

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

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Abstract

Objective: To investigate the effects of a single session of whole body vibration training on ankle plantarflexion spasticity and gait performance in chronic stroke patients.

Design: Randomized controlled trial.

Setting: Rehabilitation unit in university hospital.

Participants: Thirty subjects with chronic stroke were randomized into either a control group ($n = 15$) or a group receiving a single session of whole body vibration ($n = 15$).

Intervention: The intervention group was actually treated with whole body vibration while the control group was treated with placebo treatment.

Main measures: The spastic changes were measured clinically and neurophysiologically. Subjective evaluation of ankle spasticity was performed via a visual analogue scale. Gait performances were evaluated by the timed up and go test, 10-meter walk test and cadence. A forceplate was used for measuring foot pressure.

Results: The changes between whole body vibration and control groups were significantly different in Modified Ashworth Scale (1.33, 95% confidence interval (CI) = 1.06~1.60). The H_{\max}/M_{\max} ratio (0.14, 95% CI = 0.01~0.26) and visual analogue scale (1.87, 95% CI = 1.15~2.58) were significantly decreased. Whole body vibration could significantly improve gait velocity, timed up and go test (6.03, 95% CI = 3.17~8.89) and 10-meter walk test (1.99, 95% CI = 0.11~3.87). The uneven body weight posture on bilateral feet was also improved after vibration.

Conclusion: These results suggest that a single session of whole body vibration training can reduce ankle plantarflexion spasticity in chronic stroke patients, thereby potentially increasing ambulatory capacity.

Keywords

Whole body vibration, spasticity, gait, stroke

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Introduction

The prevalence of post-stroke spasticity has been reported to be as high as 39%.¹ Spasticity is defined as a velocity-dependent increase in tonic stretch reflexes with exaggerated tendon jerks due to hyperexcitability of the stretch reflex.² Excessive spasticity can limit functional recovery and cause pain or contracture in stroke patients.³ In addition, a spastic limb can also negatively impact walking ability, physical activities and gait, including a reduction in step length and cadence.⁴

A spastic ankle joint is a major concern since ankle plantarflexors contribute as much as 50% of positive mechanical work in a single stride to walk forward.⁵ Decreased ankle dorsiflexion might cause increased swing time and double-leg supporting time in gait cycles.^{4,6} Therefore, spastic ankles might decrease walking velocity and mobility.

The primary approaches to antispasticity management are conservative treatments and surgical intervention. Conservative treatments commonly include positioning, passive stretching, physiotherapy with active movement, splinting, medication and botulinum toxin injection.⁷ Although surgical treatment for spasticity is another therapeutic option, potential for complications might be found.

Few studies have investigated the effects of whole body vibration training on spasticity. Whole body vibration training could reduce spasticity in the knee extensors of adults with cerebral palsy⁸ and chronic spinal cord injuries.⁹ Whole body vibration can stimulate the muscle spindles and alpha motoneurons,¹⁰ and initiate a muscle voluntary contraction as a result of the tonic vibration reflex.^{11,12} Whole body vibration has been used to increase muscle strength and improve proprioceptive control. Although it can modulate motoneural excitability,¹³ its benefit for spasticity is still not fully known. The purpose of this study was to determine the ability of whole body vibration to reduce spasticity in stroke patients.

Methods

All patients with stable, chronic stroke (as confirmed by computed tomography or magnetic

resonance imaging scans) who had been admitted to the Department of Physical Medicine and Rehabilitation of the University Hospital were included. The inclusion criteria consisted of the following: a first-time, unilateral stroke due to infarction or haemorrhage with an interval of at least six months since stroke onset, spasticity of the ankle with a Modified Ashworth Scale ≥ 2 ,¹⁴ the ability to ambulate with or without assistive devices for at least 100 m, preserved cognitive and communicative ability (all subjects scored above 24 on the Mini-Mental Status Examination),¹⁵ no joint contractures and sufficient motor control to perform the functional walking tests. The exclusion criteria consisted of the following: gallbladder or kidney stones, recent leg fractures, internal fixation implants, a cardiac pacemaker, intractable hypertension, recent thromboembolism and infectious diseases.

