

Effect of whole body vibration training on mobility in children with cerebral palsy: a randomized controlled experimenter-blinded study

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Abstract

Objective: To evaluate ambulatory function and leg muscle thickness after whole body vibration training in children with cerebral palsy.

Design: A block randomized controlled trial with two groups.

Setting: Physical therapy department laboratory.

Subjects: A total of 30 (15 experimental, mean (SD) age 10.0 (2.26) years and 15 control, 9.6 (2.58)) children with cerebral palsy, 15 males and 15 females.

Interventions: The experimental group underwent whole body vibration training combined with conventional physical therapy training; the control group underwent conventional physical therapy training three days a week for eight weeks respectively.

Main outcome measures: Three-dimensional gait analyses and ultrasonographic imaging of the leg muscles were measured at pre- and post-test of intervention for eight weeks.

Results: Whole body vibration training resulted in significantly better gait speed ($P = 0.001$, from 0.37 (0.04) m/s to 0.48 (0.06)), stride length ($P = 0.001$, from 0.38 (0.18) m to 0.48 (0.18)) and cycle time ($P = 0.001$, from 0.85 (0.48) s to 0.58 (0.38)) in the experimental group compared with that in the control group. The ankle angle ($P = 0.019$, from 7.30 (4.02) degree to 13.58 (8.79)) also showed a remarkable increase in the experimental group, but not the hip ($P = 0.321$) and knee angle ($P = 0.102$). The thicknesses of the tibialis anterior ($P = 0.001$, 0.48 (0.08) mm to 0.63 (0.10)) and soleus ($P = 0.001$, 0.45 (0.04) mm to 0.63 (0.12)) muscles were significantly higher in the experimental group than in the control group. However, no significant effect was observed in the thickness of the gastrocnemius muscle ($P = 0.645$).

Conclusions: These findings suggest that whole body vibration may improve mobility in children with cerebral palsy, probably through a positive effect on the leg muscles.

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Introduction

Cerebral palsy is one of the leading causes of movement and posture disorders, which occurs to 2–3 of every 1000 individuals, and the cost of care is estimated to be 8 billion dollars.¹ Many children with cerebral palsy have a severe disability, such as the inability to walk. Improving the ability to walk is often the essential therapeutic goal for such children.¹ One of the most important factors responsible for this impaired walking ability is a muscle weakness in the leg.^{2,3} The relationship between a reduction in muscle strength in the affected leg and the ability to execute functional gait has been well established.^{3,4}

Recently, whole body vibration has emerged as an complementary approach to strength training intervention for the legs, with advantages that have gradually been shown to be comparable to those of resistance training in children with cerebral palsy.^{5–7} In whole body vibration, the participant stands on a vertically oscillating vibration platform at a particular amplitude and frequency, thereby generating a force that acts on the whole body through the legs.^{8,9} Whole body vibration has been incorporated as a strength training method because stretch reflex-induced muscle contraction can acutely raise the motor unit activity of the legs.^{8,9} Squatting exercises with a static or dynamic posture are commonly recommended¹⁰ specifically to improve the strength and physical function of children who have cerebral palsy. Several studies have shown the influence of muscle strength on improved walking ability in children with cerebral palsy.^{3,4} Although a pilot study, related whole body vibration was feasible for improving mobility function, this study only focused on determining gait function in children with cerebral palsy through gross motor function measurement and 10 m walk test.⁷ No previous three-dimensional motion capture analysis study that has investigated the effect of whole body vibration in such children includes longitudinal

quantitative and kinematic data regarding changes in gait function associated with motor recovery. The lack of a quantitative and standardized method for gait measurement, based on three-dimensional kinematics and temporal parameters, remains a critical issue in assessing the effects of whole body vibration in children with cerebral palsy.

To our knowledge, although mobility is frequently affected in children with cerebral palsy, and while there are reasons for believing that whole body vibration therapy may be helpful, the extent of its effect and the underlying mechanism are unknown. In other words, no specific effect of whole body vibration in increasing strength associated with gait function has been shown in children with cerebral palsy by using quantitative measurements that include both ultrasonographic imaging and a gait analysis method such as three-dimensional motion capture. Therefore, the purpose of this study was to examine the effects of whole body vibration on leg muscle strength and gait function in children with cerebral palsy. Our hypothesis was that this mechanical vibration stimulus to the body of children with cerebral palsy may be useful as a simple, non-invasive, and non-pharmacological intervention for improving poor muscle power of the legs and gait function.

