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Original Article

Modulating Effects of Whole-body Vibration on Cortical Activity and Gait Function in Chronic Stroke Patients

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HIGHLIGHTS

- Whole-body vibration exercise (WBVe) can provide proper somatosensory stimulation.
- WBVe increased the cortical activity in the bilateral sensorimotor cortex.
- WBVe improved gait speed and balance related to the gait function.

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Modulating Effects of Whole-body Vibration on Cortical Activity and Gait Function in Chronic Stroke Patients

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ABSTRACT

Whole-body vibration exercise (WBVe) can provide proper somatosensory stimulation and improve muscle strength in stroke patients. This study investigated the effects of WBVe on gait function and cortical activity in patients with chronic stroke. Thirty stroke patients were randomly assigned to either the WBVe or the control group. The WBVe group received the vibration in a half-squat position for 5 minutes at an intensity of 20 Hz. The control group kept the same posture but did not receive the vibration. Cortical activity was investigated using functional near-infrared spectroscopy (fNIRS). Gait function was assessed by a 10-m walk test (10MWT), a timed up and go (TUG) test, a Fugl-Meyer Assessment, and a Tinetti Performance-Oriented Mobility Assessment (TPOMA). In group analysis of the fNIRS data, oxygenated hemoglobin concentration was significantly increased in the ipsilesional supplementary motor area, bilateral sensorimotor cortex, and contralesional prefrontal cortex in the WBVe group compared to the control group ($p < 0.05$). Functional assessment demonstrated a significant interaction between time and group for the 10MWT and TUG test, suggesting that the WBVe group demonstrated meaningful improvement after intervention ($p < 0.05$). These results suggested that WBVe modulated the cerebral cortical activities and resulted in improvement of gait function in chronic stroke patients.

Trial Registration: ClinicalTrials.gov Identifier: NCT03375346

Keywords: Vibration; Near-infrared spectroscopy; Cortical excitability; Stroke; Gait

INTRODUCTION

Stroke is one of the leading causes of adult disability [1]. Stroke rehabilitation is a process through which patients with disabilities as a result of stroke manage to resume activities of daily living and reestablish their normal lifestyle through a learning process [2]. For patients with chronic stroke, the following rehabilitation approaches have been recommended

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Conflict of Interest
The authors have no potential conflicts of interest to disclose.

to improve mobility: muscle strengthening exercises, aerobic exercise, balance training, constraint-induced movement therapy, and noninvasive brain stimulation [3].

Whole-body vibration exercise (WBVe) has been suggested as a way to improve muscle function, muscle strength, and gait function in patients with stroke [4]. WBVe is a stimulus that uses vibrations generated on a machine, with oscillatory movement determined by the amplitude and frequency of the vibration [5]. WBVe also includes standing or performing movements on a vibration platform placed on a static surface. A recent systematic review and randomized controlled study revealed that WBVe was efficient in improvement of lower limb strength, ankle spasticity, balance, postural control, and mobility in stroke patients [6,7]. Other reports also suggested that WBVe induced changes in the corticospinal excitability and cortical activity in stroke patients [8,9]. Evidence from neuroimaging studies revealed the existence of cortical involvement in standing, walking, and balancing by using functional neuroimaging modalities such as functional magnetic resonance imaging, single-photon emission computed tomography, and positron emission tomography which led to the identification of supraspinal locomotor networks [10-12].

In addition, functional near-infrared spectroscopy (fNIRS) is a unique, noninvasive functional neuroimaging tool that offers several potential advantages, including less onerous constraints during measurement, a relatively small and portable structure, and a high degree of safety and noninvasiveness [13]. Because of these advantages, fNIRS can be utilized as a monitoring tool in the underpinnings of dynamic motor tasks such as posture and gait control in neurorehabilitation. Miyai et al. [14] reported gait-related cortical activation while walking on a treadmill, which showed symmetrical activation in the medial sensorimotor cortex (SMC) and supplementary motor area (SMA). Also, a longitudinal study using fNIRS revealed that the motor-related cortex activation in the affected hemisphere of patients with stroke increased with functional recovery [15]. Recent studies have reported significant changes in cortical activation during active ankle movements after WBVe intervention in stroke patients [8]. Even though WBVe is positive for cortical activation, there has been no report of changes in cortical activation during real-time WBVe in stroke patients. With this knowledge, WBVe can be utilized as an adjunctive therapeutic tool for neurorehabilitation of stroke patients.