Baseline data were collected for each subject, including gender, age, time from stroke onset, stroke type, hemiplegic side and any use of antihypertonia medications or ambulatory devices. The subjects included in the study had not changed their existing physical exercise programmes or medical treatments within the month prior to participation. A schematic outline of the study is shown in Figure 1.

Although high-frequency low-amplitude vibration is commonly used to muscle performance training, these parameters can cause muscle fatigue.¹⁶⁻¹⁸ The effects in our study were contraindicated for patients with impaired standing balance because of the increase in the risk of falling and subsequent influence on the ambulatory results.

In the whole body vibration group, subjects received a single session of vertical whole body vibration (AV-001, Bodygreen, Taiwan) with a magnitude of 12 Hz and an amplitude of 4 mm. During the intervention, subjects were positioned on the platform in a semi-squatting position with buttock support and were kept in an upright position with even weight distribution on both feet. The time course included two 10-minute periods of vibration with a 1-minute rest interval. In the control group, subjects followed the same procedures, but the vibration machine was not turned on.

In the preliminary study, the semi-squatting posture without buttock support was not suitable

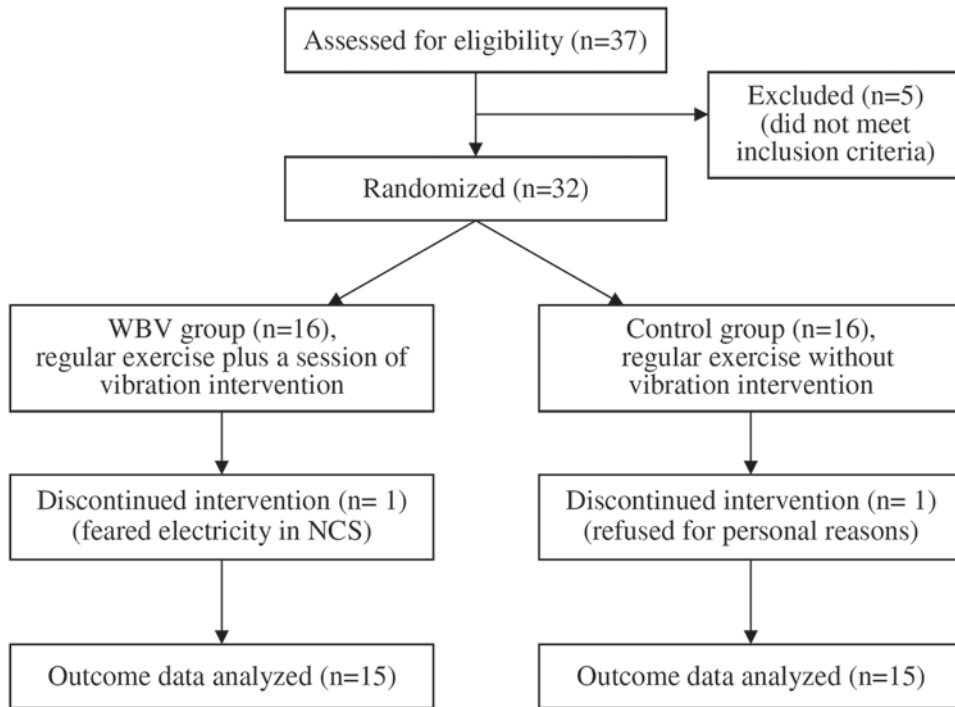


Figure 1. CONSORT flowchart of the study. WBV, whole body vibration; NCS, nerve conduction study.

because some patients could not tolerate the vibration in standing postures without support. It was also not suitable for patients in sitting postures. During the vibration, subjects were asked to distribute most of their body weight on their feet as evenly as possible. All of the subjects could walk independently with or without their original assistive devices.

