ARTICLE

The Use of Vibration as an Exercise Intervention

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CARDINALE, M., and C. BOSCO. The use of vibration as an exercise intervention. *Exerc. Sport Sci. Rev.*, Vol. 31, No. 1, pp. 3–7, 2003. *The use of vibration as a means for enhancing athletic performance is a recent issue in exercise physiology. Current evidence suggests that vibration is effective in enhancing strength and the power capacity of humans, although the mechanisms mediating this effect are unknown.* **Keywords:** neuromuscular adaptations, oscillation, muscle strength, muscle power, muscle spindle

INTRODUCTION

Vibration is a mechanical stimulus characterized by an oscillatory motion. The biomechanical parameters determining its intensity are the amplitude, frequency, and magnitude of the oscillations. The extent of the oscillatory motion determines the amplitude (peak to peak displacement, in mm) of the vibration, the repetition rate of the cycles of oscillation denotes the frequency of the vibration (measured in Hz), and the acceleration indicates the magnitude of the vibration.

It has been hypothesized that low-amplitude, low-frequency mechanical stimulation of the human body is a safe and effective way to improve muscle strength. Increases in muscular strength and power in humans exercising with specially designed exercise equipment have been reported recently (1,2,3,4,15). The effects of whole-body vibration have been studied with subjects exercising on vibrating plates (1,2,4,15) that produce sinusoidal vibrations (Fig. 1). Low-frequency vibration has been also applied locally by means of vibrating cables (9,10) and vibrating dumbbells (3). The frequencies used for exercise range from 15 to 44 Hz and displacements range from 3 to 10 mm. The acceleration values range from 3.5 to 15 *g* (where *g* is the Earth's gravitational field or 9.81 $m \cdot s^{-2}$). Thus, vibration provides a perturbation of the gravitational field during the time-course of the intervention.

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The purpose of this review is to summarize the current knowledge on the effects of vibration on human performance and to identify the potential mechanisms that underlie the enhancement of strength and power production.

THE EFFECT OF VIBRATION ON HUMAN PERFORMANCE

The possibility of using vibrations as an exercise intervention is a relatively recent idea. The first application of vibration as an exercise intervention was conducted by Russian scientists, who found that vibration was effective in enhancing strength in well-trained subjects (as cited in (9,10)). Subsequently, the effects of vibration exercise have been examined after acute and chronic exposure using different treatment protocols.

Acute enhancement of mechanical power has been shown after vibration treatment applied with vibrating cables during bilateral biceps curl (elbow flexion and extension) on a pulley machine (10). The experimental protocol consisted of vibration delivered to the subjects by means of vibrating cables producing oscillations at 44 Hz and 3-mm amplitude (10). In this experiment, both elite and amateur athletes showed improvement, respectively, of 10.4% and 7.9% in maximal power measured during the bilateral biceps curl exercise. Whole-body vibration administered through vibrating plates has been shown to enhance vertical jumping ability by 3.8%. In the same experiment, mechanical power output by the legs during horizontal leg press increased by 7% (4). Five applications of whole-body vibration at a frequency of 26 Hz lasting 60 s with 60-s rest in female professional volleyball players resulted in a shift to the right of the force-velocity and power-velocity curves as measured by an isoinertial dynamometer during the horizontal leg press exercise (2). Vibration applied for a total time of 5 min with vibrating dumbbells (30 Hz, 6-mm amplitude) produced an increase of 13% in average power in the elbow flexor muscles of elite boxers (3). The increase in mechanical power during arm flexion was associated with a reduction in the EMG root mean square (rms) activity in biceps brachii.

Chronic treatments have been also shown to produce improvement in neuromuscular properties of human skeletal muscle. Issurin *et al.* (9) superimposed vibration, with cables vibrating at 44 Hz, during weight-lifting exercises performed on pulley machines and found a significant improvement in the maximal force (+ 49.8%) and flexibility (+ 43.6%) after 3 wk of treatment. Whole-body vibration at a low frequency (26 Hz, 10-mm displacement) administered for 10 d to active subjects was capable of enhancing vertical jump height by 12% (1). These findings suggest that vibrations can effectively enhance neuromuscular performance.

