

Whole Body Vibration Exercise: Training and Benefits

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DOLNY, D.G., and G.F.C. REYES. Whole body vibration exercise: training and benefits. *Curr. Sports Med. Rep.*, Vol. 7, No. 3, pp. 152–157, 2008. In recent years, it has been suggested that exercise using whole body vibration (WBV) platforms may increase muscle activity and subsequently enhance muscle performance in both acute and chronic conditions. WBV platforms produce frequencies ranging from 15–60 Hz and vertical displacements from ~1–11 mm, resulting in accelerations of ~2.2–5.1 g. Acute exposure to WBV has produced mixed results in terms of improving jump, sprint, and measures of muscle performance. With WBV training, younger fit subjects may not experience gains unless some type of external load is added to WBV exercise. However, sedentary and elderly individuals have demonstrated significant gains in most measures of muscle performance, similar with comparable traditional resistance exercise training programs. WBV training also has demonstrated gains in flexibility in younger athletic populations and gains or maintenance in bone mineral density in postmenopausal women. These promising results await further research to establish preferred WBV training parameters.

INTRODUCTION

Humans experience the effects of externally applied forces constantly when exercising — when our feet contact the ground during locomotion or as we strike objects with sport implements. These contacts create vibrations within the tissues of the limbs, which gradually decline as soft tissues dampen these oscillations. The body relies on a number of factors to achieve this reduction in vibrations, primarily soft tissue structures but also bone, synovial fluids, specific joint positions, and muscle activity (1).

It has been suggested that externally applied forces intentionally applied directly to either muscle tendons or skeletal muscle, or indirectly through whole body vibration (WBV) platforms that subjects stand on, increases muscle activity and subsequently enhances muscle performance in both acute and chronic conditions. This summary will review the acute and chronic effects of WBV exposure, discuss the potential neuromuscular mechanisms, provide examples of typical WBV training regimens, and provide insight into potential use of WBV for unique populations.

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WHAT IS WBV?

In most WBV research studies, subjects stand on a platform or plate that produces sinusoidal oscillations either in a vertical up and down motion or that rotates about a center fulcrum producing up and down vertical motion on alternating sides of the fulcrum. These movements result in vibrations transmitted indirectly to the subject through the legs. WBV platforms produce frequencies ranging from 15–60 Hz and vertical displacements from ~1–11 mm. The accelerations that a body experiences can be estimated from the following equation: $a = A*(2\pi f)^2$ where a is the acceleration experienced expressed as an equivalent of the acceleration of earth's gravity (g), A is the amplitude of displacement, and f is the frequency of vibration in Hz. In many WBV studies, subjects experience accelerations of ~2.2–5.1 g.

As the body or body segment is subjected to these externally applied forces, skeletal muscle activity usually increases in an attempt to dampen these oscillations, leading to increases in soft tissue stiffness. An activated muscle absorbs more vibration energy (2). Dupuis and Jansen (3) reported that under vibration conditions muscle activation of the triceps was greatest at vibration frequencies similar to the resonant frequencies of the wrist and elbow (10–20 Hz). Wakeling, Nigg, and Rozitis (4) reported that most vibration damping occurred at the resonant frequencies of the tissues when the muscles were most active. They proposed that the body has a strategy to minimize its vibration regardless of the mode of the input

force (muscle tuning hypothesis). Cardinale and Wakeling (1) suggest that this strategy may have useful implications for sport training, equipment design, and rehabilitation. Presently, there has been limited research directed toward the optimal WBV platform characteristics (amplitudes and frequencies) applied chronically (training program) and subsequent muscle adaptations.

