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Full Title:

The effects of whole body vibration therapy on bone mineral density and leg muscle strength in older adults: a systematic review and meta-analysis

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Abstract

Objective: A systematic review and meta-analysis was undertaken to determine whether WBV improves bone mineral density (BMD) and leg muscle strength in older adults when compared with no intervention or conventional treatment.

Data sources: Primary sources included major electronic databases such as MEDLINE, CINAHL, and EMBASE. Secondary sources such as Physiotherapy Evidence Database (PEDro), PubMed, Science Citation Index and the reference list of each eligible article were also searched.

Review methods: Article search and selection was performed independently by two researchers. Eligible articles had to be randomized controlled trials that examined the effects of WBV on BMD or leg muscle strength in older adults (aged 50 years or above). The methodological quality of each selected article was rated by the PEDRo scale.

Results: Eighteen articles (13 randomized trials) fulfilled the selection criteria. Four were considered to have good or excellent methodological quality and the rest were rated as fair. Meta-analyses revealed that WBV has no significant effect on hip or lumbar spine BMD in older women when compared with no intervention or active exercise. WBV, however, had a significant treatment effect on knee extension dynamic strength, leg extension isometric strength, and functional measures of leg muscle strength such as jumping height and performance in sit-to-stand among older adults.

Conclusion: WBV is beneficial for enhancing leg muscle strength among older adults but there is no evidence that it is effective in improving BMD in older women. No randomized trial has examined the effects of WBV in older men.

Keywords: Aging; bone mineral density; vibration; muscle strength; rehabilitation intervention

INTRODUCTION

Fragility fractures are recognized as a major public health issue among older adults.[1,2] Fragility fractures could lead to many adverse consequences, including increased disability, mortality, reduced quality of life, and increased economic strain on the health care sector.[3-6] Decline in bone mineral density (BMD) and falls are two major contributing factors to fragility fractures among older adults, steering researchers into seeking effective strategies for enhancing bone mass and modifying fall-related risk factors.[2,7,8]

Different forms of physical exercise (e.g., resistance training, high-impact aerobic exercises) have been used as a way to promote bone mass and modify fall-related risk factors such as balance dysfunction and leg muscle weakness among older adults.[9,10] However, the traditional impact exercise approach may have an inherent risk of falls, particularly when individuals are unsupervised.[11,12] Additionally, a good proportion of older adults may have some form of chronic illnesses that render them unable to participate in vigorous impact exercise training. There is a need to search for a safe and effective alternative approach to improve bone health and reduce fall risk in older adults.

Whole body vibration (WBV), a common therapeutic approach for enhancing athletic performance, has gained popularity in geriatric rehabilitation in the past decade.[13] In WBV therapy, vibration stimuli are delivered to the body via a vibrating platform or chair. The vibration signals activate the sensory receptors in the muscles (e.g., muscle spindles), which in turn causes reflexive activation of motor units.[14,15] Thus, WBV may induce positive effects on leg muscle strength.[15] As animal studies have consistently demonstrated that dynamic loads can effectively promote bone growth,[16] WBV is also thought to have beneficial effects on bone health when applied to the human skeleton. In addition, because muscle strength is highly related to bone density in older adults, WBV may also enhance bone density indirectly through its effects on muscle activation.[17,18]

There has been an increasing research interest in WBV therapy in older adults, and a good number of randomized controlled trials (RCTs) on this subject have emerged since the early 2000s, particularly in the past two years. To date, no meta-analysis has been performed to examine the effect of WBV on both BMD and leg muscle strength in older adults.

METHODS

Research question and study selection criteria

This systematic review aimed to answer the following question: Would WBV therapy lead to better outcomes in BMD and leg muscle strength when compared with conventional therapy or no intervention in older adults? The inclusion criteria included: 1. RCTs that investigated the effects of WBV in older adults (50 years of age or older), 2. included BMD or leg muscle strength as one of the outcome measures, and 3. published in English. The exclusion criteria were: 1. research studies on the effects of WBV in individuals with a primary diagnosis of a specific pathological condition (e.g., stroke, arthritis, etc.); 2. reports in books; and 3. reports published as conference proceedings. These exclusion criteria were used because books are considered secondary sources, unlike original research papers that provide the primary source of data. Reports in conference proceedings may not have undergone vigorous peer-review processes.

Search Strategy

The following electronic databases were searched: MEDLINE (1950 - June 10, 2010), Cumulative Index to Nursing and Allied Health Literature (CINAHL) (1982 - June 10, 2010), and the Excerpta Medica database (EMBASE) (1980 - June 10, 2010). The specific search strategy for the MEDLINE database is described in Appendix 1. A similar search strategy was used for the CINAHL and EMBASE databases, with a few minor modifications due to differences in indexing and syntax. In addition, the Cochrane Library Database of Systematic Reviews, PubMed, and Physiotherapy Evidence Database were searched.[19] For these databases, the keyword "vibration" was entered to identify relevant articles, and they were last searched in June 10, 2010. The reference list of each selected article was examined to identify other potentially relevant articles. Moreover, a forward search using the Science Citation Index was performed to identify and examine any subsequent articles that referenced the eligible articles.

Data extraction and qualitative assessment

The data extraction and qualitative assessment were performed by two research team members independently. The accuracy of the extracted data was confirmed by the principal investigator. The 11-item PEDro scale, developed by the Physiotherapy Evidence Database, was used to evaluate the methodological quality of the selected studies.(Table 1)[19,20] The first item of the PEDro scale assesses external validity whereas the other ten items relate to internal validity of the study. A YES or NO response was given for the first item, whereas one point was awarded for each of the other 10 items if the criterion specified in the item was satisfied. Hence, the total score could range from 0 to 10, with a higher score indicating better methodological quality (9–10: excellent; 6–8: good; 4–5: fair; <4: poor).[21] Kappa statistics were used to assess agreement between the two raters on article selection and PEDro ratings.[22]

Quantitative Analysis

For each outcome of interest in each selected study, the difference in change score between the WBV group and the comparison group(s) was computed. This value was then divided by the pooled standard deviation to yield the standardized effect size.[23-26] The 95% confidence interval (CI) surrounding the standardized effect size was also calculated. The mean and SD values of each relevant outcome measure were requested from the respective authors if they were not reported in the article. Otherwise, the values were estimated from the graphs by recording the coordinates.[23]

In meta-analysis, the weighted effect size [standardized mean difference (SMD) and 95% CIs] were computed for all comparisons. The degree of heterogeneity was assessed by the I^2 test for each outcome. Non-significance of the I^2 test implied that the results of different studies were similar ($p>0.05$). Random-effect models were used to reduce the effects of heterogeneity between studies if appropriate. Otherwise, fixed-effect models were used. The cumulative effect of WBV therapy on each outcome was illustrated by forest plots. Additionally, Egger's regression asymmetry test was used to assess possible publication bias.[27] The analyses were performed using the Comprehensive Meta-analysis software (version 2; Biostat Inc., Englewood, NJ, USA).

RESULTS

Article selection

The flow of information through the different phases of the systematic review is described in fig. 1. After reviewing the information in the titles and abstracts, 30 papers were identified as being potentially appropriate for review. After the papers were read in detail, 12 articles did not meet the criteria and were excluded from further analysis.[28-39] As a result, a total of 18 articles fulfilled all selection criteria.[40-57] Of these, Rees et al.[48,49], Bogaerts et al.[50,51], and von Stengel et al.[54,55] each produced 2 articles from their respective trials. The reports by Roelants et al.[42] and Verschueren et al.[43] were based on the same RCT. The data reported by Gusi et al.[46] and Raimundo et al.[47] were also derived from the same trial. To summarise, 18 articles (13 RCTs) were selected for this systematic review (Table 1). The level of inter-rater agreement for article screening and final article selection was good (kappa = 0.68-0.78).

