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Review

Strength training effects of whole-body vibration?

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Whole-body vibration (WBV) has been suggested to have a beneficial effect on muscle strength. Manufacturers of vibration platforms promote WBV as an effective alternative or complement to resistance training. This study aimed to review systematically the current (August 2005) scientific support for effects of WBV on muscle strength and jump performance. MEDLINE and SPORT DISCUS were searched for the word *vibration* in combination with *strength* or *training*. Twelve articles were included in the final analysis. In four of the five studies that used an adequate design with a control group performing the same exercises as the WBV group, no difference in performance improvement was found between groups, suggesting no or only minor additional effects of WBV as such. Proposed neural mechanisms are discussed.

In recent years, vibrating platforms have become increasingly available and used at sports and rehabilitation institutes. Whole-body vibration (WBV), i.e. standing in different static positions or exercising on a vibrating platform, is being commercially promoted as an attractive and efficient complement, or even alternative, to resistance training. A pertinent question arises as to the strength of the evidence for this intervention in the scientific literature. In a recent review, Luo et al. (2005) reported contradictory results regarding chronic effects of WBV on muscle strength in the only two training studies then available meeting their inclusion criteria (Delecluse et al., 2003; De Ruiter et al., 2003). Since the termination of the literature search by Lou et al. (2005) in 2003, putative long-term effects of WBV on muscle strength have received considerable attention. In this review, we are summarizing the findings of 12 original articles that investigate possible training effects of WBV on muscle strength and jump performance. We also include a section where proposed neural mechanisms are discussed.

Search and selection criteria

Electronic databases (MEDLINE, PubMed and SPORT DISCUS, Ebsco) were searched on the August 14, 2005 back to the earliest available time (1966) for the word *vibration* in combination with *strength* or *training*. The MEDLINE search resulted in 431 hits for vibration and strength and 194 hits for vibration and training. The SPORT DISCUS search yielded 45 hits for vibration and strength and 51 hits for vibration and training.

The titles and abstracts of these publications were scanned for contents. Articles were included in further analysis if they investigated chronic effects of WBV on muscle strength and/or jump performance and included a control group. Chronic effects were defined as those measured after repeated bouts performed over a time period of at least 1 week. Articles had to be published as full-length reports of original experiments. Conference abstracts and proceedings were excluded. The reference lists of relevant articles were, in turn, scanned for additional articles that met the inclusion criteria.

Included articles

In total, 12 articles fulfilled the inclusion criteria. Judging from the authors' names and affiliations, five of these articles could be referred to one research group (Delecluse et al., 2003, 2005; Roelants et al., 2004a, b; Verschueren et al., 2004), two to another (Torvinen et al., 2002, 2003) and the remaining five articles to five separate groups (Schlumberger et al., 2001; De Ruiter et al., 2003; Russo et al., 2003; Cochrane et al., 2004; Ronnestad, 2004).

In Table 1, the following parameters of each article are presented: subjects investigated, characteristics of

Table 1. Description of the 12 reviewed articles on whole-body vibration (WBV)

