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Title:

The effect of whole body vibration on balance, mobility and falls in older adults: a systematic review and meta-analysis

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ABSTRACT

This systematic review aimed to examine the effect of WBV on balance, mobility and falls among older adults. The databases used included MEDLINE, the Excerpta Medica database, the Cumulative Index to Nursing and Allied Health Literature, the Cochrane Library Databases of Systematic Reviews, Physiotherapy Evidence Database (PEDro), PubMed, and Science Citation Index (last search in October 2011). Randomized controlled trials that investigated the effect of WBV on balance, mobility or falls in older adults were included in this review. The PEDro score was used to examine the methodological quality of the selected studies. The effect of WBV on balance, mobility and fall-related outcomes were extracted. The data extraction and rating were performed by a researcher and the results were confirmed by the principal investigator. Meta-analysis was done if 3 or more studies measured the same outcome of interest. Among 920 articles screened, fifteen articles (thirteen trials) satisfied the criteria and were included in this review. Methodological quality was good for six of the studies (PEDro score=6-7). Meta-analysis revealed that WBV has a significant treatment effect in Tinetti Total Score ($p<0.001$), Tinetti Body Balance Score ($p=0.010$) and Timed-Up-and-Go test ($p=0.004$). No significant improvement was noted in Tinetti Gait Score after WBV training ($p=0.120$). The effect of WBV on other balance/mobility outcomes and fall rate remains inconclusive. To conclude, WBV may be effective in improving relatively basic balance ability and mobility among older adults, particularly frailer ones. More good-quality WBV trials are required.

Key words: aging; balance; gait; rehabilitation; exercise

1. INTRODUCTION

Reduced balance and mobility function is common in advancing age. [1,2] Poor balance and mobility compromise independence in activities of daily living and may lead to an increase in fall risk. [3] Falls may cause fragility fractures and hence give rise to reduced quality of life, increased disability and increased economic strain on the health care system. [4-8] The deleterious consequences arising from falls have driven researchers to seek effective interventions to modify fall-related risk factors in older adults.

Recently, whole body vibration (WBV) is gaining popularity in rehabilitation of various populations. A good number of studies have examined the effects of WBV on muscle strength [9-15], and a recent meta-analysis paper [16] has demonstrated that WBV training can significantly improve various aspects of leg muscle strength among older adults. As leg muscle strength is highly correlated with balance and mobility [17-20], it is postulated that WBV may also have potential benefits on balance and mobility function. Additionally, there is some preliminary evidence that WBV can improve proprioceptive function [21] and modulate the gain of the spinal reflex pathways. [22-24] Thus, WBV training may be a viable treatment approach to reduce the fall risk among older adults through improving muscle strength, balance ability and mobility. Although Howe et al [25] included WBV as a form of exercise in their review of the effect of exercise on balance, only three WBV studies were incorporated in their review. To date, no comprehensive review has been performed to

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CI = confidence interval; CINAHL = Cumulative Index to Nursing and Allied Health Literature; EMBASE = Excerpta Medica database; PEDro = Physiotherapy Evidence Database; RCT = randomized controlled trial; SMD = standardized mean difference; TUG =Timed Up and Go; WBV = whole body vibration specifically examine the effect of WBV on balance, mobility, and falls among older adults in a systematic manner. This systematic review aimed to determine whether WBV is better than conventional therapy or no intervention in improving balance ability, mobility performance and reducing fall risk in older adults.

2. METHODS

2.1. Data Sources and Searches

An extensive literature search of electronic databases, including MEDLINE, the Excerpta Medica database (EMBASE) and the Cumulative Index to Nursing and Allied Health Literature (CINAHL) was done to identify relevant articles. The keywords used included: vibration, whole body vibration, vibratory exercise, age, aging, elder, older adult, old men, old women, postmenopause, postmenopausal, strength, muscle strength, balance, postural, body posture, clinical trial, controlled clinical trial, random allocation, experimental design and control group. The Cochrane Library Databases of Systematic Reviews, Physiotherapy Evidence Database (PEDro) [26] and PubMed were also searched using the keyword "vibration". The reference list of each selected article was examined to identify other potentially relevant papers. Moreover, a forward search was performed using the Science Citation Index. The last searched was performed on 6th October 2011.