Subjects

The subject characteristics in the selected studies are outlined in Table 2. The number of subjects included in each selected study varied between 24 and 220, with the mean age ranging from 57.3 to 81.9 years. The majority of studies used community-dwelling individuals as their subjects.[40-44,46-55,57] Bautmans et al.[45], on the other hand, studied the effects of WBV in nursing home residents. The sample used by Zheng et al.[56] contained a mix of older adults who were living in the community, shelter housing, and residential homes. Seven studies included only women in their samples.[40-44,46-47,53-55]

WBV Training Group

There are substantial differences in the WBV protocols adopted among the selected studies (Table 2). All studies used a vibrating platform to deliver WBV except Zheng et al.[56] in which a Physioacoustic chair was employed to generate vibration via low-frequency sound waves. The frequency of the WBV sessions varied from 1–7 sessions per week, for a duration of 6 weeks to 18 months. The frequency of the vibration signals used ranged from 10 to 54 Hz, with an amplitude between 0.05mm and 8mm. The peak vertical accelerations of the vibration platform covered a range from 0.05 to 32.2 units of g (Earth's gravitational constant) based on the theoretical relationship (Peak acceleration = $4\pi^2 \times \text{frequency}^2 \times \text{amplitude}$).[58] In Zheng et al., the sound-waves generated by the chair was between 27-113Hz, but the amplitude of the signals was not reported.[56] The vibration was usually delivered in bouts, with intermittent short rest periods. The number of vibration bouts delivered varied vastly, ranging from 1 to 27, for a period between 30 seconds and 10 minutes each. In most studies, the subjects were required to do certain body movements while standing on the vibration platform. The common exercises prescribed were lunges, high squats, deep squats, one-legged squats, and standing on tip-toe. Moreover, the WBV training was combined with aerobic, balance and strengthening exercises in von Stengel et al.[54-55] In Iwamoto et al.,[44] the WBV group also received daily alendronate treatment.

Comparison Group

A control group with no intervention/sham vibration was used in six studies.[40-41,48-49,53,56-57] Two studies used an active exercise group as the comparator.[45-47] In other four studies, both a no-intervention control group and an active exercise group were used for comparison.[42-43,48-51,54-55] The control group in Iwamoto et al. received Alendronate treatment only.[44]

Qualitative Assessment

The PEDro scores of four trials (five articles) were not available on the Physiotherapy Evidence Database website and were rated by our research team.[52-55,57] The PEDro score given by the two raters were the same for three of the four trials, yielding a kappa value of 0.50 (Table

1). Out of the 13 selected studies, one study was considered “excellent” (score: 9-10), four were rated “good” (score: 6-8) and eight studies were “fair” (score: 4-5).

BMD

The results of the quantitative analysis are presented in Table 3. Both Rubin et al.[41] and Gusi et al.[46] measured the BMD of the femoral neck and femoral trochanter. However, Rubin et al.[41] used sham vibration whereas Gusi et al.[46] used an intensive walk-based program as the control treatment. Therefore, these two studies were not combined to conduct the meta-analysis. When compared with sham vibration, Rubin et al.[41] showed in their primary analysis that WBV resulted in no significant effect on femoral neck or femoral trochanter BMD. Only in their post-hoc subgroup analysis did they find a trend that those who were in the highest compliance quartile (86%) had better outcomes in femoral neck BMD. Our analysis of the data from Gusi et al. revealed that WBV is not superior to the walk-based program in improving BMD of the femoral neck or trochanteric regions.[46]

Total hip BMD was measured by Verschueren et al.[43] and von Stengel et al.[54] In addition to the WBV group, both studies had two control arms (no intervention and active exercise). The first meta-analysis involved the comparison between the WBV group and no-intervention control group (143 subjects). No significant treatment effect was found (SMD = 0.05, 95% CI: -0.28 to 0.38)(fig. 2A). In the second meta-analysis, the WBV group was compared with the active exercise group (140 subjects), and the result was not statistically significant (SMD = 0.04, 95% CI: -0.30 to 0.37)(fig. 2B).

Lumbar spine BMD was measured in five studies. [41,43-44,46,54] Three of these studies (213 subjects) compared the effects of WBV with no intervention.[41,43,54] The fixed-effect model revealed no significant treatment effect of WBV (SMD = 0.00, 95% CI: -0.27 to 0.37) (fig. 2C). The results on lumbar spine BMD remained non-significant when WBV was compared with active exercise (3 studies, 168 subjects) (SMD = -0.03, 95% CI: -0.34 to 0.27) (fig. 2D).[43,46,54] Using a sample of post-menopausal women with osteoporosis, Iwamoto et al. was the only study that included medication treatment as a co-intervention.[44] Their results showed that combining WBV and alendronate therapy did not result in any more significant improvement in lumbar spine BMD than alendronate treatment alone (Table 3).

Two studies used peripheral quantitative computed tomography (pQCT) to measure BMD in other skeletal sites (Table 3). Russo et al. measured cortical BMD and trabecular BMD of the distal tibial epiphysis, but found no significant change in these parameters following WBV.[40] Zheng et al. also used pQCT to measure the tibial mid-shaft, and no significant effect was found after the vibration therapy delivered by the physioacoustic chair.[56]

Leg muscle strength

A total of 14 papers (11 studies) had leg muscle strength as an outcome measure (Table 3).[40,42-43,45,47-53, 55-57] However, different methods were used to test the strength of different muscle groups. Meta-analysis was only feasible for isometric knee extension strength, dynamic knee extension strength, isometric leg extension, jumping height, and performance in sit-to-stand.

Three studies (232 subjects) measured isometric knee extension strength.[43,51,56] Of three studies, Zheng et al. presented both the data based on intention-to-treat and on-protocol analyses.[56] Therefore, separate meta-analyses were conducted. Regardless of whether the intention-to-treat (SMD = 0.41, 95% CI: -0.16 to 0.98)(fig. 3A) or on-protocol data (SMD =

0.44, 95% CI: -0.12 to 0.99)(fig. 3B) were used, no significant effect was obtained. A sensitivity analysis was conducted by removing Zheng et al.[56] from the analysis because their method of WBV delivery (physioacoustic chair) was very different from the other two studies. In this sensitivity analysis involving the data from Verschueren et al.[43] and Bogaerts et al.[51] (206 subjects), no significant treatment effect of WBV was found when compared with no intervention (SMD = 0.60, 95% CI: -0.11 to 1.30)(fig. 3C). These two studies also had an active exercise control arm. The results revealed that WBV was not superior to active exercise in improving isometric knee extension strength (190 subjects; SMD = -1.33, 95% CI: -11.06 to 8.40)(fig. 3D).

Dynamic knee extension strength was measured in three studies.[43,47-49] The results revealed that WBV had a significant treatment effect when compared with no intervention (2 studies totaling 79 subjects) (SMD = 0.63, 95% CI: 0.18 to 1.09)(fig. 4A).[43,48-49] There was no evidence that WBV was superior to active exercise intervention in improving dynamic knee muscle strength (3 studies totaling 102 subjects) (SMD = 0.04, 95% CI: -0.35 to 0.43)(fig. 4B).[43,47-49]

Two studies (120 subjects) measured isometric leg extension strength by asking the subjects to perform a leg press test.[53,55] A significant treatment effect in favour of WBV was found when compared with no intervention (SMD = 0.57, 95% CI: 0.20 to 0.93)(fig. 4C). Jumping height was used to indicate explosive leg muscle strength in three studies.[42,47,50] Meta-analysis revealed that WBV resulted in significantly increased jumping height when compared with no intervention (2 studies, 99 subjects) (SMD = 0.51, 95% CI: 0.10 to 0.91)(fig. 5A).[42,50] When WBV was compared with active exercise intervention (3 studies, 128 subjects), however, no significant difference was found (SMD = 0.32, 95% CI: -1.89 to 2.54) (fig. 5B).[42,47,50] Finally, sit-to-stand performance was used to indicate leg functional muscle strength in three studies by measuring the time to complete the chair-rise task or the number of chair-rise that was completed within a fixed time period.[48,52,57] WBV was found to have a significant treatment effect on enhancing sit-to-stand performance when compared with no intervention (104 subjects)(SMD = 0.72, 95% CI: 0.32 to 1.12)(fig. 5C). WBV, however, was not better than active exercise intervention (78 subjects) in enhancing sit-to-stand performance (SMD = -0.21, 95% CI: -1.27 to 0.86)(fig. 5D).

Publication bias

Assessment of publication bias was only feasible for those comparisons that included a minimum of 3 studies. The results of Egger's regression showed that no publication bias existed for all valid meta-analyses having at least 3 studies ($p>0.10$).

Adverse effects

The adverse effects were few (Table 3). There were isolated cases of groin pain, transient minor tingling of the lower limbs, muscle soreness, headaches, and knee pain. However, most of these problems tended to resolve as WBV training progressed. The problem of knee pain was usually related to pre-existing degenerative diseases in the knee joint (e.g., osteoarthritis).