This study was a two-armed, randomized controlled trial with blinding of both subjects and assessors. Participants were divided by simple randomization into a whole body vibration group and a control group done by physician-1, who was not involved in the assessment of the patients or the treatments. Patient characteristics and all outcome measures before and after treatment were assessed by an experienced physician-2, who was blinded to the treatment allocations. The treatments were carried out in a closed room for either vibration training or sham treatment by physician-3. All physicians were instructed not to communicate with the

subjects about the possible goals or rationale for either treatment. After whole body vibration training for around 30 minutes, the subjects were moved to the experimental area in wheelchairs to avoid any physical activity on their feet that might influence the vibration results. Clinical assessments, neurophysiological tests and subjective improvement of the soleus spasticity were evaluated before and after the vibration. The Modified Ashworth Scale and deep tendon reflex of Achilles tendon were used for clinical assessments.^{19,20} Affected ankle spasticity was estimated according to the Modified Ashworth Scale, which has six degrees (0, 1, 2, 3, 4 and 5). The deep tendon reflex of the Achilles tendon was measured on the affected side and scored on a 5-point scale (range 0–4). The maximal amplitude of H-reflex and the H_{\max}/M_{\max} ratio were measured to assess ankle spasticity. Subjective experience of the influence of ankle spasticity on ambulation was scored by participants using a visual analogue scale (VAS). The VAS ranged from 0 to 10, with 0

representing a spasticity-free status and 10 representing a maximal spastic intensity that interferes with ambulation.²¹

The timed up and go test evaluates balance and is commonly used to examine functional mobility in community-dwelling, frail, older adults.²² In the present study, the participants sat on a standard chair and were instructed to get up and walk at a comfortable and safe pace to a line on the floor 3 meters away, then turn around and return to the chair to sit down again. The 10-meter walk test examines gait speed.²³ A 10-meter course was measured, and the start and finish lines were marked with tape on the floor. Each subject was positioned approximately a meter behind the start line and instructed to walk at a maximal pace until approximately a meter past the finish line.

The subjects were asked to stand statically with a natural posture on the forceplate (Physical Gait Software, version 2.65), and the percentage of total body weight on each foot was recorded. The static pressure on each foot was divided among six areas (Figure 2 on-line), and the pressure change for each area was individually recorded before and after

standing on each foot. No devices were allowed while the participants were standing on the forceplate.

Statistics

All outcome measures were performed three times, and the average was used for statistical analysis. The data were presented as the mean \pm standard deviation (SD) and 95% confidence intervals (95% CI). Statistical procedures were performed by using SPSS version 14.0 (SPSS Inc., Chicago, IL, USA). Paired *t*-tests were used to compare the differences between results before and after interventions in the same group. The differences between the groups were compared with two-sample *t*-tests and Fisher's exact test. A value of $P < 0.05$ was regarded as statistically significant.

Results

The flow of subjects through the study is shown in Figure 1. The demographics of the study participants are shown in Table 1. The baseline

Table 1. General characteristics of the subjects

Characteristics	WBV group ($n = 15$)	Control group ($n = 15$)	<i>P</i> -value
Age, years	56.07 (11.04)	54.93 (7.45)	0.744
Gender, <i>n</i>			>0.999 ^a
Men	10	11	
Women	5	4	
Location of stroke, <i>n</i>			0.128 ^a
Left	12	7	
Right	3	8	
Type of stroke, <i>n</i>			0.143 ^a
Ischaemic	10	5	
Haemorrhagic	5	10	
Time post stroke, months	30.40 (25.80)	38.87 (38.22)	0.483
Min-max	6-93	6-122	
Antispastic drug use, <i>n</i>	7	6	>0.999
Ambulatory device use, <i>n</i>			0.884 ^a
Regular cane	3	3	
Quadricane	5	3	

Values are mean (\pm SD).