THE POTENTIAL MECHANISMS MEDIATING THE EFFECT OF VIBRATION ON NEUROMUSCULAR PERFORMANCE

It has been suggested that muscle activation by means of vibration may induce improvements in strength and power performance similar to those observed with strength training (1,2,3). The similarity of the effect is probably related to the characteristics of the load imposed by vibration, which, as with strengthening and plyometric exercises, increase the gravitational load imposed on the neuromuscular system. Vibration exercise has been reported to increase the gravitational load up to 14 *g* (1,2,3,4,15).

Skeletal muscle is a specialized tissue that modifies its overall functional capacity in response to different stimuli. The influence of gravitational load on muscular performance is of paramount importance. In normal conditions, muscles experiencing the daily action of gravity are capable of maintaining their performance capabilities. When the gravitational load is reduced (microgravity), a marked decrease in muscle mass and force-generating capability is observed (for a review, see (7)). In contrast, an increase in the gravitational load (hypergravity) will increase in the cross-sectional area and force-generating capacity of muscle. Exercise programs designed to increase strength and power are characterized by performing exercises with an increase in gravitational load. These forms of exercise have been shown to produce specific adaptive responses in skeletal muscles involving both morphological and neural factors (6). The early gains in force-generating capacity have been attributed to changes within the nervous system, attributable to the absence of an increase in cross-sectional area of muscle fibers in the first several wk of training program (6).

Vibration exercise imposes hypergravity activity due to the high accelerations (1,2,3,4,9,10,15). The mechanical action of vibration is to produce fast and short changes in the length of the muscle-tendon complex. This perturbation is detected by the sensory receptors that modulate muscle stiffness through reflex muscular activity and attempt to dampen the vibratory waves (Fig. 2). To understand the mechanisms responsible for vibration-induced enhancement of performance, it is necessary to distinguish between the effects of vibration on an active muscle from those occurring after an application of vibration.

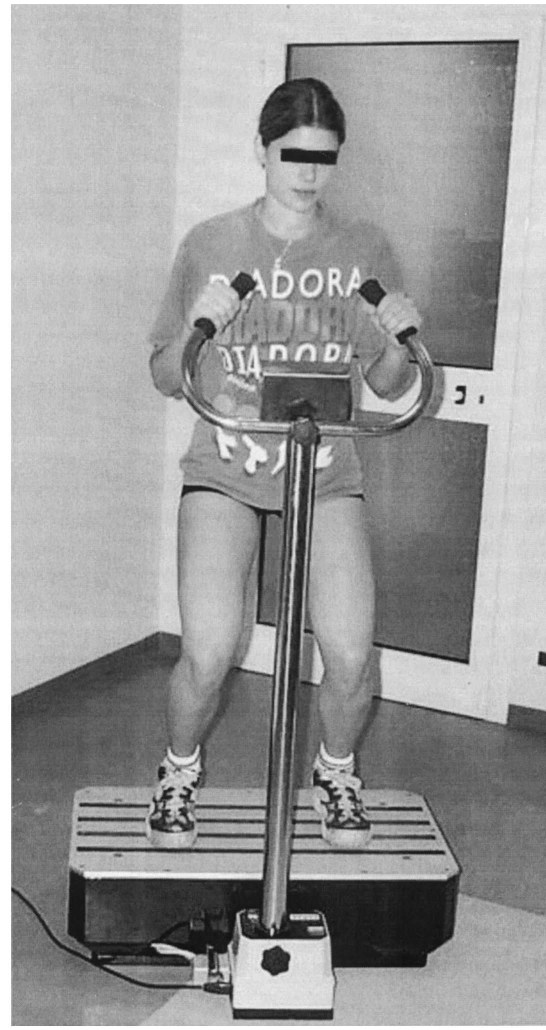

Figure 1. Whole-body vibration exercise machine.