PROPOSED MECHANISM OF WBV

The most often cited mechanism proposed with WBV exposure is the “tonic vibration reflex” (TVR), where earlier studies applied a high frequency vibration directly to a muscle tendon for a short period of time, yielding an increase in muscle activity (5). Mechanical vibration applied to skeletal muscle or tendon has been shown to excite muscle spindle primary endings, primarily Ia afferent nerve endings (6). However, when these vibrations were applied directly to a tendon for a longer period of time (>30 sec) decreases rather than increases in muscle activity were reported (6–8). These decreases might be caused by a decrease in muscle spindle firing frequency (9), increased presynaptic inhibition (10), or decrease in neurotransmitter release (11). Because WBV typically uses exposures longer than 30 sec with the vibration applied indirectly through the feet rather than directly to the tendon, explaining the potential potentiating effect of WBV upon muscle activation through previous research using direct stimulation to a muscle tendon may not be appropriate. For example, Nishihira *et al.* (12) demonstrated that 3-min exposures of WBV during unloaded isometric high squat leg position significantly increased soleus ratio of H-reflex to M-response, H-reflex and M-response threshold 5 min after WBV exposure. These results suggest that an increase in both Ia afferents and descending commands to the motoneuron pool to enhance motor unit excitability were responsible for increased motor unit activity.

If WBV training enhances muscle performance, the mechanism might be through 1) greater activation of agonists during maximally contracted muscle or decrease of antagonistic muscle activation, and/or 2) greater gains in muscle mass or increased quality of muscle contraction (13). Regarding the first point, two acute studies have demonstrated that WBV applied during an unloaded squat position yielded greater electromyography (EMG) for rectus femoris (RF) and gastrocnemius (GA) than without WBV (14,15). Because WBV applies relatively low loads to skeletal muscle, an enhanced impact upon muscle hypertrophy is unlikely. In one study, WBV training did not result in significant gains in estimates of lean body mass (15) despite a report (16) where WBV caused an acute increase in circulating levels of testosterone and growth hormone with a decrease in cortisol levels, suggesting that WBV facilitates an anabolic state for skeletal muscle. However, this result was not verified with WBV training as Kvorning *et al.* (17) reported no change in pre- versus post-training levels of circulating testosterone, growth hormone, and cortisol.

EXAMPLES OF ACUTE EXPOSURE TO WBV AND MUSCLE PERFORMANCE

Bosco *et al.* (18) tested elite female volleyball players for maximal dynamic leg press exercise with loads of 70, 90, 110, and 130 kg. WBV exposure followed, consisting of standing with the toes of one leg on the WBV platform with the knee bent at 100°. The WBV platform was set at 26 Hz and 10 mm amplitude, and subjects were exposed to 10 60-sec exposures during the single session. The control leg remained off the WBV platform. The treatment leg significantly increased average velocity, force, and power at all external loads of leg press.

Cardinale and Lim (19) compared the acute effects of standing on a WBV platform set at 30, 40, or 50 Hz while EMG activity of the vastus lateralis (VL) was measured. The greatest EMG activity was during 30 Hz, suggesting that WBV exposure frequencies at or near 30 Hz might yield the greatest muscle activation response.

Roelants *et al.* (20) compared the electromyographic response of the RF, VL, vastus medialis (VM), and GA during three unloaded isometric positions: high squat (HS), low squat, (LS), and one-legged (OL) squat with and without WBV set at 35 Hz. Compared with control, WBV exposure significantly increased EMG for all muscles during all exercises, ranging from 49% to 361% greater response. OL produced the greatest EMG for all muscles, and the EMG increase was greatest in the muscle closest to the WBV platform (GA). It has been determined that the sensitivity of Ia afferent nerves is higher with stretched (21) and pre-activated muscle (22), which may account for the response of the GA versus the other muscles of the leg. This may be the best evidence to date that when WBV is combined with traditional resistance training (RT) exercises, the additional recruitment of skeletal muscle may prove to further enhance the gains in strength and power associated with RT programs.

