Scand J Med Sci Sports 2007: 17: 2–11
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DOI: 10.1111/j.1600-0838.2006.00578.x

SCANDINAVIAN JOURNAL OF
MEDICINE & SCIENCE
IN SPORTS

Review

Effects on leg muscular performance from whole-body vibration exercise: a systematic review

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Accepted for publication 24 May 2006

The purpose of this study was to investigate the effects on leg muscular performance from whole-body vibration exercise. Literature search was performed on the databases Pubmed, Cinahl, ISI web of science (*Sci-expanded, SSCI*) and Embase (*Rehab & Physical Med*). Rating of 19 relevant studies was performed (14 on long-term exercise and five on short-term exercise) using a score system for the methodological quality. Several randomized-controlled trial studies of high to moderate quality show similar improvements from long-term regimen on muscular performance in the legs after a period of whole-body vibration exercise. As there were few studies on short-term exercise and as they had no control groups, the same convincing improvements regarding muscular performance were not achieved. Preliminarily, there is strong to moderate evidence that long-term whole-body vibration exercise can have positive effects on the leg muscular performance among untrained people and elderly women. There is no clear evidence for effects on muscular performance after short-term vibration stimuli.

Whole-body vibration exercise or vibration training has lately gained much attention and has been used widely, preferably among healthy people, such as elite athletes (e.g., Bosco et al., 1999; Cochrane & Stannard, 2005). The main argument for using vibration for muscle training has been based on the assumption that strength improvements can be easily achieved during a short time frame (Cardinale & Bosco, 2003). More and more scientific publications report various positive effects from vibration exercise, also among people with functional disabilities (Rittweger et al., 2002; Salvarani et al., 2003).

There are a few theories on how vibration can have an effect on the muscular performance (Cardinale & Bosco, 2003; Roelants et al., 2004a). The early gains in force-generating capacity have been attributed to neural factors, probably related to an increase in sensitivity of the stretch reflex, which initiates muscle contractions (Cardinale & Bosco, 2003; Roelants et al., 2004a) i.e., a stimulation of Ia-afferents via the muscle spindle, resulting in facilitating homonymous α-motor neurons. The responses may in turn trigger specific hormonal responses such as testosterone and growth hormone levels (Cardinale & Bosco, 2003). Muscular hypertrophy could be an effect of long-term adaptation from vibration, which was demonstrated as an induced enlargement of slow-and fast-twich fibers in rats (Necking et al., 1996) although, as stated by Luo et al. (2005), there is no clear consensus on the mechanism by which vibration may enhance the neuromuscular performance.

Whole-body vibration constitutes a mechanical stimulus that enters the human body via the feet when standing on an oscillating platform. These vibrating platforms are nowadays commercially available (e.g., Nemes Bosco System®, OMP, Rieti, Italy; Galileo 2000 device®, Novotec, Pforzheim, Germany; Powerplate®, North America Inc, Northbrook, IL, USA) and normally utilize high-frequency and low-amplitude vibration, which represents a strong stimulus to the skeletal muscles (Cardinale & Bosco, 2003) of the entire body, but preferably in the legs in view of the fact that the legs are closer to the vibration source. Most commonly, squat exercises without external loads are performed on the vibrating platform. Besides, vibration superimposed on exercises with external loads performed on the platform is sometimes used (Rönnestad, 2004).

Cardinale and Bosco (2003) summated the effects of vibration exercise as having a good potential to enhance the neuromuscular performance i.e., strength and power capacity among athletes. They also suggested that vibration exercise might be a tool for training and rehabilitation programs, preferably among the elderly. Luo et al. (2005) presented a review that concluded that greater exercise intensity and volume could increase strength and power. Further, they concluded that the effects were greater among athletes than in non-athletes. The articles included in the reviews by Cardinale and Bosco (2003) and Luo et al. (2005) were all retrieved between 1966 and 2003 and contained both whole-body vibration exercise and locally applied vibration stimuli.

There have been an increasing number of articles reporting muscular effects from whole-body vibration exercise on platforms. However, up till now, no critical and systematic review of these studies has been performed.

The aim of this study was to perform a systematic review of studies reporting results of leg muscular performance after whole-body vibration exercise.