Methods

Randomization was performed using sealed envelopes. The enveloped letters for the experimental group (whole body vibration) and the control group (conventional treatment) were prepared by the investigator. A piece of paper in the sealed envelope was given to the participants for group allocation. Allocation occurred before the initial assessment. A total of 30 patients with either the spastic diplegia or quadriplegia forms of cerebral palsy were recruited from a local special school and pediatric rehabilitation center. Routine clinical systematic review of

medical history, including onset, nature, medication, surgical history, previous surgery, and gross motor function measurement, were carried out. The gross motor function measure (GMFM) was used to evaluate the gross motor function. It consists of five dimensions: lying and rolling, sitting, crawling and kneeling, standing, and walking, running and jumping. Validity and reliability of the GMFM are well established in the literature.¹¹ The inclusion criteria were as follows: (1) cerebral palsy diagnosed by both a pediatric neurological doctor and a physical therapist; (2) no history of serious surgery on the spine; (3) diagnosis of weak muscles in at least one of the evaluated leg muscles; muscle weakness was determined by symptoms of the muscle's inability to perform rising from a chair (difficulty with movements) – symptoms include: fatigue, numbness in muscles, inability to support one's arms and legs, drowsiness, prolonged tiredness and lethargy; (4) no drug being taken for spasticity control; (5) good vision; (6) ability to comprehend instructions; and (7) ability to walk without the use of walking aids. The research and ethics committee of Konyang University approved this study, and all patients gave their written informed consent.

The participants were engaged in either the experimental group (whole body vibration training) or control group (conventional physical therapy training). All participants received conventional physical therapy training, regardless of treatment allocation. The experimental group underwent additional whole body vibration training for one hour per day, three days per week during an eight-week period with conventional physical therapy, whereas the control group was only treated with conventional physical therapy, which consisted of gentle massage, muscle stretching, and balance training for 30 minutes. Two physiotherapists were instructed in this study by the investigator (a physiotherapist with 15 years' experience). The whole body vibration training was administered one-on-one by one of the trained physiotherapists. The outcome assessments were measured before and after the eight-week intervention period. The physiotherapists undertaking the outcome assessment were also blinded to group allocation.

The participants were exposed to side-to-side alternating vertical sinusoidal vibration by using a

Galileo system (Novotec Medical GmbH, Pforzheim, Germany). The participants were required to be barefoot. Handlebars were provided in case of need. The frequency of whole body vibration ranged from 5 to 25 Hz and the amplitude ranged from 1 to 9 mm to allow for comprehensive and individual adjustments during this study.⁵ The training intensity and volume was increased according to the overload principle. Whole body vibration training was carried out in accordance with published studies that had used the same whole body vibration system for children with neuromuscular diseases.⁶ Each of the participants underwent a test run for familiarization before the study began.

The participant stood on the platform board (height, 0.18 m; width, 0.72 m; depth, 0.51 m) with their feet equidistant from the midpoint of the board. The feet were then increasingly displaced by 2 mm, 4 mm, and 6 mm from the center of the vibrating board, designated as "1", "2", and "3", respectively. The whole body vibration program was designed to progress more deeply to a squat ranging from 30 to 100 degrees of knee flexion. The use of a specific body position was required according to previous static and dynamic protocols.^{5,7} The current study was limited to this body squat position, which involved the heels being slightly off the ground and preventing complete extension of the hip and knee joints to avoid vibration stimulus to the organs, eyes, and head, to minimize discomfort.^{3,4}

Each whole body vibration protocol involved six elements: (1) 3 minutes of 5–8 Hz, (2) 3 minutes of 10–15 Hz, (3) 3 minute of 15–20 Hz; (4) 3 minute of 20–25 Hz; (5) 3 minute of 15–20 Hz; and (6) 3 minute of 10–15 Hz. Additionally, a 10- minute warm up and another 10- minute cool-down comprising passive range of motion exercises were included before and after the whole body vibration program; the participants were instructed to rest for 3 minutes between each of the six elements of the whole body vibration protocol.^{3,4} Overall, the protocol took approximately 1 hour to complete.