2.2. Study Selection

The titles and abstracts obtained were screened to eliminate irrelevant articles. The full texts of the remaining articles were then read in detail to identify their eligibility. The inclusion criteria were: (1) randomized controlled trials (RCT) investigating the effects of WBV on older adults (50 years old or above); (2) included balance, mobility or fall as one of the outcome measures; and (3) published in English. Articles were excluded if they were: (1) research studies on people with a primary diagnosis (e.g., multiple sclerosis); (2) reports published as conference proceedings; (3) reports in books.

2.3. Methodological Quality Assessment

The PEDro score was used to assess the methodological quality of each selected study (Table 1). A higher PEDro score indicates better methodological quality. If the rating of a particular study was not available in the PEDro website, it was rated by a research team member using the criteria stipulated by the PEDro, and the rating was confirmed by the principal investigator.

2.4. Data Synthesis and Analysis

The effects of WBV on the outcomes of interest were analyzed. Meta-analysis was performed if three or more studies measured the same outcome. For each outcome of interest in each selected study, the standardized mean difference (SMD) and 95% confidence interval (CI) was computed. Meta-analysis results are presented using forest plots (Review Manager 5.0, The Nordic Cochrane Centre, The Cochrane Collaboration, Copenhagen, Denmark). The I^2 index was used to test the heterogeneity of the included studies. Fixed–effect models were used to combine the studies if I^2 test was not significant ($p>0.05$). Otherwise, the random-effect models would be used. To assess the existence of publication bias, Egger's regression asymmetry test was performed with Comprehensive Meta-analysis software version 2 (Biostat, Englewood, New Jersey, USA). A p-value of < 0.1 (two-tailed test) indicated the presence of publication bias.

3. RESULTS

Our search yielded a total of 920 articles but only 15 met all eligibility criteria (Figure 1). Amongst these, the reports by Gusi et al [27] and Raimundo et al [28] were based on the same trial. Rees et al. produced 2 articles from their trial. [29,30] To summarize, 15 articles [9,10,27-39] (13 trials) were selected for this systematic review.

(Figure 1 near here)

3.1. Methodological Quality

Six of the studies [9,32-34,36,39] were considered to be good quality trials (PEDro score=6-7) and seven others [10,27-31,35,37,38] were considered as fair (PEDro score=4-5). (Table 1)

(Table 1 near here)

3.2. Characteristics of Study Populations

The participant characteristics are outlined in Supplementary Table 1. The sample size ranged from 24 to 220 with the mean age varying from 64.3 to 81.9 years. Most of the studies used community-dwelling individuals as their participants, while Bautmans et al [9] and Bruyere et al [33] studied older adults living in nursing home. Six of the studies included only women in their samples. [10,27,28,32,34,38,39]

3.3. Training Protocol

The training protocols are summarized in Supplementary Table 1. Eight studies [9,29-33,37-39] used vertical vibration while four [27,28,34-36] used side-alternating vibration. One study [10] did not specify the type of vibration used. The frequency of treatment sessions varied between 1 and 5 sessions per week. The duration of treatment ranged from 6 weeks to

18 months. The frequency and amplitude of the vibration signals used varied from 10 to 54 Hz, and 0.05mm to 5mm, respectively. The number of vibration bouts delivered per sessions varied from 1 to 27 for a period that last for 15s to 3 minutes for each.

3.4. Balance

The effects of WBV on balance, mobility and falls are summarized in Supplementary Table 2. Ten papers [9,27,30-35,37,38] included balance performance as an outcome measure.

3.4.1. Static Standing Balance

Six studies [27,30,31,32,37,38] assessed the effects of WBV on static balance and the results were conflicting. Three studies used the force-plate system to measure the postural sway in standing with eyes open and showed that WBV had no significant treatment effect. [32,37,38] The results were similar in the eyes-closed condition. [32,38]

Sensory Organization Test (SOT) was used in two studies conducted by Bogaerts et al. [31,32] Both studies reported that WBV had no significant treatment effect in improving SOT equilibrium scores when compared with the no-intervention control group or the conventional exercise group.

