

REVIEW

Whole body vibration exercise: are vibrations good for you?

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Whole body vibration has been recently proposed as an exercise intervention because of its potential for increasing force generating capacity in the lower limbs. Its recent popularity is due to the combined effects on the neuromuscular and neuroendocrine systems. Preliminary results seem to recommend vibration exercise as a therapeutic approach for sarcopenia and possibly osteoporosis. This review analyses state of the art whole body vibration exercise techniques, suggesting reasons why vibration may be an effective stimulus for human muscles and providing the rationale for future studies.

fitness and rehabilitation centres are using vibration in their exercise programmes, but current knowledge on appropriate safe and effective exercise protocols is very limited, and claims made by companies and pseudo-experts can be misleading.

The purpose of this review is to analyse the potential mechanisms by which muscles respond to vibration and to summarise current knowledge of the effects of vibration on human strength and power performance.

IS VIBRATION A NATURAL STIMULUS?

During all sporting activities our bodies interact with the external environment and experience externally applied forces. These forces induce vibrations and oscillations within the tissues of the body. Tissue vibrations can be induced from impact related events where either a part of the body or sporting equipment in contact with the body collides with an object. Examples of this are the impact shocks that are experienced through the leg when the heel strikes the ground during each running stride or the impact shock that occurs when a racquet is used to hit a ball. The initial impact causes vibrations within the soft tissues, after which the tissues continue to oscillate as a free vibration—that is, vibrating at their natural frequency, with the amplitude of these vibrations decaying because of damping within the tissues. Tissue vibrations can also be induced when the body experiences more continuous forms of vibration, such as may occur through the legs during skiing across a groomed slope or through the arms during bike riding. A continuously oscillating input force drives the soft tissue vibrations to be at the same frequency as the input force, but the amplitude of the vibrations will be greatest if the natural frequency of the tissues is close to that of the input force (resonance); however, the amplitude of these larger amplitude vibrations can be reduced by damping from the tissues. Therefore we can expect to experience soft tissue vibrations in all sporting activities, and the amplitude and frequency of these vibrations is partly determined by the natural frequency and damping characteristics of the tissues.

The body relies on a range of structures and mechanisms to regulate the transmission of impact shocks and vibrations through the body including: bone, cartilage, synovial fluids, soft tissues, joint kinematics, and muscular activity. Changes in joint kinematics and muscle activity

Abbreviations: WBV, whole body vibration; WBVT, whole body vibration training

Vibration is a mechanical stimulus characterised by an oscillatory motion. The biomechanical variables that determine its intensity are the frequency and amplitude. 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 determines the frequency of the vibration (measured in Hz).

Vibration has been studied extensively for its dangerous effects on humans at specific amplitudes and frequencies. On the other hand, recent work has suggested that low amplitude, low frequency mechanical stimulation of the human body is a safe and effective way to exercise musculoskeletal structures. In fact, increases in muscular strength and power in humans exercising with specially designed exercise equipment have been reported.^{1–7} In particular, the effects of whole body vibrations (WBVs) have been studied with subjects exercising on specially designed vibrating plates producing sinusoidal vibrations (fig 1). The exercise devices currently available on the market deliver vibration to the whole body by means of oscillating plates using two different systems: (a) reciprocating vertical displacements on the left and right side of a fulcrum; (b) the whole plate oscillating uniformly up and down.

WBV exercise devices deliver vibrations across a range of frequencies (15–60 Hz) and displacements from <1 mm to 10 mm. The acceleration delivered can reach 15 *g* (where 1 *g* is the acceleration due to the Earth's gravitational field or 9.81 m/s²). Considering the numerous combinations of amplitudes and frequencies possible with current technology, it is clear that there are a wide variety of WBV protocols that could be used on humans. Vibration exercise is quite a new topic in sport science. Many athletes and

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can be controlled on a short time scale and are used by the body to change its vibration response to external forces. It has been proposed that the body has a strategy of "tuning" its muscle activity to reduce its soft tissue vibrations in an attempt to reduce such deleterious effects.⁸ This idea would predict that the level of muscle activity used for a particular movement task is, to some degree, dependent on the interaction between the body and the externally applied vibration forces. It has been proposed that vibrations could be used as a training aid. However, prolonged exposure to vibrations has been shown to have detrimental effects on the soft tissues, including muscle fatigue,⁹ reductions in motor unit firing rates and muscle contraction force,^{10–11} decreases in nerve conduction velocity, and attenuated perception.¹²