DISCUSSION

Effect of WBV on BMD

Our meta-analyses showed that 6-18 months of WBV has no overall effect on hip or lumbar spine BMD in older women. It is known that osteogenesis is dependent upon complex interaction between loading frequency, magnitude, and rest periods.[16] It is possible that the WBV protocols adopted in the selected studies may not be optimal for inducing osteogenesis in older adults. The lack of significant findings may also be related to the subject characteristics. There is some evidence from previous studies that those with more compromised BMD at baseline may potentially benefit more from WBV.[59,60] Perhaps the osteogenic effect of WBV might have been more apparent if a more homogeneous group of older adults with low BMD had been studied. Indeed, although Rubin et al. could not find any significant treatment effect when intention-to-treat analysis of all 70 subjects was performed, their post-hoc subgroup analysis revealed that WBV was effective in maintaining lumbar spine BMD for individuals who were both in the highest compliance group (mean compliance rate at 86%) and in the lower-weight cohort (<65kg).[41] Moreover, while Iwamoto et al. showed that combining WBV and alendronate therapy induced no additional benefit on lumbar spine BMD than alendronate treatment alone among post-menopausal women with osteoporosis, no direct comparison was made between the effect of WBV and that of alendronate treatment.[44] It remains to be determined whether WBV is as effective as pharmacological interventions in improving BMD in older adults. It is noteworthy that among all the studies that measured bone outcomes, none had male subjects. Therefore, the results can be generalized only to older women. Whether WBV can enhance BMD in older men remains elusive.

In a previous meta-analysis on WBV by Slatkovska et al.[61], a significant treatment effect on hip BMD in favour of WBV was found when compared with no intervention, which does not agree with our findings. There are several explanations of the discrepancies in results. First, their meta-analysis did not include von Stengel et al.[54], a study which demonstrated no significant effect of WBV, probably because it had not been published at the time when their meta-analysis was performed. Second, the methodology was different. In their study, the pooled SD was estimated from the SD of the change score, which can be very small and often lead to exaggeration of the effect size.[23-26] In our study, the pooled SD was estimated form the SDs at baseline.[23,24] Third, the data from Rubin et al.[41], Verschureren et al.[43], and Gusi et al.[46] were put into the same meta-analysis in their meta-analysis. However, the sites of BMD measurement in these studies were not quite the same. Rubin et al.[41] and Gusi et al.[46] measured BMD in the femoral neck and trochanter regions whereas Verschureren et al.[43] measured total hip BMD. As it is possible that WBV may have differential effects on BMD in different anatomical regions, separate meta-analyses were done for these different hip regions in our study.

Effect of WBV on leg muscle strength

This is the first meta-analysis to specifically examine the effect of WBV on leg muscle strength in older adults. Our results also show that WBV has a significant beneficial effect on knee extension dynamic strength, leg extension isometric strength, and functional measures of leg muscle strength (i.e., jumping height, sit-to-stand). The treatment effect can be achieved within 6-10 weeks in some cases, and is comparable to other forms of active exercises (e.g., resistance training). Our results are thus consistent with those in young adults, which have also reported increased leg muscle strength following WBV.[59,62] Based on the current systematic review, there is inadequate evidence to identify what protocol is best for improving the various leg muscle strength outcomes. Only Furness et al. has compared the effects of 3 different WBV protocols (Group 1: 1 session per week; Group 2: 2 sessions per week; Group 3: 3 sessions per week; 6 weeks in duration) with controls.[52] It was found that improvement in leg muscle strength was found in Groups 2 and 3, but not in Group 1. While this study showed that a minimum treatment frequency of 2 sessions per week was required to induce a therapeutic effect, the total number of sessions (Group 1: 6, Group 2: 12, Group 3: 18) was different among the groups.[52] Therefore, whether the treatment frequency or the total number of sessions was the major factor in influencing the outcomes is uncertain.

Zheng et al. was the only study that used the physioacoustic chair to deliver the vibration, and their results did not show any significant effect of the vibration treatment on isometric knee extension strength.[56] Presumably, the physioacoustic system may be an alternative for frail individuals who cannot stand on a vibrating platform. However, although it was claimed by Zheng et al. that the sound waves produced by the chair and mechanical vibration generated by the vibratory platform are similar in their physical nature, their physiological and therapeutic effects may differ.[56]

Adverse effects

One area of potential concern is the safety of WBV. Vibration of the human body is a complex issue, and has been related to vestibular problems, circulation disorders and lower back pain.[63-66] While it is known that attenuation of the vibration occurs as the signals are transmitted through the body, substantial amplification of peak acceleration could occur at certain frequencies.[58] For example, although the peak acceleration delivered by the vibration platform is only at 1*g*, the site-specific peak acceleration at the hip could exceed 2-3*g* at a vibration frequency of 10-20Hz, particularly if a greater amplitude is used (>0.5mm).[58] There may a potential safety concern if a high-amplitude protocol is used on frail individuals with low bone mass.[58]

The peak accelerations of the platform used in many of the selected studies are above 1 unit of g (i.e., supra-gravity). Despite this, the WBV therapy seems to be well tolerated and reports of adverse events are few. It is thus reasonable to conclude that short, daily exposure to WBV therapy seems to be a feasible and safe treatment option for older adults.[58]

Limitations of the studies reviewed

Several weaknesses in the studies reviewed can be identified. First, the results may only be generalizable to a select group of older people. Most subjects involved in the selected studies are ambulatory and generally free from diseases that are common among older adults (e.g., peripheral vascular disease, musculoskeletal problems, etc.).[41,46] Second, there is a lack of good-quality RCTs. Out of the 13 studies, only four can be considered as excellent- or good-quality RCTs. Finally, none of the reviewed studies measured BMD in older men. Though more common in women than men, osteoporotic fractures are increasingly being recognized as an important health issue among elderly men.[67] Whether WBV can enhance BMD in older men awaits further research.

Limitations of the systematic review

We only included RCTs in the systematic review, as RCT is the strongest experimental design to establish cause and effect. However, the studies reviewed have quite different treatment protocols, which make direct comparison of results somewhat difficult. The outcome measures used were also very different, which partly explains why meta-analysis could not be performed for certain outcomes. Finally, we only included articles that were published in English. The exclusion of articles written in other languages may have led to bias in the results of the review. For example, we cannot rule out that publications in other languages may have very different results than those reported by the articles we reviewed.

Conclusion

This meta-analysis shows that WBV has no significant overall effect on hip and lumbar spine BMD in older women, but its effect on BMD in older man remains to be investigated. WBV has a significant effect on enhancing certain aspects of leg muscle strength in older adults. There is a need for good-quality RCTs to further investigate the effects of WBV on BMD and leg muscle strength in older adults.

CLINICAL MESSAGES

- WBV has no significant overall effect on hip or lumbar spine BMD in older women
- WBV may provide a safe and viable alternative for enhancing leg muscle strength for those who cannot tolerate other forms of exercise.

COMPETING INTERESTS

The authors have no conflict of interest.

AUTHOR CONTRIBUTIONS

RWKL: data collection, data analysis, writing the paper.

FY: data collection, data analysis.

TT: data collection, data analysis.

LRL: data collection, data analysis.

RCKC: data analysis, provision of statistical consultation, writing the paper.

MYCP: Project coordinator, data analysis, writing the paper.

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FIGURE LEGENDS

Figure 1. Flow Diagram

Eighteen articles (13 randomized trials) were included in the systematic review.

Figure 2. Meta-analysis: Total hip and lumbar spine BMD

Forest plot illustrating the results of the meta-analysis. Each set of filled square (■) and error bars represent the standardized mean difference (SMD) and 95% confidence interval (CI) for each selected study. The pooled SMD is indicated by ◆. A. Total hip BMD: Comparison between the WBV group and no-intervention control group. B. Total hip BMD: Comparison between the WBV group and active exercise group. C. Lumbar spine BMD: Comparison between the WBV group and no-intervention control group. D: Lumbar spine BMD: Comparison between the WBV group and active exercise group.

Figure 3. Meta-analysis: isometric knee extension strength

The effect of WBV on isometric knee extension strength when compared with no intervention is shown in Fig. 2A-C. A. Data from Zheng et al. was based on intention-to-treat analysis. B. Data from Zheng et al. was derived from on-protocol analysis. C. Sensitivity analysis with the data from Zheng et al. excluded. D. Comparison between the WBV group and active exercise group.