Material and methods

Literature search was performed on the databases Pubmed, Cinahl, ISI web of science (*Sci-expanded*, *SSCI*) and Embase (*Rehab & Physical Med*), using the following combination of search words: (whole-body vibration or vibration training or vibration exercise), and muscle strength. The databases HSE-line and Cochrane (Central register of controlled trials) were excluded, as no articles about whole-body vibration exercise were found. Sportdiscus and Pedro were also excluded as they only contributed with doublets. There was no time restriction in the literature search, which was completed in February 2006. For inclusion, the focus of the study was supposed to investigate the effects on leg muscular performance (strength and/or power) from whole-body vibration exercise. Further, only original articles written in English were included. Studies using locally applied vibration and studies on animals were excluded from the review.

Exclusion of studies with irrelevant content and doublets was carried out in three steps. First, the titles of the articles were read. Second, the abstracts were read. Third, the whole articles were read.

Methodological quality rating of the remaining studies was achieved by using a modified version of the criteria list (Niklasson & Carlsson, 2000) originally presented by van Tulder et al. (1997a); see Table 1. Further, a score system for rating the quality of whole-body vibration exercise was used; see Table 2. This score system included factors that are believed to influence transmission and thus the effects of vibration (Griffin, 1990). Assessment of leg muscular performance was considered to be of high quality if parameters were measured by use of a mutually objective laboratory test (i.e., isometric or isokinetic torque) and a more functional performance test (i.e., jump height). Static and dynamic strength tests were both considered relevant for evaluation of vibration exercise involving light training (e.g., squats). Both the literature search and the quality rating were performed independently by two of the authors and later compared. Any disagreements were noted and discussed until consensus, and if necessary a third author was involved. Quality ratings were carried out having the authors blinded to the title, journal name, authors and institution.

A study of long-term exercise (defined as: assessment of muscular performance after regular vibration exercise) was considered to be of high methodological quality if at least 11 of 16 points (69%) were achieved from the modified methodological score system. Studies on long-term exercise with points between seven and 10 were considered to have moderate methodological quality, whereas studies with six points or below were considered to be of low methodological quality. A study of short-term exercise (defined as: assessment of muscular performance immediately after application of a single bout of vibration stimuli) was considered to be of high quality if at least nine of 13 points (69%) were achieved. Studies on short-term exercise that received between six and eight points were considered to be of moderate quality and studies with points below six of were considered to be of low quality. The results from the respective studies were considered to be positive or negative if the specific exercise resulted in a significant change for at least one of the strength or power variables compared with a control group or with baseline. Under other circumstances, the results were considered indifferent. The degree of evidence was based on a rating system used by van Tulder et al. (1997b); strong evidence: multiple relevant, high quality randomized-control trials (RCTs); moderate evidence: one relevant, high quality RCT and one or more relevant, low-quality RCTs; limited evidence: one relevant, high-quality RCT or multiple relevant, low quality RCTs; no evidence: only one relevant, low-quality RCT, no relevant RCTs or not consistent results. No consistency was considered apparent if less than one third of the studies resulted in either positive or negative results.

Cohen's κ was used to, determine the interexaminer reliability from the methodological assessments. The answers alternatives of the assessment were dichotomized for calculation of Cohen's κ (yes or other alternative). The statistical calculations were performed on Statistical Package for the Social Sciences (SPSS, SPSS Inc., Chicago, Illinois, USA), version 11.5 for Windows.

Results

The first literature search, performed in February 2005, resulted in a total of 60 hits, whereof 24 were doublets. For the first step, 12 studies were excluded based on the title. For the rest of the studies, abstracts were all read and resulted in exclusion of further eight articles. The full article was read for all the remaining studies and exclusion of four more articles was carried out. After agreement between authors, 12 articles remained: nine (Torvinen et al., 2002b, 2003; Delecluse et al., 2003; de Ruiter et al., 2003b; Russo et al., 2003; Salvarani et al., 2003; Roelants et al., 2004a, b; Verschueren et al., 2004) about long-term exercise and three (Torvinen et al., 2002a; de Ruiter et al., 2003a) about short-term exercise. A list of the excluded articles can be obtained from the authors. In order to include the most recent studies, a second literature search was performed with time limits between February 2005 and February 2006, which resulted in three more relevant studies (Bautmans et al., 2005; Cochrane & Stannard, 2005; Delecluse et al., 2005). For the second literature search, the same methodological approach was used. Four more articles were added as they were often cited in other studies, but not found in the original literature search (Bosco et al., 1998, 2000; Cochrane et al., 2004; Rönnestad, 2004).