WBV, whole body vibration; min-max, minimal-maximum.

^a*P*-value was computed by Fisher's exact.

characteristics were similar between groups. After the intervention, for the unaffected side the H_{max}/M_{max} ratio was significantly decreased in the whole body vibration group (score change = -0.14 ± 0.21 , $P < 0.05$), but not in the control group (score change = -0.00 ± 0.07 , $P > 0.05$) (Table 2). The scores changes were significantly different between whole body vibration and control groups (0.14, 95% CI = 0.01~0.26, $P = 0.031$). On the affected side, however, the score changes were significantly different after the intervention, but not in the control group. In addition, the scores changes were not statistically different between the whole body vibration and control groups ($P = 0.066$).

Modified Ashworth Scale scores were significantly different in the whole body vibration and control groups (1.33, 95% CI = 1.06~1.60, $P < 0.0001$). The subjective assessment by VAS also showed a significant difference between the whole body vibration and control groups (1.87, 95% CI = 1.15~2.58, $P < 0.0001$). Deep tendon reflex or H-reflex on both sides was not significantly different between groups.

The performances of the timed up and go test were significantly improved in the whole body vibration group (6.03, 95% CI = 3.17~8.89, $P < 0.003$) (Table 3). In addition, 10-meter walk test scores were also significantly improved in the whole body vibration group (1.99, 95% CI = 0.11~3.87, $P = 0.039$). However, the score changes in the cadence performances were not statistically significant after whole body vibration training ($P = 0.277$).

The change in body weight loading on each foot showed a significant difference in the whole body vibration group (Table 4). Before the intervention, a higher proportion of body weight loading on the affected side was recorded. After the vibration training, the percentage of total body weight loading on the affected side showed a significant increase (-3.27 , 95% CI = -6.02 ~ -0.51 , $P = 0.022$), whereas it showed a significant decrease on the unaffected side (3.27, 95% CI = 0.51~6.02, $P = 0.022$).

The score changes of pressure loading of area E on the affected sides were significantly different after the intervention, but not in the control group.

Table 2. Change in the H-reflex, H_{max}/M_{max} ratio, Modified Ashworth Scale, VAS and Achilles deep tendon reflex from pretest to posttest for the whole body vibration group and control group

Outcome measures	WBV group		Control group		P-value	Diff (95% CI)
	Pretest	Posttest	Pretest	Posttest		
H-reflex (affected side) (mV)	4.17 (1.68)	3.88 (2.14)	5.10 (3.40)	5.11 (3.47)	0.396	0.29 (-0.40, 0.97)
H_{max}/M_{max} ratio (affected side)	0.63 (0.43)	0.34 (0.16)	0.35 (0.26)	0.30 (0.17)	0.066	0.22 (-0.02, 0.46)
H-reflex (unaffected) (mV)	2.31 (0.93)	2.61 (1.03)	2.77 (1.22)	2.95 (1.34)	0.348	0.31 (-0.36, 0.97)
H_{max}/M_{max} (unaffected side)	0.36 (0.27)	0.21 (0.13)	0.22 (0.17)	0.22 (0.14)	0.031 ^a	0.14 (0.01, 0.26)
Modified Ashworth Scale	2.60 (0.63)	1.27 (0.46)	2.20 (0.41)	2.20 (0.41)	<0.0001 ^b	1.33 (1.06, 1.60)
VAS	6.33 (2.35)	4.40 (1.99)	5.33 (1.04)	5.27 (0.96)	<0.0001 ^b	1.87 (1.15, 2.58)
Achilles deep tendon reflex	2.87 (0.52)	2.53 (0.52)	2.47 (0.52)	2.47 (0.52)	0.055	0.33 (-0.01, 0.68)

Values are mean (± SD).