Figure 4. Meta-analysis: dynamic knee extension strength and isometric leg extension strength

A. Dynamic extension strength: Comparison between the WBV group and no-intervention control group. B. Dynamic extension strength: Comparison between the WBV group and active exercise group. C. Isometric leg extension strength: Comparison between the WBV group and no-intervention control group.

Figure 5. Meta-analysis: Leg functional muscle strength (Jumping height and sit-to-stand)

A. Jumping height: Comparison between the WBV group and no-intervention control group. B. Jumping height: Comparison between the WBV group and active exercise group. C. Sit-to-stand: Comparison between the WBV group and no-intervention control group. D: Sit-to-stand: Comparison between the WBV group and active exercise group.

Table 1. Rating of the methodological quality of the selected studies using the PEDro scale

Criterion	Study												
	Russo 2003 [40]	Rubin 2004 [41]	Roelants 2004 [42] Verschueren 2004 [43]	Iwamoto 2005[44]	Bautmans 2005[45]	Gusi 2006[46] Raimundo 2009[47]	Rees 2007 [48]2008 [49]	Bogaerts 2007[50] 2009[51]	Furness 2009[52]	Machado 2010[53]	Von Stengel 2010 [54-55]	Zheng 2009[56]	Furness 2010 [57]
Eligibility Criteria	Yes	Yes	No	Yes	Yes	Yes	No	No	Yes	Yes	Yes	Yes	No
Random Allocation	1	1	1	1	1	1	1	1	1	1	1	1	1
Concealed Allocation	0	1	0	0	0	0	0	0	0	0	0	1	0
Baseline Comparability	1	1	1	1	1	1	1	1	0	0	1	1	1
Blind Subjects	0	1	0	0	1	0	0	0	0	0	1	0	1
Blind Therapists	0	1	0	0	0	0	0	0	0	0	0	0	0
Blind Assessors	0	1	1	0	1	0	0	0	0	1	1	1	0
Adequate follow-up	1	1	0	0	1	0	1	0	1	1	1	0	1
Intention-to-treat analysis	0	1	0	0	0	1	0	1	0	0	1	1	0
Between group comparisons	1	1	1	1	1	1	1	1	1	1	1	1	1
Point estimates and variability	1	1	1	1	1	1	1	1	1	1	1	1	1
TOTAL	**5**	**10**	**5**	**4**	**7**	**5**	**5**	**5**	**4**	**5**	8	**7**	6

Table 2. Characteristics of randomized controlled studies on whole body vibration therapy in older adults

Study	Subject characteristics			Protocol for WBV group							Protocol for comparison group	Follow-up period (all groups)
				WBV treatment						Additional treatment		
	Sample Size	Mean Age	Gender	Number of sessions per week	Number of vibration Bouts x duration per bout	Rest between bouts	Frequency (Hz), amplitude (mm) and peak acceleration (g) of vibration signals	Exercise on platform	Supervision			
Russo 2003[40]	Postmenopausal women (n=33) WBV, n=17 CON, n=16	61.0	F=33 M=0	2	3 bouts× 1-2 mins	60s	12-28Hz, Amplitude not specified, 0.1-10*g*	Separate the feet as far as tolerated	Not mentioned	-	No intervention	6 mo
Rubin 2004[41]	Postmenopausal women (n=70) WBV, n= 33 CON, n=37	57.3	F=70 M=0	7	2 bouts x 10 mins	10 hours	30Hz, 0.05mm, 0.2*g*	Standing on the platform	Home program, compliance monitored by electronic monitor	-	Standing on the platform without vibration, but with audible tone	12 mo
Roelants 2004[42] Verschueren 2004 [43]	Postmenopausal women (n=89) WBV, n=30 RES, n=30 CON, n=29	64.3	F=89 M=0	3	3-27 bouts × 30-60s	5-60s	35-40Hz,, 1.7-2.5mm 2.28*g*-5.09*g*	high squat, deep squat, wide-stance squat, and lunge (progress from 2 legged to 1 legged stance)	Not mentioned	-	RES: 1 hour of leg extension and leg press, 20-8RM, 2-4sets CON: No intervention	24 weeks

Iwamoto 2005[44]	Postmenopausal osteoporotic women (n=50) WBV=25 CON=25	71.3	F=50 M=0	1	4 mins	Not mentioned	20Hz, 0.7-4.2mm, 1.13*g*-2.76*g*	Stand with flexed knees	Not mentioned	5mg daily Alendronate	5mg daily Alendronate	12 mo
Bautmans 2005[45]	Nursing Home (n=24) WBV, n=13 CON, n=11	77.5	F=15 M=9	3	2-6 bouts × 30-45s	30-60s	30-54Hz, 2-5mm 9.9*g*-24.6*g*	lunge,squat, deep squat, wide stance squat, calves, calves deep	Not mentioned	-	Same exercise without vibration, but with sound of the vibration platform	6 weeks
Gusi 2006 [46] Raimundo 2009[47]	Postmenopausal women (n=36) WBV=18 CON=18	66.0	F=28 M=0	3	3-6 bouts ×1min	60s	12.6Hz, 3mm, 1.9*g*	Stand with 60º knees flexion	Expert in physical exercise	10mins warm up + 5mins bicycling + 5mins static stretching	Walking + stretching for 1 hour	8 mo
Rees 2007, 2008[48-49]	Healthy Elderly (n=45) WBV, n=15 EX, n=15 CON, n=15	73.5	F=20 M=23	3	6 bouts × 45-80s	45-80s	26Hz, 5-8mm, 13.6*g*-21.8*g*	Standing with flexed knees, dynamic lower limb exercises	Chief investigator	Low intensity walking,	EX: Exercise without vibration, Low intensity walking 3/wk CON: Low intensity walking, 3/wk	8 weeks

Bogaerts 2007, 2009 [50-51]	Community-dwelling elderly (n=220) WBV, n=94 EX, n=60 CON, n=66	67.8	F=106 M=114	3	4-15 bouts ×60s	15-60s	30-40Hz, 2.5-5.0mm, 9.1*g*-32.2*g*	squat, deep squat, wide stance squat, one legged squat, lunge, toes stand deep, moving heels	Qualified health and fitness instructor	-	EX: Cardiovascular training: 70-85% heart rate reserve. Resistance training: 50-80% of 1RM, 1-2 sets, 8-15 repetitions Balance exercises CON: No intervention	12 mo
Furness 2009 [52]	Community-dwelling older adults (n=73) Group 1: WBV (1/week), n=18 Group 2: WBV (2/week), n=18 Group 3: WBV (3/week), n=19 CON, n=18	72.0	F=38 M=35	Group 1: 1 Group 2: 2 Group 3: 3	5 bouts × 1 min	1 min	15-25Hz, 0.05mm, 0.45*g*-1.26 *g*	Standing at 110° knee extension	Not mentioned	-	CON: No intervention	6 weeks
Machado 2010 [53]	Community-dwelling older women (n=29)	77.8	F=29 M=0	3-5/week ×	3-8 bouts × 30-60 s	2-3 min	20-40 Hz, 2-4mm, 3.2*g*-19.7*g*	Squat, deep squat, wide stance squat, calves	Not mentioned	10-min warm up and cool down	CON: No intervention	10 weeks
Von Stengel 2010 [54-55]	Post-menopausal women (n=151) EX, n=50 WBV, n=50 CON, n=51	68.5	F=151 M=0	2	6 bouts × 1 min	1 min	25-35 Hz, 1.7mm, 4.3*g*-8.4*g*	Heel rises, one-legged deep squat, leg abduction	Certified instructors	20 min of aerobic training, 5 min of coordination and balance training 20 minutes of functional gymnastics	EX: same as WBV group but the vibration device was switched off. CON: light physical exercises and relaxation program once a week.	18 months

Zheng 2009 [56]	Elderly (n=39) WBV, n=30 CON, n=19	62-93	F=35 M=14	3-5	1 bout x 30mins	-	27-113Hz, amplitude and peak acceleration not specified	Sitting	Nurse	-	CON: No intervention	6 months
Furness 2010 [57]	Elderly (n=37) WBV, n=19 CON, n-18	69	F=21 M=16	3	5 bouts x 1 min	1 min	15-25Hz, , 0.45-1.26g	Standing with 70° knee flexion	Not mentioned	-	CON: No intervention	6 weeks

CON= control group; EX=exercise group; F=female; *g*=gravitational force (9.8ms^{-2}); M=male; min=minutes; mo=months; RES: resistance exercise group; s=seconds; WBV=whole body vibration

Table 3. Summary of effects of whole body vibration therapy on bone mineral density and leg muscle strength.

