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Whole-Body Vibration in Horizontal Direction for Stroke Rehabilitation: A Randomized Controlled Trial

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Data Collection B
Statistical Analysis C
Data Interpretation D
Manuscript Preparation E
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Funds Collection G

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Background: As most of the existing whole-body vibration (WBV) training programs provide vertical or rotatory vibration, studies on the effects of horizontal vibration have rarely been reported. The present study was conducted to investigate the effect of WBV in the horizontal direction on balance and gait ability in chronic stroke survivors.





Material/Methods: This study was designed as a randomized controlled trial. Twenty-one stroke survivors were randomly allocated into 2 groups (whole-body vibration group [n=9] and control group [n=12]). In the WBV group, WBV training in the horizontal direction was conducted for 6 weeks, and a conventional rehabilitation for 30 min, 3 days per week for a 6-week period, was conducted in both the WBV and control groups. Outcome variables included the static balance and gait ability measured before training and after 6 weeks.

Results: On comparing the outcome variables before and after training in the WBV group, significant differences were observed in the cadence and single support time of gait ability. However, there were no significant differences in other variables, including velocity, step length, stride length, and double support time. In addition, after training, no significant differences in all variables were observed between the 2 groups.

Conclusions: The results of this study suggest that WBV training in the horizontal direction has few positive effects on balance and gait function in chronic stroke survivors. However, further investigation is needed to confirm this.

MeSH Keywords: **Gait • Postural Balance • Stroke • Vibration**

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Background

Stroke survivors suffer from central nervous system damage, with sensory and motor system damage, which leads to consequences such as decreased control of muscle tone, delay in muscle contraction, and absence of selective movement [1,2]. In addition, stroke survivors have unstable balance and poor gait ability, which naturally limits their activities of daily living and participation in the community, while losing independence [2,3]. Consequently, the first priority for stroke survivors is recovery of independent activities, and for this, the recovery of balance in a standing posture and gait abilities is essential.

For functional recovery of stroke survivors, various methods have been suggested [4], and whole-body vibration (WBV) is a relatively novel form of exercise intervention that could improve functional recovery [5]. WBV involves the use of a vibrating platform in a static position or while performing dynamic movements. In previous studies, it was suggested that WBV training could improve physical functions. Castrogiovanni et al. [6] reported that a multi-component training, including aerobic activity and other types of training (resistance and/or strength exercises), is the best kind of exercise for improving bone mass and bone metabolism in elderly people and especially in osteopenic and osteoporotic women. With regard to whole-body vibration training, studies have suggested that it could be a valid method. Pichler et al. [7] reported that mechanical stimulation such as treadmill and vibration stimulation training inhibits the activity of RANKL in osteoporosis. In addition, Musumeci et al. [8] suggested that, in certain diseases such as osteoporosis, mechanical stimulation including treadmill and vibration platform training could be a possible therapeutic treatment. Based on their results, they proposed the hypothesis that physical activity could also be used as a therapeutic treatment for cartilage diseases such as osteoarthritis. Van Nes et al. [9] introduced WBV as a means of somatic sensory stimulation for functional recovery of stroke survivors. They also reported that somatosensory stimulation through WBV can significantly improve muscle performance, balance, and daily activities. Balance, defined as the ability to maintain the center of pressure (COP) on the support surface in given circumstances, can be held through adjusted harmony of visual, vestibular, and somatic sensory system [10], and vibration stimulation is reported to cause small changes in the skeletal muscle length of the human body and affect the motor neurons to facilitate activation of the spinal reflexes through short spindle-motor neuron connections [11].