Article	Subjects	Vibration parameters and load during WBV	Training in strength training group	Duration and frequency of WBV and training	Strength and jump tests	Differences between before and after WBV	Changes in WBV vs control group performing identical exercises	Changes in WBV vs passive control group	Changes in WBV vs control group performing strength training
Schlumberger et al. (2001)	♂ and ♀ *n* (10, 10) Age (25.4) One leg exposed to WBV the other leg used as control	25 Hz, 6 mm Acc not given 4 × 8–12 RM one-legged squats		6 w 3 sessions/w Time/session not given	Unilateral isometric leg press force	Leg press force increased 6.5%	No differences between group changes in leg press force		
Torvinen et al. (2002)	Healthy non-athletic ♂ and ♀ *n* (26, 26) Age (23.2, 25.5)	Progression 25–40 Hz at 2.5–6.4 g, 2.0 mm Body-loaded static and dynamic exercises		4 m 3–5 sessions/w 4 min/session	Countermovement jump Bilateral isometric leg press force Grip strength	Jump height increased 9.0% No change in leg press or grip strength		Jump height increased only in the WBV group No differences between group changes in leg press or grip strength	
Torvinen et al. (2003)	Healthy non-athletic ♂ and ♀ *n* (27, 26) Age (23.1, 25.5)	Progression 25–45 Hz at 2–8 g, 2 mm Body-loaded static and dynamic exercises		8 m 3–5 sessions/w 4 min/session	Countermovement jump Bilateral isometric leg press force Grip strength	Jump height increased 7.7% No change in leg press or grip strength		Jump height increased only in the WBV group No differences between group changes in leg press or grip strength	
Delecluse et al. (2003)	Untrained ♀ *n* (18, 12, 19, 18) Age (21.5, 20.6, 19.9, 21.4)	Progression 35–40 Hz at 2.28–5.09 g, 2.5–5.0 mm Body-loaded static and dynamic exercises	Progression 2 × 20–1 × 8 RM leg press and extension	12 w 3 sessions/w 3–20 min/session	Countermovement jump Isometric and isokinetic (100°/s) unilateral knee extension strength	Jump height increased 7.6% Strength increased 16.6% and 9.0%	Jump height, isometric and dynamic strength increased only in the WBV group	Jump height and strength increased only in the WBV group	Jump height increased only in the WBV group Strength increased in both groups (No statistics between groups)
De Ruiter et al. (2003)	Physically active ♂ and ♀ students *n* (10, 10) Age (20.7, 19.9)	30 Hz, 8 mm Acc not given Static standing on one flexed leg		11 w 3 sessions/w 5–8 min/session	Countermovement jump Bilateral isometric knee extension strength	No change in jump height or strength	No differences between group changes in jump height or strength		
Russo et al. (2003)	Post-menopausal ♀ *n* (14, 15) Age (60.7, 61.4)	Progression 12–28 Hz at 0.1–10 g Body-loaded static exercises		6 m 2 sessions/w 6 min/session	Squat jump	Jump power increased 4.7%		Jump power increased only in the WBV group	
Cochrane et al. (2004)	♂ and ♀ non-elite athletes *n* (12, 12) Age (all 23.9)	24 Hz, 11 mm Acc not given Body-loaded static exercises		5 days training, 2 days rest and 4 days training, Time/session not given	Countermovement and squat jump	No change in jump heights	No differences between group changes in jump heights		
Delecluse et al. (2005)	♂ and ♀ sprint-trained athletes *n* (10, 10) Age (21.0, 21.4)	Progression 35–40 Hz at 2.28–5.09 g, 1.7–2.5 mm Body-loaded static and dynamic exercises		5 w 3 sessions/w 9–18 min/session	Countermovement jump Isometric and isokinetic (100°/s) unilateral knee extension and flexion strength	No change in jump height or strength		No differences between group changes in jump height or strength (Both groups performed intense sprint training)	
Roelants et al. (2004a)	Untrained ♀ *n* (13, 12, 15) Age (21.5, 20.6, 21.6)	Progression 35–40 Hz at 2.28–5.09 g, 2.5–5.0 mm Body-loaded static and dynamic exercises	Progression 2 × 20–2 × 8 RM leg press and extension	24 w 3 sessions/w 20–30 min/session	Isometric and isokinetic (50, 100 and 150°/s) unilateral knee extension strength	Strength increased 24.4%, 5.9%, 8.3% and 7.6%		Strength increased only in the WBV group	No differences between group changes in strength
Roelants et al. (2004b)	Post-menopausal ♀ *n* (24, 25, 20) Age (64.6, 64.2, 63.9)	Progression 35–40 Hz at 2.28–5.09 g, 2.5–5.0 mm Body-loaded static and dynamic exercises	Progression 2 × 20–1 × 8 RM leg press and extension	24 w 3 sessions/w Up to 30 min/session	Countermovement jump Isometric and isokinetic (100°/s) unilateral knee extension strength	Jump height increased 19.4% Strength increased 15.0% and 16.1%		Jump height and strength increased only in WBV group	No differences between group changes in jump height and strength
Ronnestad (2004)	Resistance trained ♂ *n* (7, 8) Age range: 21–40	40 Hz Acc not given Progression 3 × 10–4 × 6 RM squats		5 w 3 sessions/w Time/session not given	Countermovement jump 1 RM squat	Jump height increased 8.8% and 1 RM 31.6%	No differences between group changes in jump height or 1 RM		
Verschueren et al. (2004)	Post-menopausal ♀ *n* (25, 23, 22) Age (64.6, 64.2, 63.9)	35–40 Hz at 2.28–5.09 g, 1.7–2.5 mm Body-loaded static and dynamic exercises	Progression 2 × 20–1 × 8 RM leg press and extension	6 m 3 sessions/w Up to 30 min/session	Isometric and isokinetic (100°/s) knee extension strength	Strength increased 15.1% and 16.5%		Strength increased only in the WBV group	No differences between group changes in strength

Level of significance for "increases" or "decreases" was in all cases $P<0.05$.

RM, one repetition maximum; m, month; w, week; WBV, whole body vibration.

the vibration and training, exposure time and intensity, strength and jump tests and results of the WBV, as such, and compared with those of the respective control groups. Specific reference to Table 1 will not be made in the following.