Single leg standing balance was measured in two studies. [27,30] The WBV group was found to perform significantly better in single leg standing balance when compared with no intervention [30] or the conventional exercise group. [27,30]

3.4.2. Anticipatory Balance

Five studies measured anticipatory balance ability. [9,33-35,38] Three used the Tinetti total score as an outcome measure. [9,33,35] The meta-analysis revealed that WBV had a significant treatment effect in improving Tinetti total score compared with controls (SMD=0.75, 95%CI=0.34-1.16; Z=3.59, $p<0.01$) (Figure 2A).

Separated analyses were done for the sub-scores in the Tinetti assessment. Meta-analysis of the Tinetti body balance score of the same three studies [9,33,35] showed significant result in favour of WBV (SMD=0.53, 95%CI=0.12-0.94; Z=2.56, p=0.01) (Figure 2B), yet no significant difference was found in Tinetti gait scores (SMD=0.31, 95%CI =-0.08-0.71; Z=1.54, p=0.12) (Figure 2C).

(Figure 2 near here)

Verschueren et al [38] assessed the postural sway after arm movements in different directions. After fast, brief arm abduction, the reduction in peak-to-peak amplitude of anterior-posterior sway, but not medio-lateral sway, was significantly more pronounced in the WBV group than the no-intervention control group. In contrast, after arm anteflexion, medial-lateral sway, but not anterior-posterior sway, was significantly improved in the WBV group.

Cheung et al [34] assessed the limit of stability and functional reach. [34,40] Their results showed that WBV group had better outcome in the former but not the latter.

3.4.3. Reactive Balance

Only Bogaerts et al [31] evaluated reactive balance, using the Motor Control Test and Adaptation Test. No significant treatment effect was found in the WBV group when compared with both the conventional exercise and control groups.

3.5. Functional Mobility

Eight papers [9,10,28,29,32,33,35,36] evaluated the effect of WBV on functional mobility.

3.5.1. Time Up and Go (TUG)

Seven studies used TUG as outcome measure. [9,10,29,32,33,35,36] All but one [35] reported a significant treatment effect in favour of WBV compared with no intervention. As Bogaerts et al [32] requested the participants to perform TUG at both maximal speed and preferred speed, two separate meta-analyses were done (Figure 3). The results showed that the WBV group demonstrated a significant treatment effect when compared with the control group, regardless of whether the preferred speed data (SMD=0.34, 95%CI=0.11 to 0.57; Z=2.92, p<0.01) (Figure 3A) or the maximal speed data (SMD=0.36, 95%CI=0.13 to 0.58; Z=3.06, p<0.01) (Figure 3B) from Bogaerts et al [32] were used.

Three studies [9,33,29] compared the effect of WBV with conventional exercise on TUG, conflicting results were reported. Rees et al [29] found no significant difference between the exercise group and the WBV group, whereas Bautmans et al [9] and Bruyere et al [33] claimed that WBV group had better TUG performance.

(Figure 3 near here)

3.5.2. Walking Speed

Three studies [28,29,32] included walking speed as an outcome measure. The results were conflicting. Raimundo et al [28] reported that their 1 hour walk-based training programme with stretching exercise is superior to WBV in improving walking speed after eight months. Rees et al [29] reported a result in favour of WBV training when compared with low intensity walking exercise alone. The improvement, however, was similar to the exercise group performing similar exercises without vibration. Compared with the control group, which had only vitamin D and calcium supplement, Bogaerts et al [32] reported that the addition of WBV training resulted in significant improvement in 10-meter walk in preferred speed, but not maximal speed. Only Rees et al [29] included stair mobility time as an outcome measure and reported that WBV did not confer any significant benefit.

3.5.3. Shuttle walk

Bogaerts et al [32] reported that the WBV group showed significantly more improvement than the control group in shuttle walk performance after six months of training.

3.6. Fall Risk Score and Incidence of Falls

Two studies included assessments related to falls. [32,39] Bogaerts et al [32] used Physiological Profile Assessment [41] to evaluate the effect of WBV on fall risk. No significant additional treatment effect of WBV was found when compared with the control group. However, after dividing the participants into low, moderate and high risk groups, the percentage of participants who had a high risk for falling decreased significantly in the WBV group whereas increased significantly in the control group after the training period.