Balance is a major component required for controlling or maintaining the COP in mobility and locomotion in which the support surface changes [12]. The information on changes of the support surface along with the biomechanic information needed for movement control is passed on to the central

nervous system by muscle spindles, Golgi tendon organs, and joint receptors in the proprioception sense; thus, they have a very important role in controlling balance [13,14]. In addition, Muller and Redfern [15] performed a comparative analysis of the latency of beginning muscle activity by measuring electromyogram (EMG) activation degree of muscle strength of the lower extremities caused by movement of the COP while the support surface moved back and forth. Consequently, the latency of activation of the tibialis anterior muscle was rapid on the support surface moving forward and that of the soleus muscle was rapid when moving backward. Given these reports, for recovery of balance ability, the horizontal vibration in all directions might be needed more than the vertical or rotatory vibration provided by the original WBV training. Additionally, our bodies maintain standing posture using ankle strategy, hip strategy, or both [16]. The ankle strategy, which is the postural control strategy that starts first in postural sway, enables immediate recovery of standing balance through ankle joint muscle contraction [16]. Horizontal vibration, therefore, may significantly activate not only stimulation of somatosensory, but also ankle strategy or hip strategy.

However, since most of the existing WBV training programs provide only vertical or rotatory vibrations, studies on effects of horizontal vibrations have been rarely reported. Accordingly, the present study examined the effects of horizontal WBV in an antero-posterior or medio-lateral direction on balance and gait abilities of stroke survivors.

Material and Methods

Design and setting

A randomized clinical trial was conducted in a rehabilitation center.

Participants

This study was conducted on chronic stroke survivors. Inpatients in a rehabilitation center were recruited through advertisements in the hospital and were screened according to the following criteria: 1) disease period more than 6 months; 2) at least 24 MMSE points; 3) at least 10 m independent gait; 4) no medicines taken that could affect balance; 5) no orthopedic injuries in lower extremities; and 6) no problems in visual and auditory sense. The exclusion criteria were as follows: uncontrolled blood pressure or angina, history of seizure, any intervention other than conventional therapy, or refusal to use WBV. Overall, 30 stroke survivors were recruited, among whom 6 who did not meet the criteria were excluded. The general traits and homogeneity test results of the participants are shown in Table 1.

Table 1. General characteristics of subjects.

Characteristics	Whole body vibration group	Control groups	p
Gender (M/F, %)	6/3 (67/33)	8/4 (67/33)	1.000
Age (year)	59.78 (5.78)	61.25 (10.06)	.700
Height (cm)	166.56 (10.06)	166.42 (9.27)	.974
Weight (kg)	68.00 (10.14)	71.08 (14.51)	.593
Duration (month)	84.11 (10.76)	98.42 (22.76)	.098
Etiology (Infarction/Hemorrhage, %)	6/3 (67/33)	8/4 (67/33)	1.000
Affected side (Lt/Rt, %)	7/2 (78/22)	6/6 (50/50)	.195

MMSE – Mini Mental State Examination, Values are presented as mean (SD).

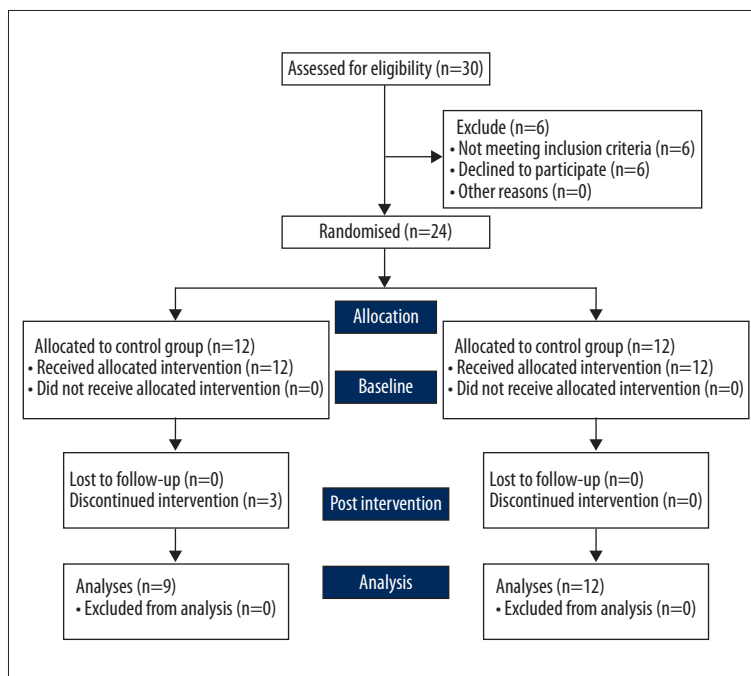


Figure 1. Flow diagram for the study.

