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Influence of Whole-Body Vibration Training Without Visual Feedback on Balance and Lower-Extremity Muscle Strength of the Elderly

A Randomized Controlled Trial

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Abstract: The purpose of this study was to investigate the influence of whole-body vibration (WBV) training without visual feedback on balance and lower-extremity muscle strength in the elderly.

Elderly subjects who did not exercise regularly participated in this study. Subjects were randomly divided into a WBV with eyes open group, a visual feedback-deprived plus WBV (VFDWBV) group, and a control group (0 Hz, eyes open). WBV training was provided over a 3-month period, 3 times per week for 5 min each session. Balance performance was measured with the limits of stability test, and muscle strength was measured with an isokinetic dynamometer.

A total of 45 elderly subjects with an average age of 69.22 ± 3.97 years, divided into a WBV group (n = 14), a VFDWBV group (n = 17), and a control group (n = 14), completed the trial. Statistically significant differences were found in the balance performance of the 3 groups at different time points (time × group interaction: F = 13.213, $P < 0.001$), and the VFDWBV group had more improvement in balance than the WBV and control groups. The strength of the knee extensor and flexor muscles had time × group interactions: F = 29.604, $P < 0.001$ and F = 4.684, $P = 0.015$, respectively; the VFDWBV group had more improvement on lower-extremity muscle strength than the WBV and control groups. The 6-month follow-up showed that the rates of hospital visits for medical services due to falls were 0% in the WBV group (0/14), 0% in the VFDWBV group (0/17), and 28.57% in the control group (4/14).

Results showed that WBV training at 20 Hz without visual feedback can significantly improve the balance performance and lower-extremity muscle strength of the elderly.

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Abbreviations: ANOVA = analysis of variance, LOSl = imits of stability, VFDWBV = visual feedback-deprived plus whole-body vibration, WBV = whole-body vibration.

INTRODUCTION

Balance deficit is 1 of the significant factors leading to falls in the elderly. Aging induces the gradual decline of sensory functions, central processing, musculoskeletal and motor control, and neural pathways, and thus leads to poor postural stability.[1] Studies on the relationships among age, vision, and body postural control have found that decreased visual acuity, a restricted field of vision, and declining depth perception, all of which are effects of aging, are closely related to body postural control.[2,3] Sensorimotor deficits induced by aging may lead to changes in postural responses and visual operation, especially the performance of complicated and difficult tasks.[4]

Past studies have also found that, compared with younger people, the body postural control of the elderly is more dependent on visual information, suggesting that body postural control in the elderly places particular emphasis on visual information feedback.[5] This phenomenon was confirmed in a study by Sheldon,[6] who found that visual information has the most significant influence on body postural control and stability of the elderly. Once visual feedback is changed or interfered with, the body swing of the elderly will be significantly increased. However, no such phenomenon has been found in younger individuals. Subsequent relevant studies have also verified that the elderly use visual information to control and adjust body postural stability and balance.[7,8] The phenomenon of visual-information-dependent body postural control can be improved, and visual dependence can be reduced, by increasing physical activity.[7]

It has been recommended that some balance-training methods be implemented under eyes-closed conditions to generate better effects. For example, eyes-closed training in Taichi can increase proprioception, somatosensory perception of the position and movement of the limbs and the trunk, and information regulation feedback on muscle tension.[9] In a study by

Danion et al,[8] gymnasts were blindfolded and asked to engage in simple movements, such as walking and manipulating a wheelchair. The results showed that the subjects' performance was reduced when they were blindfolded. However, that study also found that, when blindfolded, the gymnasts could use proprioception to obtain more clues and further exhibit better performance.[8]