Von Stengel et al [39] compared the incidence of falls in three groups (WBV+exercise group, exercise group, and control group) during the 18-month intervention period. Compared with the no-intervention group, WBV+exercise group showed a significantly less number of falls. No significant difference in fall incidence was found between the exercise group and control group.

3.7. Publication Bias

The result of Egger's regression showed that no publication bias existed for all four meta-analyses done in this review ($p>0.10$).

3.8. Adverse Effects

Three studies explicitly reported that no adverse effect was found associated with WBV. [10,32,39] Seven studies did not report any adverse effect [27-30,35-37] but whether or not adverse events were monitored and recorded is not clear. Based on the data provided by Verschueren et al [38] and Bogaerts et al [31], 9 out of 119 participants complained of knee pain after WBV training. Verschueren et al [38] reported that the knee pain was related to mild degenerative changes due to previous knee injuries. Erythema, edema, itching of legs, headache and groin pain were reported by a few participants after the first training session. [9,34,38] Transient minor tingling of lower limbs (n=2) and muscle soreness (n=6) were also reported. [33,34] One participant was reported to become afraid after exposing to WBV. [9] Most adverse effects were temporary. [33,34,38]

4. DISCUSSION

4.1. Balance

4.1.1. Static Standing Balance

The evidence on the effect of WBV on static balance is conflicting. All studies investigating balance in standing on both legs reported no significant results while all studies evaluating single-leg-standing balance favoured WBV. It is possible that single-leg-standing is more compromised among older adults and thus has more room for improvement. Another possible explanation could be the use of different vibration devices. All four studies [31,32,37,38] reporting non-significant effect used the device manufactured by Powerplate, which generates vertical WBV. The two studies [27,30] reporting results in favour of WBV used the device manufactured by Galileo. Of these, vertical sinusoidal vibration was used in Rees et al [30] whereas side-alternating vibration was used in Gusi et al [27]. It is possible that the added instability from side-alternating vibrations may pose a more challenging training condition in improving medio-lateral postural control, which has been found particularly compromised in older adults. [42] Additionally, the studies reported non-significant results used a frequency range from 35 to 40 Hz [31,32,37,38] while those reported significant results used a frequency range between 12.6Hz and 26Hz. [27,30] The transmissibility of vibration differs depending on the type of vibration and the specific combinations of frequencies and amplitudes. [43-46] The difference in treatment effect may thus be highly related to the WBV protocol. [47,48]

The participants' characteristics may also affect the response to WBV treatment. Rees et al [30] reported more improvement among participants with poorer initial one-leg postural steadiness score, suggesting that relatively frail elderly may benefit more from WBV. However, upon thorough review of the studies, no specific difference in participants' characteristics could be found to explain the discordance in results.

4.1.2. Anticipatory Balance

Our analysis revealed that WBV is effective in improving the Tinetti total score. In sub-score analysis, WBV could only significantly improve Tinetti body balance score, but not Tinetti gait score. The former measures more basic balance ability such as sitting and standing balance, whereas the latter assesses balance in walking. It may imply that the WBV protocols used in these three studies are effective in improving basic but not more advanced dynamic balance ability.

Other aspects of anticipatory postural control such as the Limit of Stability test and postural sway after fast arm movements were measured in two studies. [34,38] Although some positive findings were reported, no solid conclusion can be made due to the limited evidence.

4.1.3. Reactive Balance

The effect of WBV on reactive balance is inconclusive, as only one study used the Motor Control Test and Adaptation Test as outcomes and reported negative findings. [31]

4.2. Functional Mobility

Our meta-analysis showed that WBV has a significant beneficial effect on TUG performance among older adults when compared with no intervention. Furness & Maschette [35] was the only study that did not show a significant treatment effect on TUG. One potential reason of the difference in results could be related to the exceptionally low amplitude used (0.05mm) in their study. In contrast, the other studies [9,10,29,33,36] involved amplitudes of at least 0.5mm. Upon further examination of the WBV protocols incorporated, no other trend could be identified to explain the difference in the effect sizes obtained.