Study	Bone mineral density (BMD)	Leg muscle strength	Adverse Effects
Russo 2003 [40]	Cortical volumetric BMD: 0.13 (-0.56, 0.81)[a] Trabecular volumetric BMD: -0.06 (-0.74, 0.62)	Jump test (Muscle Parameters): • Force: -0.12 (-0.80, 0.57) • Velocity: 0.45 (-0.24, 1.15) • Power: 0.25 (-0.43, 0.94)	• • Knee pain that is related to osteoarthritis (n=1)
Rubin 2004 [41]	<u>All subjects (intent-to-treat analysis):</u>[b] Femoral neck BMD, : -0.03 (-0.49, 0.44) Femoral trochanter BMD: 0.01 (-0.46, 0.48) Spine BMD: 0.01 (-0.46-0.48) <u>Highest compliance group (86%):</u>[c] Femoral neck BMD: 2.17% Femoral trochanter BMD: 1.23% Spine BMD: 1.50% <u>Highest compliance group (86%) and lower-weight cohort (<65kg):</u>[c] Femoral neck BMD: 2.10% Femoral trochanter BMD: 1.92% Spine BMD*: 3.35%	NA	None
Roelants 2004 [42] Verschueren 2004 [43]	<u>Based on 70 subjects:</u> Total hip BMD: WBV vs CON: 0.11 (-0.45, 0.67) WBV vs EX*: 0.11 (-0.47, 0.68) Lumber Spine BMD: WBV vs CON: -0.05(-0.61, 0.51) WBV vs EX: -0.03 (-0.60, 0.54) Total body BMD: WBV vs CON: 0.08 (-0.48, 0.64) WBV vs EX: 0.04 (-0.53, 0.62)	<u>Based on 70 subjects:</u> Isometric knee extensor strength: WBV vs CON*: 1.01 (0.41, 1.60) WBV vs EX: 0.06 (-0.51, 0.64) Dynamic knee extensor strength at 100º /s: WBV vs CON*: 0.77 (0.19, 1.35) WBV vs EX: 0.32 (-0.26, 0.89) <u>Based on 89 subjects:</u> Isometric knee extensor strength : WBV vs CON*: 0.84 (0.25, 1.42) WBV vs EX: -0.06 (-0.66, 0.53) Dynamic knee extensor strength at 100º /s: WBV vs CON*: 0.68(0.11, 1.26) WBV vs EX: 0.11 (-0.48, 0.71) Knee extension speed of movement:	• Some reported erythema, edema, and itching of the legs after the first session of vibration training, but rapidly resolved after the training session • Knee pain that is related to mild degenerative changes due to previous knee injuries (n=2)

		• *With external resistance of 1% isometric maximum:* WBV vs CON*: 0.75 (0.17, 1.33) WBV vs EX: 0.29 (-0.31, 0.88) • *With external resistance of 20% isometric maximum* WBV vs CON*: 0.61 (0.04, 1.18) WBV vs EX: 0.24 (-0.35, 0.84) • *With external resistance of 40% isometric maximum* WBV vs CON: 0.23 (-0.33, 0.79) WBV vs EX: 0.04 (-0.55, 0.64) • *With external resistance of 60% isometric maximum* WBV vs CON*: 0.17 (0.39, 0.73) WBV vs EX: -0.58 (-1.19, 0.02) Counter movement jumping height: WBV vs CON*: 0.68 (0.11, 1.26) WBV vs EX: 0.16 (-0.43, 0.75)	
Iwamoto 2005 [44]	Lumbar spine BMD: 0.08 (-0.47, 0.63)	NA	• Not mentioned
Bautmans 2005 [45]	NA	Number of sit-to-stand in 30 seconds: 0.45 (-0.41, 1.32) Close chain bilateral leg extension 40cm/s: • Work: 0.09 (-0.77, 0.95) • Maximal force: 0.18 (-0.68, 1.04) • Maximal power: 0.17 (-0.69, 1.03) • Maximal explosivity: 0.44 (-0.43, 1.30) Close chain bilateral leg extension and 60cm/s: • Work: 0.09 (-0.77, 0.95) • Maximal force: 0.33 (-0.54, 1.19) • Maximal power: 0.32 (-0.54, 1.18) • Maximal explosivity: 0.19 (-0.67, 1.05)	• Groin pain after the first exercise session (n=1) • Became afraid (n=1)
Gusi 2006 [46] Raimundo 2009[47]	Femoral neck BMD*: 0.33 (-0.41, 1.08) Trochanter BMD: 0.21 (-0.53, 0.96) Lumbar spine BMD: 0.00 (-0.74, 0.74)	Timed Chair rise : -1.33 (-2.16, -0.50) Vertical jump height : 0.18 (-0.58, 0.94) Peak torque: Concentric knee extensors at 60º/s, right: -0.55 (-1.32, 0.22) Concentric knee extensors at 60º/s, left: -0.28 (-1.04, 0.48) Concentric knee extensors at 300º/s, right: -0.38 (-1.14, 0.38) Concentric knee extensors at 300º/s, left: 0.00 (-0.75, 0.75) Eccentric knee extensors at 60º/s, right: -0.12 (-0.87, 0.64)	• Not mentioned

		Eccentric knee extensors at 60º/s, left: -0.03 (-0.79, 0.72) Average power : Concentric knee extensors at 300º/s, right: -0.56 (-1.33, 0.21) Concentric knee extensors at 300º/s, left: -0.10 (-0.86, 0.65)	
Rees 2007, 2008[48-49]	NA	Sit to stand time: WBV vs CON*: 1.11 (0.34, 1.88) WBV vs EX: 0.24 (-0.48, 0.96) Torque in %BW: • Hip flexion 60º /s: WBV vs CON: 0.14 (-0.57, 0.86) WBV vs EX: -0.00 (-0.75, 0.74) • Hip extension 60º /s: WBV vs CON: 0.14 (-0.57, 0.86) WBV vs EX: -0.00 (-0.75, 0.74) • Knee flexion 60º /s: 0 WBV vs CON: 0.29 (-0.43, 1.01) WBV vs EX: 0.13 (-0.61, 0.87) • Knee extension 60º /s: WBV vs CON*: 0.42 (-0.30, 1.14) WBV vs EX: 0.03 (-0.71, 0.77) • Ankle dorsiflexion 30º /s: 0 WBV vs CON: 0.15 (-0.57, 0.87) WBV vs EX: 0.03 (-0.71, 0.77) • Ankle plantarflexion 30º /s: WBV vs CON*: 0.85 (0.10, 1.60) WBV vs EX*: 0.48 (-0.27, 1.23) Torque in Nm/kg: • Hip flexion 60º /s: WBV vs EX: 0.00 (-0.75, 0.74) • Hip extension 60º /s: WBV vs EX: 0.01 (-0.73, 0.75) • Knee flexion 60º /s: WBV vs EX: 0.11 (-0.63, 0.86) • Knee extension 60º /s: WBV vs EX: 0.05 (-0.70, 0.79) • Ankle dorsiflexion 30º /s: WBV vs EX: 0.08 (-0.66, 0.82) • Ankle plantarflexion 30º /s: WBV vs EX*: 0.54 (-0.22, 1.29) Power: • Hip flexion 60º /s : WBV vs EX: 0.08 (-0.67, 0.82) • Hip extension 60º /s: WBV vs EX: 0.00 (-0.74, 0.75)	• Not mentioned