Whole-body vibration (WBV) training is a novel sports training method in which a vibration platform is used to generate regular up-and-down shifts from the bottom of the feet to the whole body to stimulate receptors in the body to generate regulatory responses. Vibration stimulation was first used to relieve tension in patients with muscle spasms. Since the 1990s, scholars have further researched the application of vibration training to the training of athletes to help them generate more muscle strength, power, and exhibit better sports performance.[10–13] In recent years, many animal-related and clinical studies have indicated that WBV has a positive influence on bone density performance and lower-limb blood circulation.[14] In terms of neuromuscular performance, past studies have verified that WBV training can improve the muscle strength, flexibility, and sports performance of athletes and the general public.[15,16] Past studies have also shown that WBV training has a positive effect on the balance and functional performance of the elderly.[17,18] In addition, because this method is quite safe and convenient,[12] some studies have included it in the therapy regimens of patients with stroke and multiple sclerosis, and its efficacy has been verified.[19,20]

The purpose of this study was to investigate whether excluding visual feedback during WBV training would affect the balance and lower-extremity muscle strength of the elderly, as well as to provide research results as an important reference for future WBV training programs to improve the balance and the lower-extremity muscle strength of the elderly.

MATERIALS AND METHODS

This study was 1 part of the research project of "Effects of Vibration Training on Physiology in the Human Body." The complete date range for participant recruitment and follow-up was from January 5, 2010 to October 31, 2011, and the clinical trial's registered number was ChiCTR-ICR-15006239.

Design

A sample estimate of 51 subjects was determined using G-Power 3.1 (University of Kiel, Germany), based on an effect size f = 0.25 (medium) and a statistical power of 0.95 (3 groups, 3 measurement times) with a repeated measures analysis of variance (ANOVA) method (with-between interaction). This study, a single-blind randomized trial, used the block randomization method, and the evaluator did not know which subjects were randomized to which group. The research project was conducted according to the Declaration of Helsinki and was approved by the hospital Institutional Review Board for research involving human subjects (Taichung Hospital, Ministry of Health and Welfare, Taiwan, I980009). All of the participants were fully informed of the study content before their participation in this study, and all signed informed consent forms.

The inclusion criteria for the subjects in this study were: age over 65; a lack of reported regular exercise; and the ability to stand independently without any assistance. The exclusion criteria included: medication treatment that could affect the normal metabolism of the musculoskeletal system; fractures or surgery within the past 3 months; and medical history of neuromuscular disease, Parkinson, Alzheimer, vertigo, and so on.

The subjects meeting the inclusion criteria were randomized to the experimental group and the control group. The device used in this study was a commercially available WBV training device (Commercial Grade Vibration Machine LV-1000, X-trend, Taiwan). The subjects were randomized into a WBV group, a visual feedback-deprived plus WBV (VFDWBV) group, and a control group (0 Hz, eyes open). The subjects assigned to the VFDWBV group receiving the WBV training, were asked to close their eyes and wear a blindfold to block their visual feedback. The WBV training lasted for 3 months, and the subjects received WBV training 3 times per week for 5 min each time based on a peak-to-peak amplitude of 4 mm at 20 Hz, and resulting in a peak acceleration of 1.5 g. During the training sessions, the subjects stood on the vibration platform with the knees slightly flexed (about 20°). In the nontraining period, the 3 groups maintained their original lifestyles and did not participate in other sports.

The subjects participating in the experiment were evaluated before and after training (separated by 3 months) and in a follow-up visit (after 6 months). The evaluation items included the limits of stability (LOS) test and evaluation of the strength of the knee extensor/flexor muscles. The fall incidences of the subjects were recorded, and telephone interviews and paper-based questionnaires were used to ask and confirm whether the participants had sought medical attention due to falls within this study period.

OUTCOME MEASURES

Limits of Stability Test

This study used the Biodex Balance system (Biodex Medical Systems, Inc., Shirley, NY) to measure the subjects' movement in a designated direction without losing balance, striding, or reaching out their hands and feet for assistance; namely, the maximum angular distance between a subject's 2 feet and his/her center of gravity while standing. This experimental device calculated the maximum stable range of the body according to the subjects' height. Because the subjects were asked to move directly toward the target, the best expected outcome was a straight path. During this test, 8 targets were presented in each direction, and the subjects were randomly given instructions. The subjects were requested to move their center of gravity toward the targets, touch them, and then return to the center. The formula was (actual distance traveled/straight line distance to target) × 100%, and the unit of expression was a percentage (%). A higher LOS value indicated better control over the center of gravity, or better balance. This balance evaluation system has been verified as having moderate to good reliability and validity.[21]

