

Effects of Three Weeks of Whole-Body Vibration Training on Joint-Position Sense, Balance, and Gait in Children with Cerebral Palsy: A Randomized Controlled Study

Myung-Sook Ko, MSc, PT;^{*†} Yon Ju Sim, MSc, PT;^{*‡} Do Hyun Kim, MSc, PT;[§]
Hye-Seon Jeon, PhD, PT^{*}

ABSTRACT

Purpose: To observe the effects of whole-body vibration (WBV) training in conjunction with conventional physical therapy (PT) on joint-position sense (JPS), balance, and gait in children with cerebral palsy (CP). **Methods:** In this randomized controlled study, 24 children with CP were randomly selected either to continue their conventional PT or to receive WBV in conjunction with their conventional PT programme. Exposure to the intervention was intermittent (3 min WBV, 3 min rest) for 20 minutes, twice weekly for 3 weeks. JPS, balance, and gait were evaluated before and after treatment. **Results:** Ankle JPS was improved after 3 weeks of WBV training ($p = 0.014$). Participants in the WBV group showed greater improvements in speed ($F_{1,21} = 5.221$, $p = 0.035$) and step width ($F_{1,21} = 4.487$, $p = 0.039$) than participants in the conventional PT group. **Conclusion:** Three weeks of WBV training was effective in improving ankle JPS and gait variables in children with CP.

Key Words: cerebral palsy; gait; postural balance; proprioception; whole-body vibration.

RÉSUMÉ

Objectif : Observer les effets de l'entraînement par vibration de tout le corps (VTC) conjugué à la physiothérapie conventionnelle sur la sensation de la position de l'articulation (SPA), l'équilibre et la démarche chez les enfants atteints de paralysie cérébrale (PC). **Méthodes :** Au cours de cette étude contrôlée randomisée, 24 enfants atteints de PC ont été choisis au hasard pour continuer leur physiothérapie (PT) conventionnelle ou recevoir un entraînement par VTC conjugué à leur programme de PT conventionnelle. L'exposition à l'intervention était intermittente (3 min. VTC, 1 min. repos) pendant 20 minutes, deux fois par semaine pendant trois semaines. On a évalué la SPA, l'équilibre et la démarche avant et après le traitement. **Résultats :** La SPA au niveau de la cheville s'est améliorée après trois semaines d'entraînement par VTC ($p = 0,014$). Les participants du groupe VTC ont montré des améliorations plus importantes aux niveaux de la vitesse ($F = 5,221$, $p = 0,03$) et de la longueur du pas ($F = 4,487$, $p = 0,039$) comparativement aux participants du groupe suivant une physiothérapie conventionnelle. **Conclusion :** Trois semaines d'entraînement par VTC ont réussi à améliorer la SPA au niveau de l'articulation de la cheville et les variables de la démarche chez les enfants atteints de PC.

Cerebral palsy (CP) is a sensory-motor disorder associated with pathology of the normal postural reflex mechanism and the sensory input system.¹ Proprioception, the receipt of information about changes in joint position, is closely associated with control of gait and posture;² according to Wingert and colleagues,³ children who have CP with gait disturbance show a reduced proprioceptive sense compared with typically developing children. There may be important differences between therapeutic approaches aimed at enhancing proprio-

ception in children who have decreased ability to self-correct posture.

Whole-body vibration (WBV) was recently introduced as a novel way to improve proprioceptive sense, bone density, balance, and motor skills.⁴ Vibration may directly stimulate muscle spindles and Golgi tendon organs.⁵ Increases in proprioceptive sense have been observed in healthy young adults after WBV exercise.⁶ According to a systematic review by del Pozo-Cruz and colleagues,⁷ the immediate effects of WBV include observed increases in

From the: ^{*}Department of Physical Therapy, The Graduate School, Yonsei University; [‡]Department of Rehabilitation Medicine, Wonju Medical Center, Wonju; [†]Department of Occupational Therapy, College of Health and Welfare, Woosong University, Daejeon; [§]HIP&MAL Laboratory, Department of Rehabilitation Science, Inje University, Gimhae, Republic of Korea.

Correspondence to: Hye-Seon Jeon, Department of Physical Therapy, Yonsei University, 1 Yonseidae-gil, Wonju City, Gangwon-do 220-710, Republic of Korea; hysesonj@yonsei.ac.kr.

