MED SPORT 2003;56:287-92

The acute effects of two different whole body vibration frequencies on vertical jump performance

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Aim. Vibration exercise is a novel exercise intervention, which is applied in athletes and general populations with the aim of improving strength and power performance. The present study was aimed to analyse the adaptive responses to different whole body vibration frequencies.

Methods. Fifteen untrained subjects were randomly assigned to a 5 min whole body vibration (WBV) training session on a vibrating plate producing sinusoidal oscillations at 20 Hz (low frequency) and 40 Hz (high frequency) with constant amplitude. Squat jump, countermovement jump and sit and reach test were administered before and after the WBV treatment.

Results. Low frequency WBV stimulation was shown to significantly increase hamstrings' flexibility by 10.1% ($p<0.001$) and squat jump by 4% ($p<0.05$). High frequency (40 Hz) of WBV stimulation determined a significant decrease in squat jump (-3.8%; $p<0.05$) and in counter movement jump (-3.6; $p<0.001$).

Conclusion. The results showed the influence of WBV frequency on acute adaptive responses. In particular, the untrained subjects in the presented study, showed acute enhancement in neuromuscular performance with low-frequency WBV stimulation.

Key words: Vibration exercise - Neuromuscular performance - Vertical jump - Vibration frequency.

Mechanical stimulation in the form of vibration has been recently shown to produce specific adaptive responses in humans.[1-9] It has been hypothesized that a low-frequency, low-amplitude vibratory stimulation it is a safe and effective exercise intervention. A single session of 5 min of whole body vibration (WBV) has been shown to induce a shift of the force-velocity and power-velocity curve to the right in well trained female volleyball players.[3] A single session of 10 min divided in 2 sets of 5 bouts of 60 s WBV with 60 s rest in between sets has been shown to improve vertical jumping performance and determine an increase in testosterone and growth hormone production in well-trained individuals.[10] Recent evidence from Torvinen *et al.*[5] suggests that short-time exposure to WBV cab lead to an improvement in vertical jump performance and force generating capacity in lower limbs. On the other side, prolonged administration has been shown to induce fatigue and inhibit neuromuscular performance.[1, 8, 11] Although vibration is being employed from athletes in their training regimes, it is still unclear how it is possible to effectively use this novel exercise intervention. Few studies looking at the acute effects of WBV have shown contradictory results. In particular, the effect of different vibration frequencies on neuromuscular per-

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TABLE I. — *Data are expressed as mean±SD.*

Parameter	Pre	Post	Significance
20 Hz group			
Squat jump (cm)	24±2.5	25±3.1	p<0.05
Counter movement jump (cm)	29.5±4.4	30.1±4.5	NS (p=0.07)
Flexibility (cm)	20.5±8.6	22.6±8.4	p<0.001
40 Hz group			
Squat jump (cm)	26.5±4.7	25.4±4.4	NS (p=0.07)
Counter movement jump (cm)	33.8±5.51	32.5±5.1	p<0.001
Flexibility (cm)	23.6±5.9	22.9±6.7	NS (p=0.268)

formance is still unclear. Therefore, the purpose of this study was to analyse the acute effects of 2 different WBV frequencies on vertical jump and flexibility.

Materials and methods

Subjects

Fifteen subjects (2 women and 13 men) voluntarily participated to the study. They were all involved in recreational sport activities. They were randomly divided into 2 groups: a high frequency group (HFG) and a low frequency group (LFG). Subjects with previous history of fractures or bone injuries were excluded from the study. The HFG was constituted from 7 subjects (age: 20.4±0.5 years, height: 1.79±0.05 m; weight: 78±9.4 kg). Eight subjects were assigned to the LFG (age: 21±2.2 years, height: 1.76±0.1 m; weight: 75.2±18.2 kg). The protocol was approved by the local ethics committee.

Procedures

The subjects were familiarized with the protocol and the WBV treatment the day before the experimental trial. At the beginning of the experimental session anthropometric measures (height and weight) were recorded together with the age of the subjects. Following this phase a 10 min standard warm up consisting of running, jumping and stretching exercises was performed. After the warm up, the subjects performed the followings tests: sit and reach test (S&R), squat jump (SJ), and counter movement jump (CMJ). Between groups comparison did not reveal statistically significant differences at baseline for all the measured variables.

Sit and reach test was performed on a sit and reach box in which subjects were seated with their heels firmly planted against the heel board, and feet approximately 1 foot apart. Testing procedures have been described elsewhere.[12] Three trials were performed and the best one was used for statistical analysis.