Strength of Knee Extensor/Flexor Muscles

Muscle strength was measured using the Biodex System III Pro isokinetic dynamometer (Biodex Medical Systems, Inc.). In this test, the subjects sat on the dynamometer chair with a back angle of 85° from a horizontal position. Straps kept the subjects firmly in the chair. The peak muscle torque of the knee extensors and flexors in each leg was concentrically measured at 60° per s (5 repetitions each), according to standard procedures (knee flexion range: 10° to 100°).[22]

Statistical Analysis

Statistical methods were used to present the subjects' basic information and various measurement variables, and the chi-squared test and 1-way ANOVA were used to analyze whether there were any differences in the data among the 3 groups. Repeated measures ANOVA were used to analyze the differences among the groups' pretest, post-test, and follow-up data, and the interaction of times versus groups. Differences among the groups were compared using Scheffe post hoc analysis, and the Fisher exact test was used to test the difference in hospital-admission frequency due to falls among the 3 groups. The effect size (d) of different periods within the study was calculated by dividing the absolute value of mean change by the standard deviation of the change in the same subjects. The data were analyzed using the statistical analysis software SPSS 14.0 with all significance levels set at $\alpha = 0.05$.

RESULTS

A total of 51 elderly individuals who did not exercise regularly enrolled in the study. After the randomization, 3 subjects in the WBV group and 3 subjects in the control group withdrew from this study due to transportation issues. In the end, a total of 45 subjects with an average age of 69.22 ± 3.97 completed the research trial (as shown in Figure 1). Table 1 shows the basic information pertaining to the WBV group (n = 14), the VFDWBV group (n = 17), and the control group (n = 14). There was a difference in age (F = 5.474, P = 0.008), but there were no statistically significant differences in gender, height, weight, body mass index, pretest balance, or lower-extremity knee extensor/flexor muscle strength (P > 0.05) among the 3 groups.

There were statistically significant differences in balance performance among the 3 groups at different time points (time × group interaction: F = 13.213, P < 0.001). In addition, the

post hoc comparison showed that balance performance was better in the VFDWBV group and the WBV group than in the control group at Month 3 and Month 6 (P < 0.001, as shown in Figure 2). Table 2 shows more-detailed comparison data.

The strength of the knee extensor and knee flexor muscles had time × group interactions: F = 29.604, P < 0.001 and F = 4.684, P = 0.015, respectively. Relative to the pretraining performance, the post-training knee extensor strength of the VFDWBV group improved by 37.89% (P < 0.001), and the post-training knee flexor strength improved by 19.40% (P = 0.002). However, only the knee extensor strength of the WBV group showed improvement, with an increase of 15.40% (P < 0.001). There was no significant improvement in the control group (more detailed information as shown in Table 3).

At the 6-month follow-up, 0 subject from the WBV group (0%, 0/14), 0 subject from the VFDWBV group (0%, 0/17), and 4 subjects from the control group (28.57%, 4/14) reported hospital visits due to falls. Fisher exact test found that the incidence of falls was higher in the control group than in the other groups (P = 0.013).

DISCUSSION

This study found that, after 3 months of WBV training, the balance of the elderly in the WBV group and the VFDWBV group improved significantly. This finding is consistent with the research results of numerous past studies.[17,18,23] In a study by Lord et al, elderly women received 1 year of sports training. The results showed that the body stability of the sports training group significantly correlated with lower-extremity muscle strength, reaction time, neuromuscular control, and degree of body sway.[24] Those results may explain why the lower-extremity muscle strength and dynamic balance of the WBV groups were better than those of the control group. Ebersbach et al enrolled patients with Parkinson disease as subjects, and used an intervention based on 3 weeks of WBV (at a frequency of 25 Hz and an amplitude of 3.5–7.0 mm) to investigate the influence of WBV on gait and balance. Their results showed that WBV significantly improved the performance of gait/balance.[25] Bautmans et al[18] enrolled male and female elderly individuals as subjects and used an intervention based on 6 weeks of WBV (at a frequency of 30–40 Hz and amplitude of 1.25–2.5 mm). After the intervention, the agility/dynamic balance of the WBV group was significantly better than that of the control group.[18] Based on these findings, it appears that a period of WBV training can indeed improve the balance performance of the elderly.