Cohen's κ was determined to be 0.75 ($P<0.001$) for the methodological quality rating and 0.78 ($P<0.001$) for the vibration assessment. The results from the methodological quality rating are presented in Table 3.

Table 1. Criteria list for the methodological quality assessment

Question	Description of what is required to reach a positive answer
Patient selection	
a Were the eligibility criteria specified?	A description of eligibility criteria is specified
b Treatment allocation. Was a method of randomization performed?	A randomization process is described
c Were the groups similar at baseline regarding the most important prognostic indicators?	A description of respective groups age, weight, and height is presented and is similar between groups
Intervention	
d1 Were the index interventions explicitly described?	The index intervention is explicitly described so that it is possible to replicate the study
d2 Were the control interventions explicitly described?	The control intervention is explicitly described so that it is possible to replicate the study
f Were co-interventions avoided and comparable?	If the co-interventions (or not) are presented and comparable
g Was the compliance acceptable in all groups?	A presentation showing that subjects performed at least two thirds of the number of training sessions
Outcome measurement	
i Was the outcome assessor blinded to the intervention?	If the blindness of the assessor is described
k Were adverse effects described?	If adverse effects (or no reports of adverse effects) are mentioned
l Was the withdrawal/drop-out rate described and acceptable?	*If withdrawal/drop-out was explained. The total amount of drop-outs cannot exceed 20%*
Timing of follow-up measurements	
m1 Was a short-term follow-up measurement performed?	Presentation of results immediately after vibration exercise
m2 Was a long-term follow-up measurement performed?	Presentation of results one more time after immediate results
n Was the timing of the outcome assessment in both groups comparable?	*The timing of the outcome assessments is comparable between groups*
Statistics	
o Was the sample size for each group described?	The sample size is justified by a statistical power calculation
p Did the analysis include an intention-to-treat analysis?	*If drop-outs' baseline data were included in the results*
q Were point estimates and measures of variability presented for the primary outcome measures?	Measures of relevant outcome were performed at baseline and presented

Answer alternatives are yes, no, don't know or not relevant. Each yes yields one score. Total number of scores is 16 for studies about long-term exercise and 13 for studies on short-term exercise. Italic letters refer to the questions excluded for evaluation of studies on short-term exercise.

Table 2. Criteria list for evaluation of vibration exercise

Characteristics	Question
1. Damping	Is the footwear during vibration exercise specified?
2. Magnitude	Is the magnitude or amplitude of vibration specified?
3. Direction	Is the direction of vibration specified?
4. Frequency	Is the frequency of vibration specified?
5. Type	Is the waveform of vibration specified?
6. Duration	
a	Is the duration of the individual exercise session specified?
b	Is the number of exercise sessions specified?
c	Is the full length of the exercise period specified?
7. Posture	Is the posture adopted during vibration exercise described?

Answer alternatives are yes or no. Each yes yields one score, i.e., maximum of 9.

Nine of 14 studies on long-term exercise showed an increase in leg strength or power, measured by isometric or isokinetic strength tests or by jump height. Eight of these studies concerned untrained or elderly subjects, mostly women (Table 4a). All studies on short-term exercise concerned young people. Three studies of five on short-term exercise showed improvements in strength or power, two of these involved physically active subjects (Table 4b).

Eight studies of 14 about long-term exercise that deal with untrained or elderly (post-menopausal) women had high or moderate quality; they were all controlled and all but one had used a randomization procedure. All studies about short-term exercise used a before–after procedure, with the subjects being their own controls (Table 4b). Among the studies about short-term exercise, there were three studies that used a randomization process; two of them were regarded as having high quality and one was regarded as having moderate quality. Two of the studies that had used a randomization procedure showed positive results on leg muscular performance from short-term vibration stimuli. The majority of the included studies specified most of the sought for vibration parameters. Waveform, direction and damping were the most infrequently reported parameters. Both a laboratory and a functional measure of muscular performance were widely used and often involved both static and dynamic parameters.