The natural frequency of a vibrating system depends on its stiffness and mass. Within the skeletal muscles, each cross bridge between the actin and myosin myofilaments generates some stiffness,¹³ and so the tissue stiffness (and therefore natural frequency) can be increased with increases in muscle activity. Indeed, studies have shown that increases in the natural frequency of whole muscle groups do concur with the joint torques developed by the muscle and typically range between 10 and 50 Hz for the lower extremity muscles (zero to maximal activity¹⁴). Muscles can also damp externally applied vibrations, and, indeed, more vibration energy is absorbed by activated muscle¹⁵ than by muscles in rigor,¹⁶ suggesting that the active cross bridge cycling is an important part of the damping process. Studies have shown that the damping coefficients of whole muscle groups increase with muscle activity,^{15–17} supporting the idea that the cross bridge mechanisms are important. A maximally activated muscle can damp free vibrations so that the tissue oscillations are virtually eliminated after a couple of cycles.¹⁸ It is thus possible that muscles are activated to minimise the vibrations that occur within the tissues, but does this actually happen during WBV exercise?

VIBRATION AND MUSCLE ACTIVATION: THE MUSCLE TUNING HYPOTHESIS

Evidence for muscle tuning requires information on the nature of the input force, the vibration response of the tissue, and the level of muscle activity. These can be difficult to measure because vibrations induced in the tissues can cause movement artefacts, which may interfere with measurement of muscle activity. Nonetheless, in a study of hand held vibrating tools,¹² it was found that activation of the triceps brachii was greatest between vibration frequencies of 8 and 16 Hz, coinciding with the resonant frequencies measured at the wrist and elbow (10–20 Hz). In a similar experiment, vibration was recorded directly from the soft tissue groups in the lower extremities while subjects stood on a vibration platform.¹⁸ The natural frequencies for the tissues for each posture were determined by measuring the vibration response to a complex vibration covering a range of

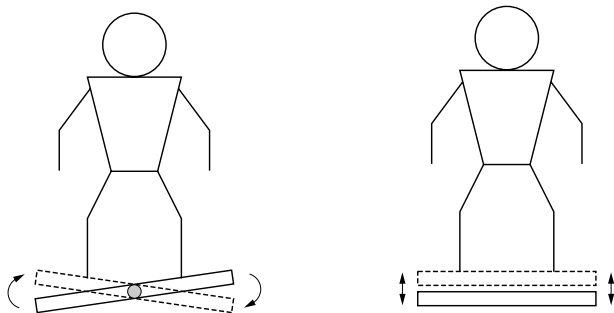


Figure 1 Different designs of whole body vibrating plates.

frequencies and therefore accounted for changes in resonance that occurred with altered limb posture and muscle activity. The vibration response of the soft tissues was measured for a range of input vibration frequencies (10–65 Hz), and it was found that most vibration damping occurred at the resonant frequencies of the tissues, concurring with the highest levels of muscle activity. The responses of the lower extremities to continuous vibrations or sequences of single, impact-like input were similar. This suggests that the body has a strategy to minimise its vibrations regardless of the mode of the input force.¹⁸ These studies support the muscle tuning paradigm, but these concepts should be tested further. For instance, the effect of the amplitude of the input vibrations on the tuning response has not yet been determined. Is there a minimum amplitude below which the body is not triggered to respond? At high vibration amplitudes, the maximum damping from the tissues will not be as effective at dissipating the vibration energy. We do not yet know the most effective range of vibration amplitudes that can be applied safely while eliciting a significant tuning response.