This study also found that eliminating visual feedback during the WBV training led to further improvements in muscle strength and balance performance in the elderly. The most significant age-related change is the elderly's decreased muscle strength, the main cause of which being decreased muscle mass.[26] Past studies have verified that participating in well-planned workouts can effectively improve the muscle strength, endurance, and flexibility of the elderly.[27,28] In addition, balance-related tests can effectively prevent falls and disabilities. Past studies on the relationship between special sensory motor function and body postural stability showed that if the support base is fixed, the increase in body sway is related to poor perceptual sensitivity of tactile and joint positions. When individuals open their eyes and stand on a soft base (peripheral perception can be reduced), the increase in body sway is related to poor visual acuity, a decrease in vibration sense, a decrease in the muscle strength needed for dorsiflexion, and a decrease in joint-position perception. When individuals close their eyes and
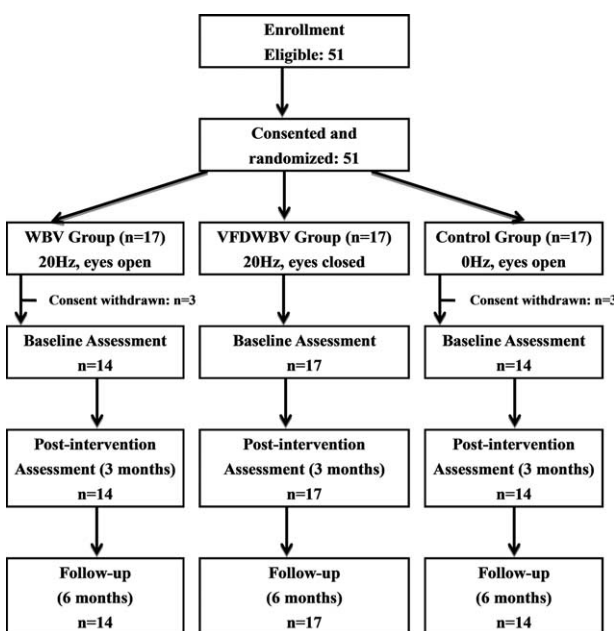

FIGURE 1. Flowchart of the study. VFDWBV = visual feedback-deprived plus whole-body vibration, WBV = whole-body vibration.

TABLE 1. Baseline Characteristics of the Participants

	WBV Group (N = 14)	VFDWBV Group (N = 17)	Control Group (N = 14)	P^*
Gender, male/female	8/6	7/10	7/7	0.793[†]
Age, y	67.21 ± 2.29	71.41 ± 5.01	68.57 ± 2.50	0.008
Height, cm	158.96 ± 6.13	160.18 ± 5.62	163.57 ± 8.70	0.193
Weight, kg	61.93 ± 9.47	61.47 ± 7.71	62.00 ± 10.16	0.984
Body mass index	24.47 ± 3.09	23.92 ± 2.49	23.09 ± 2.79	0.425
Limits of stability, %	28.57 ± 11.91	31.47 ± 4.30	28.71 ± 8.87	0.574
Strength of knee extensors, Nm	79.04 ± 22.56	80.97 ± 22.76	81.96 ± 24.38	0.944
Strength of knee flexors, Nm	38.11 ± 13.02	35.38 ± 15.30	36.25 ± 14.11	0.867