EXERCISE TRAINING WITH WBV

Nordlund and Thorstensson (13) conducted a literature review of WBV with studies that included a control group and had a training period lasting at least 1 wk. In the studies where the control group performed the identical type of training as the WBV group, four of five reported no differences between WBV and control groups for strength and jump performances. These studies also used younger, relatively active adults. When WBV training was compared with passive control groups (no exercise), consistently greater improvements in muscle performance were reported. This only demonstrates that WBV is preferred to performing no exercise at all to improve muscle strength and jumping performance. Many of these studies also used mixed-gender or postmenopausal women over the age of 60.

In a second review by Rehn, Lidstrom, Skoglung, and Lindstrom (23), they concluded that there is strong to moderate evidence that long-term WBV exercise can have positive effects upon the leg muscular performance among untrained subjects and the elderly. In their review, of 9 of 14

studies that reported significant improvements of leg strength or power, eight used untrained or elderly subjects, of which the majority were female. However, there was no clear evidence of benefits for muscular performance after short-term (single bout) vibration exposure. Of the five studies analyzed, three showed positive results with young adult subjects.

Additionally, there is a wide range of WBV protocols used in the literature. The typical vibration frequency used is about 26–30 Hz, although 35 and 40 Hz also are used. The amplitudes range from ~2–10 mm, and studies use exercises ranging from unloaded, exclusively isometric stances through the use of dynamic, added resistance exercise. In each case, the authors did not provide a rationale for selecting the WBV parameters. They appear to mimic volume and intensity manipulation one uses for traditional resistance training programs. This further highlights the need for more research before vibration training is recommended as a component of any training program.

EXAMPLES OF EXERCISE TRAINING WITH WBV

Ronnestad (24) trained male subjects for 5 wk. One group performed 6–10 RM squat exercise while standing on a WBV platform set at 40 Hz, while the other group performed the squat exercise without WBV. Both groups significantly increased squat 1-RM and CMJ performance; however the WBV group's increases were greater: 32.4% versus 24.2% and 9.0% versus 4.2%, for squat and CMJ, respectively.

Postmenopausal subjects were assigned to either a WBV program (maintaining high squat, deep squat, wide stance, and lunge positions on a WBV platform set from 35–40 Hz and 2.5–5.0 mm), traditional resistance training (leg press and leg extension with 8–20 RM loads), or assigned to a control group throughout the training period (24 wks). Measures of isometric and dynamic knee extension strength gains were similar comparing both training groups, while the WBV group improved more with CMJ performance. These results suggest that unloaded WBV exercises are just as effective as traditional RT for increasing leg strength in older women (25).

Annino *et al.* (26) trained ballet dancers for 8 weeks, three times per week on a WBV platform, standing in a half squat position for five 40-sec periods with 60 sec rest. Compared with dancers who only performed regular training and demonstrated small increases in performance measures, the WBV group increased CMJ 6.3% and average leg extension power and velocity by 25% and 26%, respectively.

Improvements in muscle rate of force development, sprint speed, and velocity of limb movement as a result of traditional versus WBV training also have demonstrated little additive benefit of applying WBV (27). Most WBV studies use static body positions held for 30–60 sec. This assumes that both agonists and antagonists are co-contracted, which may question the relative benefit of using only static exercise during WBV for improving ballistic, dynamic activities such as jumping and sprinting.

WBV AND FLEXIBILITY TRAINING

WBV training may have beneficial effects for improving flexibility and range of motion when added to traditional flexibility training programs. For example, 22 young (11.3 + 2.6 yr) gymnasts were assigned to either normal flexibility training or WBV applied during flexibility training (28). Subjects who only performed flexibility training improved right and left forward split ~2% while the gymnasts who were only exposed to vibration improved ~9.5%. The combined group increased 18.5%. When subjects performed static stretches prior to a CMJ and static jump test, a significant decline in jump height was observed. When stretching was performed on the vibration device, there was no subsequent decline in any parameter (peak force, RFD, or jump height). It appears that adding vibration exposure to flexibility training significantly improves flexibility while maintaining explosive strength. Stone *et al.* (29) demonstrated that static stretching hurts acute explosive performances, maximal strength, rate of force development (RFD), and power. The benefit of WBV may be caused by a decrease in musculotendinous stiffness, muscle antagonist inhibition, and increased pain threshold.

