

**EFFECTS OF DIFFERENT FREQUENCIES OF WHOLE BODY VIBRATION ON MUSCULAR PERFORMANCE**

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**Abstract.** The effects of different frequencies (20, 30, and 40Hz) of whole body vibration were analyzed in order to determine which one of them is the most effective for muscular performance training. Thirty-one subjects participated in the study maintaining their regular exercise habits but avoiding any strength or jump training. All subjects underwent exposure to the three frequencies with all the other vibration training variables remaining unchanged; the application order was assigned randomly. The vertical sinusoidal vibration protocol consisted of 6 exposures of 60s duration each, with 2-min rests in between. The tests used for assessment of muscular performance were the following: 1RM, SJ, CMJ, and muscle power. The performed tests showed increase for the 20- and 30Hz frequencies, being greater the increases for the 30Hz frequency for SJ ( $p<0.001$ ), CMJ ( $p<0.01$ ), and power ( $p<0.001$ ); strength values, on the contrary, did not show any significant changes for any of the frequencies. In contrast, the 40Hz frequency had a tendency to decrease the values in all the analyzed parameters. It can be derived that, when applied to physically active subjects, the 30Hz frequency is the most ideal for eliciting improvement in neuromuscular behavior with whole body vibration training.

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*Key words:* Vibration training - Vertical jump - Muscular strength - Muscular power

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## Introduction

One of the newest neuromuscular training methods that is quickly developing and gaining popularity is the so called whole body vibration training (WBV). WBV is based, despite a few modifications, on a vertical sinusoidal vibration generating platform, working at frequencies between 25 and 40 Hz. The platform generates a mechanical stimulus that is transmitted throughout the body where it stimulates sensory receptors such as the muscle spindle. As a result, contractions similar to those that take place in the tonic vibration reflex through the activation of alpha motor neurons [10,14,15,20,22] are generated. In the beginning WBV was directed towards improving the strength velocity performance of elite athletes. Nowadays, however, its use is being more and more generalized and reaching more users. In spite of its increasing popularity, there is a relative lack of consensus about the benefits of WBV in the different areas. The lack of consensus arises from the different studies available in the literature.

There have been many papers on research done about Whole Body Vibration (WBV), more specifically about the acute effects such training method produces after only one vibration session both on muscle strength and power [7,14,18], electromyographic signals [9,13], and jumping capacity [9,12,14,29]. Other studies, however, have used several training sessions demonstrating the improvement on jumping ability (CMJ) after 10 days as well [6]. However, Rittweger *et al.* [26] found a decrease in jumping capacity. So, the results produced by WBV are not free of contradictions. One of the reasons for such contradictions is the different frequencies applied in the different training protocols of the studies.

The purpose of the present study is to analyze different frequencies and try to clarify a bit which one is the most appropriate to produce improvements in the parameters assessed (jumping ability, strength and power).

## Materials and Methods

*Subjects:* Thirty-one young male subjects volunteered to participate in the study. The mean (SD) characteristics of the subjects were as follows: age 19.7 (1.9) years, height 176.5 (5.3) cm, weight 71.5 (10.7) kg. A doctor reviewed their medical histories to assess if they were suitable for the study, and each subject filled a questionnaire about their physical activity habits. Exclusion criteria were osteoarticular (including fracture or injury) problems. Each participant was informed about the study procedure with its possible benefits and risks, and signed a written consent document approved by the University of Córdoba Ethics



Committee. All subjects were physically active, participating in different sport modalities except for regular resistance or jump training performance.

*Warm-up and stretching protocol:* All subjects performed a 5-min warm-up (3 min 25W + 2 min 50W) with a cycloergometer (Ergoline 900, Ergometrics, Germany) followed by a 5 min program of stretching for femoral quadriceps, hamstrings, and triceps surae.

*Performed tests. Jump tests:* The lower body explosive strength characteristics, expressed by means of the body gravity center elevation (vertical jump), were assessed with an infrared rays platform (A.F.R Technology®), integrated in the MuscleLab™ system (Model PFMA 3010e, Ergotest, Norway).