Training protocols and sporting equipment that cause specific alterations in muscle activity during exercise may have important implications for athletic training, rehabilitation after injury, and competitive performance. For instance, the hardness of a shoe midsole causes changes in the time to peak impact force at heel strike.^{19–22} This time and the associated loading rate are a correlate of the major frequency content of the impact force; impact forces that drive the soft tissues of the lower extremity closer to resonance cause increases in muscle activity and vibration damping from those tissues.²³ It is conceivable that different types of equipment may be designed in future: training equipment, which promotes increased muscle activity, and competition equipment, which reduces the muscle activity required for vibration damping and thus allows more of the muscle activity to be used for the sporting task. Vibration platforms are the most recent example. They have been developed with the idea of promoting muscle activity, hence providing an effective training stimulus. Are they effective?

METABOLIC EFFECTS OF VIBRATIONS

The possibility of using vibrations as an effective training tool can be considered a recent idea. However, it should be noted that early work by Whedon *et al*²⁴ reported some positive effects of oscillating beds on plaster immobilised patients. The possibility of using vibration in an athletic setting was introduced relatively recently by Russian scientists, who developed specific devices to transmit vibratory waves from distal to proximal links of muscle groups, mainly during the performance of isometric exercises.²⁵ Recently many studies have been conducted with the aim of understanding the acute and chronic responses to WBV training (WBVT).

WBVT has been shown to cause clear metabolic responses similar to other forms of exercise. In a study by Rittweger *et al*,²⁶ WBVT to exhaustion with an extra weight showed an O₂ uptake of less than 50% of VO₂MAX. An acute reduction in vertical jump was observed, suggesting that vibration exercise to fatigue can impair neuromuscular performance. The early impairment of muscle performance was shown to be recovered 20 seconds after the end of the fatiguing vibratory exercise. Another experiment conducted by Kerschman-Schindl *et al*²⁷ showed a significant increase in muscle blood volume in the calf and thigh and a significant increase in mean blood flow velocity in the popliteal artery after vibration exercise on a vibrating plate (26 Hz, 3 mm amplitude). The mean blood flow measured by Doppler ultrasound increased from 6.5 to 13 cm/s, and this acute response was attributed mainly to the effect of vibrations in

reducing the viscosity of blood and increasing its speed through the arteries. The above studies seem to indicate that WBVT may represent a mild form of exercise for the cardiovascular system.²⁶⁻²⁸ However, owing to the relatively low level of stimulation, it is unlikely that an athletic population could benefit from such a training stimulus if the aim is to improve cardiovascular performance. However, elderly people could make use of this form of exercise when other solutions are not possible. Also, because of its reported beneficial effects in reducing low back pain,²⁹ pain sensation, and pain related limitation, it may be a viable alternative for a patient who cannot run and/or lift weights. However, the extensive literature on the dangerous effects of WBV on the spine (for a review, see Cardinale and Pope³⁰) suggests that more, well controlled, long term intervention studies are needed before WBVT can be prescribed for patients with low back pain.

ACUTE EFFECTS OF VIBRATION ON NEUROMUSCULAR PERFORMANCE

Most of the studies so far conducted have focused on the acute and chronic effects of WBVT on neuromuscular performance. In our studies, WBV exercise has been shown to acutely enhance strength and power capabilities in well trained people.¹⁻² Acute application of five minutes of WBVT at 26 Hz and 10 mm peak to peak amplitude were in fact shown to shift the force-velocity and power-velocity relations to the right in the vibrated legs of well trained volleyball players.¹ Finally, WBVT applied for a total of 10 minutes (26 Hz, 4 mm) was shown to improve vertical jumping ability, increase concentrations of testosterone and growth hormone, and decrease cortisol concentrations in recreationally active people.² The results of this preliminary study have been used by many companies to advertise WBVT as a way to boost anabolic hormones, reduce stress, and accelerate muscle remodelling. For this reason, it is important to recognise that the study has many limitations, the primary one being the absence of a control condition. Also, not all studies have shown acute increases in strength/power performances and hormone concentrations. Torvinen *et al.*,³¹ for example, have shown acute increases in knee extension maximal strength and vertical jumping height after four minutes of WBVT when a relatively large amplitude was applied (4 mm) with a tilting plate as compared with no significant acute effects when low amplitude whole plate oscillation (2 mm) was applied.³² Results from our laboratory have also shown that, when vibration duration is relatively long (seven minutes), an acute decrease in vertical jumping ability is observed even in well trained subjects.³³ Recent work from De Ruiter *et al.*,³⁴ in which subjects exercised on a vibrating plate for 5 × one minute (frequency 30 Hz, amplitude 8 mm) with two minutes rest in between, showed an acute reduction in maximal voluntary knee extension force. Also, in their well controlled study, the authors showed that vibration depressed voluntary activation of the leg extensor muscles up to 180 minutes after the exercise bout. Finally, Di Loreto *et al.*³⁵ have recently shown that 10 minutes of WBVT at 30 Hz with a relatively small amplitude did not produce any change in the serum concentrations of growth hormone, insulin-like growth factor 1, and free and total testosterone.