Three-dimensional gait analyses were recorded at 120 Hz using a six-camera motion capture system (Qualisys, Qualisys Inc., Goeteborg, Sweden). Prior to data collection, the motion capture system was calibrated when the average residual for each camera was only <1.6 mm according to the guidelines.

The accuracy of our three-dimensional gait analysis was estimated to be 1.5–3.0 mm. Retroreflective markers (diameter, 14 mm) were attached to specific anatomical landmarks including the anterior superior iliac spine, the superior border of the patella, a lateral point to the knee joint line, the tibial tuberosity, the lateral malleolus, the posterior aspect of the heel on the calcaneus bone, and between the second and third metatarsal heads of the foot.

The participants stood comfortably with their feet placed shoulder width apart on the floor, equidistant from the midline, and were recorded. The parents confirmed that the performance was representative of their children's common gait pattern. Movements were recorded simultaneously with each camera and stored on a computer disk for analysis. Motion and calculations were recorded using the Q-trac C version 2.51, Q-trac V version 2.60, and Q-Gait 2.0 software (Qualisys, Qualisys Inc., Gothenburg, Sweden) for each time frame, along with joint angles and temporal parameters. For each child, six walking trials were recorded, with at least two acceptable trials. Gait speed, stride length, and cadence were compared with age norms.

Pretest and posttest data on leg muscle thickness were measured using ultrasonographic imaging (Logiq C5, GE Healthcare Inc., Wauwatosa, USA) with a 7.5-MHz linear transducer. This study had an experimenter-blinded design, and all the ultrasonographic imaging scans were consistently taken by two blinded investigators (two radiologists). The thicknesses of the leg muscles including the tibialis anterior, gastrocnemius, and soleus muscles were determined.^{12–14} In addition, great care was taken to maintain the same standardized position of the participants. The reliability and validity of ultrasonographic imaging for measuring the thicknesses of the tibialis anterior, gastrocnemius, and soleus muscles have been reported to be high.^{13,15}

Standard statistical analysis included computation of the mean and standard deviation values and two-way analysis of variance (ANOVA) with repeated measures. All variables were tested for normality by using the one-sample Kolmogorov–Smirnov test, which showed normal distribution of the data. The two-way ANOVA with repeated

measures was used to assess the main effects and their interaction effects in gait function factors and muscle thicknesses between the experimental and control groups. The collected data were analyzed using a statistical package program (SPSS version 16.0, SPSS Inc., Chicago, USA). A probability of $P < 0.05$ was considered to be statistically significant.

Results

In total, 30 patients with cerebral palsy were recruited for this study. Although 32 participants were initially recruited, two participants (one from each group) were excluded because they declined to participate in this study. A flowchart of this study is shown in Figure 1. The demographic and clinical characteristics of the patients including age, height, body mass, and gross motor function measurement are presented in Table 1. The data indicated that the groups had similar demographic characteristics and functional levels.

Two-way ANOVA with repeated measure showed a significant group \times time interaction effect in the gait speed ($F_{1,28} = 52.518$, $P = 0.001$), stride length ($F_{1,28} = 81.140$, $P = 0.001$) and cycle time ($F_{1,28} = 49.763$, $P = 0.001$), respectively (Table 2). All of the gait parameters including gait speed, stride length, and cycle time improved significantly in the experimental group (Table 2).

Two-way ANOVA with repeated measure revealed a significant group \times time interaction effect in the ankle angle ($F_{1,28} = 6.249$, $P = 0.019$), but not in the hip angle ($F_{1,28} = 1.021$, $P = 0.321$) and knee angle ($F_{1,28} = 2.864$, $P = 0.102$) (Table 3). Significant difference appeared in the ankle angle through the two-way ANOVA with repeated measure, suggesting that the children with cerebral palsy showed remarkable improvement compared with controls.