Thus, the aim of the present study was to investigate the modulating effects of short-term WBVe on cortical activity and gait function in patients with chronic hemiplegic stroke.

MATERIALS AND METHODS

Participants

The study was designed with a randomized controlled trial in patients with chronic stroke over 6 months after onset. Patients were enrolled in this study with the following inclusion criteria: 1) patients who suffered from their first-ever stroke for more than six months after stroke onset, and 2) unilateral hemiplegia or hemiparesis with the ability to walk at least 10 m without assistive devices. Patients were excluded if they were aged younger than 19 years or older than 80 years or could not perform a half-squat on a vibration platform due to problems such as visual field defects pain, balance deficit, or a risk of falling due to dizziness. Pregnant women were also not allowed to participate in the present study. In total, 30 participants were included in our investigation. All participants gave informed consent after receiving

both verbal and written information about the study and its possible risks. The study was approved by the Institutional Review Board of Samsung Medical Center according to the Declaration of Helsinki (IRB no. 2015-07-092). This study was registered at ClinicalTrials.gov (NCT03375346).

Experimental protocol and procedure

Out of 30 participants, 15 were randomly assigned to the WBVe group receiving a single session of WBVe via a vibrating platform (Galileo® Med S; Novotec Medical, Pforzheim, Germany) with a vibration frequency of 20 Hz and amplitude of 4 mm while keeping a half-squat position on the platform. We used rotational vibration to follow the report of Zaidell et al. [16], which suggested that rotational vibration may be a safe platform to minimized head vibration and more suitable for subjects who cannot keep balance in the squatting position. The control group participated in the same session with the same posture without the application of vibration. The evaluator was blinded as to which group each subject belonged. After the pre-session functional assessment, all participants performed an experimental or control session with simultaneous fNIRS measurement (Fig. 1). Following an initial 10-second preparation period, participants remained standing on the tilt table over the stationary platform during the next 5 minutes, and baseline fNIRS activity was recorded. Participants were then instructed to maintain a half-squat position (knee joint angle at 160 deg) with an incline of 60 deg [17]. After a 3-minute half-squat position period, WBVe was delivered for 5 minutes. The fNIRS was measured until one additional minute after the end of WBVe while each subject maintained the same position (i.e., half-squat).

Outcome assessments

The primary outcome measure of this study was cerebral cortical activity based on changes in oxygenated hemoglobin (oxyHb) concentration during WBVe, acquired by fNIRS. Secondary outcome measures were functional assessment data obtained before and after the intervention using the 10-m walk test (10MWT) [18], a timed up and go (TUG) test [19], a Fugl-Meyer Assessment (FMA) [20], and a Tinetti Performance-Oriented Mobility Assessment (TPOMA) [21].

The fNIRS

In the present study, we used the NIRScout® system (NIRx Medical Technology, Berlin, Germany), which is a multi-modal compatible fNIRS platform. This system consisted of 8 sources and 16 detectors which covered the cortical areas of the sensorimotor cortex, premotor cortex (PMC), supplementary motor area, and prefrontal cortex (PFC) using 31 channels of interest. The NIRScout® used two different wavelengths, 760 nm and 850

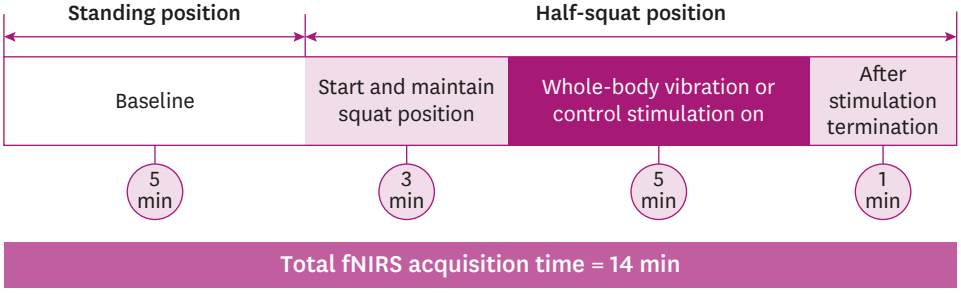

Fig. 1. Experimental protocol. Experimental design for the WBVe study.
WBVe, whole-body vibration exercise; fNIRS, functional near-infrared spectroscopy.