Discussion

The results from this systematic review show that there is strong to moderate evidence that long-term whole-body vibration exercise can have positive

Table 3. Overview of the results from the methodological quality rating

Author	a	b	c	d1	d2	f	g	i	k	l	m1	m2	n	o	p	q	Number of positive answers	Quality rating
Long-term																		
Bautmans et al. (2005)	+	+	+	+	+	+	+	+	–	+	+	–	+	–	+	+	13	High
Bosco et al. (1998)	+	+	+	+	+	+	–	–	–	+	+	–	+	–	–	+	10	Moderate
Cochrane et al. (2004)	+	+	+	+	+	+	–	–	–	+	+	–	+	–	–	–	9	Moderate
Delecluse et al. (2003)	+	+	+	+	+	–	+	–	+	+	+	–	+	+	–	+	12	High
Delecluse et al. (2005)	+	+	+	+	+	+	+	–	+	–	+	–	+	–	–	+	11	High
de Ruiter et al. (2003b)	–	–	+	+	+	–	–	–	+	+	+	+	+	–	–	+	9	Moderate
Roelants et al. (2004b)	+	+	+	+	–	–	+	–	+	–	+	+	+	+	–	+	11	High
Roelants et al. (2004a)	+	–	+	+	+	–	+	–	+	–	+	–	+	+	–	+	10	Moderate
Russo et al. (2003)	+	+	+	+	–	–	–	–	+	+	+	–	+	–	–	+	9	Moderate
Rönnestad (2004)	+	+	–	+	+	+	+	–	–	+	+	–	+	–	–	+	10	Moderate
Salvarani et al. (2003)	+	+	+	+	+	–	–	–	–	–	+	+	+	–	–	+	9	Moderate
Torvinen et al. (2002b)	+	+	+	+	–	–	+	–	+	+	+	+	+	–	–	+	11	High
Torvinen et al. (2003)	+	+	+	+	–	–	+	–	+	+	+	+	+	+	–	+	12	High
Verschueren et al. (2004)	+	+	+	+	+	+	–	–	+	–	+	–	+	–	–	+	10	Moderate
Short-term																		
Bosco et al. (2000)	+	–	–	+	–	–	+	–	–		+	–		–		+	5	Low
Cochrane et al. (2005)	+	+	–	+	+	+	–	–	–		+	–		–		+	7	Moderate
de Ruiter et al. (2003a)	–	–	–	+	–	+	–	–	–		+	+		–		+	5	Low
Torvinen et al. (2002c)	+	+	+	+	+	+	+	–	+		+	+		+		+	12	High
Torvinen et al. (2002a)	+	+	+	+	+	+	+	–	+		+	+		–		+	11	High

Sign "+" for a positive answer (see Table 1 and "Method") and sign " – " for other answers (no, don't know, not relevant).

effects regarding leg muscular performance. This is verified by several high- or moderate-quality studies. As most of these studies involved untrained and elderly (post-menopausal women), the effects from long-term whole-body vibration exercise appear to be most beneficial for these groups. The effects from short-term whole-body vibration exercise on leg muscular performance seem more uncertain as there were only five studies included and none of them were controlled. However, in total, three of them showed positive results among young people. In view of the fact that physically inactive subjects appear to have the highest benefit from long-term whole-body vibration exercise, neural adaptations may be an explanatory mechanism. To verify chronic effects other than neural ones, specific morphological investigations of the muscle tissue are necessary (e.g., muscle biopsies). Neural mechanisms are the only explanation for the results regarding short-term whole-body vibration exercise.

The review by Luo et al. (2005) also concluded that neuromuscular performance can be improved by vibration exercise, but preferably among athletes. However, their conclusion was based on studies involving both whole-body vibration and locally applied vibration. Luo et al., though, did not mark the studies with a quality label. Further, the difference between the reviews is that Luo et al.'s literature search was based on fewer databases, which in turn resulted in eight studies on the effects of whole-body vibration compared with 19 studies in this review. The distribution of articles on long-term respective short-term exercise was also different in relation to this review. Cardinale and Bosco (2003) summated six articles in a review, and similar to Luo et al., they also concluded vibration exercise as having a good potential to enhance the neuromuscular performance among athletes. The review by Cardinale and Bosco though was not systematic and did not distinguish the results from locally applied or whole-body vibration.