At this stage, owing to the differences in WBVT protocols used in the different studies, it is difficult to ascertain the acute effects of the WBVT intervention on the neuroendocrine and neuromuscular systems. However, it is important to consider that a certain degree of muscle activation is needed from lower limb muscles to damp the vibrations²³⁻³⁶ originated by vibrating plates. In fact, this extra muscle activity results in a greater rate of oxygen uptake during

exposure to vibrations.³⁷⁻³⁸ It should be remembered that, according to the muscle tuning theory, the magnitude of the muscular response is related to the interaction between the amplitude and frequency of the vibration input and the intrinsic neuromuscular properties. It is possible that many studies have failed to show any positive effect of vibration because the applied vibrations did not stimulate the target muscles at their resonant frequencies. It should also be noted that most of the studies have focused on leg extensors, while neglecting plantar flexors which have been shown to increase their electromyographic activity up to five times the baseline values with vibration.⁴ It is clear that more studies are needed to ascertain the influence of the above variables on humans.

CHRONIC EFFECTS OF VIBRATION ON NEUROMUSCULAR PERFORMANCE

Chronic studies seem to provide more supportive evidence for the possibility of using WBVT effectively in different populations. A few weeks of training seem to produce conflicting results.

In our study in 1998³⁹ 10 days of WBV (26 Hz, 10 mm, total exposure time 100 minutes) resulted in an increase in average jumping height (+11.9%) and power output during repeated hopping in active subjects. No change was observed in counter movement jump performance. Five training sessions of five minutes each (30 Hz, 8 mm amplitude, total exposure 25 minutes) did not affect maximal voluntary contraction and voluntary activation of leg extensors in untrained students.³⁴ The same authors also analysed the effects of 11 weeks of WBVT on maximal voluntary contraction measured with an isometric leg extension task (maximal voluntary contraction), maximal force generating capacity, and stimulated maximal rate of force rise.⁴⁰ The results showed no change in all variables except for an increase in stimulated maximal rate of force rise in the group undergoing WBVT detected at week 14. The subjects in this study were exposed to WBVT three times a week starting with five sets of one minute each with one minute seated rest in between. Exercise duration was progressively increased up to eight sets of one minute each. However, even if the total exposure time to WBVT was relatively high (169 minutes), it is important to note that the training period was not continuous because of two weeks of non-training allowed between week 5 and week 7 of the study. Nine days of WBVT have also been recently shown to have no effect on jumping ability, sprinting, and agility tests in sport science students.⁴¹ In the light of the above, it seems clear that, when WBVT is performed with small amplitudes for a short time by physically active people, it is unlikely to produce significant improvements in force and power generating capacity of the lower limbs. However, when resistance exercise is performed on a vibrating plate, it seems that even physically active people can improve vertical jumping ability more than by resistance exercise alone.⁴² When standing on a vibrating plate, young healthy people generate relatively low force levels in their lower limbs compared with their maximal voluntary capacity. Hence, even if the vibration stimulation can increase their muscle activity, it is likely that this would not be enough to produce any significant change in their ability to forcefully activate their muscles. So, if well trained populations use vibration exercise with the aim of improving neuromuscular performance, an optimal amplitude and frequency should be coupled with an optimal level of muscle activity on which the vibration stimulation can be superimposed. Of course, this should be the aim of future studies and for this reason we have recently patented an exercise device able to allow the user to perform vibration exercise while controlling the level of force and muscle mechanics (Patent Number WO2004009173).