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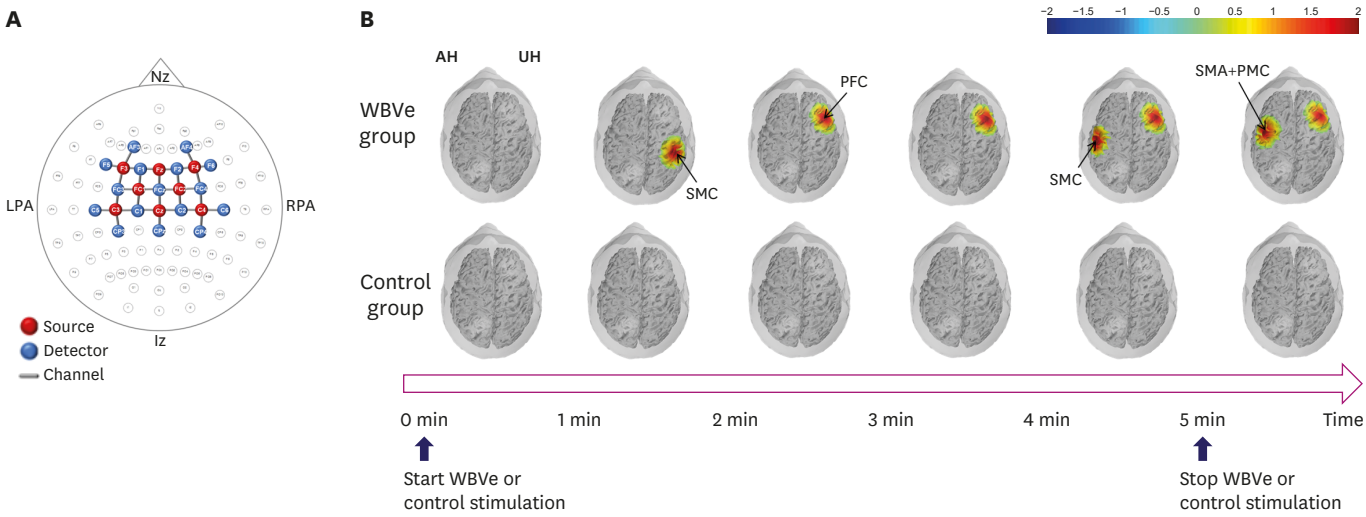

Fig. 2. Arrangement of the fNIRS measurement channels and cortical activation patterns during WBVe. (A) Arrangement of the 31 fNIRS measurement channels across the brain. (B) Results of group SPM analysis for fNIRS data: t-contrast map of oxygenated hemoglobin concentration compared to starting baseline are presented in the WBVe group (n = 15) and the control group (n = 14) over time ($p < 0.05$).
fNIRS, functional near-infrared spectroscopy; WBVe, whole-body vibration exercise; SPM, statistical parametric mapping; SMC, sensorimotor cortex; PMC, premotor cortex; PFC, prefrontal cortex; LPA, left pre-auricular points; RPA, right pre-auricular points; Nz, the nasion; Iz, the inion; AH, affected hemisphere; UH, unaffected hemisphere.

nm, with the sampling rate set to 7.81 Hz. The optodes were positioned according to the international 10/10 system and the channel distance (i.e., the distance between the source and detector) was 3.0 cm (Fig. 2A).

Changes in oxyHb concentration were recorded using the nirsLAB™ software (v. 2016.05; NIRx Medical Technologies, LLC, Minneapolis, MN, USA). To investigate cortical activity according to the brain lesion side of stroke patients, a flip from the right to left was performed in the data preprocessing stage in cases of a right-side brain lesion. Thus, the lesions of all included stroke patients were set on the left.

Discontinuities and spike artifacts of signals obtained from the 31 channels were removed and replaced by the nearest signals. The raw data were first low-pass filtered at 0.1 Hz to remove baseline noise [22] and to eliminate possible respiration and heart rate signals [23]. Although oxyHb and deoxyhemoglobin (deoxyHb) signals were obtained, only oxyHb concentration was used for analysis due to its superior signal-to-noise ratio relative to deoxyHb [24]. The oxyHb concentration was calculated from preprocessed filtered data using a modified Beer-Lambert law for each of the 31 channels [25]. The oxyHb mean value of each channel of each subject was calculated over 540 seconds after baseline measurement.