Ethical considerations

All participants who fulfilled the inclusion criteria participated in the study after the purpose and procedures of the study were fully explained to them. All procedures were approved by the Kyungnam University Institutional Review Board, and all patients provided signed informed consent prior to participating in the study.

Procedures

Data on the general and medical characteristics of the stroke survivors were collected; then, the subjects were allocated into 2 groups using random number tables: 12 people in the WBV training group and 12 in the control group. In addition, static balance and gait abilities were tested and measured before

and after training. Both groups received conventional rehabilitation training, and for the intervention, WBV conducted in the horizontal direction was additionally applied only in the WBV training group. Two participants who were discharged during the study and 1 person who did not wish to participate in the WBV group were dropped from the study. As a result, 21 survivors (9 people in WBV group and 12 in the control group) participated in the study to the end (Figure 1).

Interventions

Whole-body vibration (WBV) training in the horizontal direction

The WBV (Extream 1000; AMH International Inc., Republic of Korea) was used in this study. The device is a slide-alternating



Figure 2. Whole-body vibration in horizontal direction.

vibrator working as a platform with an amplitude of 30 mm (anterior to posterior) and a frequency of 1–36 Hz. The participants stood on a platform with 8.4 cm inner distance between the heels of both feet, 9° hallux valgus angle of big toes, and vibration amplitude of 3 mm by adjusting the standard distance from the rotatory axis. To concentrate the vibrations on the pelvis of a patient standing independently, they were required to adopt a slight flexion posture in the hip joint, knee joint, and ankle joint (Figure 2). Whole-body vibration training was attempted for 30 min in total, split into 2 sets, with 1 set of 15 min. For 6 weeks, the training was conducted 18 times, 3 times per week. The intensity of vibration was increased depending on the individual’s ability, as shown in Table 2. Before the intervention, procedures for using the device and its safety issues were explained by a research assistant.

Conventional rehabilitation training

Both the whole-body vibration training group and control group had conventional rehabilitation training for 60 min. The conventional rehabilitation training included movement facilitation emphasizing the neurodevelopmental treatment approach, balance training, gait training, and task-specific repetitive functional training. The training programs were selected by the therapist based on individual patient needs [17].

Outcome measures

Static balance

The force platform (PDM Multifunction Force Measuring Plate, Zebris, Germany) was used to measure static balance. This force platform is a 32×47 cm plate with 1504 pressure sensors in it,

Table 2. Progression of intensity in WBV.

Participants	Session																	
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Participants 1	5.5	5.5	5.5	5.5	5.5	5.5	6.5	7.5	7.5	8.5	8.5	8.5	8.5	8.5	8.5	8.5	8.5	8.5
Participants 2	8.5	10.5	10.5	10.5	10.5	10.5	13.5	13.5	13.5	15.5	15.5	17.5	17.5	20.5	20.5	20.5	22.5	23.5
Participants 3	10.5	10.5	10.5	10.5	10.5	10.5	15.5	15.5	15.5	15.5	15.5	15.5	20.5	20.5	22.5	23.5	23.5	24.5
Participants 4	6.5	7.5	8.5	8.5	8.5	9.5	9.5	9.5	9.5	9.5	9.5	9.5	10.5	10.5	10.5	11.5	11.5	12.5
Participants 5	7.5	7.5	7.5	7.5	7.5	7.5	8.5	6.5	6.5	6.5	6.5	6.5	7.5	7.5	7.5	7.5	7.5	8.5
Participants 6	7.5	7.5	7.5	7.5	7.5	7.5	9.5	9.5	9.5	9.5	9.5	9.5	10.5	11.5	11.5	12.5	12.5	12.5
Participants 7	6.5	6.5	6.5	6.5	6.5	6.5	7.5	7.5	8.5	9.5	9.5	9.5	10.5	10.5	10.5	12.5	12.5	12.5
Participants 8	5.5	7.5	7.5	7.5	7.5	7.5	10.5	10.5	10.5	10.5	10.5	10.5	12.5	12.5	12.5	12.5	12.5	13.5
Participants 9	6.5	6.5	6.5	6.5	6.5	6.5	9.5	9.5	10.5	10.5	10.5	10.5	12.5	12.5	15.5	17.5	18.5	18.5

Table 3. Comparison of static balance between whole body vibration and control groups.

