ORIGINAL ARTICLE

High-Frequency Whole-Body Vibration Improves Balancing Ability in Elderly Women

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ABSTRACT. Cheung W-H, Mok H-W, Qin L, Sze P-C, Lee K-M, Leung K-S. High-frequency whole-body vibration improves balancing ability in elderly women. Arch Phys Med Rehabil 2007;88:852-7.

Objective: To investigate the efficacy of high-frequency whole-body vibration (WBV) on balancing ability in elderly women.

Design: Randomized controlled trial. Subjects were randomized to either the WBV intervention or the no-treatment control group.

Setting: Community-living elderly women.

Participants: Sixty-nine elderly women aged 60 or above without habitual exercise.

Intervention: Side alternating WBV at 20Hz with 3 minutes a day and 3 days a week for 3 months in the WBV intervention group. Those in control group remained sedentary with normal daily life for the whole study period.

Main Outcome Measures: Limits of stability in terms of reaction time, movement velocity, directional control, endpoint excursion, maximum excursion, and the functional reach test were performed at baseline and endpoint.

Results: Significant enhancement of stability was detected in movement velocity ($P<.01$), maximum point excursion ($P<.01$), in directional control ($P<.05$).

Conclusions: WBV was effective in improving the balancing ability in elderly women. This also provides evidence to support our user-friendly WBV treatment protocol of 3 minutes a day for the elderly to maintain their balancing ability and reduce risks of fall.

Key Words: Accidental falls; Balance; Frail elderly; Posture; Randomized controlled trials; Rehabilitation; Vibration.

WHOLE-BODY VIBRATION (WBV) IS A new biophysical modality to provide systemic vibration signals for mechanical stimulation. There are several animal and clinical studies showing its positive effects on bone mineral density[1,2] and blood circulation in lower extremities.[3,4] With respect to the effects on muscle performance, WBV was reported to improve vertical jumping height[5,6] and muscular contractile properties[7] in healthy young subjects as well as to increase muscle strength in the elderly.[8-10] Torvinen et al,[11] however, reported that WBV intervention had no effect on the dynamic or static balance of the young subjects for either 4-month[6] or 8-month treatment. On the other hand, there was a report[12] indicating that 6-week static WBV exercise was beneficial for mobility of institutionalized elderly in a randomized controlled trial (RCT). Also, WBV was shown to positively influence the postural control and mobility in multiple sclerosis (MS)[13] and unilateral chronic stroke patients.[14] The elderly are therefore possible beneficiaries of WBV because they have poor muscular performance[15,16] and low bone quality.[17-19] Despite the benefits on muscular performance, the efficacy of WBV on balancing ability is still uncertain, which may be dependent of age and physical conditions. To show the effect of WBV on balancing ability in the elderly will certainly help to widen the applications of WBV because it will be useful for preventing fall-associated osteoporotic fractures because of poor balancing ability.

Several mechanistic findings indicate that WBV induces several neural and muscular changes, such as stimulation of human spindle endings,[20,21] and changes in biogenic amines,[22] which might implicate the improvement of contractile properties and strength of muscle and hence the balancing ability. It is therefore believed that the positive effects of WBV on the muscular performance[12-14] should help to enhance the balancing ability.[23-25] Accordingly, we hypothesized that WBV would enhance the balancing ability of elderly women. The present study was designed as a prospective RCT to prove our study hypothesis.

METHODS

Subject Recruitment

Seventy-five elderly women were recruited in the study. The inclusion criteria were being female, being age 60 years or older, and being able to stand independently without any aids. The exclusion criteria were (1) having any hormonal replacement therapy or drug treatment that could affect normal metabolism of musculoskeletal system; (2) having any hypo- or hyperparathyroidism, renal, liver, or chronic disease; (3) being previous or current smokers or drinkers; and (4) having habitual exercise or participate in any supervised exercise. Activity levels of subjects were asked again at the end of the study based on our established short version of the Health Habits and History Questionnaire[26] to assess any extra habitual exercise taken, and subjects were excluded if their activity habit had changed during the study period. Written consent was obtained from all subjects before enrollment into the study. The study protocol was approved by the Clinical Research Ethics Committee of the Chinese University of Hong Kong.