Statistical analysis

Functional assessment data was analyzed using SPSS v. 20.0 (IBM Corp., Armonk, NY, USA). To assess normality in the analyzed parameters, the Shapiro-Wilk test was used. Fisher's exact test was used in the categorical variables, and the continuous variables were tested with an independent t-test when they were parametric, and the Mann-Whitney U test when they were nonparametric. The effect of WBVe was evaluated with a repeated measures analysis of variance with time and condition (WBVe or control) as independent variables. The statistical significance level was set at 0.05.

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This study examined the oxyHb difference between the WBVe group and the control group during the intervention periods. The fNIRS measurement data analysis was performed using the statistical parametric mapping [26] package of the nirsLAB™ software for significant cortical activation during stimulation. An uncorrected threshold of p = 0.05 was used to display the region. The within-subject analysis was used to identify changes in each cortical signal of the participants. Following the completion of the within-subject analysis, the between-subject analysis was performed to confirm the difference in signal changes before and during the intervention in each group. The t-statistic maps computed for group analysis were plotted onto a conventional brain template. The SMC area related to balance and mobility was selected as the region of interest (ROI). For comparison of the activities of the SMC between the groups, the mean values of the oxyHb were obtained from the averages of the ROI channels. Paired t-test was performed to compare the values between the baseline period and the stimulation period point, and unpaired t-test was performed to compare the values between groups at a defined time-point in the stimulation period. The statistical significance level was set at 0.05.

RESULTS

One patient who complained of fatigue during the experiment period dropped out of the control group. Therefore, 29 patients with chronic stroke (15 in the WBVe group and 14 in the control group) completed this study. There were no significant differences in general characteristics or motor function at baseline between the 2 groups (Table 1). No serious adverse effect other than fatigue in one participant was reported during or after the experimental session.

Table 1. Demographic and clinical characteristics of the participants

Group	WBVe group (n = 15)	Control group (n = 14)	p value
Age (yr)	58.73 ± 9.09	53.42 ± 9.55	0.245*
Gender	15	14	1.000†
Men	12 (80.0)	11 (78.6)	
Women	3 (20.0)	3 (21.4)	
Side of stroke lesion	15	14	0.427†
Left hemisphere	9 (60.0)	11 (78.6)	
Right hemisphere	6 (40.0)	3 (21.4)	
Type of stroke	15	14	1.000†
Infarction	10 (66.7)	10 (71.4)	
Hemorrhage	5 (33.3)	4 (28.6)	
10MWT (sec)	13.07 ± 6.13	9.07 ± 4.26	0.057‡
TUG test (sec)	17.03 ± 8.89	11.34 ± 5.83	0.051‡
FMA			
FMA total	76.36 ± 28.39	80.29 ± 24.30	0.769‡
FMA upper extremity	48.21 ± 23.37	51.93 ± 15.42	1.000‡
FMA lower extremity	28.14 ± 7.39	28.36 ± 9.23	0.667‡
TPOMA			
Total score	19.50 ± 5.29	19.46 ± 5.21	0.981‡
Gait score	9.00 ± 2.22	8.77 ± 2.20	0.830‡
Balance score	10.50 ± 3.35	10.69 ± 3.15	0.981‡

Values are expressed as number (%) or mean ± standard deviation.
WBVe, whole-body vibration exercise; 10MWT, 10-m walk test; TUG, timed up and go; FMA, Fugl-Meyer Assessment; TPOMA, Tinetti Performance-Oriented Mobility Assessment.
*The p values for categorical variables are based on an independent t-test; †Fisher's exact test; ‡Mann-Whitney U test.

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Table 2. Changes in gait function and balance after intervention

Group	WBVe group (n = 15)		Control group (n = 14)		p value
	Before	After	Before	After	
10MWT (sec)	13.07 ± 6.13	11.65 ± 5.09	9.07 ± 4.26	9.07 ± 4.01	0.006*
TUG test (sec)	17.03 ± 8.89	14.21 ± 6.59	11.34 ± 5.83	10.58 ± 5.12	0.011*
FMA total	76.36 ± 28.39	76.50 ± 28.50	80.29 ± 24.30	80.29 ± 23.10	0.795
FMA UE	48.21 ± 23.37	48.29 ± 23.42	51.93 ± 15.42	51.79 ± 14.84	0.530
FMA LE	28.14 ± 7.39	28.21 ± 7.44	28.36 ± 9.23	28.50 ± 8.783	0.825
TPOMA total	19.50 ± 5.29	19.64 ± 5.11	19.46 ± 5.21	19.46 ± 5.21	0.169
TPOMA gait	9.00 ± 2.22	9.07 ± 2.09	8.77 ± 2.20	8.77 ± 2.20	0.345
TPOMA balance	10.50 ± 3.35	10.57 ± 3.30	10.69 ± 3.15	10.69 ± 3.15	0.345

Values are expressed as the mean ± standard deviation.
WBVe, whole-body vibration exercise; 10MWT, 10-m walk test; TUG, timed up and go; FMA, Fugl-Meyer Assessment; UE, upper extremity; LE, lower extremity; TPOMA, Tinetti Performance-Oriented Mobility Assessment.
*Results of the 2-way analysis of variance test showed a difference between the 2 groups ($p < 0.05$).