		Whole body vibration group		Control groups		p
		Pre	Post	Pre	Post	
Eyes open	Sway velocity (cm/s)	2.76 (0.61) ^a	2.74 (.65) ^a	2.64 (0.59)	2.76 (0.76)	.937 ^b
	Path length (cm)	82.93 (18.22)	82.14 (19.64)	80.82 (15.95)	82.92 (22.74)	.935
	Area (cm ²)	4.36 (2.534)	4.33 (2.748)	4.42 (2.55)	4.09 (2.70)	.841
Eyes close	Sway velocity (cm/s)	3.63 (1.36)	3.67 (1.38)	3.18 (0.814)	3.06 (0.875)	.227
	Path length (cm)	108.91 (40.64)	110.17 (41.16)	95.81 (24.48)	91.86 (26.21)	.228
	Area (cm ²)	8.31 (6.71)	7.71 (6.23)	6.11 (2.86)	5.27 (3.35)	.261

Values are presented as Mean (SD), ^a paired t-test, ^b independent t-test, * p<.05.

one per cm², which measures movement of the COP during taking static standing posture or walking. Its range of pressure is 1–120 N/cm², extraction speed of static pressure is 2–5 Hz, that of dynamic pressure is around 90 Hz, and accuracy is ±5%. Participants stood on the force platform bare-footed in the most comfortable spot. When measured with the participants' eyes opened, they were required to keep their eyes on a 15 cm-diameter dot placed 3 m ahead. When measured with the participants' eyes closed, they had to keep their eyes shut, wearing a blindfold to block light completely and earplugs to ensure accurate measurements. Under these conditions, measurements were performed for 30 s [18]. The participants were given breaks of 3 min at every interval to minimize the effects of the activity on muscle fatigue. Following 3 consecutive measurements, the mean value was used for data collection.

Gait

Walkway (GaitRite, CIR system, Inc., USA) was used to estimate gait function. This Walkway is the device used to test mainly spatiotemporal gait abilities. The participants stood on the front of this Walkway platform, and at an agreed verbal signal from a research assistant, they began walking at the most comfortable speed, while looking ahead, out of the 461×88 cm plate. The ICC of test-retest reliability of this device is 0.72–0.94 [19]. This test was conducted 3 times and its mean value was calculated.

Statistical analysis

All statistical analyses were performed using SPSS 18.0 (IBM Corporation, Armonk, NY, US), and normality test of variables was performed using the Shapiro-Wilk test. The paired-samples *t* test was used for comparison of the difference in before and after dependent variables of training in groups. Differences between the 2 groups at the end of the 6-week training period were assessed using the independent-samples *t* test. The statistical alpha level (α) was set at .05.

Results

Changes in static balance

The changes in sway velocity (cm/s), path length (cm), and area (cm²) are shown in Table 3. With eyes open, the sway velocity was 2.76 (0.61) cm/s before training and 2.74 (0.65) cm/s after training in the WBV training group. In the control group, it was 2.64 (0.59) cm/s and 2.76 (0.76) cm/s, respectively. The path length was 82.93 (18.22) cm before training and 82.14 (19.64) cm after training in the WBV training group. In the control group, it was 80.82 (15.95) cm and 82.92 (22.74) cm, respectively. The sway area was 4.36 (2.534) cm² before training and 4.33 (2.748) cm² after training in the WBV training group. In the control group, it was 4.42 (2.55) cm² and 4.09 (2.70) cm², respectively. All variables with eyes open showed no significant difference between before and after training in each group, and between the groups after training.

With eyes closed, the sway velocity was 3.63 (1.36) cm/s before training and 3.67 (1.38) cm/s after training in the WBV training group. In the control group, it was 3.18 (0.814) cm/s and 3.06 (0.875) cm/s, respectively. The path length was 108.91 (40.64) cm before training and 110.17 (41.16) cm after training in the WBV training group. In the control group, it was 95.81 (24.48) cm and 91.86 (26.21) cm, respectively. The sway area was 8.31 (6.71) cm² before training and 7.71 (6.23) cm² after training in the WBV training group. In the control group, it was 6.11 (2.86) cm² and 5.27 (3.35) cm², respectively. All variables with eyes closed showed no significant difference between before and after training in each group, and between groups after training.