WBV also has been applied directly to muscles of the leg when young gymnasts trained 5 d weekly for 4 wk, placing lower extremity muscles on a specially designed vibrating box set at 30 Hz and 2 mm. The subjects demonstrated a significantly greater ROM in their right leg rear but not their left leg rear split performance (30). Van den Tillar (31) evaluated the combined effect of WBV and proprioceptive neuromuscular facilitation (PNF) stretching with PNF only. Subjects in the combined group stood in a squat position on a WBV platform set at 28 Hz for three 30-sec exposures before PNF flexibility training. The combined group improved ROM 30% versus a 14% improvement for the PNF-only group.

POTENTIAL HEALTH-RELATED BENEFITS OF WBV

Bone mineral density

In addition to the potential benefits for muscle performance, WBV may provide an even greater stimulus for maintaining or improving bone health. Gusi, Raimundo, and Leal (32) assigned 28 post-menopausal women to a walking or a WBV training group for 8 months. The WBV trained 3 d weekly with six 1-min exposures (standing with knees flexed to 60° on a platform set at 12.6 Hz and 3 mm) while the walking group exercised for 55 min, 3 d weekly. The WBV group significantly increased BMD of the femoral neck 4.3%, while the increase at the spine was NS. Additionally, measurement of balance improved 29% in the WBV group. Torvinen *et al.* (33) conducted an 8-month randomized control trial where subjects (men and women aged 19–38 yr) were assigned to a control or an intervention group where subjects were exposed to 4 min, 3–5 times weekly on a platform set to vibrate at 25 to 45 Hz in ascending order. In spite of a 7.8% gain in jump height, bone mineral content, serum markers of bone turnover, and estimates of bone mass and structure were not affected at any

skeletal site. The subjects in the WBV group assumed a series of body positions during the 4-min exposure, which the authors proposed may have altered the distribution of body oscillations, thus reducing the accelerations experienced by the subjects. Short bouts of extremely low-level mechanical vibrations (~0.3 g), several orders of magnitude below that associated with vigorous exercise, increased bone and muscle mass in the weight-bearing skeleton of young adult females with low BMD (34). Should these musculoskeletal enhancements be preserved through adulthood, this intervention may prove to be a deterrent to osteoporosis in the elderly. A 1-yr prospective, randomized, double-blind, and placebo-controlled trial (35), 70 postmenopausal women demonstrated that brief periods (<20 min) of a low-level (0.2 g, 30 Hz) vibration applied during quiet standing can effectively inhibit bone loss in the spine and femur, with efficacy increasing significantly with greater compliance, particularly in those subjects with lower body mass. The spine of lighter women (<65 kg), who were in the highest quartile of exercise compliance, exhibited a relative benefit of active treatment of 3.35% greater BMD. For the mean compliance group, a 2.73% relative benefit in BMD was reported. These preliminary results indicate the potential for a noninvasive, mechanically mediated intervention for osteoporosis.

SAFETY ISSUES WITH WBV

It is well known in an occupational setting that chronic exposure to a vibrating source may be quite deleterious to overall health and well-being (36). Although the exposure to WBV is typically much lower in frequency and amplitude (thus lower g forces) than that of many occupational jobs, the transmission of vibrations from the WBV platform to the neck and head should be avoided. **The resonant frequency (ResF) of the human body standing fully clothed ranges from 9–16 Hz in humans** (37), with mean values for males and females very similar (12.2 vs 12.3 Hz). ResF is when the acceleration ratio between a body segment and the vibration source is maximum. ResF increases with muscle stiffness and decreases with body mass. This transmissibility factor also differs by body position. Little is known relative to WBV and RF during various types of exercise. **The most common side effects of WBV exercise appear to be erythema, itching, and edema of the legs** (38,39). Recent recommendations (40) proposed a systematic study of the resonance frequencies for various body positions with respect to the vibrating source, different body weights, and differing levels of muscle stiffness. For now, to avoid high transmission factors to the head, all WBV

training should be conducted with some degree of flexion of the ankle, knee, and hip joints. Another technique is to either stand upright with only the forefoot (heels off) in contact with the platform or to stand on the platform but raise the heels off the platform. Both techniques should reduce the transmission of vibrations to the torso, neck, and head.