VFDWBVI = visual feedback-deprived plus whole-body vibration, WBVI = whole-body vibration.
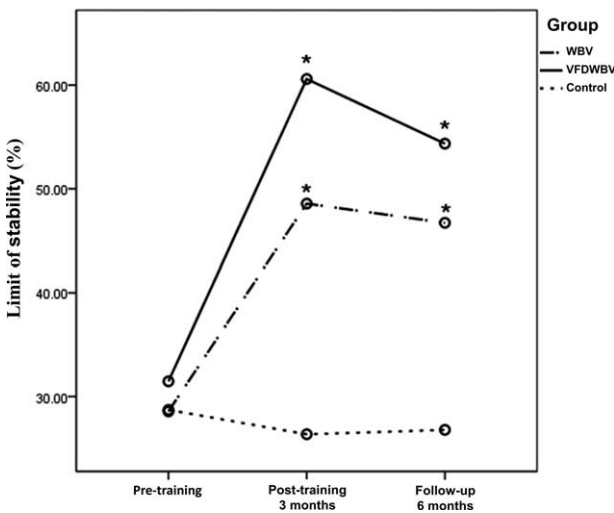* Analysis by 1-way analysis of variance.
† Analysis by Chi-squared test.

FIGURE 2. Test results of balance performance for the 3 groups. VFDWBV = visual feedback-deprived plus whole-body vibration, WBV = whole-body vibration. "∗" denotes a statistically significant difference in the WBV and VFDWBV groups versus the control group ($P < 0.001$), using the Scheffe method.

stand on a soft base; however, the increase in body sway is related to poor tactile perception, decreased muscle strength of the quadriceps and dorsiflexion, and increased reaction time. One study suggested that the poor body postural stability of the elderly is related to decreases in lower-extremity perception, decreases in muscle strength of the quadriceps and dorsiflexion, and delayed reaction times.[29] For the eyes-closed condition, past studies, in which the subjects were requested to stand on 1 foot, found that body postural control is poorer when the eyes are closed than when the eyes are open.[30] This trend is particularly common in the elderly. Therefore, the static balance of the elderly can be improved through training based on standing on 1 foot with the eyes closed. The results indicated post-training improvements in balance.[31] Hu and Woollacott[32] used sensory organization to implement body postural control training in the elderly. They found that when the training group was deprived of sensory information, their body sway was lower than that of the control group, and their standing time was also longer. Therefore, such training is beneficial for the body postural control of the elderly.[32] Past studies have also indicated that the decline of the sensory system and its functions is a significant cause of the decline of body postural control in the elderly. The influence of visual information is most significant, as the postural control of the elderly is affected by visual information.[33,34] Therefore, individuals with a high risk of falls

TABLE 2. Comparison of the Training Effect on Balance Performance of Different Groups

	Differences Between Means		95% Confidence Interval				
	Time-Points	Value	Lower Limit	Upper Limit	t	P^*	Effect Size, d
WBV group (N = 14)	Post−Pre	20.00 ± 11.36	13.44	26.56	6.587	<0.001	1.76[†]
	Follow-up−Pre	18.14 ± 10.80	11.91	24.38	6.287	<0.001	1.68[†]
	Follow-up−Post	−1.86 ± 1.83	−2.92	−0.80	−3.789	0.002	1.02[†]
VFDWBV group (N = 17)	Post−Pre	29.12 ± 8.80	24.59	33.64	13.639	<0.001	3.31[†]
	Follow-up−Pre	22.88 ± 7.69	18.93	26.84	12.271	<0.001	2.98[†]
	Follow-up−Post	−6.24 ± 5.14	−8.88	−3.59	−5.000	<0.001	1.21[†]
Control group (N = 14)	Post−Pre	−2.36 ± 4.03	−4.68	−0.03	−2.188	0.048	0.58
	Follow-up−Pre	−1.93 ± 5.43	−5.06	1.21	−1.330	0.207	0.36
	Follow-up−Post	0.43 ± 6.82	−3.51	4.37	0.235	0.818	0.06

VFDWBV = visual feedback-deprived plus whole-body vibration, WBV = whole-body vibration.
* Analysis by paired t test.
† Mean of the effect size (d) is large (>0.8).