Changes in spatiotemporal gait function

The changes of gait velocity (cm/s), cadence (step/min), step length (cm), stride length (cm), single support time (s), and double support time (s) are shown in Table 4. No significant

Table 4. Comparison of gait between whole body vibration and control groups.

	Whole body vibration group		Control groups		<i>p</i>
	Pre	Post	Pre	Post	
Gait velocity (cm/s)	30.77 (29.25)	34.23 (30.83) ^a	34.51 (19.60)	38.34 (21.30)	.721 ^b
Cadence (step/min)	54.99 (21.64)	63.60 (21.33)*	72.57 (22.69)	75.72 (19.37)	.190
Step length (cm)	30.27 (14.08)	29.99 (15.27)	28.23 (11.09)	29.33 (12.59)	.915
Stride length (cm)	60.68 (28.53)	60.33 (30.70)	56.64 (22.34)	58.87 (25.35)	.906
Single support time (sec)	.48 (0.13)	.41 (0.13)*	0.38 (0.09)	0.36 (0.10)	.407
Double support time (sec)	661.79 (1.17)	1.45 (0.97)	1.21 (1.01)	0.98 (0.61)	.193

Values are presented as Mean (SD), ^a paired t-test, ^b independent t-test, * $p < .05$.

improvement in gait velocity, step length, stride length, and double support time was observed after training compared with before training in both groups. In the WBV training group, however, the cadence changed from 54.99 (21.64) step/min before training to 63.60 (21.33) step/min after, and the single support time also changed significantly from 0.48 (0.13) s before training to 0.41 (0.13) s after ($p < .05$). In the control group, cadence and single support time did not show significant difference between before and after training. Furthermore, in comparison of both groups after training, no significant difference emerged in gait velocity, cadence, step length, stride length, single support time, and double support time all together.

Discussion

The current study was conducted to determine whether the horizontal WBV training for stroke survivors has effects on improvement of static balance and gait function. The results of this study showed no significant difference between the WBV training group and the control group after training. The cadence and single support time in the WBV training group, however, showed significant improvements after training.

Many studies on WBV have been reported. Some studies have reported that WBV significantly improves physical function, while other studies reported that WBV has few effects on improvement of physical function. Hence, the real effects of WBV are still under discussion. WBV involves the use of a vibrating platform in a static position or while performing dynamic movements, which has been suggested as a means of improving functional recovery in prior studies. One study that evaluated the best exercises to improve bone mineral density and bone metabolism in elderly patients, including women with osteopenia and osteoporosis, reported the efficacy of multiple component exercise including aerobics, tolerance, and strength training (Castrogiovanni et al.) [6]. Similar findings were reported by Musumeci et al., with the addition of

the effectiveness of vibration platform training in improving components of the musculoskeletal system in this group of patients [8]. WBV training has also been suggested as a useful alternative to current modalities of improving physical function due to its adaptability to the patient cohort. Pichler et al. [7] found that mechanical stimulation as a result of treadmill and vibration stimulation inhibits the activity of RANKL in osteoporosis, suggesting its possible utility as a therapeutic treatment for diseases of the cartilage such as osteoarthritis.

Chan et al. [20] reported that one-time application of WBV training to chronic stroke survivors had significant effects on spasticity, weight shift, and gait function compared with the control group. However, Brogardh et al. [21] reported no significant effects on muscle strength, balance, and gait after application of WBV exercise to chronic stroke survivors 12 times for 6 weeks. Likewise, Marind et al. [22] reported no significant effects on muscle strength, muscle architecture, and balance after application of WBV exercise to stroke survivors 17 times for 3 months. The present study also found no significant effects on balance and gait between the 2 groups, as well as showing a negative effect on horizontal WBV. The WBV used in this study provides horizontal vibration in an antero-posterior or medio-lateral direction when in standing posture, and this vibration can cause the COP of the body to keep moving in a dynamic posture rather than providing sensory stimulation in static posture. In other words, it could have more effects on dynamic balance than static balance. In addition, we did not investigate the effects on dynamic balance, and the subjects in the WBV training group showed significant improvement in static balance. Furthermore, it seems that the effects of conventional rehabilitation training could be weak since the control group also consisted of chronic stroke survivors whose potential for recovery was very low.