Strength and jump performance after WBV

Changes in muscle strength performance in the WBV groups ranged from −0.9% to 24.4%. Changes in jump performance after WBV ranged from 4.5% to 16%, whereas the one study that measured changes in one repetition maximum in squat found an improvement of 31.6% (Ronnestad, 2004). Repeated measures designed statistics showed significant changes in one or more test parameters with the WBV intervention in nine of the 12 studies. Two of these nine studies reported changes in jump performance, but not in isometric bilateral leg press force and grip strength. Eight of the 10 studies evaluating jump performance, and five of the eight studies assessing changes in lower limb strength performance demonstrated improvements after WBV. However, before ascribing any improvements to the WBV *per se*, the design of the studies with respect to the characteristics of the control group has to be scrutinized.

WBV results in relation to control group used

All studies included in this review had to have a control group. However, some used more than one control group, and, furthermore, the activities of the control groups varied markedly, which is of significance when interpreting the results.

As WBV generally implies that some sort of physical effort is made while on the platform, e.g. standing in a squatted position on one or both legs, it is essential that the possible training effects of these exercises be separated from those of WBV as such. This requires an experimental paradigm where the control group performs identical training exercises as the WBV group, only without vibration. Five of the 12 articles are based on such a paradigm. In all those five articles, but one, there were no differences between WBV and control groups in strength and jump performance. The reason for the deviating results in the study by Delecluse et al. (2003) are not evident, but it can be noted that the study was performed on untrained women, whereas the other four studies were carried out on mixed-gender groups of subjects, of apparently higher fitness level. It can be concluded that in a clear majority of the studies using an adequate experimental design, there was no effect that could be ascribed to WBV *per se*, but rather to the concomitant exercises being performed on the platform. Below, some comments will be made on studies using other types of control groups.

Eight articles have compared a WBV group with a passive control group, not performing any extra exercise at all. In light of the findings described above, it was not surprising that most studies reported “larger improvements” in strength and/or jump performance in the WBV than in the control group, as no improvements occurred in the latter group. Further, in the two studies by Torvinen et al. (2002, 2003) there were no improvements in either the WBV or the passive control group in leg press force and grip strength. A special case was a study performed by Delecluse et al. (2005), who added WBV to intense background training, common for both control and WBV groups. No improvements were found in either group, thus suggesting no extra benefit from WBV exposure.

Four of the studies using a passive control group also used an “active” control group, performing strength-training exercises of alleged higher intensity than those performed on the vibrating platform. All, but one (Delecluse et al., 2003), lacked a control group carrying out identical exercises as the WBV group. The findings of no difference between improvements in lower extremity strength and jump height (Roelants et al., 2004a, b; Verschueren et al., 2004) in the WBV and the strength training groups do not imply training effects of WBV, *per se*. It could be that the exercises performed by the WBV and strength training groups were of a similar intensity. The load imposed by the exercises carried out on the vibrating platform, e.g. squatting on one leg, appears to be fairly high for the untrained and/or elderly subjects and not too different from the load of the strength training exercises, as judged from the rather high number of repetitions. In the only study (Delecluse et al., 2003) reporting an exclusive improvement in jump height in the WBV group, as compared with all three types of control groups, it could be noted that the WBV group had a significantly lower initial performance level than the strength-training control group, i.e. presumably a greater potential for improvement, and that they, even after the period of WBV, did not reach the initial performance level of the strength-training control group.

Conclusions should, of course, not be extended beyond the methods and materials used in the studies hitherto performed and included in this review. Restrictions include vibration parameters (frequency, amplitude and duration), largely steered by manufacturers’ recommendations; periodicity, apparently adopted from common routines for strength training; and total durations of exposure, which were relatively short, as often in this type of studies. Concerning the materials, most studies have been performed on either gender-mixed groups or on post-menopausal women in their 60s. It is noteworthy that the five studies using an adequate design, with a control group performing identical exercises, and showing no net (four studies) or minor (one study) effects of WBV, were carried out on young adults, most of them with a reasonably high initial level of fitness.

Proposed neural mechanisms

The theoretical deliberations advanced in essentially all the reviewed papers for expecting chronic effects of WBV include neural adaptations related to an increased muscle activation caused by augmented excitatory input from muscle spindles exposed to vibration. Early studies are referred to, showing a vibration-induced increase in muscle activation, a so-called tonic vibration stretch reflex (Eklund & Hagbarth, 1966; Brown et al., 1967). However, the connection between these basic experiments and the WBV is tenuous, and it is seldom discussed, and never demonstrated, how such a mechanism would cause a sustained positive effect on muscle strength and jump performance.