Two different vertical jumps have been used for the data recording: Squat Jump (SJ), and Counter Movement Jump (CMJ) [3,4,16,19]. Briefly, the Squat Jump (SJ) is a test used to assess lower body power as well as the ability to recruit motor units. It is performed from the half squat position with a knee angle of 90°, after a brief pause, the subject performing the test jumps upwards as high as possible. The Counter Movement Jump (CMJ) is a test used to assess explosive strength with reutilization of elastic energy and taking advantage of the myotatic reflex [4]. The test starts with a preparatory movement of knee extension going down to a 90°knee flexion and, without pausing, jumping upwards as high as possible. Both jumps were performed without using the arms; for such purpose the subjects were asked to keep their hands on their hips (1).

The gravity center elevation (height in meters) above ground level was calculated for both tests by means of the flight time ( $t_v$ ) in s with the application of ballistic laws.

$$h = t_v^2 \cdot g \cdot 8^{-1} \text{ (m);}$$

where h is the height and g is gravitational acceleration ( $9.81 \text{ m} \cdot \text{s}^{-2}$ ).

The jump flight time was measured with the Muscle Lab™ system, which has a digital chronometer that, when connected to the platform, is able to estimate the flight time.

Three trials were performed for each jump, the best one of each was used for the statistical analysis.

*1RM and power:* Although the subjects had previously performed the jump tests, they performed a set of eight repetitions at the loads of 30-40% of the perceived maximum as a specific warm-up.

Lower body maximal strength and power was assessed by using the 1RM estimate given by the MuscleLab™ system. The subjects were set in a half squat position, with shoulders touching the bar and the starting knee angle for movement execution was set at 90°. When told to do so, subjects performed a concentric



extension of the leg muscles (extensors of hip, knee, and ankle) starting from the flexed knee position until reaching full extension at 180°, such movement was performed against a resistance that was determined by weight plates added to both ends of the bar. The subjects were given instructions to perform a purely concentric action from the starting point, keeping shoulders at an abducted position of 90° in order to assure consistency of shoulder and elbow joints during the movement execution [24].

Also, subjects were asked to keep the trunk as erect as possible during all the time the movement execution lasted. As this test was also used for estimating maximal power, subjects were asked to perform the movement as quickly as possible [28].

All tests were performed using a Multipower (GervaSport™), which is an apparatus for performance of squat exercise in which the bar is displaced only in the vertical position as allowed by linear bearings.

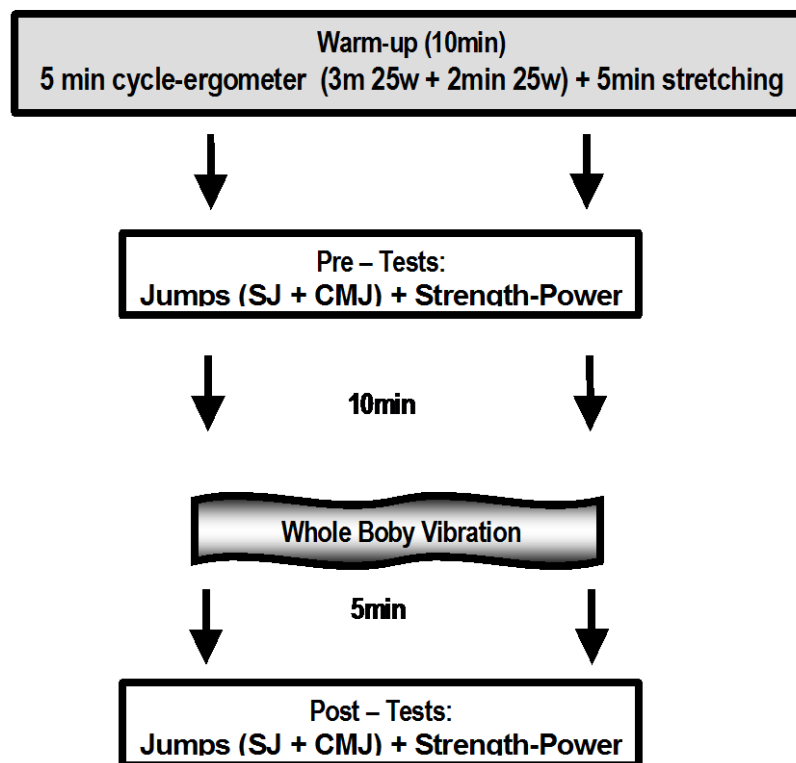
Four different loads added to body weight were used for estimating both the maximal power and maximal strength (1RM): 25, 45, 65 y 85kg. Three trials were performed for each load and the best recording (maximum average velocity) was used for posterior analysis. During the test performance, data were collected about the bar displacement, maximum average velocity (m/s), and average power (watts), by using the lineal encoder of the Muscle Lab™ system, which has a microprocessor that works internally with a 10- $\mu$ s resolution. When the load is moved, the optical transducer signal interrupts the microprocessor at each 0.07mm displacement. The maximal strength (1RM), velocity, and power calculations were performed as previously described [5]. Average power and 1RM were calculated by means of the range of motion used to perform a whole repetition.