Two-way ANOVA with repeated measure showed a significant group \times time interaction effect in the muscle thicknesses of the tibialis anterior ($F_{1,28} = 56.830$, $P = 0.001$) and soleus ($F_{1,28} = 30.781$, $P = 0.001$), respectively (Table 4). However, no significant group \times time interaction effect was observed in the thickness of the gastrocnemius

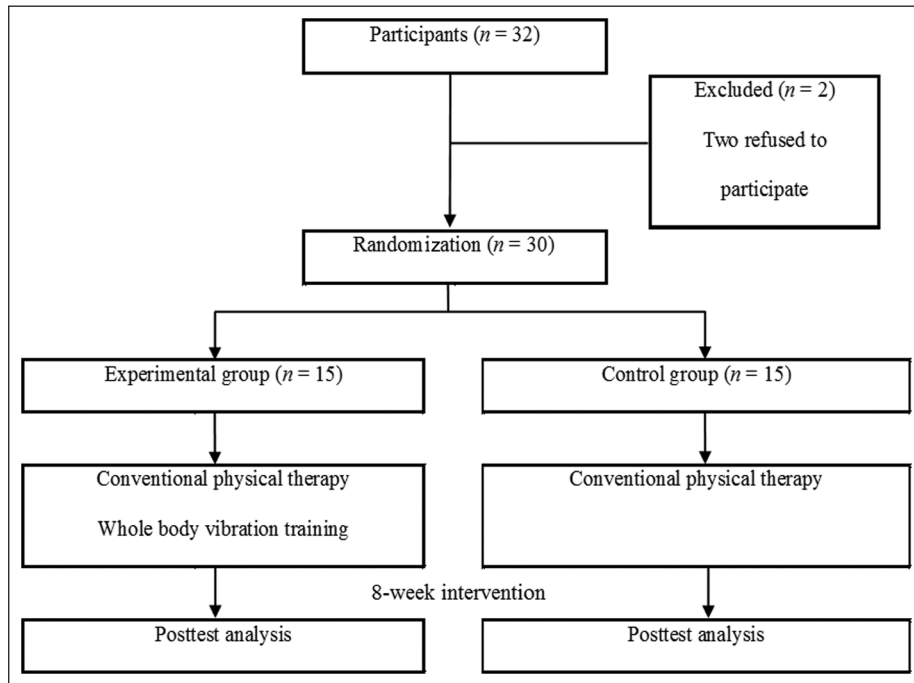


Figure 1. Study flowchart.

Table 1. Mean (SD) of general characteristics of the participants.

Characteristics	Experimental (n = 15)	Control (n = 15)	P-value (Two-tailed)
Sex (man/woman)	6/9	9/6	0.289
Age (years)	10.00 (2.26)	9.66 (2.58)	0.710
Height (cm)	130.59 (12.04)	128.26 (13.77)	0.626
Body mass (kg)	27.91 (8.14)	29.17 (7.27)	0.658
GMFM (score)	78.40 (2.82)	79.53 (4.19)	0.392

GMFM, gross motor function measure.

Table 2. Mean (SD) of comparisons of gait parameters.

Variable	Test	Group effect		Time effect		Interaction effect			
		Experimental (n = 15)	Control (n = 15)	F(1,28)	P-value	F(1,28)	P-value	F(1,28)	P-value
GS (m/s)	Pretest	0.37 (0.04)	0.39 (0.05)	1.810	0.189	69.052	0.001	52.518	0.001
	Posttest	0.48 (0.06)	0.40 (0.05)						
SL (m)	Pretest	0.38 (0.18)	0.35 (0.07)	2.259	0.144	87.380	0.001	81.140	0.001
	Posttest	0.48 (0.18)	0.35 (0.08)						
CT (s)	Pretest	0.85 (0.48)	0.73 (0.29)	0.001	0.972	57.843	0.001	49.763	0.001
	Posttest	0.58 (0.38)	0.72 (0.25)						

GS, gait speed; SL, stride length; CT, cycle time.

Table 3. Mean (SD) of comparisons of sagittal kinematics (degree).