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Randomization

The recruited subjects were randomly designated, in a 2:1 ratio, to either the WBV treatment unit group or the control group unit, respectively. The 2:1 ratio was based on our anticipated high dropout rate in treatment group, as explained in the Statistical Analysis section. Randomization was performed by an independent research assistant with the use of sealed envelope. Subjects were asked to perform a baseline measurement on their limits of stability and functional reach as described later. The WBV intervention started within 1 week after the baseline measurements were taken; control subjects remained sedentary with normal daily life during the entire study period.

WBV Treatment

Subjects in the WBV treatment group were asked to receive all the treatments throughout the study in a community center in Shatin district of Hong Kong. The WBV was performed by using the Galileo 900,[a] which is a side-alternating vibration device working as a teeterboard with amplitude of 0 to 5.3mm (medial to distal) and a variable frequency of 5 to 30Hz.[14] The amplitude was controlled by adjusting the foot position from 1 to 3, with the larger the position, the greater the amplitude. Before the treatment, procedures of using the Galileo 900 were instructed by the research assistant and its safety issues explained. During treatments, subjects were instructed to stand on the oscillating platform operating at 20Hz in bare feet at the second foot position for 3 minutes a day for 3 days a week for 3 months. All unusual or uncomfortable complaints from subjects during the WBV treatment were documented. All assessments of balancing ability were repeated for both groups at the end of study. The compliance rate, defined as the number of treatment sessions attended over the total number of treatment sessions, was recorded by the responsible research assistant.

Outcome Assessments

Limits of stability. Subjects' limits of stability were assessed on a Basic Balance Master system.[b] This device is a verified assessment tool to measure the path of the subject's center of gravity (COG) during exercise for analysis, which initiates and quantifies volitional movements.[27] The COG is defined as the point at which the entire mass of a body acts, whereas the limits of stability is the furthest angular distance from the vertical position that a person's COG can deviate without loss of balance. All assessments were performed according to the manufacturer's instructions. Briefly, subjects stood on a standardized foot position of the forceplate as recommended by the manufacturer. With their arms by the side of their bodies, subjects were instructed to sway their body toward 8 surrounding target positions, according to the relative positions shown on the computer screen. The measured parameters included reaction time, movement velocity, directional control, endpoint excursion, and maximum excursion. Reaction time was defined as the time in seconds between the signal to move and the initiation of movement; movement velocity was defined as the average speed of COG movement (expressed in degrees per second) between 5% and 95% of the distance to the primary endpoint; endpoint excursion was defined as the distance traveled by the COG on the primary attempt to reach the target, expressed in percent of limits of stability; maximum excursion was defined as the furthest distance traveled by the COG during the trial, expressed in percent of limits of stability; and directional control was defined as a comparison of the amount of movement in the intended direction (toward the target) to the amount of extraneous movement (away from the target) in terms of the following equation: (amount of intended movement – amount of extraneous movement)/(amount of intended movement), expressed in percentage accuracy.[28,29] The composite score of the 8 directions was used for calculation. The length of each target trial was 8 seconds, and subjects were requested to move the COG cursor as quickly and accurately as possible. If they were incapable of reaching the location, they were asked to sway as far as possible in the direction of the target without losing balance. Each subject had 5 to 10 minutes of familiarization with the system before conducting the test.

Functional reach test. The functional reach test (FRT) was conducted according to our established and validated protocol.[26,30] Each subject was asked to stand on the measuring board, keeping the knees straight, with no gap between the feet. Subjects were requested to lean forward from an initial upright posture as far as possible to reach the maximal anterior position. The greatest horizontal level their fingers could reach, with their trunk bending forward, was recorded; 3 attempts were made, and the greatest forward reach was used for data analysis. Greater distance indicated better balancing ability. Test-retest reliability for this measure was established in 128 subjects between the ages of 20 and 87 years (intraclass correlation coefficient, .92).[30]

Statistical Analysis

The primary endpoint of this study was movement velocity because other studies indicated an improvement of mobility or movement after vibration treatments.[8,12] The null hypothesis of this study was that WBV provided no effect on the balancing ability, whereas the alternative was that WBV enhanced the outcomes of the treated subjects. A sample size of 50 for the study was estimated to achieve a statistical power 0.8. This calculation was based on a previous similar study,[10] with an expectation of 16% increase of dynamic muscle strength in postmenopausal women after 6 months of WBV training. Only the subjects achieving 70% or higher compliance[2] in the WBV intervention group would be included in the analysis, and it was estimated that only half of the subjects in this group would reach 70% or higher compliance; therefore, 50 subjects in the intervention group and 25 in the control group were needed.