The methodological procedure used in this review was executed by means of recommendations from the Cochrane Back Review Group (van Tulder et al., 1997a) i.e. the literature search and methodological scoring were carried out independently by two persons blinded for the articles author, journal and title. Good agreement was achieved between the authors. The quality assessments were performed using widely accepted criteria from the Cochrane Back Group, and several databases were utilized for the literature search. This review however, did, not include articles written in languages other than English and using a combination of search words may have restricted the literature search slightly. Adding "grey literature" has limited this negative aspect and the review does, to our knowledge, contain all relevant and accessible English literature about muscular performance from whole-body vibration exercise published before February 2006. The methodological score system was modified from the original version, which was used for scoring RCTs on the treatment of low back pain. The validity of the new version has not been tested. Further, some questions in the score system may seem more important than others, but there is no weighting procedure. The choice of a cut-off for high-

Table 4a. Overview of studies included on long-term exercise

Author and year	Purpose	Type of study	Subjects	Exercise	Results on muscle performance	Specification of vibration exercise	Specification of muscle performance
Bautmans et al. (2005)	Investigate the effects of 6 weeks of WBVE on linear isokinetic leg extension	Randomized-controlled trial Two groups: 1. WBVE 2. Static exercise	Twenty-four nursing home residents (15 female, nine male, mean age 77.5 ± 11.0)	WBVE in a progressive program using various light exercises. 1–3 × 30–45 s	No significant differences between groups regarding muscle strength or power	A: 2–5 mm F: 30–40 Hz S: 8	Closed chain bilateral leg extension. Linear isokinetic multi-joint dynamometer
Bosco et al. (1998)	Investigate the effects of 10 days of WBVE on jumping performance	Randomized controlled trial Two groups: 1.WBVE 2. Control	14 physically active subjects (age 19–21)	WBVE in various defined postures90 s2 minposition (10 min daily)	Power output, height of best jump and mean jump height in continuous jumping significantly improved (6–12%)	Acc: 54 m/s^2 A: 10 mm F: 26 S: 9	Countermovement jump and continuous jump. Measured on a contact mat
Cochrane et al. (2004)	Investigate effects of 9 days of WBVE on vertical jump, sprint and agility performance	Randomized-controlled trial Two groups: 1.WBVE 2. Control	Twenty-four healthy active (16 men) mean age 23.9 ± 5.9	WBVE exercise for 9 days (5 days training, 2 days recovery, and further 4 days of training) in standardized positions	No significant differences between groups	A: 11 mm F: 26 S: 7 (direction and type not specified)	Countermovement jump, concentric squat jump, sprint tests and agility (505, up and back test)
Delecluse et al. (2003)	Investigate and compare the effects of a 12-week period of WBVE and resistance training on human knee-extensor strength	Randomized-controlled trial Four groups: 1. WBVE 2. Resistance 3. Placebo 4. Control	Sixty-seven untrained females (21.4 ± 1.8 years)	Progressive WBVE with static and dynamic knee-extensor exercise (three times per week: 3–20 min/session)	Static and dynamic knee-extensor strength increased significantly ($P<0.001$). Static 17% and dynamic 9% Countermovement height enhanced significantly ($P<0.001$) with 7.6%. No improvement in ballistic strength	Acc: 2.3–5.1 *g* A: 2.5–5 mm F: 35–40 Hz S: 9	Isometric and isokinetic strength tests, ballistic strength and countermovement jump height
Delecluse et al. (2005)	Investigate the effects of a 5-week training period of additional WBVE	Randomized-controlled trial Two groups: 1. WBVE 2. Control group	Twenty-five sprint-trained athletes,18 male, aged 17–30 years	Unloaded static and dynamic standard leg exercises on a vibration platform. The program was progressive, 3 × 6 exercises between 30 and 60 s with rest periods three times per week	No change in isometric and dynamic muscle strength regarding knee-extensors and knee-flexors No significant difference in maximal knee extension velocity No significant difference in jump performance	Acc: 2.3–5.1 *g* A: 1.7–2.5 mm F: 35–40 Hz S: 7 (damping, direction and type not specified)	Isometric and isokinetic tests recorded on a motor-driven dynamometer Velocity recorded on a dynamometer from various angles Vertical countermovement jump (CMJ) with hands positioned on the waist. Obtained flight time calculated from contact mat
de Ruiter et al. (2003b)	Investigate the effects of 11 weeks of WBVE on muscular performance	Controlled trial Two groups: 1.WBVE 2. Control	Twenty healthy students (12 male) mean age 19 and 20 (exp resp control group)	Progressive WBVE without additional loads, three times per week, between five and eight sets of 1 min	No improvement of MVC. No change in jump height compared with the control group	A: 8 mm F: 30 Hz S: 7 (damping, type and direction not specified)	Maximal isometric force production (MVC), maximal of voluntary force rise (MFGC), countermovement jump height