*Training protocol:* Following the 5 min of cycle-ergometer warm-up and the five min of static stretching for quadriceps, hamstrings, and triceps surae, the training session was commenced. The training protocol consisted of 6 exposures of 60 s duration with 2-min rest between exposures to vertical sinusoidal WBV with the application of three different frequencies in three different days. The frequencies employed were 20, 30, and 40 Hz while the amplitude was kept constant at 4 mm. The order of the frequency application was randomized in three different visits to the lab with a rest period of a minimum of 72 h in between each visit in order to avoid residual effects from previous sessions (NEMES, Ergotest, Italy) (Fig. 1).

*Reproducibility of the variables:* Tests were repeated during three different days (Monday, Wednesday and Friday) in the week previous to training. The intra-class correlation values (inter-day) were the following: SJ= 0.93; CMJ= 0.96, 1RM= 0.91 and Power 0.95.



*Statistical analysis:* Traditional statistical methods were used in order to calculate both means and standard deviations (SD). The normality of the samples was calculated according to the Shapiro-Wilk test. An analysis of variance (ANOVA) with repeated measures and the Bonferroni adjustment for multiple comparisons were used to compare mean values. For the statistical significance the following symbology was used:  $p \leq 0.05$  (\*),  $p \leq 0.01$  (\*\*),  $p \leq 0.001$  (\*\*\*). The significance level was set at  $p < 0.05$  (\*); for all the statistical tests the SPSS 10.0 package for windows was used.



**Fig. 1**  
Data-recording protocol



## Results

The values obtained when analyzing the four parameters (SJ, CMJ, 1RM and power) are presented in table 1. It is noteworthy that there were not any differences found in the pretest values for any of the frequencies analyzed. Likewise, it is important to remember that the application of the different frequencies was randomized.

**Table 1**

Performance test parameters (SJ, CMJ, 1RM, and power) using three different frequencies of vibration

Frequency Hz	Mean (SD)		Difference Post – Pre	Sig. P <sup>b</sup>	95% CI	
	Pre <sup>a</sup>	Post			Lower	Upper
Squat Jump (cm)						
20	35.83 (5.21)	37.16 (3.89)	1.33	0.033	0.117	2.548
30	35.84 (4.50)	37.09 (4.57)	1.25	<0.001	0.717	1.792
40	36.93 (4.60)	36.01 (4.58)	-0.92	0.025	-2.053	-0.147
Counter Movement Jump (cm)						
20	39.63 (4.96)	39.94 (4.42)	0.31	0.480	0.582	1.209
30	39.25(6.24)	41.04 (5.35)	1.79	0.002	0.718	2.855
40	40.73 (5.58)	39.63 (5.20)	-1.10	0.020	-2.009	-0.184
1 RM (kg)						
20	242.77 (37.28)	248.15 (39.38)	5.38	0.252	-4.04	14.82
30	255.15 (44.60)	254.00 (50.27)	-1.15	0.851	-13.61	11.31
40	254.22 (35.23)	247.55 (53.82)	-6.67	0.321	-20.17	6.83
Power (w)						
20	1366.65 (216.19)	1386.76 (214.12)	20.11	0.029	2.16	38.06
30	1367.72 (214.04)	1430.20 (222.46)	62.48	<0.001	36.15	88.82
40	1365.84 (205.65)	1382.64 (235.28)	16.80	0.147	-6.23	39.82