The data were expressed in mean ± standard deviation (SD) and analyzed with SPSS.[c] An independent *t* test was used to compare the demographic data of both groups. Two-way analysis of variance was used to analyze the parameters for the limits of stability and the FRT between 2 groups. *P* values less than .05 were considered to be significant.

RESULTS

Demographics

Seventy-five of the 85 elderly women recruited were eligible and willing to participate in the study. Twenty-five were randomized to the control group and 50 to the intervention group. Only 24 and 45 subjects completed the study in the control and intervention group, respectively (average age, 72.36±4.93y). There were 18 (26.1%) subjects who had a history of fall in the previous year. The mean number of diseases and prescriptions of the subjects was 4.33±2.43 and 1.71±1.58, respectively, during the study period. There was no significant difference in the demographic and baseline data, as shown in table 1.

Dropout and Compliance

Six subjects dropped out (5 from the intervention group, 1 from the control group) during the study period and refused to come back for reassessment for health or other personal rea-

Table 1: Demographic and Baseline Data of Subjects in Both Control and WBV Groups

Parameter	Control (n=24)	WBV Treatment (n=45)	*P*
Age (y)	72.0±6.01	72.51±4.45	.689
Height (cm)	150.88±5.33	151.51±5.62	.650
Weight (kg)	58.50±8.95	57.63±9.42	.711
No. of comorbidities	4.79±2.64	4.08±2.17	.223
No. of medication	1.96±1.60	1.58±1.57	.345
History of fall, n (%)	5 (20.8)	13 (28.9)	.468
Reaction time (s)	1.17±0.36	1.22±0.42	.694
Movement velocity (deg/s)	1.96±0.61	1.89±0.46	.635
Endpoint excursion (% of limits of stability)	39.39±9.25	43.27±7.67	.092
Maximum point excursion (% of limits of stability)	57.26±12.00	56.54±9.55	.791
Directional control (% of accuracy)	63.57±10.54	62.43±10.53	.688
Functional reach (cm)	22.00±11.09	21.39±7.13	.782

NOTE. Values are mean ± SD or as otherwise indicated.

sons. Of the remaining subjects (n=45) in the treatment group, all had completed the 3 months of intervention, with a mean compliance of 93.3% (range, 75%–100%) (fig 1). All subjects in both groups did not change their activity habits throughout the 3-month period.

Limits of Stability and Functional Reach

Comparing the findings between the control and treatment groups (table 2), significant improvement was shown in movement velocity ($P<.01$) and maximum point excursion ($P<.01$). Directional control also reached marginal significant level ($P<.05$). Other parameters, including reaction time and endpoint excursion, however, were not significant ($P>.05$). For the FRT, the intervention group showed more improvement than the control group, although it was not statistically significant ($P=.22$).

Complications

There were no serious complications observed in subjects who had received the WBV treatment. Six subjects (12%) reported muscle soreness and 1 (2%) headache after receiving the first few sessions of WBV treatment (see fig 1). However, these complications ceased after approximately 10 sessions.

DISCUSSION

The present study questioned the efficacy of WBV on balancing ability with regard to the limits of stability and the FRT in elderly women. To our knowledge, this was the first investigation to evaluate the effect of side-alternating vibration machine on balancing ability of elderly women in terms of the limits of stability. The findings showed significant enhancement in stability with respect to movement velocity, maximum point excursion, and directional control in elderly women after the WBV interventions as compared with the controls.

The present prospective RCT showed that 3 months of WBV could significantly improve limits of stability parameters to different extents. This finding was substantiated by others who have reported significant improvement after 6 months of WBV on speed of movement and knee-extension strength in older women,[8] whereas the 6-week WBV intervention for institutionalized elderly also indicated a positive impact on motor control in the subjects.[12] Enhancement in postural control and mobility was detected in MS patients[13] as well as unilateral chronic stroke patients.[14] All the enhancements in muscle function related outcomes shown in these studies support the effectiveness and feasibility of using WBV on enhancing the muscle performance and hence the balancing ability. Clinically, poor balancing ability is closely related to the risk of falling in the elderly, which may lead to serious medical consequences including hip fractures and head injuries.[31] The findings of the present study will open up a new area to apply WBV in the prevention of falls and its related injuries among the elderly in the future.