Roelants et al. (2004a)	Investigate effects of 24 weeks of WBVE on knee-extension strength and speed of movement and on countermovement jump performance	Randomized-controlled trial Two groups: 1.WBVE 2. Resistance training 3. Control	Eighty-nine post-meno-pausal women, aged 58–74 years	Progressive WBVE three times per week (maximum 30 min/session) with static and dynamic knee extensor training. The other group performed dynamic leg press and leg extension	Static and dynamic knee extensor strength increased significantly ($P<0.001$) and also speed of movement, but there were no differences between training groups. Increased countermovement jump height ($P<0.001$). These changes were observable already after 12-weeks training	Acc: 2.3–5.1 *g* A: 2.5–5.0 mm F: 35–40 Hz S: 9	Knee extension isometric strength, dynamic strength and speed of movement. Countermovement jump performance
Roelants et al. (2004b)	Investigate and compare the effects of 24 weeks of WBVE and fitness training on body composition and muscle strength	Controlled trial Three groups: 1.WBVE 2. Fitness 3. Control	Forty-eight untrained females (21.3 ± 2.0 years)	Progressive WBVE combined with light movements (3–20 min/ session). Training group followed a standardized cardiovascular and resistance training program	A significant strength gain in both exercise groups ($P<0.001$) compared with a control group. WBVE group increased their strength by 7–25%	Acc: 2.3–5.1 *g* A: 2.5–5.0 mm F: 35–45 Hz S: 5 (type and direction specified by manufacturer? posture, damping and vibration source not specified)	Knee-extensor strength evaluated by isometric and isokinetic tests
Russo et al. (2003)	Investigate effects of 6 months of WBVE on muscle power and bone characteristics	Randomized-controlled trial Two groups: 1. WBVE 2. Control	Twenty-nine post-menopausal women (mean age 61 ± 7 years)	Progressive WBVE. Three 2-minute sessions for a total of 6 min/training session, twice weekly	Muscle power increased by about 5% ($P=0.004$) after 6 months	F: 12–28 Hz S: 6 (magnitude, damping and type not specified)	Muscle power calculated from ground reaction forces of a force platform produced by jumping as high as possible (before take-off)
Rönnestad (2004)	Compare effects on squats performed on a vibration platform (with and withourt vibration) for 5 weeks	Randomized-controlled trial Two groups: 1. WBVE+squat 2. Squat	Sixteen recreationally resistance-trained men (21–40 years)	Squats on a vibration platform (6–10 RM), two to three times per week with and without vibration. Increasing external loads were encouraged	1 RM and countermovement jump increased significantly in both groups. No differences between groups	F: 40 Hz S: 5 (damping, magnitude, direction and type not specified)	Maximum squat (1 RM) on a Smith machine. Countermovement jump (flight time)
Salvarani et al. (2003)	Investigate the effects of 2 weeks of WBVE	Randomized-controlled trial Two groups: 1. WBVE 2. Isometric training	Twenty subjects (17 males) with reconstructed anterior cruciate ligament, mean age 26–29 years	WBVE, 10 sessions, five 1-minute sessions daily with 1 min rest between	Increase in muscle strength among the WBV group (28%) ($P<0.005$)	F: 30 Hz S: 5 (damping, magnitude, direction and type not specified)	Isometric contraction for 5 s for oblique medial vastus, biceps femoris and soleus. Force measured by a load cell
Torvinen et al. (2002b)	Investigate effects of a 4-month WBVE on muscle performance and body balance	Randomized-controlled trial Two groups: 1. WBVE 2. Control	Fifty-six healthy non-athletic subjects (21 men) aged 19–38 years	Progressive WBVE with 4 min sessions, 3–5 times per week combined with light exercises	A 10.2% ($P=0.001$) improvement in jump height, 3.7% ($P=0.034$) improvement in lower limb strength after 2 months; however, it diminished by the end of the 4month intervention	Acc: 2.5–6.4 *g* A: 2 mm F: 25–40 Hz S: 9	Jump height (CMJ), maximal isometric strength of the leg extensors