On the other hand, sedentary, injured, and elderly people with impaired muscle activation capabilities may benefit from currently available WBVT applications. In this case the results seem to be more encouraging. In fact, Torvinen *et al*⁴³ showed a net improvement of 8.5% in vertical jumping ability after four months of WBVT performed with static and dynamic squatting exercises with small vibration amplitudes (2 mm) and frequencies ranging from 25 to 40 Hz in sedentary subjects. A 12 week WBVT programme (frequency 35–40 Hz and amplitude 2.5–5 mm) induced a significant enhancement in isometric, dynamic, and explosive strength of knee extensor muscles in healthy, untrained, young adult women.⁴ Also, vertical jump improved only in the group undergoing WBVT and not in the group performing conventional resistance exercise. However, it should be noted that the resistance exercise programme in this study was of relatively low intensity (started with a load of 20 repetition maximum and reached 10 repetition maximum in the last four weeks) and the exercises (leg press and leg extensions) were performed to failure and not with explosive movements, reducing the possibility of such a programme producing significant changes in explosive measures. The same authors also showed that 24 weeks of WBVs were effective in producing a rightward shift in the force-velocity relation of knee extensor muscles and an increase in fat-free mass in untrained female subjects.⁵ Despite not being significantly different from the standard training groups, the results observed by both Delecluse *et al*⁴ and Roelants *et al*⁵ highlight the possibility that long term programmes of WBVT may produce significant improvements in muscle function of the leg extensors in untrained subjects. As more supportive evidence, a recent study from the same group⁷ showed that WBVT was superior to a low intensity resistance training programme in improving isometric and dynamic muscle strength in middle aged and older women (58–74 years). The WBVT programme was also effective in increasing bone mineral density of the hip even though the improvement was very small (+0.93%) and within the error of measurement used for establishing bone mineral density. Finally, Torvinen *et al*⁴⁴ have shown that eight months of WBVT with small amplitude (2 mm) improved vertical jumping ability in young healthy sedentary subjects compared with a control group, but did not change dual energy x ray absorptiometry derived bone mineral content measures, markers of bone turnover, and postural sway.

The latest results support our idea that the current technology/methods of use of WBVT (standing on a vibrating plate with low force generation in the lower limbs) are unlikely to produce significant improvements in performance in well trained athletes and physically active young subjects, and, even if they do, conventional resistance exercise should still be superior. However, this technology may be of benefit to the elderly or in rehabilitation programmes, as little effort is required and there is no complicated technique to master. Special populations in particular seem to benefit from acute bouts of WBVT. Unilateral chronic stroke patients, for example, have been shown to improve postural stability after a few minutes of WBVT at 30 Hz and 3 mm amplitude.⁴⁵ Also, heart transplant patients seem to be able to exercise on vibrating plates with no adverse events.⁴⁶ Furthermore, owing to the potential of this intervention to stimulate bone remodelling,^{47–49} it is possible that WBVT may be a possible non-pharmacological intervention for the prevention of osteoporosis, but more evidence needs to be gathered with well controlled studies.

CONCLUSIONS

The current evidence indicates that WBVT may be an effective exercise intervention for reducing the results of

the ageing process in musculoskeletal structures. It would also appear that vibration may be an effective counter-measure to microgravity and disuse. However, it is important to conduct further studies to understand the neurophysiological mechanisms involved in muscle activation with vibration in order to be able to prescribe safe and effective WBVT programmes. Not only the optimal frequency and amplitude need to be identified but also the level of muscle activation that would benefit more from vibration stimulation. Considering current WBVT technology, it is possible to confirm that the procedure seems safe when subjects stand on vibrating plates for a relatively short time with knees semiflexed to limit transmission of vibrations to the head. However, when vibration transmission frequency is too high, some can experience motion sickness-like symptoms.⁵⁰ As we know from occupational medicine that prolonged exposure to WBVT can have major negative effects on health, proper care should be taken when exercise programmes are prescribed so as to guarantee safety.

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COMMENTARY

This brief review discusses the most important results on the mechanisms of the action of whole body vibration. The authors are correct in saying that whole body vibration can be used as an effective exercise intervention for reducing the actions of the ageing process on skeletal muscles. However, its use as a training tool for high level athletes requires further investigation.

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