WBV, whole body vibration; H-reflex, Hoffmann reflex; H_{max}/M_{max} ratio, maximum Hoffmann reflex/maximum M response ratio; VAS, visual analogue scale.

^a $p < 0.05$ by 2-sample t-test between WBV and control groups.

^b $p < 0.001$ by 2-sample t-test between WBV and control groups.

^c $p < 0.05$ by paired t-test within the groups.

Table 3. Change in timed up to go test, 10-meter walk test and cadence from pretest to posttest for WBV group and control group

Outcome measures	WBV group		Control group		P-value	Diff (95% CI)
	Pretest	Posttest	Change score	Posttest		
Time up to go test (seconds)	53.95 (30.38)	47.47 (26.72)	-6.48 (4.89)	31.95 (14.74)	0.0003 ^a	6.03 (3.17, 8.89)
10-meter walk test (seconds)	31.60 (18.88)	29.51 (17.10)	-2.09 (3.17)	24.57 (14.50)	0.039 ^b	1.99 (0.11, 3.87)
Cadence (steps/min)	64.99 (23.79)	62.78 (21.71)	-2.21 (5.76)	43.08 (30.42)	0.104	2.67 (-0.61, 5.95)

Values are mean (\pm SD).

WBV, Whole body vibration.

^a $p < 0.001$ by 2-sample t-test between WBV and control groups.

^b $p < 0.05$ by 2-sample t-test between WBV and control groups.

Table 4. Change in distribution of total body weight loading on each foot from pretest to posttest for WBV group and control group

Outcome measures	WBV group		Control group		P-value	Diff (95% CI)
	Pretest	Posttest	Change score	Posttest		
TBW% on affected side (%)	43.15 (5.81)	46.62 (6.64)	3.47 (4.30)	46.33 (4.59)	0.022 ^a	-3.27 (-6.02, -0.51)
TBW% on unaffected side (%)	56.85 (5.82)	53.38 (6.64)	-3.47 (4.30)	53.67 (4.59)	0.022 ^a	3.27 (0.51, 6.02)

Values are mean (\pm SD).

TBW%, percentage of total body weight; WBV, whole body vibration.

^a $p < 0.05$ by 2-sample t-test between WBV and control groups.

In addition, those were not statistically different between the whole body vibration and control groups ($P = 0.177$) (Table 5 on-line). Similarly, after whole body vibration training, the changes of pressure loading of area F on the unaffected sides were significantly different, but not in the control group. These were not statistically different between the whole body vibration and control groups. After whole body vibration training, the pressure loads of area E on the unaffected sides were significantly decreased in the whole body vibration group (score changes = -22.71 ± 26.32 , $P = 0.002$), but not in the control group (score changes = 4.33 ± 10.59 , $P > 0.05$). The scores changes were significantly different between the whole body vibration and control groups (27.04, 95% CI = 11.67~42.41, $P = 0.002$).

Discussion

This is a randomized controlled trial in which we are interested in investigating the effects of a single session of whole body vibration training on ankle spasticity in subjects with chronic stroke. Our results showed that after whole body vibration training, ankle spasticity was significantly decreased and gait performance was significantly improved.

As a result, we hypothesized that both the H-reflex and the H_{\max}/M_{\max} ratio on the affected side would decrease after vibration training. The results show that although the H_{\max}/M_{\max} ratio on both the affected ($P < 0.02$) and unaffected ($P < 0.03$) sides decreased significantly within the whole body vibration group, only the H_{\max}/M_{\max} ratio on the unaffected side decreased significantly in the whole body vibration group while compared to the control group. We suggest that there is a trend toward a reduction in the H_{\max}/M_{\max} ratio after vibration training. The H-reflex on the affected and unaffected sides did not decrease in either group. It is possible that the mechanism of spasticity cannot be fully explained by a simple monosynaptic reflex or a single pathway²⁴ such as that between a type 1a afferent sensory neuron and an alpha efferent motoneuron. The study of their recovery should be further investigated. Armstrong et al.²⁵ reported that all subjects displayed significant suppression of the

H-reflex during the first minute after whole body vibration, whereas only some of the subjects showed such suppression at 30 minutes. In that study, it was noted that some level of potentiation occurred during this period and that not all of the subjects were fully recovered within 30 minutes. As there was a limit to determining the recovery time, it is difficult to conclude how much recovery time is required. In our study, the effects could be maintained for 48 hours with VAS assessments.

