweger et al. [21] described that squat with vibration (26 Hz: 5 mm, rotational platform) and extra-load (40% of

Table 2. Exercise data during squat without vibration (NO VIB) and two sessions of squat with vibration (VIB 2: $f = 40$ Hz, $A = 2$ mm and VIB 4: $f = 40$ Hz, $A = 4$ mm)

	NO VIB	VIB 2	VIB 4
Borg's scale (RPE)	14 \pm 2	16 \pm 2	17 \pm 2*
Heart Rate (beats \cdot min ⁻¹)	153 \pm 18	160 \pm 23	159 \pm 21
VO_2 (ml \cdot min ⁻¹ \cdot kg ⁻¹)	27 \pm 5	29 \pm 6	28 \pm 4
VO_2 (ml \cdot min ⁻¹)	2028 \pm 379	2117 \pm 429	2065 \pm 378
RER	0.91 \pm 0.10	1.04 \pm 0.15*	1.07 \pm 0.1*†
Metabolic power (J/s)	715 \pm 133	774 \pm 169*	757 \pm 147
Energy expended (kJ)	129 \pm 24	139 \pm 30*	136 \pm 26

Values are given as mean during 3 min, SD is given in parentheses.

* Significantly different from NOVIB, † significantly different from VIB 2 mm at $p < 0.05$.

body mass) at the 6 s rate movement (3 s: up and 3 s: down) induced an increase of VO_2 to 14 ml/min/kg. This difference could be in part explained by the higher intensity of exercise in our study (additional weight of 50% of body mass and rate of movement two times higher). Recently, Hazell and Lemon [15] have shown that synchronous WBV increased VO_2 by 23% during vibration exercise session compared with the exercise session without vibration. In another study, Milleliri et al. [18] have compared energy expenditure during dynamic training with and without WBV in regularly trained women and these authors demonstrated that the addition of vibration stimulus to multiple exercise during 30 min increased energetic expenditure by 15 % in comparison with the same exercise without vibration. Furthermore, Cochrane et al. [6] found that VO_2 , HR and blood pressure increased significantly both for younger and older people with vibration and additional load. They concluded that the increase of VO_2 uptake (1.2 ml O_2 /min/kg) could be insufficient stimulus to improve cardiovascular fitness. Previous studies have shown that energy turnover could be controlled parametrically by increasing frequency, amplitude and by the addition of an external weight. Thus, there might be a linear correlation between frequency and VO_2 uptake and each vibration cycle could be associated with an oxygen demand of 2.5 $\mu\text{l O}_2$ /kg [21], [22]. Our results are in line with DaSilva et al. [8], which have shown that the energy expenditure during 5 sets of 10 squatting exercises with vibration (30 Hz) was 17% higher than the same exercise without vibration. Our results indicated that the metabolic power (J/s) and the energy expended (kJ) were higher in the VIB2 compared with NOVIB and VIB4 (Table 2). Garatachea et al. [12] have analyzed the energy expenditure during squat of 30% of the subject's body weight. Compared with the exercises without vibration, their results have shown a significant increase in the energy expenditure with vibration stimulation (30 Hz, 4 mm of amplitude). However, contrary to our results, they have indicated a significant increase of VO_2 for the amplitude of 4 mm. They have also shown that the reduction in the duration of the squat exercise can significantly increase the VO_2 with and without vibration. In the present study, the vibration stimulation was higher (40 vs. 30 Hz) and the HR are higher compared with the HR of Garatachea et al. [12]. Thus, the difference concerning the VO_2 could be in part explained by the difference in the level of intensity of the squat exercise between the two studies. Our results confirmed that during the squat exercise the modification of amplitude could alter the energy expended not only dur-

ing static posture but also dynamic one during the squat exercise with a high level of intensity. These could suggest that during an exercise with a high level of intensity, the increase of amplitude (from 2 to 4 mm) did not involve an increase in metabolic power. In order to achieve the maximum energy expenditure, we suggest that the optimal condition is not necessary to the exercise with the higher amplitude of vibration stimulation. These results could be taken into account by coaches and by subjects that would like to decrease their body mass.