Variable	Experimental Test	Control		Group effect		Time effect		Interaction effect	
		(n = 15)	(n = 15)	F(1,28)	P-value	F(1,28)	P-value	F(1,28)	P-value
HA	Pretest	13.42 (7.03)	9.28 (10.90)	0.959	0.336	3.401	0.076	1.021	0.321
	Posttest	14.23 (6.87)	12.04 (11.23)						
KA	Pretest	9.14 (8.79)	10.06 (16.05)	0.196	0.661	2.167	0.152	2.864	0.102
	Posttest	14.31 (12.23)	9.70 (10.60)						
AA	Pretest	7.30 (4.02)	6.99 (4.27)	3.148	0.087	5.595	0.025	6.249	0.019
	Posttest	13.58 (8.79)	6.82 (7.54)						

HA, hip angle; KA, knee angle; AA, ankle angle.

Table 4. Mean (SD) of comparisons of muscle thickness (mm).

Variable	Experimental Test	Control		Group effect		Time effect		Interaction effect	
		(n = 15)	(n = 15)	F(1,28)	P-value	F(1,28)	P-value	F(1,28)	P-value
TA	Pretest	0.48 (0.08)	0.53 (0.07)	0.404	0.530	67.196	0.001	56.830	0.001
	Posttest	0.63 (0.10)	0.54 (0.08)						
GCM	Pretest	0.47 (0.05)	0.47 (0.04)	0.021	0.887	2.921	0.099	0.217	0.645
	Posttest	0.47 (0.05)	0.47 (0.04)						
SL	Pretest	0.45 (0.04)	0.48 (0.07)	5.092	0.032	33.148	0.001	30.781	0.001
	Posttest	0.63 (0.12)	0.49 (0.06)						

TA, tibialis anterior; GCM, gastrocnemius; SL, soleus.

muscle ($F_{1,28} = 0.217$, $P = 0.645$), indicating that the experimental group showed effective gains in the tibialis anterior and soleus muscles, attributable to the intervention.

Discussion

The results of this study revealed a main finding. The improvement in actual walking and mobility parameters including gait speed, stride length, cycle time, and ankle angle was greater in the experimental group than in the control group. Walking and mobility associated with leg strengthening is of key importance to patients with cerebral palsy during rehabilitation because independent ambulation is an essential factor for most daily living activities.^{3,4} Therefore, gait speed, stride length, cycle time, and ankle angle are considered critical aspects that demonstrate recovery in walking and mobility during cerebral palsy rehabilitation.

Previous studies have reported a positive effect of whole body vibration training on gait function associated with muscle strength in elderly people and people with various neurological disorders such as stroke hemiplegia and Parkinson disease.^{16–18} Moreover, most of these studies have relied on the use of only a few measurements and the thickness of the quadriceps muscle, without considering the need for more scientific and quantitative measurements. Although Ruck et al.⁷ recently demonstrated that this vibration therapy appeared to be safe and had some effects on mobility in children with cerebral palsy, there still remains a lack of a standardized method on mobility function.

Various gait parameters such as gait speed, stride length, cycle time, hip angle, and knee and ankle angle in the sagittal plane have been measured in whole body vibration training; however, in contrast to most variables examined in whole body vibration studies, walking function in children with cerebral palsy has only been measured using gross motor

function measurement.^{5,6} Kinematic data obtained by three-dimensional gait analysis could provide more valid information on gait performance when combined with ultrasonographic imaging data on muscle thickness, specifically indicating increased gait function. Additionally, studies on gait parameters have found that muscle strength and selective motor control correlate better with gait function data than with other factors, such as range of motion and spasticity.^{3,4} However, to our knowledge, no study has provided valid and reliable measurements, such as data obtained from three-dimensional gait analysis, on the effect of whole body vibration training in children with cerebral palsy.

The tibialis anterior, gastrocnemius, and soleus muscle thickness measurements obtained by ultrasonographic imaging are suggested to be practically accurate and trustworthy, consistent with previous findings investigating the thicknesses of these muscles.¹²⁻¹⁴ As anticipated, intervention-related changes in altered muscle thickness were successfully quantified by ultrasonographic imaging.