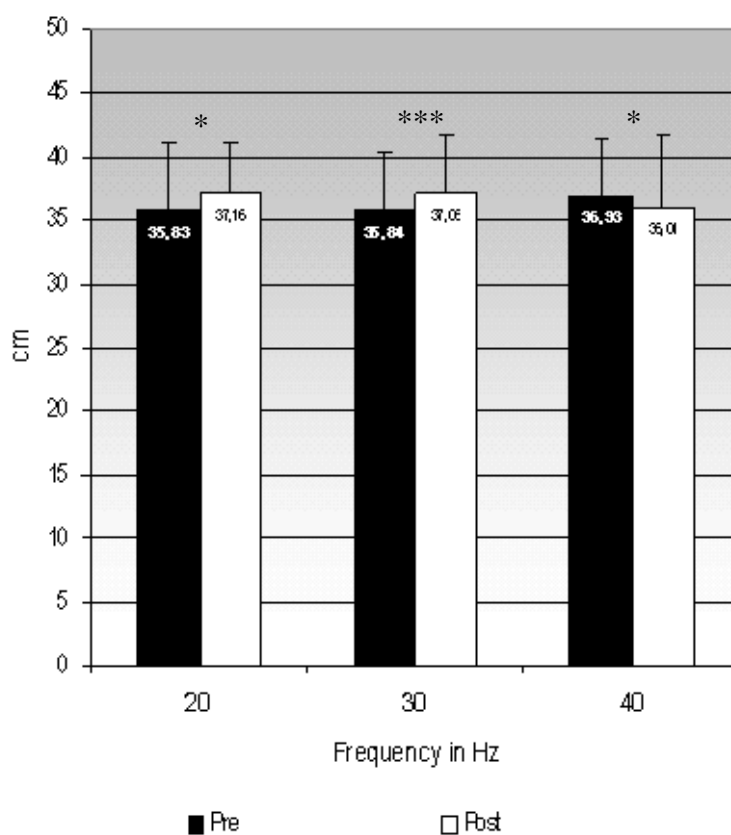
<sup>a</sup>There were no differences between the pre-values;

<sup>b</sup>Analysis of variance with repeated measures

*SJ*: After the application of just one session of WBV training at three different frequencies (20, 30, and 40Hz) in three different days, the results show significant increases for frequencies of 20 ( $p<0.05$ ) and 30 Hz ( $p<0.01$ ). Meanwhile, the



application of WBV with a frequency of 40Hz produced a significant decrease ( $p<0.025$ ) in the parameter analyzed (Fig. 2).