TABLE 3. Comparison of Pre- and Postvibration Training Effect on Lower-Extremity Muscle Strength of Different Groups

		95% Confidence Interval				
	Differences Between Means	Lower Limit	Upper Limit	t	P^*	Effect Size, d
Strength of knee extensors, Nm						
WBV group (N = 14)	12.17 ± 8.17	7.46	16.89	5.579	<0.001	1.49[†]
VFDWBV group (N = 17)	30.68 ± 14.62	23.16	38.19	8.653	<0.001	2.10[†]
Control group (N = 14)	1.43 ± 6.59	−2.37	5.23	0.812	0.432	0.22
Strength of knee flexors, Nm						
WBV group (N = 14)	1.71 ± 6.13	−1.82	5.25	1.047	0.314	0.28
VFDWBV group (N = 17)	6.85 ± 7.63	2.93	10.78	3.702	0.002	0.90[†]
Control group (N = 14)	−0.50 ± 6.70	−4.37	3.36	−0.279	0.785	0.07

VFDWBV = visual feedback-deprived plus whole-body vibration, WBV = whole-body vibration.
[*] Analysis by paired t test.
[†] Mean of the effect size (d) is large (>0.8).

are advised to receive WBV training with their eyes closed to enhance postural control, further increase muscle strength, improve balance, and reduce mortality due to falls.

Past studies have indicated that the main reason WBV training can improve muscular function and performance is that it improves the efficiency of the spinal reflex and neuromuscular control system.[10–13] WBV training generates simulated mechanical vibrations, activates the neuromuscular control system, increases the level of excitement and the number of motor units recruited, and coordinates synergistic and antagonistic muscles during rapid muscle contractions, thus enhancing muscle function.[11] Previous studies have also indicated that WBV training can enhance muscle joint contractions, and the results have been verified by EMG data.[35] Therefore, WBV training can generate adaptive neuromuscular responses, increase muscle strength, and affect balance. The most frequently cited neurophysiological mechanism of vibration training is the sensitivity of the tonic vibration reflex (TVR) and the increased muscle spindles caused by cyclic mechanical stimulation.[36] Therefore, the strength of the knee extensor and flexor muscles can be increased by the cyclic mechanical stimulation during WBV training.[37,38]

The bone myoregulation reflex (BMR) is another neural mechanism that can explain how WBV affects muscle strength.[39] BMR refers to the reflex mechanism of muscle activity caused by osteocytes exposed to cyclic mechanical loading. Osteocytes exposed to mechanical loading will transmit input information to the central nervous system and affect neuronal regulation.[39,40] If individuals stand with their knees slightly bent, WBV will generate hyper gravity and increase the extension moment of the knee joints, which may increase the mechanical loading on a cross-sectional area of the femur. If the osteocytes in the area are exposed to stronger mechanical stimulation, osteocyte compression will increase. Therefore, based on the BMR mechanism, WBV leads to an increase in muscle strength, in addition to an increase in bone mineral density, through the reflex of muscle activity caused by mechanical loading.[39,40]

In all cases, this study found that both the WBV group and the VFDWBV group did not experience any falls within 1 year. However, the incidence of falls in the control group was 28.57%, which was close to the incidence (30%) in the general elderly population over the age of 65.[41] This finding verified

that the training of the WBV group and the VFDWBV group could effectively reduce the incidence of falls in the elderly. A past study on the relationship between body balance and the incidence of falls within 1 year showed that a medial lateral deficit of the body significantly correlates with the incidence of falls.[42] Spontaneous body sway to the left and right, especially when the eyes are closed, could be the best predictor for the future risk of falls in the elderly.[42] As part of intervention strategies for the prevention of falls, further investigations should be conducted into how WBV improves body balance control.

This study found that without visual feedback, in combination with WBV training, had a more positive effect on the improvement of balance and lower-extremity muscle strength. Therefore, the setting of visual feedback should be an important control factor in future training programs developed for different populations with varying needs. Future studies are advised to consider excluding visual feedback as part of the WBV training model. However, it is also necessary to pay attention to the safety of the participants during training and prevent falls on the vibration platform. Future studies should also consider the regulation of other sensory stimulation (proprioception and vestibular stimulation) and the persistence of the effects.

This study found that the balance performance of the VFDWBV group was better than that of the WBV group. In addition, WBV training without visual feedback was found to improve the balance and muscle strength of elderly individuals who did not exercise regularly and who were able to walk independently. It is hoped that future studies can be conducted to help other populations with poor balance, such as stroke patients or those with other balance deficits.

ACKNOWLEDGMENTS

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