In the present study, movement velocity, maximum point excursion, and directional control were improved after WBV interventions. Because these functional parameters involve the ability to recruit muscle fibers, muscular adaptation, and neuromuscular coordination, these improvements indicate that WBV would be effective in enhancing neuromuscular rehabilitation. This could be particularly well reflected by the beneficial effects of WBV on stroke[14] and MS[13] patients. These outcomes also agreed with other mechanistic studies that WBV could induce several neural and muscular changes such as the stimulation of human spindle endings[20,21] and changes in biogenic amines.[22] Among these improvements in the limits of stability parameters, movement velocity and maximum point excursion were the most sensitive in response to the WBV treatment, as reflected from their high significance levels. Besides, the treatment protocol used in this study was 3 minutes a day and 3 days a week, which was a mild and fast regimen for elderly women. Other studies applied complicated programs for the elderly, involving different exercises and durations in different weeks[8,12] or systematic increase of training volume.[10] Therefore, the protocol applied in this study is relatively user friendly for the elderly, and the application of WBV can be used to prevent fall incidences caused by poor balancing ability, thus potentially reducing the rate of osteoporotic fractures.

Measuring limits of stability for the assessment of balancing ability was used in this study because limits of stability is a good and reliable indicator of dynamic balance.[28,29] The ability to control the movement of the COG over the base of support is critical to normal balance.[27] Therefore, increased fall risk can be reflected from delayed reaction time, slow movement velocity, constricted limits of stability boundary, or uncontrolled COG movement. The key advantage of this computerized assessment of limits of stability is the ability to obtain objective, quantitative measurements quickly and reliably while the subjects are providing biofeedback. In this study, functional reach was assessed in addition to the limits of stability because the FRT is a single-item measure of dynamic balance clinically used by physiotherapists. Despite the similar nature of both tests, the FRT was still necessary because it had been reported that the FRT and the limits of stability tests should not be used interchangeably.[32]