Vertical jumping tests were conducted on a resistive platform [13] connected to a digital timer (accuracy±0.001s) (Ergojump, Psion XP, MA.GI.CA. Rome, Italy) which was recording the flight time (t_f) and contact time (t_c) of each single jump. In order to avoid unmeasurable work, horizontal and lateral displacements were minimised, and the hands were kept on the hips through the tests. The rise of the center of gravity above the ground (h in meters) in was measured from flight time (t_f in seconds) applying ballistic laws:

$$h=t_f^2 \cdot g \cdot 8^{-1} \text{ (m)} \quad [1]$$

where g is the acceleration of gravity (9.81 $m \cdot s^{-2}$).

Two different jumping tests were performed: squat jump (SJ), in which subjects were jumping from a semi-squatting position without counter movement and counter movement jump (CMJ) in which subjects were allowed to perform a counter movement with lower limbs before jumping. Three trials for each test were performed, the best result was considered for statistical analysis.

Treatment procedures

Subjects were exposed to vertical sinusoidal WBV using the device called NEMES LC (Ergotest, Greece). The frequencies used

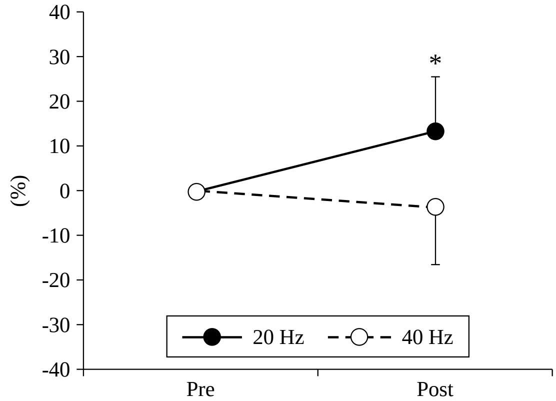

Figure 1.—The percentage changes in flexibility after the vibration intervention. *p<0.05 for between treatments comparisons.

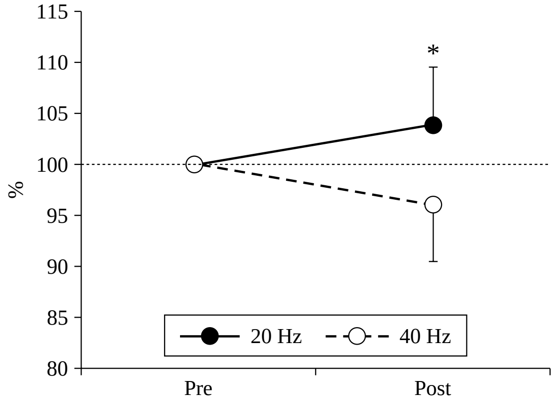

Figure 2.—The percentage changes in squat jump after the vibration intervention. *p<0.05 for between treatments comparisons.

in this study were 20 Hz for the LFG and 40 Hz for the HFG (Peak-to-peak displacement=4 mm; theoretical acceleration=6.4 g (20 Hz) and 25.7 (40 Hz) g, where g is equal to 9.81 $m \cdot s^{-2}$). The subjects were exposed to 5 bouts lasting 60 s each of WBV while standing on the vibrating plate in semi-squatting position. Sixty s rest in between each bout was allowed. Sixty s following the last bout of WBV testing took place again.

Statistical methods

Conventional statistical methods used included mean, standard deviation and paired and unpaired Student's t-test. The level of significance was set at $p<0.05$.

Results

Whole body vibration with low frequency (20 Hz) determined a statistically significant increase in hamstrings flexibility (+13.5%; $p<0.001$) and squat jump (+3.9%; $p<0.05$). Counter movement jump also improved but did not reach statistical significance (+2.3%; $p=0.07$). Whole body vibration stimulation with high frequency determined a non statistically significant reduction in squat jump (-4%; $p<0.07$) and counter movement jump (3.8%; $p<0.001$). A non statistically significant decrease in flexibility was also observed (-3.3 %; $p=0.268$) (Table I).

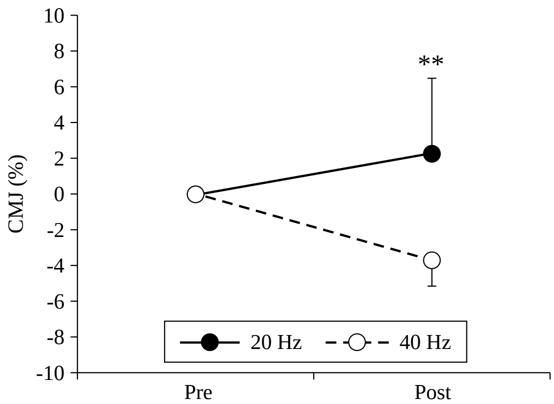

Figure 3.—The percentage changes in counter movement jump after the vibration intervention. *p<0.005 for between treatments comparisons.