To improve the efficacy of whole body vibration training, we used the training method reported by Ruck et al.⁷ and Stark et al.⁵ for children with cerebral palsy. Several studies have reported training methods for the application of whole body vibration;^{5,7} however, specific training guidelines for cerebral palsy are lacking and only one session or short-term effect has been reported. The effects of whole body vibration frequencies of 10–26 Hz for balance and gait, 27 Hz for speed, and 30–40 Hz for balance, on proprioception, range of motion, handgrip strength, functional activities, and bone density in stroke patients and aging adults have been examined.¹⁶ In the current study, participants performed unsupported dynamic squats while exposed to vibration at various frequencies and amplitudes. In addition, exposure to vibration was limited to a maximum of three minutes and the patients maintained a semi-squat stance with knee flexion for every frequency and amplitude while the leg muscles were actively involved to reduce the transmission of vibrations to the head.⁵⁻⁷

In this study, improved walking ability was observed to a greater extent in the experimental group after whole body vibration training. The

present gait parameter findings showed that gait speed (0.37 m/s → 0.48 m/s), stride length (0.38 m → 0.48 m), cycle time (0.85 s → 0.58 s), and ankle angle (7.30 degree → 13.58 degree) improved by approximately 30%, 30%, 32%, and 86%, respectively, after intervention. Importantly, gait speed is in line with the finding by Ruck et al.⁷ that walking speed improved by 38% in children with cerebral palsy after a six-week whole body vibration training. In general, gait speed and muscle strengthening in patients with cerebral palsy is known to be strongly correlated.^{3,4} The change in gait speed after strengthening exercises in children with cerebral palsy has been previously reported to be 0.02 m/s.¹⁹ In this study, the change in gait speed was 0.11 m/s after whole body vibration training. Additionally, the improvement in ankle angle was even greater than the improvement in gait speed in the experimental group. In contrast, the hip and knee angles showed a tendency to increase after whole body vibration, although the mean changes failed to achieve statistical significance.

The effectiveness of whole body vibration training can be also elucidated by quantitative measurements. The thicknesses of the tibialis anterior and soleus muscles before the intervention were approximately 0.48 cm and 0.45 cm, respectively, and increased after the intervention by approximately 0.63 cm (31%) and 0.63 cm (40%), respectively. This morphological improvement in muscle thickness occurred in parallel with the increased strengthening of ankle dorsiflexion and plantar flexion. The walking and mobility improvements in the experimental group may be explained by the transfer effect through the strengthening of the leg muscles after whole body vibration training. In other words, the analysis of gait speed, stride length, cycle time, and ankle angle by three-dimensional motion capture and the subsequent leg muscle thickness measurements by ultrasonographic imaging were consistent with the positive effect of whole body vibration intervention on the children with cerebral palsy.

In contrast, the thickness of the gastrocnemius muscle showed no change. These findings further indicate that whole body vibration may have biomechanically affected the soleus single-joint muscle

and selectively stimulated the deeper soleus muscle rather than the superficial gastrocnemius against the vibration and gravity, thus leading to strengthening, which a key contributor to gait ability. In other words, the gastrocnemius muscle, which involves the ankle and knee joints, was not affected by the bent knee joint stance used when whole body vibration was applied.

This study has several shortcomings, and this information could be used to enhance a more robust and large-scale future clinical study. First, this study only included children with the spastic diplegia or hemiplegia type of cerebral palsy. The study population may be considered as a factor limiting the generalization of our results to other populations. Second, we did not test the reliability of the ultrasonographic imaging measurements of the tibialis anterior, gastrocnemius, and soleus muscles. However, ultrasonographic imaging measurements have been found to be reliable and valid in previous studies.^{12–14} Third, this study involved a relatively small number of patients. Lastly, this study had a short follow-up. We do not know if the benefit is retained. Therefore, a study investigating the effects of whole body vibration training on a large number of patients with longer interventions is needed to improve the clinical benefits for children with cerebral palsy.

Clinical messages

- Whole body vibration training leads to an improvement in gait function as measured by speed.
- Whole body vibration training appears to lead to increased strength in muscle, which may underlie the change in gait speed.
- Three-dimensional gait analysis and ultrasound imaging help elucidate the underlying effects of treatment.

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