Table 4a. (continued)

Author and year	Purpose	Type of study	Subjects	Exercise	Results on muscle performance	Specification of vibration exercise	Specification of muscle performance
Torvinen et al. (2003)	Assess effects of an 8-month WBVE on bone, muscular performance and body balance	Randomized-controlled trial Two groups: 1. WBVE 2. Control	Fifty-six non-athletic subjects (21 men) aged 19–38 years	Progressive WBVE (4 min/day, 3–5 times per week) combined with light movements	7.8 % net benefit in the vertical jump height ($P = 0.003$). Isometric lower limb strength not improved	A: 2 mm F: 25–45 Hz S: 8 (type not specified)	Maximal isometric strength of leg extensors, vertical countermovement jump test
Verschueren et al. (2004)	To assess musculoskeletal effects of 6 months of high-frequency WBVE	Randomized-controlled trial Three groups: 1. WBVE 2. Resistance 3. Controls	Seventy post-menopausal women (60–70 years)	Progressive WBVE three times per week (duration per session maximum 30 min) combined with knee-extensor exercise (static and dynamic)	Vibration exercise improved isometric and dynamic muscle strength (15–16%, $P < 0.01$)	Acc: 2.3–5.1 g A: 1.7–2.5 mm F: 35–40 Hz S: 8 (direction not specified)	Isometric and isotonic strength tests of knee extensors

WBVE, whole-body vibration exercise; Acc, acceleration; A, amplitude; F, frequency; S, score from the evaluation of vibration exercise (maximum = 9); g, earth acceleration (9.81 m/s^2).

and low-quality studies was performed arbitrarily before quality rating was performed. A cut-off being one point higher i.e. 12 points of 16 (75%), will result in reducing the number of high-quality studies on long-term exercise to three, but this will not alter the conclusion. Changing the cut-off to 13 of 16 points (81%) will, however, affect the conclusion regarding long-term exercise. Increasing the cut-off point up till 10 (77%) for studies about short-term exercise will not change the number of high-quality studies.

Most studies included in this review used vibration parameters, with vibration characterized as high frequency and low amplitude. This means that the frequency is higher than normal resonance frequencies identified for the human body and that the amplitude is smaller than what is found in environments with whole-body vibration exposure i.e. in vehicles. There were a rather wide variety of applied vibration parameters, but the frequencies used in studies about long-term exercise varied from 12 to 45 Hz and the amplitudes ranged between 1.7 and 5 mm, and seemed to be a good combination for muscular long-term exercise in the legs. Further, regular vibration exercise two to five times per week for at least 11 weeks seems to be good exercise arrangement for muscular effects for older and untrained people. This rather wide variety in vibration parameters and the differences in the exercise regimens between studies could very well explain the various outcomes. In elderly women, this review shows that whole-body vibration exercise can lead to muscular performance between 5% and 16%. Similar improvements were achieved by subjects performing resistance training in these studies but with no vibration stimuli (Roelants et al., 2004a; Verschueren, 2004). This improvement could also be compared with gains when ordinary strength training has been performed in similar groups, where an increase between 20% and 76% has been reported in a recent review by Asikainen et al. (2004). However, in the review by Asikainen et al. (2004), the strength could have been measured by means of 1 RM on the training device itself, which can be higher than those obtained from an isokinetic dynamometer. Although statistical improvements were found, it is important to consider the clinical value of the gains, which were considered rather low.