Between treatments analysis revealed a statistically significant difference in all variables analyzed (Figures 1, 2, 3).

Discussion and conclusions

The results of this study have shown that different acute effects can be observed with different vibration frequencies in sedentary subjects. The reduction in vertical jumping ability observed following 10 min of vibration exercise with a frequency of 40 Hz is in line with previous investigations which have identified an acute impairment in neuromuscular performance following WBV exercise.[6, 8, 11, 14]

They reported a significant marked reduction in vertical jump [6, 14] and maximal knee extensors force [11] following WBV exercise with similar protocols.

Five minutes of WBV with a low frequency (20 Hz) were shown to acutely enhance neuromuscular performance as measured by vertical jumping ability. This observation is also consistent with previous findings [1-3, 5] which found acute improvements in vertical jumping ability and force-generating capacity in humans following 4 to 5 min WBV at frequencies ranging from 15 to 30 Hz.

Any acute effect of WBV training was expected to be of neural origin. In particular, the role of agonist/antagonist muscle activity in the modulation of joint stiffness has been hypothesized to be the responsible for acute adaptive responses.[15] In this study different vibration frequencies were shown to have different effects on knee joint stiffness since the change in vertical jumping ability was parallel to the change in hamstrings' flexibility. During vibration the body and the skeletal muscle undergo to small changes in muscle length. The peculiar characteristics of the vibratory stimulus determine an activation of Ia afferent fibers.[16] Mechanical vibrations applied to the muscle itself or the tendon elicit a reflex muscle contraction named tonic vibration reflex (TVR).[17] This reflex contraction is caused by an excitation of muscle spindles leading to an enhancement of the activity of the Ia loop.[18, 19] Facilitation of the excitability of spinal reflexes has been shown to be elicited through vibration to quadriceps muscle.[20] Lebedev and Peliakov [21] also suggested that vibration may elicit excitatory flow through short spindle – motoneurons connections in the overall motoneuron inflow. The neural circuitry involved in the tonic vibration reflex has been quoted to be similar to the one observed for the tendon tap reflex. It then involves the activation of the homonimous motor units and the decrease in excitability of the motor neurons innervating the antagonist muscle through the reciprocal-inhibition circuit. Since no EMG measurement was performed in this study, it was not possible to measure the actual effect of vibration on agonist and antagonist muscles acting on the knee joint. However, the changes in vertical jumping ability and the correspondent changes in hamstrings flexibility seem to suggest that vibration exercise is capable of acutely affect joint stiffness.

Vibrations are perceived not only by spindles, but also by the skin, the joints and secondary endings. All those structures contribute to the facilitatory input to the γ-system [22, 23] which in turn affects sensitivity of the primary endings. Hollins and Roy [24] found that sinusoidal stimuli ranging from 10 to 100 Hz with a small amplitude applied to the left index fingerpad were perceived by Meissner and Pacinian afferents and were able to trigger spindle activation. The modulation of neuromuscular response to vibration is then not only to be referred to spindle activation, but to all the sensory systems in the body. Various parameters can affect the synergies in the sensory system and determine specific responses. Vibration is thought mainly to inhibit the contraction on antagonist muscles *via* Ia inhibitory neurons.[25] However there is also some evidence that vibrations can produce also coactivation. Rothmuller and Cafarelli [16] applying vibrations to the patellar tendon and measuring biceps femuris coactivation have observed this phenomenon. Jones and Hunter [26] also found an increased coactivation when applying vibrations. This phenomenon has been attributed to central mechanisms increasing presynaptic inhibition of Ia afferents transferring the inhibition to antagonist motoneurons.[16] This has been observed when vibrations were applied in fatiguing conditions or when vibration was causing fatigue.