Given that Keenan et al. [23] reported a positive correlation between gait function and balance, the finding of no significant differences in gait function between the 2 groups in the

present study is probably due to the fact that no improvement in balance was observed. Nevertheless, the WBV used in this study was horizontal, and it could be different from WBV used in previous studies, which generally provides vibration in a vertical or rotatory direction. Therefore, the results of this study showed that WBV had no significant effect, similar to the findings of some previous studies, but, notably the WBV used in this study was different from that used in the previous studies. The use of the same WBV form as in the previous studies will enable a fair assessment. The slow gait velocity of stroke survivors is associated with decrease of cadence [24], and when compared with healthy adults, it was characterized by decrease in cadence, increase in gait cycle time and double support period, and decrease in support phase, as well as increase in the swing phase of affected sides compared with unaffected sides [25]. In this study, after the WBN training, the WBV training group showed significant effects ($p < .05$) in cadence and single support time of support phase, which were the gait variables. These results are supported by some previous studies. Chan et al. [20] reported a significant increase of weight bearing of the affected side in body weight loading measured by the force plate after WBV training, and found that the effects of weight bearing reduce plantar flexion and inversion of the affected side of the ankle. Furthermore, they stated that such an improvement of motor control of ankle could be used in a range of motion in the ankle in relation to balance during ambulation and help maintain balance [26]. Although this study did not investigate weight bearing, the effects on cadence and single support time can be caused by an improvement of ability to shift weight. The WBV we used provides horizontal vibration, and since even healthy adults can have muscle fatigue when the frequency in WBV training is more than 30 Hz [27], most studies with stroke survivors used a frequency of WBV under the maximum 30 Hz, according to each patient's sensibility, and set amplitude at 3 mm, the same as for healthy adults [27,28]. In the present study, the frequency of WBV was 10~20 Hz and amplitude was 30 mm. The vibration provided under these conditions would cause the subjects' weight to shift in an antero-posterior or medio-lateral direction, and especially the vibration in a medio-lateral direction would provide the experience where weight shifts to the affected side. These effects of WBV could have helped improve cadence, along with improving single support time to the affected side. Nonetheless, cadence and single support time showed no significant differences in comparison with

the control group after the training, and no significant improvement was observed in other gait parameters (e.g., gait velocity, double support time, step length, and stride length) and all variables such as balance function. Therefore, the effects of WBV are still unclear.

The present study clearly demonstrated that horizontal WBV training has no positive effects on improving static balance and spatiotemporal gait function of chronic stroke survivors. However, the significant improvements, noted in some of the gait parameters after training compared with before training, suggest the potential of horizontal WBV as an effective intervention. Nonetheless, the results of this study and some limitations cannot prove the effects of WBV. In particular, the limitations of this study could be the small number of participants and relatively short period of 6 weeks of WBV application. In addition, the study did not clearly show frequency, amplitude, and intensity of vibration, which can be determinants of the effects of application of WBV.

Therefore, future studies will need to make up for the limitations of this study and verify more plainly the effects of WBV. In addition, the comparison of horizontal WBV used in this study with vertical or rotatory WBV, which is used more generally, should be performed to determine which form of WBV is more effective.

Conclusions

The present study was one of the few studies conducted to determine whether the horizontal WBV training for stroke survivors has effects on the improvement of static balance and gait function. The results of this study showed that the cadence and single support time in the WBV training group showed significant improvements after training. However, in this study, there were a few limitations, including the small number of participants, the relatively short period of WBV application (6 weeks), and the failure to clearly show frequency, amplitude, and intensity of vibration, which can be determinants of the effects of application of WBV. Thus, based on these results, WBV training in the horizontal direction may have a few positive effects on balance and gait function in chronic stroke survivors; however, further studies are needed to determine and accurately elucidate the effect of WBV training in the horizontal direction.

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