Future studies should be performed in order to find an ideal combination of various vibration parameters for full effect and with a specific body region and function in target and also to access the functional importance. Researchers are encouraged to specify all vibration parameters and not solely refer to the manufacturers. In addition, there should also be more studies about short-term exercise as diverse results were revealed among the few studies in this review. Moreover, the major part of the studies in this

Table 4b. Overview of studies included on short-term exercise

Author and year	Purpose	Type of study	Subjects	Exercise	Results	Specification of vibration exercise	Specification of muscle performance
Bosco et al. (2000)	Investigate the acute effects of 60 s WBVE	Case study	Fourteen physically active male subjects, mean age 25 ± 4.6	Ten sessions of 60 s WBVE. 60 s of rest between the sessions with a knee angle at 100°of flexion	Mechanical output of leg extensor muscles significantly enhanced with 7% ($P = 0.003$) Jumping performance significantly enhanced by 4% ($P < 0.001$)	Acc: 17 *g* A: 4 mm F: 26 Hz S: 9	Dynamic leg press exercises on a slide machine with extra loads of 160% of the subjects' mass (70% of 1RM) Flight time and contact time were recorded and jump height was calculated, using a resistive platform
Cochrane et al. (2005)	Investigate effects of a 5-min WBVE session	Randomized cross-over (case study)	Eighteen female elite field hockey players (21.8 ± 5.9)	WBVE in six various positions. Four positions for 1 min and two positions for 30 s	8.1 ± 5.8% increase in ACMVJ height compared with cycling or control (standing)	A: 6 mm F: 26 Hz S: 8 (type not specified)	Vertical jump test (Six countermovement jumps with arm swing (ACMVJ) on a contact timing mat. Separated with a rest period of 10 s
de Ruiter et al. (2003a)	Investigate effects of a 5-minute WBVE session	Case study	Twelve untrained students (seven males) 23.3 (4.2) years	One standard WBVE session 5 × 1 min vibration ,with a 2 min rest in between	Maximal knee extensor force reduced 90 s after vibration. MRFR not affected by vibration	A: 8 mm F: 30 Hz S: 7 (direction and type not specified)	Maximal voluntary contraction (MVC) force was determined as the highest value from three to six maximal voluntary knee extensions
Torvinen et al. (2002c)	Investigate effects of a 4-minute WBVE on muscle performance and body balance	Randomized cross-over (case study)	Sixteen young healthy subjects (eight males), 18–35 years	Multidirectional WBVE with light movements	No change in muscle performance or balance at 2 and 60 min after the exercise session	A: 2 mm F: 25-40 Hz S: 8 (type not specified)	Maximal isometric strength of leg extensors and a vertical countermovement jump test
Torvinen et al. (2002a)	Investigate effects of a 4-min vibration bout on muscle performance and body balance	Randomized cross-over (case study)	Sixteen young healthy subjects (eight men, 24–33 years)	Multidirectional WBVE with light movements	Transient net benefit (2.5%) in jump height, 3.2% benefit in isometric extension strength	A: 10 mm F: 15-30 Hz S: 8 (type not specified)	Isometric extension strength of lower extremities and jump height

WBVE, whole-body vibration exercise; A, amplitude; F, frequency; MRFR, maximal rate of isometric force raise; S, score from the evaluation of vibration exercise (maximum = 9); Acc, acceleration; *g*, earth acceleration (9.81 m/s^2).

review included healthy subjects, except for one, which included subjects with a reconstructed anterior cruciate ligament (Salvarani et al., 2003). From a rehabilitation aspect, it would be useful to test vibration exercise also on other various patient groups. This should nonetheless be done with caution as the wrong combination of vibration parameters is well known to be able to cause adverse health effects such as cardiovascular and neural symptoms and disorders (Griffin, 1990) and as the underlying mechanisms are not fully understood. Risks groups could be patients with radiating pain from spinal nerves and cardiopulmonary disorders. There were not many side effects reported from the studies; however, one subject experienced shin pain (de Ruiter et al., 2003b), and others reported erythema, itching of the legs (Russo et al., 2003; Roelants et al., 2004b) and edema (Roelants et al., 2004b).

From these systematically and critically reviewed studies, it can be inferred that there is evidence that long-term whole-body vibration exercise can have positive effects on the leg muscular performance among untrained people and elderly women, although the precise mechanisms behind this effect are unclear and its clinical significance may be questioned.

Perspectives

Whole-body vibration exercise is used widely among healthy and physically active people, mainly to increase strength and power in the lower limb muscles. The popularity of this relatively new exercise method seems to be increasing. It appears from this review, however, that especially untrained people have a greater benefit from long-term vibration exercise than physically active people.

Key words: vibration training, vibration exercise, strength, power, whole-body vibration.

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