Mechanical vibrations applied to the muscle itself or the tendon can elicit a reflex muscle contraction named "Tonic Vibration Reflex" (8). The deformation of the soft tissues caused by vibration is capable of activating muscle spindles and leading to an enhancement of the stretch-reflex loop. Thus, the excitatory inflow during vibration stimulation is mainly related to the reflex activation of the α-motor neuron. An increase in EMG activity is usually observed during vibration treatment with values higher than the ones observed during voluntary muscular activity. Accordingly, we found the root mean square EMG of biceps brachii muscle to be 200% higher in boxers exercising with a vibrating dumbbell compared with performing a voluntary arm flexion with a load equal to 5% of the subjects' body mass (3). This effect could be related to an increased synchronization of motor units due to the application of vibration. Reflex muscle activity represents the response of the neuromuscular system

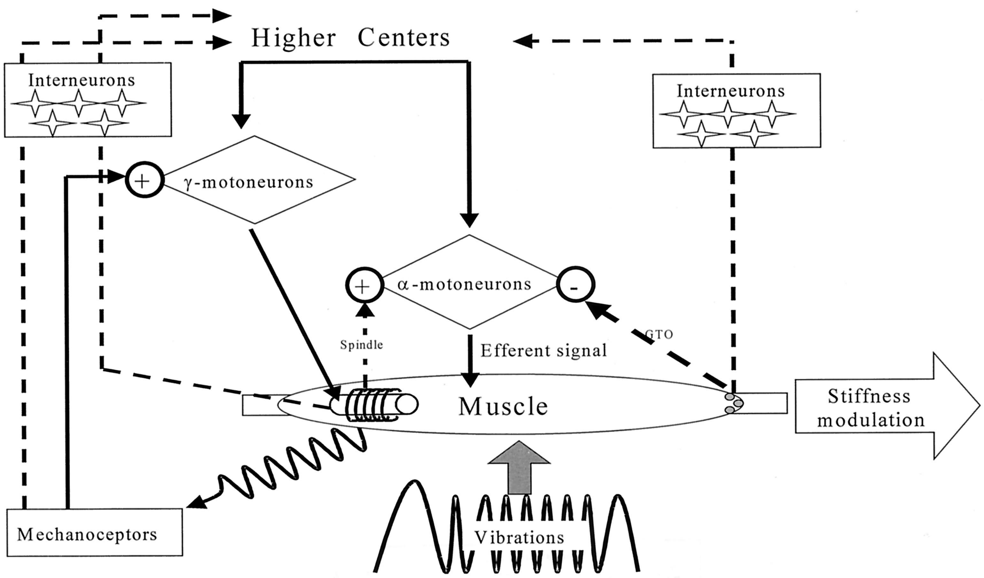

Figure 2. Schematic diagram illustrating stiffness regulation during vibration stimulation. The quick change in muscle length and the joint rotation caused by vibration trigger both α and γ motor neurons to fire to modulate muscle stiffness. Higher centers are also involved via a long loop.

to a strong perturbation caused by mechanical vibration. This reaction can be mediated not only by monosynaptic but also by polysynaptic pathways. The primary endings of the muscle spindle are more sensitive to vibration than are the secondary endings and Golgi tendon organs. Vibration is perceived not only by neuromuscular spindles, but also by the skin, the joints, and secondary endings (13). Consequently, whether using whole-body or locally applied vibration, these sensory structures likely facilitate the γ-system during the application of vibration and enhance the sensitivity of the primary endings.

The acute enhancement of neuromuscular performance after vibration is probably related to an increase in the sensitivity of the stretch reflex. Furthermore, vibration appears to inhibit activation of antagonist muscles through Ia-inhibitory neurons, thus altering the intramuscular coordination patterns leading to a decreased braking force around the joints stimulated by vibration. For example, pilot data from a recent investigation have shown after the application of vibration there was both an increased in vertical jump height and an increase in the range of motion about the hip joint due to improved flexibility of the hamstrings. Therefore, vibration might stimulate the proprioceptive discharge occurring during muscle stretch and fast joint rotation although the actual change in the above parameter is minimal.