RECOMMENDATIONS FOR EXERCISE TRAINING WITH WBV

When designing WBV training programs, there are several factors to consider:

1. Type of vibration platform — vertical verse reciprocating sinusoidal oscillations
2. Vibration frequency — typically ranges from about 25–45 Hz
3. Amplitude — ranges from ~1–10.5 mm
4. Body position(s) — joint angles of limbs on platform for static exercise
5. Number of Exercises — static and/or dynamic
6. Number of sets for each exercise
7. Number of Sessions per week
8. Duration of WBV exposure per exercise
9. Rest period between exercises
10. Footwear

Subjects in many training studies have worn gymnastic shoes to decrease risk of bruising and minimize the dampening effect from the soles of sport shoes. WBV training should have a progressive overload sequence that includes gradually adding either more sessions per week, more exercises per session, more sets per exercise, more intense exercises (one-legged exercises more stressful than two-legged), greater duration per exercise, or shorter rest interval between exercises. Common unloaded static or dynamic WBV exercises are high squat, low squat, wide stance squat, one-legged squats, and lunges.

See Table for an example of a WBV training program for postmenopausal women.

For younger, athletic subjects, since WBV exposure alone may not be a sufficient stimulus for eliciting chronic adaptations in muscle hypertrophy, strength, and power, it is recommended that this population use WBV either as 1) a “preconditioning” activity immediately before performing traditional RT and conditioning programs or 2) perform RT simultaneously with WBV. Additional exercises performed by healthy, fit subjects may include wide stance squat jumps, jump onto platform and hold landing, and dynamic one-legged squats. Some WBV platforms are large enough to

TABLE. Example of whole body vibration (WBV) training for postmenopausal women.

Level	WBV Frequency (Hz)	Amplitude (mm)	Number of Exercises	Reps per Exercise	Duration (sec)	Rest Period (sec)
Beginner	30	~1–2	2	1–2	30	60
Intermediate	30–35	~2–3	4	3	45	30
Advanced	35–40	~4–5	6–8	3	60	10

accommodate most traditional RT movements, while others restrict movements to stationary foot placements with limited loading.

Although the evidence for acute benefit of WBV exposure upon muscle performance is equivocal, there appear to be no negative or adverse effects upon subsequent performance. Little information is available investigating whether WBV applied before a resistance exercise enhances chronic neuromuscular adaptations. Additionally, with the greater muscle activity reported performing RT and conditioning exercises with WBV (14,20), the possibility does exist whereby this added stimulus could provide benefits to highly trained subjects who may be searching for small, incremental improvements because of their advanced state of training.

CONCLUSION

Based upon present experimental evidence, WBV alone will provide limited or no benefit in improving muscle strength and/or jumping performance compared with similar exercise training without WBV in young, fit subjects. In sedentary and elderly subjects, there is a greater likelihood for WBV to improve muscle performance to at least the same if not greater extent than traditional training methods. Rehn *et al.* (23) recommended that further studies be performed in order to find an ideal combination of various vibration parameters (frequency, amplitude, duration, and body position) for full effect and with a specific body region and function in target to determine the functional importance. Caution is warranted because the wrong combination of vibration parameters may cause adverse health effects, such as cardiovascular and neural symptoms and disorders (36). Using WBV to maintain or improve BMD has shown promise, with results from longer, randomized control trials supporting the efficacy of WBV training. Finally, subjects diagnosed with coronary disease and hypertension should avoid WBV until more research investigates WBV effects upon total peripheral resistance and coronary blood flow.

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