		• Knee flexion 60º /s: WBV vs EX: 0.18 (-0.57, 0.92) • Knee extension 60º /s: WBV vs EX: 0.12 (-0.63, 0.86) • Ankle dorsiflexion 30º /s: WBV vs EX: 0.00 (-0.74, 0.74) • Ankle plantarflexion 30º /s: WBV vs EX: 0.58 (-0.17, 1.34)	
Bogaerts 2007 2009 [50-51]	NA	Men Isometric knee extensor strength (Nm): WBV vs CON: 0.44 (-0.12, 1.00) WBV vs EX: -0.16 (-0.68, 0.37) Explosive strength (Jump height, cm): WBV vs CON: 0.34 (-0.22, 0.90) WBV vs EX: -0.02 (-0.50, 0.54) Women[c] Isometric knee extension strength (Nm) : WBV vs CON*: 10.1% WBV vs EX: 1.7% All subjects (men and women) Isometric knee extensor strength (Nm): WBV vs CON: 0.28 (-0.04, 0.60) WBV vs EX: -0.11 (-0.44, 0.22)	• Knee pain (n=7) • Drop out due to health problems (details not mentioned) (n=9).
Furness 2009[52]	NA	5-Chair stands test: WBV (1/week) vs CON: -0.52 (-1.8, 0.15) WBV (2/week) vs CON: 0.15 (-0.51, 0.80) WBV (3/week) vs CON: 0.33 (-0.32, 0.98)	• Not mentioned
Machado 2010 [53]	NA	Leg extension (leg press test) Maximal voluntary isometric contraction (W)*: 1.00 (0.19, 1.82) Maximal power test At 20% maximal voluntary contraction (W): 0.26 (-0.51, 1.03) At 40% maximal voluntary contraction (W): 0.41 (-0.37, 1.18) At 60% maximal voluntary contraction (W): 0.56 (-0.22, 1.34)	• No adverse effects

Von Stengel 2010 [54-55]	Lumbar spine BMD (mg/cm^2): WBV vs CON: 0.06 (-0.34, 0.47) WBV vs EX: -0.03 (-0.44, 0.38) Total hip BMD(mg/cm^2): WBV vs CON: 0.02 (-0.39, 0.42) WBV vs EX: 0.00 (-0.41, 0.41)	Leg extension (leg press test): WBV vs CON*: 0.46 (0.05, 0.87) WBV vs EX: 0.21 (-0.20, 0.61) Trunk flexion : WBV vs CON*: 0.46 (0.05, 0.87) WBV vs EX: 0.26 (-0.15, 0.67) Trunk extension: WBV vs CON: 0.34 (-0.07, 0.75) WBV vs EX*: 0.00 (-0.40, 0.41) Counter Movement Jump: WBV vs CON: 0.30 (-0.10, 0.71) WBV vs EX: 0.24 (-0.17, 0.65)	• No adverse effects
Zheng 2009 [56]	<u>On protocol</u> Tibia BMD: -0.16 (-0.84, 0.51) <u>Intention-to-treat:</u> Tibia BMD: -0.03 (-0.62, 0.56)	<u>On protocol</u> Grip strength: -0.01 (-0.89, 0.87) Knee extension strength (N/Kg): -0.08 (-0.96, 0.80) <u>Intention-to-treat:</u> Grip strength: 0.05 (-0.78, 0.88) Knee extension strength: -0.17 (-1.00, 0.67)	• Excessive tiredness (n=1)
Furness 2010 [57]		STS *: 0.84 (0.17, 1.51)	• Not mentioned

BMD=bone mineral density; CON=control group; EX=exercise group; NA: outcome not measured; WBV=whole body vibration
* significant treatment effect in favour of WBV.
[a]The values shown represent the standardized effect size (95% confidence interval). Amore positive SES indicates a greater treatment effect in favor of WBV.
[b]The SDs for the WBV and control groups could not be obtained from Rubin et al.[41] To calculate the effect size, the SDs were estimated by using the SD values in Gusi et al. [46], as the site of skeletal measurements were the same for both studies, and the subject characteristics were also similar.
[c]The SDs were not reported and could not be estimated for the subgroup analyses, The value shown here is the difference in percent change score between the two groups.
[d]Bogaerts et al. [50]did not provide the baseline values for women. The value shown here is the difference in percent change score between the two groups.

Figure 1. Flow Diagram

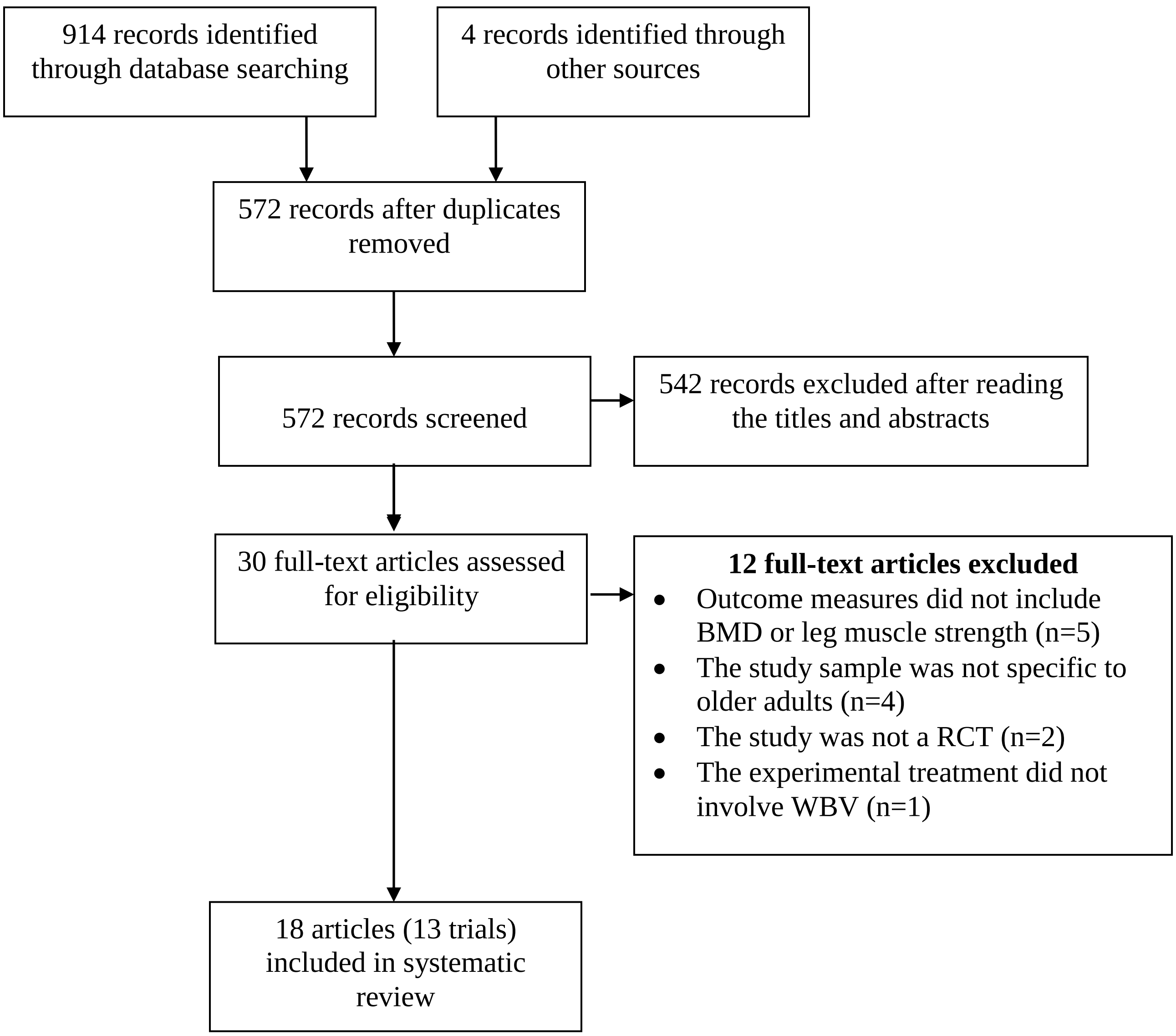
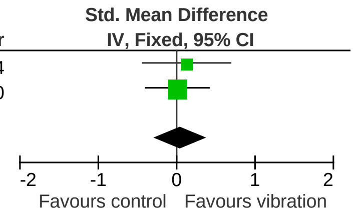


Figure 2. Meta-analysis: Total hip and lumbar spine BMD

A

Study or Subgroup	Vibration Mean	SD	Total	Control Mean	SD	Total	Weight	Std. Mean Difference IV, Fixed, 95% CI	Year
Verschueren [43]	0.01	0.136	25	-0.006	0.109	24	34.2%	0.13 [-0.43, 0.69]	2004
von Stengel [54]	0	0.127	46	-0.001	0.131	48	65.8%	0.01 [-0.40, 0.41]	2010
Total (95% CI)			**71**			**72**	**100.0%**	**0.05 [-0.28, 0.38]**	

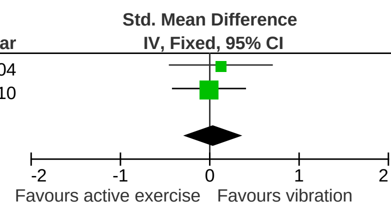
Heterogeneity: Chi² = 0.12, df = 1 (P = 0.73); I² = 0%
Test for overall effect: Z = 0.29 (P = 0.77)