It is also important to consider the influence of vibratory stimulation on central motor command. It has been shown that the primary and secondary somatosensory cortex, together with the supplementary motor area, constitutes the central processing unit of afferent signals (12). Vibration applied at different frequencies that is capable of producing kinesthetic illusion has been shown to activate the supplementary motor area, the caudal cingulate motor area, and area 4a of the brain (12). Moreover, the supplementary motor area of the brain that is activated by vibration (12) is activated early during self-initiated movements (5). The vibration stimulus then influences the excitatory state of the peripheral and central structures, which could facilitate subsequent voluntary movements. The postvibration enhancement of performance includes an increase an vertical jump height by 2.5% in the first min after 4 min of the treatment (15), an increase in vertical jump by 3.8% after a total of 10 min of whole-body vibration (5), and an increase of 13% in the average power recorded during arm flexion in well-trained subjects (4) after 5 min of locally applied vibration. These improvements in performance have disappeared 60 min after the treatment (15). It is likely that the greater levels of force after vibration are due to both an enhancement of the stretch reflex and the excitatory state of the somatosensory area. Current evidence, however, does not allow an explanation of the specific neural adaptations that accompany a vibration treatment.

Recent evidence suggests that the acute neural potentiation observed after vibration exercise is relatively short lasting. For example, an acute administration of vibration increased vertical jump height for 2 min after the treatment but this effect had disappeared after 1 h (15). It appears that the duration of the vibration exercise is important. Relatively short exposure (4–5 min divided in bouts lasting 1 min each with 1-min rest in between bouts), for example, is capable of enhancing subsequent voluntary strength exertion. Long-duration vibration, however, reduces the force-generating capacity of muscle (14). The long-duration effect could be due to either activation of inhibitory feedback (*e.g.*, Golgi tendon organs) or reduced sensitivity of muscle spindles, such as that caused by depletion of neurotransmitter or presynaptic inhibition. A summary of the potential mechanisms determining an increase in neuromuscular performance is schematically represented in Figure 3. The vibratory stimulus, being perceived by different sensory structures, stimulates the neuromuscular system to produce reflex muscle activation. If the vibratory stimulus is relatively short, it creates the potential for a more powerful and effective voluntary activation