Objective scores of spasticity (Modified Ashworth Scale) decreased significantly in the whole body vibration group. The finding of spasticity reduction after vibration was similar to that in previous studies,^{8,9} demonstrating the possible benefits of vibration training for ankle spasticity in patients with stroke. Furthermore, the subjective experience of the therapeutic effect as evaluated by the VAS²¹ also revealed a significant decrease, suggesting subject satisfaction following whole body vibration training.

Other vibration effects on spasticity, including presynaptic inhibition and postactivation depression, should be considered.²⁴ Presynaptic inhibition of Ia-afferents reduces the release of neurotransmitters to the motoneurons and thereby weakens the effects of Ia-afferents on motoneurons, resulting in inhibition of the H-reflex amplitudes. In our study, the H-reflex amplitudes did not change significantly after vibration; however, significant changes in Modified Ashworth Scale were found. From the results, correlations between presynaptic inhibition and spasticity should be further studied.²⁴

Based on past studies,^{16,17,26} many researchers have shown the beneficial effects of whole body vibration training on balance and walking ability. In the present study, the timed up and go test results in the whole body vibration group showing significant improvement after treatment, reflecting better functional mobility in stroke patients after vibration training and probably a reduced risk of falling.²⁷ The 10-meter walk test indicated that gait speed significantly increased after treatment. Improvement in gait velocity is therefore clinically meaningful in terms of changes in stroke-related function and quality of life, especially for household ambulation.²⁸

Although the cadence values in the study group demonstrated a beneficial effect on vibration training, the results were not statistically significant. It may be that the subjects lacked sufficient time to develop a new gait pattern and that more time might be needed to adjust muscular adaptation or neuromuscular coordination after vibration treatment. Thus, long-term follow-up might be needed to show a difference in the 10-meter walk test after whole body vibration training.

Gait performance was improved after whole body vibration training. Decreased ankle spasticity might affect the gait performances, especially in terms of mobility and speed. The improvement in ankle joint control could increase gait velocity.^{4,6} This finding might indicate that whole body vibration is effective in enhancing neuromuscular rehabilitation.

The forceplate data showed that the percentage of body weight loading distributed on the affected side increased ($P = 0.022$) after vibration training, indicating that the participants shifted their body weight from the unaffected side toward the affected side during static standing. These effects might be due to less plantar flexion and ankle inversion of the affected ankle. Mecagni et al.²⁹ reported that ankle range of motion may be associated with balance during ambulation and also indicated that all ankle motions contribute to the maintenance of balance during gait.

This study demonstrated a beneficial effect of whole body vibration training in stroke patients, but it had some limitations. First, more participants could have been included to increase the power of the statistical analyses. It also may have been beneficial to follow the progress of the participants to investigate the impact of whole body vibration training on stroke patients over a longer period of time.

In summary, a single session of whole body vibration training appears to successfully reduce ankle spasticity in stroke patients, thereby improving gait performance, particularly with regard to walking mobility and gait speed. This training was well tolerated and appreciated by most patients and could be used as a valuable adjunctive therapy in the management of stroke patients with spasticity.

Clinical messages

- Whole body vibration could reduce ankle plantarflexor spasticity in patient with chronic stroke.
- With decreased ankle spasticity gait performance, especially in gait speed, improved significantly.

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Conflict of interest

No commercial party provides financial support or has financial interest in the results of this study. The authors declare that there is no conflict of interest.

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