Functional assessments

Functional data analysis revealed a significant effect of time ($F = 7.034$; $p = 0.013$) and an interaction between time and group ($F = 8.717$; $p = 0.006$) for the 10MWT. The TUG test also demonstrated a significant effect of time ($F = 17.991$; $p < 0.001$) and an interaction between time and group ($F = 6.561$; $p = 0.016$). However, there were no significant effects seen via FMA or TPOMA (Table 2). Therefore, our findings indicate that 5 minutes of WBVe produced a positive effect on gait function but not on motor impairments or mobility in chronic stroke patients.

fNIRS results

Fig. 2 shows the cortical activation patterns in terms of oxyHb in response to the stimulation in the WBVe group and the control group. The cortical maps showed regions with statistically significant differences between baseline and stimulation block over a time window of 1 minute. As a result of the group analysis, the oxyHb concentration was significantly increased in the ipsilesional SMA, bilateral SMC, and contralesional PFC in the WBVe group over time ($p < 0.05$). There were no significant changes during the first minute of WBVe stimulation, but after 1 minute the oxyHb increased in the order of contralesional SMC, contralesional PFC and ipsilesional SMC. There was a significant increase in contralesional PFC and ipsilesional SMA for 1 minute after stimulation was terminated. However, there were no significant change in the control group (Fig. 2B).

Grand averaged values of oxyHb over a time window of 1 minute are reported in Fig. 3 in order to better elucidate the temporal dynamics of the acquired signals. In the WBVe group, there was a significant increase in oxyHb of the ipsilesional SMC compared to baseline in the 3 to 5 minutes after the onset of stimulation ($p < 0.05$). Compared to the control group, the ipsilesional SMC in the WBVe group showed higher activation in the stimulation period ($p < 0.05$).

DISCUSSION

The results of the present study demonstrated that short-term WBVe induced activation of the motor-related cerebral cortical areas and improved gait function in chronic stroke patients. Gait speed after short-term WBVe was faster in chronic stroke patients, although motor impairment, mobility, and balance displayed no significant changes. These findings corresponded with those of earlier studies showing that ankle joint control was improved by WBVe, which could contribute to gait speed [27]. Improvement of gait speed is also clinically important in relation to improving a patient's mobility function and quality of life

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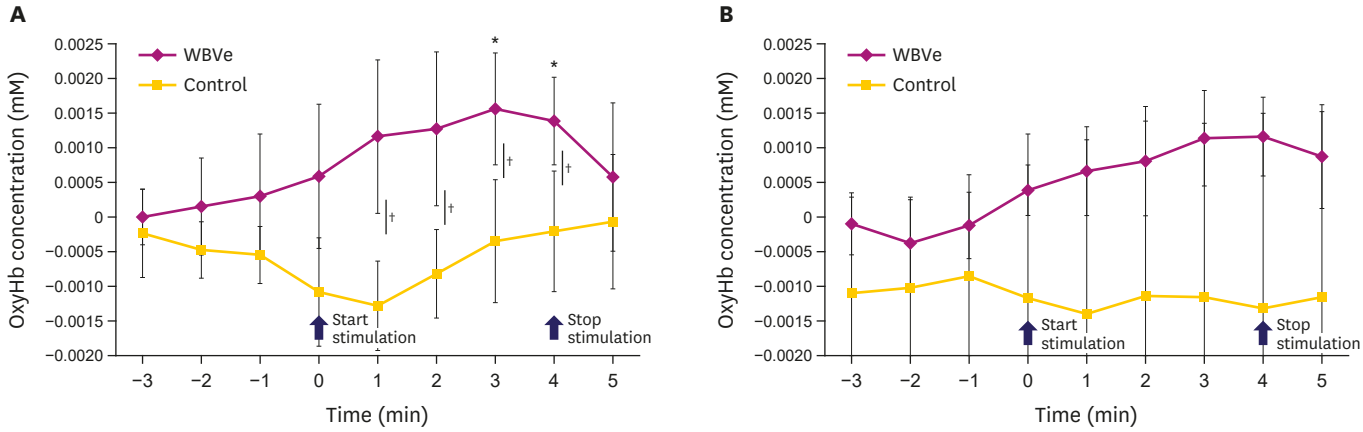