**Fig. 2**

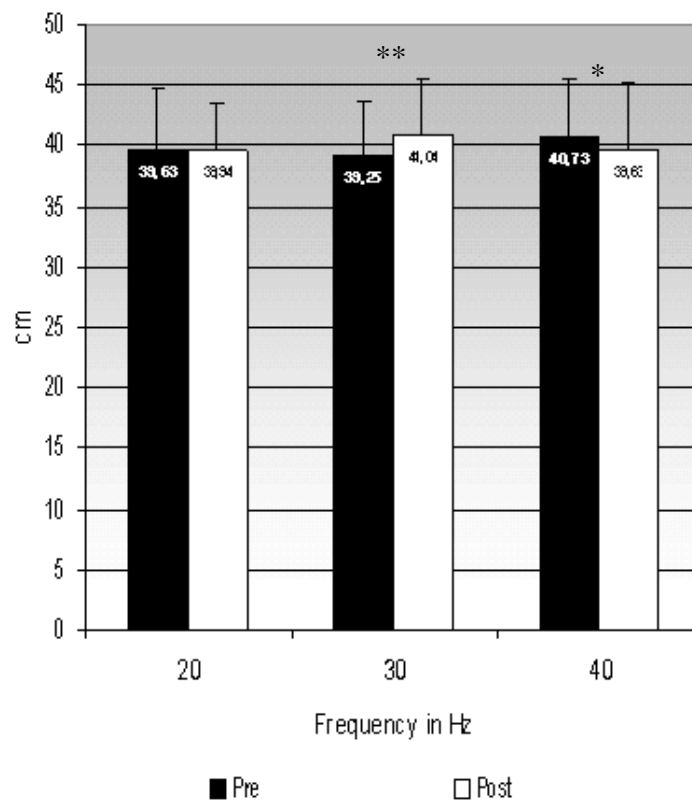
SJ test values (cm) using three different frequencies of vibration;

\*Mean differences significant for  $p<0.05$  level;

\*\*Mean differences significant for  $p<0.01$  level



*CMJ*: After the application of just one session of WBV training at three different frequencies (20, 30, and 40Hz) in three different days, the results show increases for both frequencies of 20 and 30Hz; however, the 20Hz frequency only produced a slight increase while the 30Hz frequency reached statistical significance ( $p<0.01$ ). In the meantime, the application of WBV with a frequency of 40Hz produced a significant decrease ( $p<0.05$ ) in the analyzed parameter (Fig. 3).



**Fig. 3**

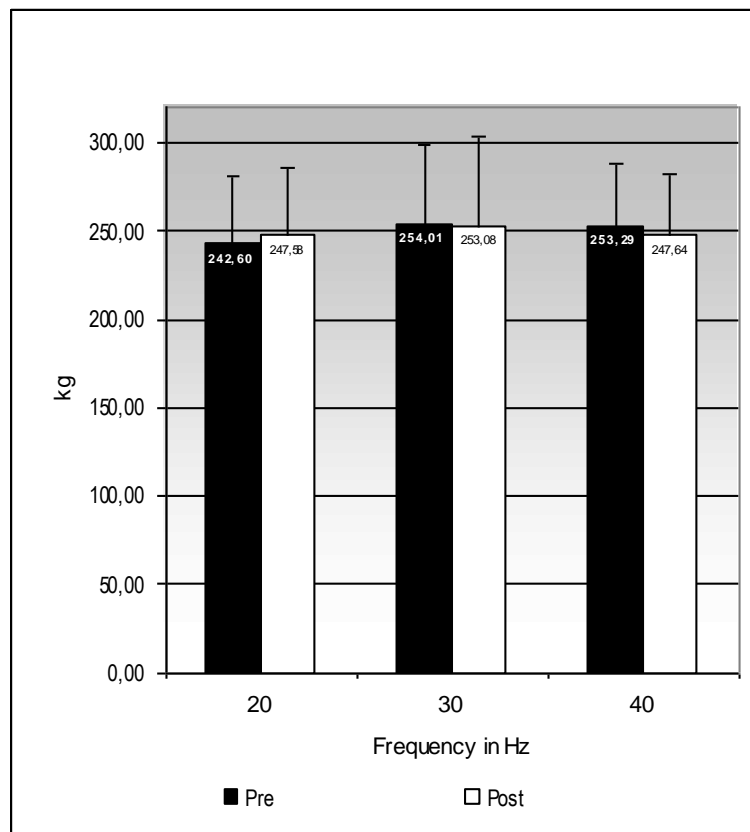
CMJ test values (cm) using three different frequencies of vibration;

\*Mean differences significant for  $p<0.05$  level;

\*\*Mean differences significant for  $p<0.01$  level



*1RM*: After the application of just one session of WBV training at three different frequencies (20, 30, and 40Hz) in three different days, the results show an increase for the frequency of 20Hz while the 30 and 40Hz frequencies produced a small decrease (such decrease was bigger for the frequency of 40 than for that of 30) in the parameter analyzed. None of the results were statistically significant (Fig. 4).