B

Study or Subgroup	Vibration Mean	SD	Total	Active exercise Mean	SD	Total	Weight	Std. Mean Difference IV, Fixed, 95% CI	Year
Verschueren [43]	0.01	0.136	25	-0.005	0.094	22	33.4%	0.12 [-0.45, 0.70]	2004
von Stengel [54]	0	0.127	46	0.001	0.115	47	66.6%	-0.01 [-0.41, 0.40]	2010
Total (95% CI)			**71**			**69**	**100.0%**	**0.04 [-0.30, 0.37]**	

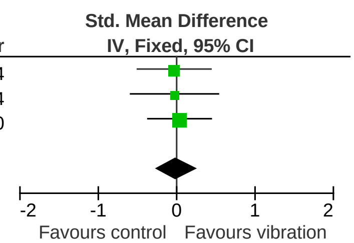
Heterogeneity: Chi² = 0.14, df = 1 (P = 0.71); I² = 0%
Test for overall effect: Z = 0.21 (P = 0.83)



C

Study or Subgroup	Vibration Mean	SD	Total	Control Mean	SD	Total	Weight	Std. Mean Difference IV, Fixed, 95% CI	Year
Rubin [41]	-0.01	0.12	33	-0.006	0.13	37	32.8%	-0.03 [-0.50, 0.44]	2004
Verschueren [43]	0	0.143	25	0.004	0.146	24	23.0%	-0.03 [-0.59, 0.53]	2004
von Stengel [54]	0.01	0.153	46	0.004	0.166	48	44.2%	0.04 [-0.37, 0.44]	2010
Total (95% CI)			**104**			**109**	**100.0%**	**-0.00 [-0.27, 0.27]**	

Heterogeneity: Chi² = 0.06, df = 2 (P = 0.97); I² = 0%
Test for overall effect: Z = 0.00 (P = 1.00)



D

Study or Subgroup	Vibration Mean	SD	Total	Active exercise Mean	SD	Total	Weight	Std. Mean Difference IV, Fixed, 95% CI	Year
Verschueren [43]	0	0.143	25	0.001	0.136	22	27.9%	-0.01 [-0.58, 0.57]	2004
Gusi [46]	-0.01	0.12	14	-0.01	0.13	14	16.7%	0.00 [-0.74, 0.74]	2006
von Stengel [54]	0.01	0.153	46	0.019	0.168	47	55.4%	-0.06 [-0.46, 0.35]	2010
Total (95% CI)			**85**			**83**	**100.0%**	**-0.03 [-0.34, 0.27]**	

Heterogeneity: Chi² = 0.03, df = 2 (P = 0.99); I² = 0%
Test for overall effect: Z = 0.21 (P = 0.83)

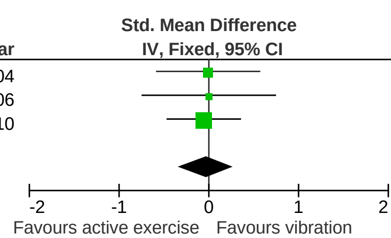
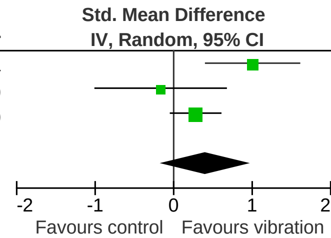


Figure 3. Meta-analysis: isometric knee extension strength

A

Study or Subgroup	Vibration Mean	Vibration SD	Vibration Total	Control Mean	Control SD	Control Total	Weight	Std. Mean Difference IV, Random, 95% CI	Year
Verschueren [43]	18.3	22	25	-3.7	21	24	32.4%	1.01 [0.41, 1.60]	2004
Zheng (ITT) [56]	0.4	1.2	18	0.6	1.1	8	24.2%	-0.17 [-1.00, 0.67]	2009
Bogaerts [51]	12.7	42.29	92	0.5	44.74	65	43.4%	0.28 [-0.04, 0.60]	2009
Total (95% CI)			**135**			**97**	**100.0%**	**0.41 [-0.16, 0.98]**	

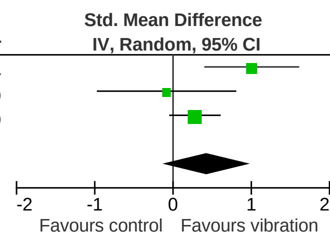
Heterogeneity: Tau² = 0.17; Chi² = 6.24, df = 2 (P = 0.04); I² = 68%
Test for overall effect: Z = 1.40 (P = 0.16)



B

Study or Subgroup	Vibration Mean	Vibration SD	Vibration Total	Control Mean	Control SD	Control Total	Weight	Std. Mean Difference IV, Random, 95% CI	Year
Verschueren [43]	18.3	22	25	-3.7	21	24	32.6%	1.01 [0.41, 1.60]	2004
Zheng (on-protocol) [56]	0.5	1.2	13	0.6	1.1	8	22.5%	-0.08 [-0.96, 0.80]	2009
Bogaerts [51]	12.7	42.29	92	0.5	44.74	65	44.8%	0.28 [-0.04, 0.60]	2009
Total (95% CI)			**130**			**97**	**100.0%**	**0.44 [-0.12, 0.99]**	

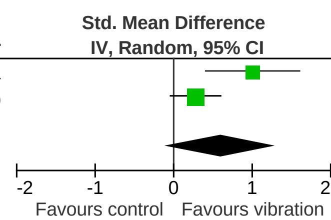
Heterogeneity: Tau² = 0.15; Chi² = 5.64, df = 2 (P = 0.06); I² = 65%
Test for overall effect: Z = 1.54 (P = 0.12)



C

Study or Subgroup	Vibration Mean	Vibration SD	Vibration Total	Control Mean	Control SD	Control Total	Weight	Std. Mean Difference IV, Random, 95% CI	Year
Verschueren [43]	18.3	22	25	-3.7	21	24	43.7%	1.01 [0.41, 1.60]	2004
Bogaerts [51]	12.7	42.29	92	0.5	45.06	65	56.3%	0.28 [-0.04, 0.60]	2009
Total (95% CI)			**117**			**89**	**100.0%**	**0.60 [-0.11, 1.30]**	

Heterogeneity: Tau² = 0.20; Chi² = 4.42, df = 1 (P = 0.04); I² = 77%
Test for overall effect: Z = 1.66 (P = 0.10)



D

Study or Subgroup	Vibration Mean	Vibration SD	Vibration Total	Active exercise Mean	Active exercise SD	Active exercise Total	Weight	Mean Difference IV, Fixed, 95% CI	Year
Verschueren [43]	18.3	22	25	16.8	24.2	22	53.6%	1.50 [-11.79, 14.79]	2004
Bogaerts [51]	12.7	42.29	92	17.3	43.79	57	46.4%	-4.60 [-18.88, 9.68]	2009
Total (95% CI)			**117**			**79**	**100.0%**	**-1.33 [-11.06, 8.40]**	

Heterogeneity: Chi² = 0.38, df = 1 (P = 0.54); I² = 0%
Test for overall effect: Z = 0.27 (P = 0.79)

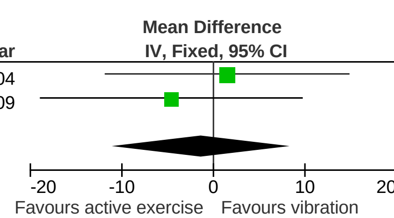
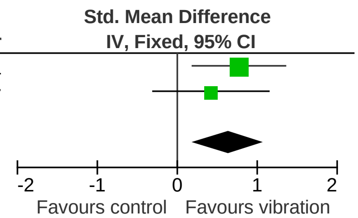


Figure 4. Meta-analysis: dynamic knee extension strength and isometric leg extension strength

A

Study or Subgroup	Vibration Mean	Vibration SD	Vibration Total	Control Mean	Control SD	Control Total	Weight	Std. Mean Difference IV, Fixed, 95% CI	Year
Verschueren [43]	13.7	15.2	25	1.7	15.4	24	60.8%	0.77 [0.19, 1.35]	2004
Rees [48, 49]	13.3	35.4	15	-2.4	37.1	15	39.2%	0.42 [-0.30, 1.15]	2007
Total (95% CI)			**40**			**39**	**100.0%**	**0.63 [0.18, 1.09]**	

