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

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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.
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...
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.

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

Figure 2. Whole-body vibration in horizontal direction.
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)                 | 2.74 (0.65)    | 2.64 (0.59)  | 2.76  | 0.76 | .937†   |
| Path length (cm)     | 82.93 (18.22)               | 82.14 (19.64)  | 80.82 (15.95)| 82.92 | 22.74 | .935    |
| Area (cm²)           | 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 (cm²)           | 8.31 (6.71)                 | 7.71 (6.23)    | 6.11 (2.86)  | 5.27  | 3.35 | .261    |

Values are presented as Mean (SD), * paired t-test, † independent t-test, ‡ p<.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 3.18 (0.814) cm² and 3.06 (0.875) 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) cm², 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
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
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.
References:

1. Garland SI, Gray VL, Knorr S: Muscle activation patterns and postural control following stroke. Motor Control, 2009; 13: 387–411
2. Langhorne P, Coupar F, Pollock A: Motor recovery after stroke: A systematic review. Lancet Neurol, 2009; 8: 741–54
3. Ursin MH, Bergland A, Fure B et al: Gait and balance one year after stroke: Relationships with lesion side, subtypes of cognitive impairment and neuroradiography findings-a longitudinal, cohort study. Physiotherapy, 2018 [Epub ahead of print]
4. Veebeek JM, van Wegen E, van Peppen R et al: What is the evidence for physical therapy poststroke? A systematic review and meta-analysis. PLoS One, 2014; 4: e87987
5. Lu J, Xu G, Wang Y: Effects of whole-body vibration training on people with chronic stroke: A systematic review and meta-analysis. Top Stroke Rehabil, 2015; 22: 161–68
6. Castrogiovanni P, Trovato FM, Szychlinska MA et al: The importance of muscle activation patterns and postural control following stroke. Motor Control, 2009; 13: 387–411
7. Pichler K, Loreto C, Leonardi R et al: RANKL is downregulated in bone cells by physical activity (treadmill and vibration stimulation training) in rat with glucocorticoid-induced osteoporosis. Histol Histopathol, 2013; 28: 1185–96
8. Musumeci G, Loreto C, Leonardi R et al: The effects of physical activity on apoptosis and lubricin expression in articular cartilage in rats with glucocorticoid-induced osteoporosis. J Bone Miner Metab, 2013; 31: 274–84
9. van Nes II, Geurts AC, Hendricks HT, Duysens J: Short-term effects of whole-body vibration on postural control in unilateral chronic stroke survivors: Preliminary evidence. Am J Phys Med Rehabil, 2004; 83: 867–73
10. Cheng PT, Wu SH, Liaw MY et al: The effects of whole-body vibration on ankle plantarflexion spasticity and gait performance in survivors with chronic stroke: A randomized controlled trial. Clin Rehabil, 2012; 26: 1087–95
11. Lebedev MA, Poliakov AV: Analysis of the interference electromyogram of human soleus muscle after exposure to vibration. Neurorheologija, 1991; 23: 57–65
12. Berg K, Norman KE: Functional assessment of balance and gait. Clin Geriatr Med, 1996; 12: 705–23
13. Nasher LM, Mccullom G: The organization of human postural movements: A formal basis and experimental synthesis. Behav Brain Sci, 1985; 8: 135–72
14. Riccio GE, Stoffregen TA: Affordances as constraints on the control of stance. Hum Movement Sci, 1988; 7: 265–300
15. Müller ML, Redfern MS: Correlation between EMG and COP onset latency in response to a horizontal platform translation. J Biomech, 2004; 37: 1513–81
16. Horak FB, Nashner LM: Central programming of postural movements: Adaptation to altered support-surface configurations. J Neurophysiol, 1986; 55: 1369–81
17. Mesci N, Ozdemir F, Kabayel DD, Tokuc B: The effects of neuromuscular electrical stimulation on clinical improvement in hemiplegic lower extremity rehabilitation in chronic stroke: A single-blind, randomised, controlled trial. Disabil Rehabil, 2009; 31: 2047–54
18. Park DS, Lee G: Validity and reliability of balance assessment software using the Nintendo Wii balance board: Usability and validation. J Neuroeng Rehabil, 2014; 11: 99
19. Kuys SS, Brauer SG, Ada L: Test-retest reliability of the GAITRite system in people with stroke undergoing rehabilitation. Disabil Rehabil, 2011; 33: 1848–53
20. Chan KS, Liu CW, Chen TW et al: Chen, Effects of a single session of whole-body vibration on ankle plantarflexion spasticity and gait performance in survivors with chronic stroke: A randomized controlled trial. Clin Rehabil, 2012; 26: 1087–95
21. Brogårdh C, Flansbjer UB, Lexell J: No specific effect of whole-body vibration training in chronic stroke: A double-blind randomized controlled study. Arch Phys Med Rehabil, 2012; 93: 253–58
22. Marin PI, Ferrero CM, Menéndez H et al: Effects of whole-body vibration on muscle architecture, muscle strength, and balance in stroke survivors: A randomized controlled trial. Am J Phys Med Rehabil, 2013; 92: 881–88
23. Keenan MA, Perry L, Jordan C: Factors affecting balance and ambulation following stroke. Clin Orthop Relat Res, 1984; 182: 165–71
24. Wagenaar RC, Beek WJ: Hemiplegic gait: A kinematic analysis using walking speed as a basis. J Biomech, 1992; 25: 1007–15
25. Von Schroeder HP, Coutts RD, Lyden PD et al: Gait parameters following stroke: A practical assessment. J Rehabil Res Dev, 1995; 32: 1848–53
26. Mecagni C, Smith JP, Roberts KE, O'Sullivan SB: Balance and ankle range of motion in community-dwelling women aged 64 to 87 years: A correlational study. J Biomech, 2000; 33: 1004–11
27. van Nes II, Latour H, Schils F et al: Long-term effects of 6-week whole-body vibration on balance recovery and activities of daily living in the postacute phase of stroke: A randomized, controlled trial. Stroke, 2006; 37: 2331–35
28. Tihanyi TK, Horváth M, Fazekas G et al: One session of whole-body vibration in horizontal direction increases voluntary muscle strength transiently in survivors with stroke. Clin Rehabil, 2007; 21: 782–93