First, the tonic vibration stretch reflex was originally demonstrated as a result of a brief exposure of high-frequency stimulation applied directly onto a tendon, and constituted a transient increase in muscle activation (Eklund & Hagbarth, 1966; Brown et al., 1967). In WBV, longer exposures are used, the frequency is considerably lower and the vibration is applied unspecifically under the feet. Additionally, both the frequency and the amplitude of the oscillations decrease as they are transplanted cranially (Yue & Mester, 2002). Later experiments on vibration applied directly to a tendon have shown that there was rather a decrease than an increase in voluntary muscle activation as the exposure to the vibration was prolonged for more than 30 s (Bongiovanni et al., 1990; Ribot-Ciscar et al., 1998; Shinohara, 2005), which is most often the case in WBV. A decrease in activation could be due to a reduced Ia-input to the motoneurone pool induced by a reduction in muscle spindle firing frequency (Ribot-Ciscar et al., 1998), increased presynaptic inhibition (Hultborn et al., 1987) or a decrease in neurotransmitter release caused by homosynaptic postactivation depression (Curtis & Eccles, 1960; Hultborn et al., 1996; cf. Nordlund et al., 2004). In addition, muscle spindle firing induced by vibration of a muscle or tendon excites not only the homonymous motor neurones but also interneurones in the spinal cord, which inhibit motoneurones of antagonist muscles, via reciprocal inhibition (Crone & Nielsen, 1994). The outcome of WBV with respect to level of activation during exposure is therefore difficult to predict.

For an assumed increased level of activation during WBV to have a chronic effect on muscle strength performance, it would either have to cause a sustained increase in the ability to activate maximally the agonistic muscles and/or decrease any excessive activation of antagonists, i.e. improve coordination. Another theoretical possibility would be that an increased activation would cause an increased load on the agonist muscles during WBV and thereby eventually induced local adaptations, e.g. hypertrophy or increased muscle "quality" in terms of specific tension or improved rate of force production.

Concerning the ability to increase maximal voluntary activation, it is worth noticing that acutely applying local vibration over a muscle has been demonstrated to increase neural activation only when the muscle is relaxed or when it is activated at a submaximal intensity (Hagbarth et al., 1986; Bongiovanni & Hagbarth, 1990). No effects were found at the maximal voluntary level of activation (Bongiovanni & Hagbarth, 1990). In two of the reviewed articles, individual examples are given, where acute WBV while standing in a squatted position was accompanied by higher EMG amplitudes in the rectus femoris and gastrocnemius muscles (Delecluse et al., 2003; Verschueren et al., 2004). In both studies, the EMG recordings presented were obtained during brief periods of time, 20–25 s, thus shorter than the time commonly used in the WBV "training," and probably too short to show a subsequent decline in EMG (cf. above). None of the reviewed articles attempted to use EMG to study putative chronic effects of WBV on the ability to activate voluntarily muscles maximally. Interestingly, one study addressed this issue by estimating the level of voluntary activation using the so-called interpolated twitch technique (De Ruiter et al., 2003). This means that the maximal voluntary torque (strength) output is compared with that attainable via a superimposed electrical stimulation. No effects of WBV could, however, be demonstrated.

A hypothetical effect of WBV on muscle strength and jump performance via an increase in submaximal activation during vibration exposure and a subsequent increase in muscle mass appears unlikely, mainly because of the relatively low load imposed on the muscle–tendon unit. Attempts to investigate possible hypertrophy in WBV and a matched control group using estimation of lean body mass did not result in any significant changes in either of the groups (Verschueren et al., 2004). A possibility of muscle quality changes has been looked at indirectly, via rate of voluntary torque (force) development, maximal speed of movement and sprint speed, but, generally, no effects of WBV have been demonstrated (Schlumberger et al., 2001; Delecluse et al., 2003; De Ruiter et al., 2003; Cochrane et al., 2004). A circumstance to consider is that higher activation of certain muscles must imply higher activation also of antagonists, to maintain the static positions often used in WBV. This brings up the issue of specificity of exposure and possible effects on coordination. The oscillatory motion induced by WBV is not focused to one muscle or muscle group, but affects, more or less, the whole body, including agonist and antagonist muscle groups. In addition to the unpredictable consequences of reciprocal inhibition mentioned above, this lack of specificity leads to a questioning of the theoretical benefits of WBV on performance in coordinative tasks, e.g. jumping.

Perspectives

According to the reviewed literature, WBV appears to provide no or only minor additional effects on muscle strength and jump performance as compared with performing the same exercises without WBV. Thus, they provide no basis for recommending WBV as a replacement, or addition, to resistance training, at least not in healthy fit people, i.e. the group that most frequently train at sport institutes and gyms. The studies on sedentary or elderly people were not designed so that it is possible to isolate effects of WBV from effects of resistance training. Evaluating potential benefits of WBV, such as increasing bone density (Eisman, 2001; Johnell & Eisman, 2004), or potential risks, such as those experienced in a working environment (Nelson & Brereton, 2005), is beyond the scope of this review.

Key words: systematic review, exercise, muscle force, muscle strength, oscillation, neural mechanisms, jumping, strength training.

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