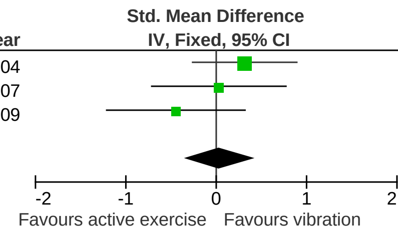
Heterogeneity: Chi² = 0.55, df = 1 (P = 0.46); I² = 0%
Test for overall effect: Z = 2.74 (P = 0.006)



B

Study or Subgroup	Vibration Mean	Vibration SD	Vibration Total	Active exercise Mean	Active exercise SD	Active exercise Total	Weight	Std. Mean Difference IV, Fixed, 95% CI	Year
Verschueren [43]	13.7	15.2	25	8.7	16	22	46.1%	0.32 [-0.26, 0.89]	2004
Rees [48, 49]	13.3	35.4	15	12.1	44.4	13	27.8%	0.03 [-0.71, 0.77]	2007
Raimundo [47]	-0.11	0.27	14	0.01	0.25	13	26.1%	-0.45 [-1.21, 0.32]	2009
Total (95% CI)			**54**			**48**	**100.0%**	**0.04 [-0.35, 0.43]**	

Heterogeneity: Chi² = 2.43, df = 2 (P = 0.30); I² = 18%
Test for overall effect: Z = 0.18 (P = 0.85)



C

Study or Subgroup	Vibration Mean	Vibration SD	Vibration Total	Control Mean	Control SD	Control Total	Weight	Std. Mean Difference IV, Fixed, 95% CI	Year
Machado [57]	38.1	41.01	13	0.84	30.26	13	19.9%	1.00 [0.18, 1.82]	2009
von Stengel [55]	119	170.9	46	35.5	190.1	48	80.1%	0.46 [0.05, 0.87]	2010
Total (95% CI)			**59**			**61**	**100.0%**	**0.57 [0.20, 0.93]**	

Heterogeneity: Chi² = 1.34, df = 1 (P = 0.25); I² = 25%
Test for overall effect: Z = 3.02 (P = 0.003)

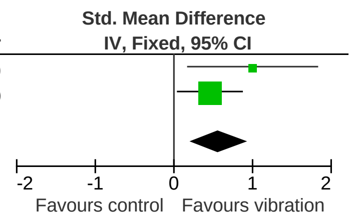
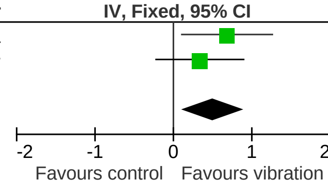


Figure 5. Meta-analysis: Leg functional muscle strength (Jumping height and sit-to-stand)

A

	Vibration			Control				Std. Mean Difference		Std. Mean Difference
Study or Subgroup	Mean	SD	Total	Mean	SD	Total	Weight	IV, Fixed, 95% CI	Year	IV, Fixed, 95% CI
Roelants [42]	21.7	36.94	24	-1.88	30.65	25	48.3%	0.68 [0.11, 1.26]	2004	
Bogaerts [50]	1.8	3.5	25	0.3	5.09	25	51.7%	0.34 [-0.22, 0.90]	2007	
Total (95% CI)			**49**			**50**	**100.0%**	**0.51 [0.10, 0.91]**		

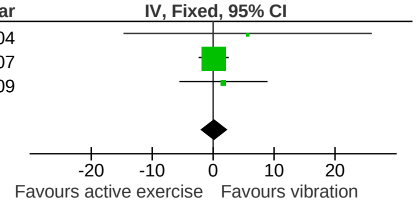
Heterogeneity: Chi² = 0.72, df = 1 (P = 0.40); I² = 0%
Test for overall effect: Z = 2.47 (P = 0.01)



B

	Vibration			Active exercise				Mean Difference		Mean Difference
Study or Subgroup	Mean	SD	Total	Mean	SD	Total	Weight	IV, Fixed, 95% CI	Year	IV, Fixed, 95% CI
Roelants [42]	21.7	36.94	24	16.03	31.62	20	1.2%	5.67 [-14.59, 25.93]	2004	
Bogaerts [50]	1.8	3.5	25	1.7	5.5	32	89.1%	0.10 [-2.25, 2.45]	2007	
Raimundo [47]	1.57	3.3	14	-0.13	12.7	13	9.7%	1.70 [-5.42, 8.82]	2009	
Total (95% CI)			**63**			**65**	**100.0%**	**0.32 [-1.89, 2.54]**		

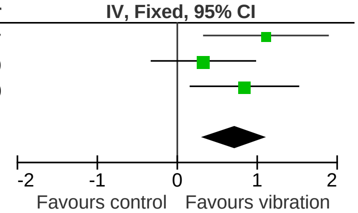
Heterogeneity: Chi² = 0.45, df = 2 (P = 0.80); I² = 0%
Test for overall effect: Z = 0.28 (P = 0.78)



C

	Vibration			Control				Std. Mean Difference		Std. Mean Difference
Study or Subgroup	Mean	SD	Total	Mean	SD	Total	Weight	IV, Fixed, 95% CI	Year	IV, Fixed, 95% CI
Rees [48]	1.22	0.8	15	0.09	1.15	15	26.7%	1.11 [0.33, 1.89]	2007	
Furness [52]	2.51	2.47	19	1.51	3.45	18	38.1%	0.33 [-0.32, 0.98]	2009	
Furness [57]	3	2.5	19	0.4	3.5	18	35.2%	0.84 [0.16, 1.52]	2010	
Total (95% CI)			**53**			**51**	**100.0%**	**0.72 [0.32, 1.12]**		

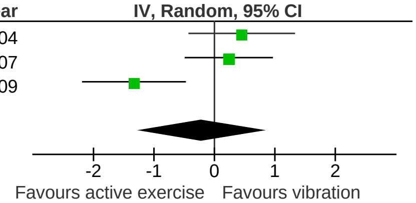
Heterogeneity: Chi² = 2.49, df = 2 (P = 0.29); I² = 20%
Test for overall effect: Z = 3.50 (P = 0.0005)



D

	Vibration			Active exercise				Std. Mean Difference		Std. Mean Difference
Study or Subgroup	Mean	SD	Total	Mean	SD	Total	Weight	IV, Random, 95% CI	Year	IV, Random, 95% CI
Bautmans [45]	1.8	4.1	10	0.1	3.1	11	32.4%	0.45 [-0.42, 1.32]	2004	
Rees [48, 49]	1.22	0.8	15	1.02	0.83	15	34.8%	0.24 [-0.48, 0.96]	2007	
Raimundo [47]	0.27	0.7	14	1.23	0.7	13	32.8%	-1.33 [-2.18, -0.48]	2009	
Total (95% CI)			**39**			**39**	**100.0%**	**-0.21 [-1.27, 0.86]**		

Heterogeneity: Tau² = 0.72; Chi² = 10.42, df = 2 (P = 0.005); I² = 81%
Test for overall effect: Z = 0.38 (P = 0.70)



Appendix 1. Search Strategy (MEDLINE)

1. exp Vibration/ or vibration.mp.
2. exp Vibration/ or whole body vibration.mp.
3. vibratory exercise.mp.
4. 1 or 2 or 3
5. aged.mp. or exp “Aged, 80 and over”/ or exp Aged/
6. Aging.mp. or exp Aging/
7. elder*.mp. or exp Frail Elderly/
8. older adult*.mp.
9. old* men.mp.
10. old* women.mp.
11. postmenopausal.mp. or exp Postmenopause/
12. 5 or 6 or 7 or 8 or 9 or 10 or 11
13. strength*.mp. or exp Muscle Strength/
14. exp Postural Balance/ or balance.mp.
15. postural.mp.
16. posture.mp. or exp Posture/
17. bone*.mp. or exp “Bone and Bones”/
18. randomized controlled trial*.mp. or exp Randomized Controlled Trial/
19. clinical trial*.mp. or exp Clinical Trial/
20. random allocation.mp. or exp Random Allocation/
21. cross-over study.mp. or exp Cross-Over Studies/
22. control group.mp. or exp Control Groups/
23. experimental*.mp.
24. follow-up study.mp. or exp Follow-Up Studies/
25. 18 or 19 or 20 or 21 or 22 or 23 or 24
26. 13 or 14 or 15 or 16 or 17
27. 4 and 12 and 25 and 26
28. limit 27 to (English language and humans)