Individual fitness status should also be considered when developing vibration exercise protocols. As supportive evidence, well-trained individuals showed an acute improvement in force-generating capacity [2, 3] and untrained subjects showed an acute decrease following similar vibration exercise protocol.[11] In our study, untrained individuals showed acute improvement in vertical jumping ability and hamstrings flexibility following low frequency vibration exercise and acute decrease in vertical jumping and hamstrings' flexibility following high-frequency vibration exercise. The muscle-tendon complex acts as a low pass filter and is able to attenuate vibration transmission to the spindles. Those capabilities of the musculotendinous units have been clearly identified in the lower limbs while running. In fact, impact forces during running have been found to produce vibrations, which are transmitted to the body at a frequency component between 10 and 20 Hz.[27] The soft tissues of the lower limb damp those vibrations coming from heel contact changing their stiffness. The adjustment of the stiffness of the lower limbs based upon the shock wave received is also based on the sensory receptors in the muscle itself, in the tendons (Golgi tendon organs), but also in the joints, ligaments and in the skin. In our opinion the "muscle tuning" hypothesis underlined by Nigg and Wakeling [27] and Wakeling and Nigg [28] is to be considered also as the possible adaptive response to the application of vibrations. Different individuals can adapt to different vibration frequencies since they possess different bandwith properties of their spindles, different amounts and location of mechanoceptors and proprioceptors, different viscoelastic properties of the muscle tendon complex and different percentages of type II fibers. Previous authors have reported that a frequency below ~20 Hz induces muscle relaxation, whereas at frequencies above ~50 Hz severe soreness may emerge in untrained subjects.[9] The enhancement of performance observed with low frequency stimulation could be due to several aspects. First, it is possible that the low frequency stimulation used in our study was not strong enough to cause muscle fatigue and was triggering a limited TVR. Also, relaxation of hamstrings muscles, as shown by an increase in flexibility, would have facilitated vertical jumping ability, which is characterised by high-speed knee joint rotation. Second, it is likely that the high frequency treatment elicited a strong TVR, increasing the neuromuscular activation of the lower limbs in order to damp the vibratory waves transmitted to the body. Stressful vibratory stimulation could in fact increase co-contraction of the hamstrings. Our results seem to support this view. As previously suggested,[15] when the vibration stimulus does not produce fatigue and is of relatively short duration can determine an increased excitatory state of the CNS and facilitate force-generating capacity in humans. On the other hand, when the opposite occur (vibratory stimulus is too stressful causing fatigue), force generating capacity is impaired. Considering the background of our subjects (untrained individuals) it should not be far fetched to suggest that a good progression program with vibration exercise should start with the use of lower frequencies of stimulation. Moreover further studies are needed in order to elucidate the exact neurophysiological mechanisms involved in the adaptive responses to vibration exposure in different populations. Vibration exercise it's a novel form of exercise and only few studies have been so far conducted on combining different frequencies/amplitudes of stimulation. The results of our study suggest that untrained individuals are able to increase force-generating capacity acutely with low-frequency vibration stimulation. The main conclusion of the present study suggests that future work is needed in order to develop safe and effective protocols for vibration exercise in different subjects and in different muscle groups.

Acknowledgements.—The authors would like to acknowledge Gordon Smith, Leanne Cairns, Iain Haslam, Alan MacKenzie and Randawa Gurneelam for technical assistance.

Riassunto

Gli effetti acuti di due diverse frequenze di vibrazione sulla prestazione di salto verticale

Obiettivo. L'utilizzo delle vibrazioni come mezzo di allenamento rappresentano una novità nel campo dell'attività fisica. Le vibrazioni sono, infatti, utilizzate da atleti e non atleti con l'obiettivo di migliorare le prestazioni di forza e potenza. Lo scopo di questo studio consiste nell'analizzare le risposte acute a 2 diverse frequenze di vibrazione.

Metodi. Sedici soggetti sedentari sono stati assegnati in maniera random a diversi trattamenti di 5 min di vibrazioni applicate a tutto il corpo per mezzo di una pedana vibrante che produceva oscillazioni sinusoidali alle frequenze di 20 Hz (bassa frequenza) e 40 Hz (alta frequenza). L'altezza di salto verticale misurata mediante l'esecuzione dello *squat jump* e del *counter movement jump* e la flessibilità dei muscoli ischio-crurali mediante il test del *sit and reach* vennero verificate prima e dopo il trattamento in entrambi i gruppi.

Risultati. Il gruppo sottoposto al trattamento con bassa frequenza dimostrò un miglioramento statisticamente significativo del 10,1% (p<0,001) nel *sit and reach* e del 4% (p<0,05) nello *squat jump*. Il gruppo sottoposto al trattamento ad alta frequenza (40 Hz) mostrò un decremento statisticamente significativo nello *squat jump* (-3,8%; p<0,05) e nel *counter movement jump* (-3,6; p<0,001).

Conclusioni. I risultati indicano che, in soggetti sedentari, le vibrazioni producono diverse risposte acute in seguito all'utilizzo di diverse frequenze di vibrazione. In particolare, i soggetti del presente studio dimostrarono un miglioramento acuto della prestazione di salto verticale in seguito a stimolazioni a bassa frequenza.

Parole chiave: Vibrazioni - Prestazione neuromuscolare - Salto verticale - Frequenza di vibrazione.

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