Fig. 3. Mean oxyHb changes in the SMC during WBVe. Results of oxyHb time series changes obtained by the fNIRS demonstrated significant mean oxyHb concentration changes in the affected SMC (A), but not in the unaffected SMC (B).
SMC, sensorimotor cortex; WBVe, whole-body vibration exercise; fNIRS, functional near-infrared spectroscopy; oxyHb, oxygenated hemoglobin.
*Paired t-test was performed to compare the values between baseline and at a defined time-point ($p < 0.05$); †Unpaired t-test was performed to compare the values between groups at a defined time-point ($p < 0.05$).

after stroke by promoting changes in indoor gait function [28]. Other studies reported that improvement in motor performance by WBVe temporarily altered the cortical function [8,9], and then led to an increase in cortical-spinal excitability as the effect of vibration exercise [8]. Therefore, after determining its long-term effects, WBVe might be suggested as an additional therapeutic modality for improving gait function in chronic stroke patients.

To the best of our knowledge, this is the first real-time fNIRS imaging study of WBVe in stroke. The fNIRS data in this study revealed increased cortical activities observed in the ipsilesional SMA, contralesional PFC, and bilateral SMC after WBVe application when compared with the control group. In previous fNIRS reports, activation of the bilateral SMA and SMC were observed during treadmill walking in stroke patients [14]. Previous studies also reported that the SMA appears to play a role in the early stages of movement representation and planning. These results are consistent with functional imaging studies using PET [29] and fNIRS [14] that involved the SMA in human locomotion. Increased SMA activity might be due to movement preparation and stepping reactions to prevent participants from falling [14]. In the present study, WBVe obviously produced activation of the SMA similar to treadmill walking, even without movement in the lower limb joints.

It has been reported that the PFC is essential for postural control in hemiplegic patients after stroke [30]. The PFC activity might reflect the role of maintaining attention, controlling executive function, and regulating postural control [31]. Stroke patients may need to recruit the PFC to compensate for reduced cognitive and/or motor control in locomotion [32]. Therefore, the increased PFC activity seen during and after WBVe can be interpreted as increasing attention paid to maintaining posture and motor control.

Cerebral cortical activities were also increased in the bilateral SMC during and after WBVe. Following passive cycling, activation in the SMC, SMA, and PMC areas was reported [33]. Activation of the SMC occurred not only in active movement but also during passive movement of the upper limb in patients with stroke [34]. The SMC is additionally known to be involved in locomotion control with subcortical structures and the spinal cord, along with an estimated central pattern generator [35]. Assuming that WBVe represents passive exercise

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training done through proprioceptive stimulation, our findings seem to be consistent with those of previous studies.

The present study has some limitations. First, the duration of the WBVe was relatively short, with only a single session. However, our results may provide the rationale for further studies investigating the changes in cerebral cortical activity after a more extended period of vibratory stimulation, as well as long-term changes of cortical activity after repeated WBVe sessions. Second, we could not compare the effect of WBVe according to the stroke lesion or severity of motor impairment because of the relatively small subject size. Third, although there was no significant difference in initial TUG and 10MWT between the groups, the final differences in these measures were rather large. In future study, it may be necessary to obtain the cortical activity changes from a larger number of patients having different stroke lesions or motor disorders, and use advanced imaging analysis techniques, such as network analysis, to adjust for initial differences.

Despite these limitations, we found that a single session of WBVe increased cortical activity in the specific motor-related cortices in chronic stroke patients. Based on these results, further studies are recommended to confirm the possibility of WBVe as a tool of neurorehabilitation for stroke patients. By measuring the long-term effects of repeated WBVe on neural plasticity in stroke patients, WBVe can be suggested as an ancillary rehabilitation treatment method for use with these patients.