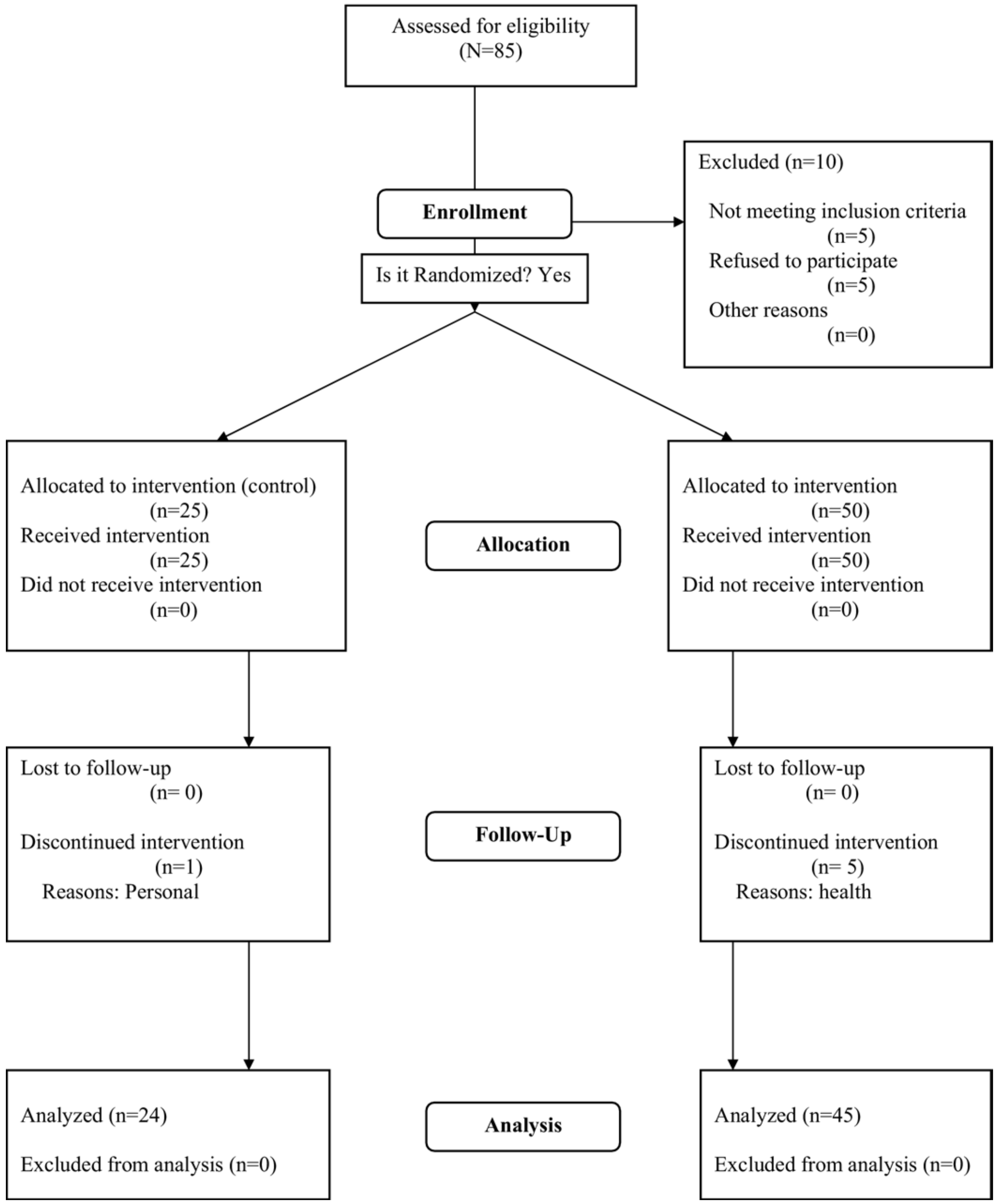

Fig 1. CONSORT flowchart of the study.

On the other hand, Torvinen et al's studies showed that the WBV intervention did not affect the dynamic or static balance of the subjects in short-term (4-mo)[6] or long-term (8-mo) treatment.[11] This discrepancy from our findings could be explained by the difference in target subjects between the 2 studies. In most of the studies with positive effects on muscle

Table 2: Limits of Stability and Function Reach Compared Between Control and WBV Groups

Parameter (% change)	Control (n=24)	WBV Treatment (n=45)	*P*
Reaction time (s)	−25.59±24.37	−34.47±26.03	.210
Movement velocity (deg/s)	14.96±31.72	53.49±54.38	.003†
Endpoint excursion (% of limits of stability)	11.12±33.46	20.36±30.07	.261
Maximum point excursion (% of limits of stability)	3.36±20.91	18.84±18.26	.003†
Directional control (% of accuracy)	−6.61±19.72	4.32±19.64	.049*
Functional reach (cm)	6.59±34.56	23.77±63.01	.221

NOTE. Values are mean percentage change ± SD.
*$P<.05$.
†$P<.01$.

performance, including the present one, target subjects were mostly elderly or postmenopausal women[8,10,12] or physically weak people like MS[13] and unilateral chronic stroke patients.[14] However, the target subjects in Torvinen's studies[6,11] were young healthy nonathletic volunteers aged 19 to 38 years. This implies that young healthy people with good muscle quality may not readily gain additional benefits from WBV. But this does not completely exclude the efficacy of WBV on young subjects because Cochrane and Stannard[5] have reported that acute WBV training increased flexibility performance in elite female field hockey players. This might be attributed to the intensive training in Cochrane's study, in which WBV at 26Hz accompanied with 6 different exercises was performed, whereas the oscillation was ascended from 25 to 40Hz for 4 minutes only in Torvinen's study.[11]

Variations in vibration machines and training protocols may also explain the different outcomes in these clinical studies. In most studies, vibration platforms with a vertical mode of oscillation were used including Power Plate,[8,10,12,d] Zeptor-Med system,[13,e] and Kuntotäry.[6,11,33,f] Other studies,[5,14] including the present one, used the Galileo platform, which is of a side-alternating vibration mode. Although no study has compared the effects or functions before, the 2 vibration modes differ in terms of the mechanism and stimulated muscles, which need further investigations to depict their differences.

Study Limitations

The limitation of this study was the lack of dummy machines for placebo control. Subjects in the control group had to keep sedentary with normal daily life throughout the whole study. This limitation was minimized by the monitoring of their involvement in habitual exercise or supervised exercise. Those exceeding the amount of exercise were not recruited in this study. Also, the imbalanced number of subjects in 2 arms was because of our overestimation of the dropout rate for the intervention group.

CONCLUSIONS

Three-month high-frequency vibration therapy with 3 minutes a day and 3 days a week significantly enhanced the balancing ability of elderly women in terms of movement velocity, maximum point excursion, and directional control. Of these parameters, movement velocity and maximum point excursion were the parameters with the most significant improvement. These findings provide good evidence to support the efficacy of WBV on enhancing muscular performance in elderly women and hence balancing ability. The long-term impact of WBV on balancing ability and its potential application in prevention of falls or related injuries are also worthwhile for further studies.

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