Three studies [28,29,32] used walking speed measures to assess the effects of WBV, with mixed results. Bogaerts et al [32] reported that the WBV group has better outcome than control group in preferred walking speed and shuttle walk performance but not maximal walking speed. Rees et al [29] demonstrated that WBV confers no additional benefit on improving stairs mobility. This is in line with the aforementioned findings in Tinetti assessment in that WBV protocols used here may not be adequate to improve performance in more challenging mobility tasks.

4.3. Fall and Fall Risk Score

The effect of WBV on fall risk score and actual incidence of falls remains uncertain. Bogaerts et al [32] reported that the change in overall fall risk score did not differ significantly between the WBV and control groups. Only in post-hoc analysis did they find a significantly more reduction in the number of high-risk individuals in the WBV group, again suggesting that more compromised individuals may benefit more from the WBV.

von Stengel et al [39] is the only study that used the actual number of falls as the outcome. While it seems that WBV has additional benefit on reducing falls when coupled with a comprehensive exercise programme, their results need to be interpreted with caution. Although they found that the WBV+exercise group, but not the exercise group, has significantly lower fall rate than the control group, there was no significant difference in fall rate between the WBV+exercise and exercise groups. The effect of WBV alone on fall rate thus remains uncertain.

4.4. Adverse Effects

Among the studies included in this review, the occurrence of adverse events is rare. Only 29 out of 455 participants in the WBV group reported adverse effects that are potentially related to WBV exposure. The effects were all mild and usually subsided soon after training progressed. Overall, WBV seems to be well tolerated among older adults although the long-term hazards require more research.

4.5. Limitations of the studies reviewed

All participants involved in the selected studies are generally healthy older adults. Additionally, six out of the 13 studies included only female participants. The result can only be generalized to people with similar characteristics. The number of good quality trials is limited. Only 6 of the 13 trials are regarded as good quality trials. Moreover, different vibration platforms (e.g., Galileo Vs Powerplate) have different technical characteristics and may induce different therapeutic effects. However, it is difficult to delineate the effects of the model of the vibration platform used, because the selected studies used different protocols (e.g., number of sessions per week, number of weeks of treatment, etc.). None of the selected studies attempted to compare the effects of different vibration platforms.

4.6. Limitations of the systematic review

Meta-analysis could not be performed for many of the outcome measures as the treatment protocols and outcome measures used were distinct, making direct comparison difficult. Additionally, the medians instead of the means from Bogaerts et al [32] were used to calculate the SMD for the meta-analysis of TUG as the mean values could not be obtained from the original authors. However, as the sample size of Bogaerts et al [32] is larger than 25, it is reasonable to replace the means by the medians in the meta-analyses. [49] Finally, many studies failed to report the data according to the recommendations of the International Society of Musculoskeletal and Neuronal Interactions. [50] The unstandardized reporting of treatment protocols and results makes interpretation difficult.

5. CONCLUSION

This review revealed that WBV is effective in improving relatively basic dynamic balance ability and functional mobility in older adults, particularly the frailer ones. Its effect on falls, however, remains uncertain. WBV may be a viable alternative for those older adults who are unable to participate in other forms of exercise training. Further research is required to identify the optimal protocol of WBV for improving balance and mobility in older adults. The effect of WBV among older adults having poorer general health would also need more research.

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FIGURE CAPTIONS

Figure 1. Flow Diagram

Fifteen articles (thirteen trials) were included in this systematic review.

Figure 2. Meta-analysis: Tinetti score

Forest plot was used to present the result of the meta-analysis. Filled square (■) and error bars illustrated the standardized mean difference (SMD) and 95% confidence interval (CI), respectively. The pooled SMD is indicated by ♦. A. Tinetti Total Score: Comparison between the WBV group and control group. B. Tinetti Body Balance Score: Comparison between the WBV group and control group. C. Tinetti Gait Score: Comparison between the WBV group and control group. For Furness 2009, only the data obtained from the groups that underwent 3 treatment sessions per week were included for analysis.

Figure 3. Meta-analysis: Timed-Up-and-Go Test

A. Timed-Up-and-Go Test: Comparison between the WBV and control group. Preferred speed data from Bogaerts 2011 was used for analysis. B. Timed-Up-and-Go Test: Comparison between the WBV and control group. Maximum speed data from Bogaerts 2011 was used for analysis.