REFERENCES

1. Tankisheva E, Bogaerts A, Boonen S, Feys H, Verschueren S. Effects of intensive whole-body vibration training on muscle strength and balance in adults with chronic stroke: a randomized controlled pilot study. Arch Phys Med Rehabil 2014;95:439-446.
PUBMED | CROSSREF
2. Park YJ, Park SW, Lee HS. Comparison of the effectiveness of whole body vibration in stroke patients: a meta-analysis. BioMed Res Int 2018;2018:5083634.
PUBMED | CROSSREF
3. Hatem SM, Saussez G, Della Faille M, Prist V, Zhang X, Dispa D, Bleyenheuft Y. Rehabilitation of motor function after stroke: a multiple systematic review focused on techniques to stimulate upper extremity recovery. Front Hum Neurosci 2016;10:442.
PUBMED | CROSSREF
4. Lee G. Does whole-body vibration training in the horizontal direction have effects on motor function and balance of chronic stroke survivors? A preliminary study. J Phys Ther Sci 2015;27:1133-1136.
PUBMED | CROSSREF
5. Lau RW, Yip SP, Pang MY. Whole-body vibration has no effect on neuromotor function and falls in chronic stroke. Med Sci Sports Exerc 2012;44:1409-1418.
PUBMED | CROSSREF
6. Alashram AR, Padua E, Annino G. Effects of whole-body vibration on motor impairments in patients with neurological disorders: a systematic review. Am J Phys Med Rehabil 2019;98:1084-1098.
PUBMED | CROSSREF
7. Huang M, Pang MY. Muscle activity and vibration transmissibility during whole-body vibration in chronic stroke. Scand J Med Sci Sports 2019;29:816-825.
PUBMED | CROSSREF
8. Miyara K, Kawamura K, Matsumoto S, Ohwatashi A, Itashiki Y, Uema T, Noma T, Ikeda K, Shimodozono M. Acute changes in cortical activation during active ankle movement after whole-body vibration for spasticity in hemiplegic legs of stroke patients: a functional near-infrared spectroscopy study. Top Stroke Rehabil 2020;27:67-74.
PUBMED | CROSSREF

9. Mileva KN, Bowtell JL, Kossev AR. Effects of low-frequency whole-body vibration on motor-evoked potentials in healthy men. Exp Physiol 2009;94:103-116.
PUBMED | CROSSREF
10. Wittenberg E, Thompson J, Nam CS, Franz JR. Neuroimaging of human balance control: a systematic review. Front Hum Neurosci 2017;11:170.
PUBMED | CROSSREF
11. la Fougère C, Zwergal A, Rominger A, Förster S, Fesl G, Dieterich M, Brandt T, Strupp M, Bartenstein P, Jahn K. Real versus imagined locomotion: a [^{18}F]-FDG PET-fMRI comparison. Neuroimage 2010;50:1589-1598.
PUBMED | CROSSREF
12. Zwergal A, la Fougère C, Lorenzl S, Rominger A, Xiong G, Deutschenbaur L, Schöberl F, Linn J, Dieterich M, Brandt T, Strupp M, Bartenstein P, Jahn K. Functional disturbance of the locomotor network in progressive supranuclear palsy. Neurology 2013;80:634-641.
PUBMED | CROSSREF
13. Mihara M, Miyai I. Review of functional near-infrared spectroscopy in neurorehabilitation. Neurophotonics 2016;3:031414.
PUBMED | CROSSREF
14. Miyai I, Tanabe HC, Sase I, Eda H, Oda I, Konishi I, Tsunazawa Y, Suzuki T, Yanagida T, Kubota K. Cortical mapping of gait in humans: a near-infrared spectroscopic topography study. Neuroimage 2001;14:1186-1192.
PUBMED | CROSSREF
15. Miyai I, Yagura H, Hatakenaka M, Oda I, Konishi I, Kubota K. Longitudinal optical imaging study for locomotor recovery after stroke. Stroke 2003;34:2866-2870.
PUBMED | CROSSREF
16. Zaidell LN, Pollock RD, James DC, Bowtell JL, Newham DJ, Sumners DP, Mileva KN. Lower body acceleration and muscular responses to rotational and vertical whole-body vibration at different frequencies and amplitudes. Dose Response 2019;17:1559325818819946.
PUBMED | CROSSREF
17. Yang F, King GA, Dillon L, Su X. Controlled whole-body vibration training reduces risk of falls among community-dwelling older adults. J Biomech 2015;48:3206-3212.
PUBMED | CROSSREF
18. Green J, Forster A, Young J. Reliability of gait speed measured by a timed walking test in patients one year after stroke. Clin Rehabil 2002;16:306-314.
PUBMED | CROSSREF
19. Ng SS, Hui-Chan CW. The timed up & go test: its reliability and association with lower-limb impairments and locomotor capacities in people with chronic stroke. Arch Phys Med Rehabil 2005;86:1641-1647.
PUBMED | CROSSREF
20. See J, Dodakian L, Chou C, Chan V, McKenzie A, Reinkensmeyer DJ, Cramer SC. A standardized approach to the Fugl-Meyer assessment and its implications for clinical trials. Neurorehabil Neural Repair 2013;27:732-741.
PUBMED | CROSSREF
21. Canbek J, Fulk G, Nof L, Echternach J. Test-retest reliability and construct validity of the tinetti performance-oriented mobility assessment in people with stroke. J Neurol Phys Ther 2013;37:14-19.
PUBMED | CROSSREF
22. Kober SE, Bauernfeind G, Woller C, Sampl M, Grieshofer P, Neuper C, Wood G. Hemodynamic signal changes accompanying execution and imagery of swallowing in patients with dysphagia: a multiple single-case near-infrared spectroscopy study. Front Neurol 2015;6:151.
PUBMED | CROSSREF
23. Robbins D, Elwell C, Jimenez A, Goss-Sampson M. Localised muscle tissue oxygenation during dynamic exercise with whole body vibration. J Sports Sci Med 2012;11:346-351.
PUBMED
24. Zhang D, Zhou Y, Yuan J. Speech prosodies of different emotional categories activate different brain regions in adult cortex: an fNIRS study. Sci Rep 2018;8:218.
PUBMED | CROSSREF
25. Strangman G, Culver JP, Thompson JH, Boas DA. A quantitative comparison of simultaneous BOLD fMRI and NIRS recordings during functional brain activation. Neuroimage 2002;17:719-731.
PUBMED | CROSSREF
26. Tak S, Ye JC. Statistical analysis of fNIRS data: a comprehensive review. Neuroimage 2014;85:72-91.
PUBMED | CROSSREF
27. Chan KS, Liu CW, Chen TW, Weng MC, Huang MH, Chen CH. Effects of a single session of whole body vibration on ankle plantarflexion spasticity and gait performance in patients with chronic stroke: a randomized controlled trial. Clin Rehabil 2012;26:1087-1095.
PUBMED | CROSSREF