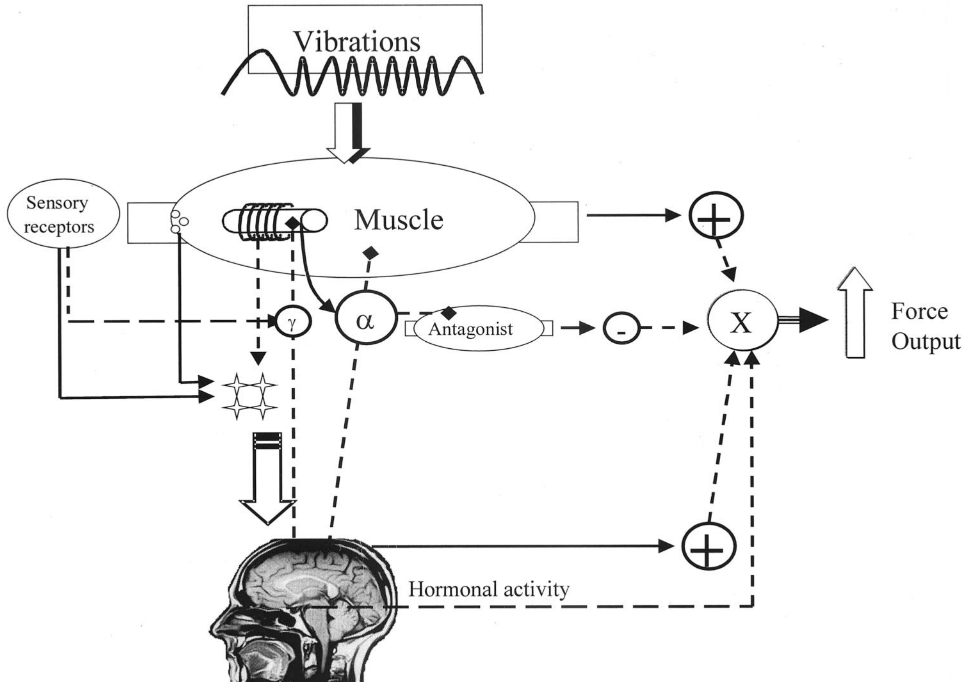

Figure 3. Schematic diagram illustrating the potential mechanisms that mediate the enhancement of force-generating capacity after acute and chronic exposure to vibration. Vibrations determine an increased excitatory state of the neuromuscular system due to an increase in the sensitivity of stretch reflexes and the stimulation of the specific areas of the brain. The central influence also influence the hypothalamus-hypophysis axis, which triggers the secretion of specific hormones. All these factors contribute to the increase in force-generating capacity of skeletal muscle.

of skeletal muscle. The relative significance of these different mechanisms could be assessed by examining the effect of vibration on various evoked responses, such as with transcranial magnetic stimulation and the H-reflex.

Hormonal factors could also be involved in the neuromuscular adaptations. The responses of mammals to external environmental changes inevitably involve neural and hormonal responses, including changes in gravitational acceleration (7,11). Prolonged exposure to microgravity has been shown to result in a decrease in muscle mass and force-generating capacity (7). Moreover, studies conducted on astronauts have shown that microgravity produces a decline in androgen levels and growth hormone (in 11) in salivary, urinary, and plasma samples. This is due to the fact that microgravity represents a strong perturbation to the homeostasis of the body because of the lack of physical tension on the musculoskeletal system, loss of hydrostatic pressure, and alteration of the sensory-motor system. In contrast, an increase in gravitational load by means of strengthening exercises has been shown to increase the previously mentioned hormones. This particular form of exercise provides high stress on the musculoskeletal structures and requires high levels of neural activity. It represents an increased demand as compared with the homeostatic conditions and then stimulates rapid physiological responses. During strength training exercise, rapid endocrine activation is triggered by collaterals of the central motor command and transmitted to the hypothalamic neurosecretory and autonomic centres. The responses are further supported by feedback influences from proprioceptors and metaboreceptors in the muscle. The mechanical characteristics of vibration could provide an adequate stimulus for specific hormonal secretion. In addition to the effects on sensory feedback, for example, vibration also increases testosterone and growth hormone levels in humans (4). Furthermore, recent investigations underscore the interaction between proprioceptors and hormonal responses. For example, the modulation of a muscle afferent-pituitary axis on bioassayable growth hormone secretion has been identified after vibration-induced activation of specific muscles (11). It seems reasonable to suggest that the increased levels of testosterone observed after vibration treatments are related to the increased force output. In particular, the possible influence of this androgen hormone on calcium-handling mechanisms in skeletal muscle could facilitate a more powerful muscular activation.

CONCLUSION AND APPLICATION

Vibration represents a strong stimulus for musculoskeletal structures due to the need to quickly modulate muscle stiffness to accommodate the vibratory waves. This response is mediated by monosynaptic and polysynaptic afferent pathways, which are capable of triggering specific hormonal responses. It appears that a subsequent voluntary activation can be performed with central and peripheral structures in an elevated excitatory state.

These findings suggest that vibration could represent an effective exercise intervention for enhancing neuromuscular performance in athletes. However, it seems appropriate to consider other applications to the general population. We are convinced that vibration could be an effective exercise intervention for reducing the effects of aging on musculoskeletal structures. The potential influence of vibration on hormonal activity also opens interesting perspectives for its application in training and rehabilitation programs for different pathologies. Due to the enormous potentials of vibration exercise treatments, it is also important to study the effects of long-term vibration exercise programs on different physiological parameters and define safe exercise protocols based upon individual responses to vibration stimuli. Ultimately, the effects of vibration exercise on musculoskeletal interactions need to be analyzed, to verify the effectiveness of this form of exercise on bone remodeling, including the potential effects on osteoporosis.

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