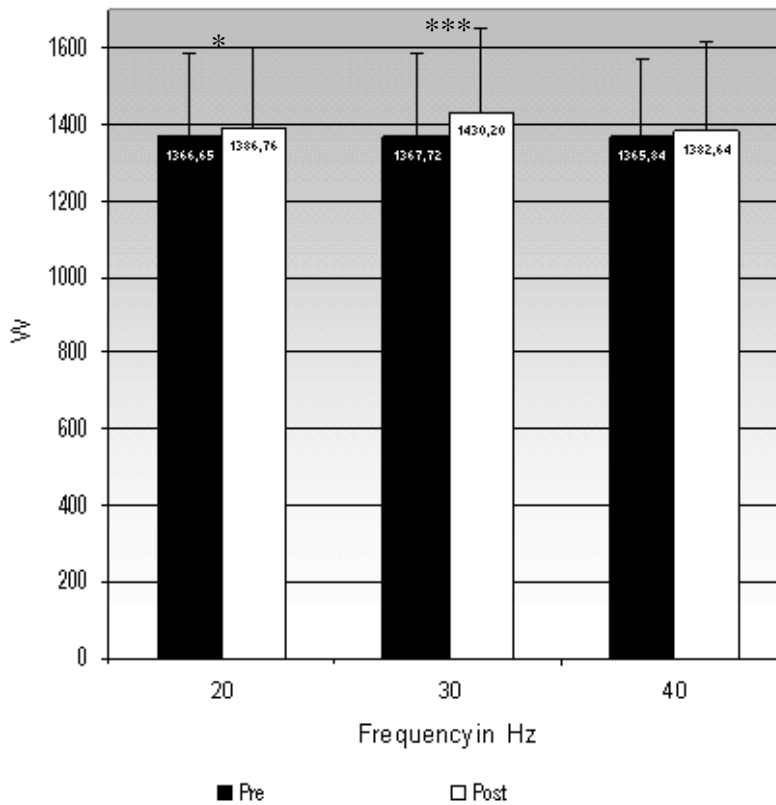


**Fig. 4**

1RM test values (kg) for lower body using three different frequencies of vibration



*Power:* When considering the values obtained with the maximal power test after the application of just one session of WBV training at three different frequencies (20, 30, and 40Hz) in three different days, it can be derived that there are significant increases for the frequencies of 20 ( $p<0.05$ ) and 30Hz ( $p<0.01$ ). The 40Hz frequency produced just a slight increase (Fig. 5).



**Fig. 5**  
Maximum power test values (W) for lower body using three different frequencies of vibration

\*Mean differences significant for  $p<0.05$  level;

\*\*\*Mean differences significant for  $p<0.001$  level



## Discussion

It can be observed, from the results obtained, that each frequency produces an effect on the analyzed parameters, not being able to state that there is just one frequency that improves such parameters in a uniform manner.

With regards to jump ability, as measured by means of the SJ and CMJ tests, it can be observed that it is improved after the application of 20- and 30Hz frequencies; such finding is in agreement with those found by other authors [6,9,12,28]. On the other hand, the 40Hz frequency produces performance deterioration; such finding is in agreement with those published by Rittweger *et al.* [26], De Ruiter [27], Bosco *et al.* [8] and Cardinale and Lim [12]. It has been observed some fatiguing effect when applying such frequency, this fact has even been expressed by the subjects and is in agreement with a study by Torvinen *et al.* [29] in which the authors found some signs of fatigue in the EMG signal when using the 40Hz frequency.