28. Schmid A, Duncan PW, Studenski S, Lai SM, Richards L, Perera S, Wu SS. Improvements in speed-based gait classifications are meaningful. Stroke 2007;38:2096-2100.
PUBMED | CROSSREF
29. Fukuyama H, Ouchi Y, Matsuzaki S, Nagahama Y, Yamauchi H, Ogawa M, Kimura J, Shibasaki H. Brain functional activity during gait in normal subjects: a SPECT study. Neurosci Lett 1997;228:183-186.
PUBMED | CROSSREF
30. Mihara M, Miyai I, Hattori N, Hatakenaka M, Yagura H, Kawano T, Kubota K. Cortical control of postural balance in patients with hemiplegic stroke. Neuroreport 2012;23:314-319.
PUBMED | CROSSREF
31. Woollacott M, Shumway-Cook A. Attention and the control of posture and gait: a review of an emerging area of research. Gait Posture 2002;16:1-14.
PUBMED | CROSSREF
32. Al-Yahya E, Johansen-Berg H, Kischka U, Zarei M, Cockburn J, Dawes H. Prefrontal cortex activation while walking under dual-task conditions in stroke: a multimodal imaging study. Neurorehabil Neural Repair 2016;30:591-599.
PUBMED | CROSSREF
33. Lin PY, Chen JJ, Lin SI. The cortical control of cycling exercise in stroke patients: an fNIRS study. Hum Brain Mapp 2013;34:2381-2390.
PUBMED | CROSSREF
34. Dechaumont-Palacin S, Marque P, De Boissezon X, Castel-Lacanal E, Carel C, Berry I, Pastor J, Albucher JF, Chollet F, Loubinoux I. Neural correlates of proprioceptive integration in the contralesional hemisphere of very impaired patients shortly after a subcortical stroke: an FMRI study. Neurorehabil Neural Repair 2008;22:154-165.
PUBMED | CROSSREF
35. Dietz V, Müller R, Colombo G. Locomotor activity in spinal man: significance of afferent input from joint and load receptors. Brain 2002;125:2626-2634.
PUBMED | CROSSREF