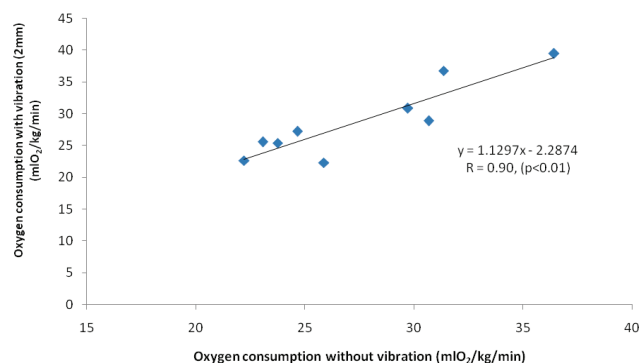


Fig. 3. Correlation between the oxygen consumption with and without vibration

Our results (Fig. 3) indicate a strong and significant correlation between VO_2 with and without vibration stimulation. This result is in line with Garatachea et al. [12] and Rittweger et al. [21]. Our results suggest also that a variation of the intensity of the exercise could affect the progression of the amount of VO_2 involved in the vibration stimulation. The vibration stimulation increased the VO_2 and consequently the energy expended when the intensity of dynamic exercise was low. However, when the intensity of dynamic exercise was high (like in the present study), the vibration stimulation in synchronous vertical platform has no effect on the VO_2 consumption but only on the energy expended. When the stimulus of vibration was applied on muscles during dynamic exercises at a relatively high intensity, it is possible that the additional muscular activation due at the tonic vibration reflex was low, and thus the influence on the increase of VO_2 is not marked. The tonic vibration reflex could have an effect during exercise involving moderate contractions but not during maximal contractions [17]. This hypothesis is in line with Moran et al. [19] that have shown that applying vibration at 65 Hz frequency on biceps tendon during arm curl at 70% of 1RM have no influence on electromyographic responses. The results of the present study suggest that when the subjects perform a dynamic exercise with

a relatively high intensity, the tonic vibration reflex was not or was very low when compared with the demands of the muscular exercise. It could be interesting in further study to determine precisely the level of intensity of exercise since the addition of vibration stimulus does not allow a significant increase in VO_2

In the present study, we have shown that the RER was increased in the exercise with vibration stimulus (0.91 ± 0.10 vs 1.04 ± 0.15 and 1.07 ± 0.1 , for NOVIB, VIB2 and VIB4, respectively). These changes were due to the increase of VCO_2 rejection. The modification of RER suggests that the exercises with vibration were performed with different proportion of energetic substrate compared with NOVIB. During the heavy resistance training, there have been shown the predominant anaerobic glycolytic pathways and consequently the increase of using carbohydrate substrate [24]. The vibration stimulus sensitized the Ia afferent fibers which could activate type II muscular fibers via large α -motor neurons [4]. This muscular fiber type is known to have low oxidative and high glycolytic capacity. This propriety could explain why during our vibration exercise VO_2 values were not significantly altered and why we obtained higher CO_2 values for the exercises with vibration. The increase of RER with vibration compared to the NOVIB shown in our study is in line with the results of Da Silva et al. [8]. These authors observed an increase of 6% RER during 5 sets of 10 squat vibration exercises compared to the same exercise without vibration.

Our results have shown that the RPE was significantly higher in VIB4 (17 ± 2) compared with VIB2 (16 ± 2) and NOVIB (14 ± 2). These results are in accordance with the results of the study conducted by Rittweger et al. [21], Cochrane et al. [6] and El Aji et al. [10]. This increase of RPE was observed even if the VO_2 was not different between the NOVIB and experimental vibration conditions. Indeed, Rittweger [23] has also demonstrated that the RPE could be independent of metabolic factors. This data could be explained by the fact that (1) the vibration stimulus could generate a residual muscular activity which could induce the perception of WBV exercise harder than without vibration, (2) most subjects who have performed WBV could have an unusual sensation partly due to a movement illusion [24], and (3) by the higher energy expenditure during the vibration conditions.

The present study has several limits. Firstly, further studies should be performed with a greater sample size to confirm the present results. Secondly, tests

should be performed at different lower intensities of exercise and with a longer duration to reflect the real training session duration with WBV. These measurements should determine the level of intensity where the vibration stimulus could increase the energy expended. At the same time, it would be interesting to further study to complete this data with electromyographic measurements to analyze the role of the tonic vibration reflex especially at high intensity of exercise. Even with these limits, the present study provides original findings illuminating the effect of the vibration stimulus on the metabolic data during dynamic exercise performed at a high level of intensity.

5. Conclusions

The results of our study suggest that acute WBV (vertical vibrations) combined with dynamic squat exercises with additional weight do not produce a significant effect in VO_2 uptake compared to the same exercise without vibration stimulus. However, our results have shown that the addition of vibration stimulus increased the RER and the energy expenditure especially in condition with a 2 mm amplitude. These results suggest that the energy expended during heavy resistance training could be increased by the addition of vibration stimulation. These results could be used by coaches and researchers to increase the difficulty of heavy resistance training for the trained athlete or to increase the energy expended during the workouts if the goal is a decrease of body mass.

Acknowledgments

The authors would like to thank Victoria Asch for his help in the writing of the manuscript.

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