As said before, the SJ values improved in a significant manner both when applying the 20 and the 30Hz frequencies; this fact is in agreement with another study done using the 20Hz frequency [12]; however, in the present study highly significant ( $p < 0.001$ ) improvements using the 30 Hz frequency have been found as well. Whereas the SJ test results show the behaviour already described, the CMJ on the other hand shows that only the 30Hz frequency reaches statistical significance, showing just a slight increase with the 20Hz frequency. Similar results to those obtained in the present study have also been reported in the literature by authors using frequencies that were close to 30Hz [9,29].

In accordance to the results obtained with the use of the 40Hz frequency in this study, several authors have reported a decrease in vertical jump ability when using such frequency for SJ and CMJ [12] and for CMJ [8,26,27,29]. Such investigations have identified a decrease in neuromuscular performance after exercise with WBV. In the meantime, just one study found significant increases in CMJ after the application of a single WBV session with cyclists and significant increases for the SJ of cyclists and physically active subjects using that same frequency of 40 Hz [25].

The fact that the 20Hz frequency has produced an improvement of the SJ but not of the CMJ whereas that of 30Hz improves both jump tests, being that of the CMJ greater than that of SJ, can be due to the stretch-shortening cycle (SSC) only present in the CMJ, which might need a 30Hz frequency in order to be stimulated. Such cycle requires that before the concentric work is done (push-up phase), the leg extensor muscles be stretched in an active way (eccentric phase). There is a



possibility that the spinal pathway or the cortical reflex be involved in the SSC [2], and that the vibration training affects such pathways, therefore explaining the CMJ improvement, however the question as to why 30Hz is the frequency that produces the highest increase still remains.

Other experiments show a greater EMGrms activity (due to the reflex pathway) when using a 30Hz frequency [13]. This fact would be in agreement with the results of the present study; furthermore, it would explain the improvement of the CMJ when applying the 30Hz frequency. However, previous observations with constant displacement amplitude have shown that the monosynaptic inhibition does not vary with vibration frequency [21]. Others state that the increases induced by vibration on the EMG activity and, thus, the subsequent degree of motor units synchronization are dependent upon vibration frequency [22].

Regarding strength and power parameters, the changes observed with the 20Hz frequency show an increase in both parameters; while the increase in strength did not reach statistical significance the increase in power did ( $p < 0.05$ ).

On the contrary the 30Hz frequency produced apparently contradictory effects; thus, the strength exhibited a slight decrease while power increased in a much more significant manner ( $p < 0.001$ ) than in the 20Hz application ( $p < 0.05$ ). This increase in power so significant cannot be explained easily once the subjects had become familiarized with the exercise execution (ICC= 0.95 in the learning period). Our results, however, are consistent with the ones published by Bosco *et al.* [7] who, using national level-trained subjects, found greater increases in power and velocity than in strength (though the three parameters improved significantly), thus confirming that a single vibration session can increase muscle power.

It also has to be mentioned that it is not possible that the order in which the frequencies were applied would be able to influence the results since this was assigned in a random manner. Such changes in power after the application of 6 min of vibration at 30Hz have only been observed after several weeks of specific training for explosive strength and plyometric training [17]. The improvement observed in power has been ascribed to the improvement in the neuromuscular behaviour caused by an increased activity of the superior motor center [23]. According to Cardinale and Bosco [11], it is possible that the vibration training can cause a dramatic improvement of the neural traffic that regulates the neuromuscular behavior, fact that could offer an explanation to the increases observed in muscle power in the present study as well as in that of Bosco *et al.* [7].

It has to be noted, however, that when using the 40Hz frequency both strength and power experienced a decline, without reaching statistical significance however.



With regards to all that has previously been said, it can be concluded that the most ideal frequency for the WBV training might be that of 30Hz, and, thus, such frequency should be chosen in practice. However, it is important to bear in mind that there are other parameters that are inherent too to the WBV training, being such parameters amplitude, exposure time, recovery time between each exposure and total number of series. All these factors are of extreme importance and can modify the effect produced by the frequency and therefore must be taken in account when undergoing a WBV training.

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