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Table 1 Participant Characteristics

Characteristic	Mean (SD)*		<i>p</i> -value
	WBV group (<i>n</i> = 12)	Control group (<i>n</i> = 12)	
Basic demographics			
Age, y	9.37 (2.69)	9.52 (2.16)	0.53
Sex, M:F	5:7	5:7	
Height, cm	122.31 (18.73)	133.95 (15.22)	0.23
Weight, kg	27.99 (9.90)	30.50 (11.14)	0.53
Mobility status			
GMFCS stage, no. at I/II/III	5/2/5	8/4/0	
GMFM-88 score	85.77 (9.59)	92.82 (5.33)	0.04†
CP type			
Diplegia, no.	8	6	
Hemiplegia, no. (R:L)	4 (2:2)	6 (3:3)	

*Except where otherwise indicated.

† $p < 0.05$.

WBV = whole-body vibration; GMFCS = Gross Motor Functional Classification System; GMFM-88 = Gross Motor Function Measure; CP = cerebral palsy.

oxygen consumption, muscle temperature, blood flow, and muscle power. Although del Pozo-Cruz and colleagues also suggested that muscle strength, balance, and osseous tissue content could be improved after extended WBV therapy,⁷ another group of studies reported no long-term benefits in balance, mobility, or bone density associated with WBV therapies.^{8,9} Similarly, Gerodimos and colleagues¹⁰ found that strength, power, and balance remained unchanged, and de Ruyter and colleagues¹¹ observed a decrease in these measures after a single session of WBV.

For a person with CP, proprioception is more profoundly impaired in the more pathologically affected limb. Current studies^{9,12} of people with CP have suggested that long-term WBV training (8–24 wk) is an effective therapy, but long-term intervention is not realistic for children attending school. The aim of our study, therefore, was to investigate the therapeutic efficacy of 3-week WBV training for children with CP in terms of proprioception, balance, and gait parameters.

METHODS

Participants

Before recruiting participants for this study, we performed a power analysis using G*Power version 3.1.5 (Heinrich-Heine-Universität, Düsseldorf, Germany), based on the results of a pilot study involving five participants and assuming an effect size of 0.54, a probability of 0.05, and 80% power. Because the estimated target sample size was 23, we recruited 24 participants for this experiment. Inclusion criteria were diagnosis of CP by a paediatric neurologist; between 7 and 13 years old; ability to understand and follow researchers' instructions; and ability to walk independently or with an assistive mobility

device, based on Gross Motor Function Classification System (GMFCS) criteria for Levels I–III.¹³

Potential participants were excluded if they had received botulinum toxin injection within the previous 6 months, had undergone selective dorsal rhizotomy or orthopaedic surgery within the previous 12 months, had moderate to severe intellectual disability, or had experienced a seizure episode within the past 12 months. Participants were randomly assigned to either the WBV training group ($n = 14$) or the control group ($n = 12$). Both groups received traditional physical therapy (PT) twice per week. Originally, the WBV training group had 14 participants, but 2 dropped out, 1 because of nausea and the other because of schedule conflicts with another therapy. Table 1 summarizes participants' general characteristics, most of which were not significantly different between groups; the exception was pre-intervention Gross Motor Function Measure score, an indicator of mobility status, which was significantly higher in the control group than in the WBV group.

Therapeutic protocol

Approval for the study was obtained from the Ethical Review Board of the Ministry of Health and Welfare, Republic of Korea. Both groups participated in a training programme twice per week for 3 weeks and received a 30-minute conventional PT session that included passive stretching of the lower limb muscles followed by techniques to reduce spasticity and facilitate normal patterns of movement while also working on motor functions. Participants in the WBV group also received 9 minutes of WBV per session. The Galileo System vibration unit (Novotec Medical, Pforzheim, Germany) was used for WBV training. Participants stood on the device with bare feet, with knees slightly flexed about 30° from full

extension, and the vibrator generated side-to-side alternating vertical sinusoidal vibrations, with vibration frequency set to 20–24 Hz and amplitude set to 1–2 mm. Participants were instructed to avoid holding onto the support rail if possible, although they were allowed to do so if necessary. They were asked to focus on standing with equal weight on both legs.

The peak-to-peak displacement to which the feet are exposed during WBV increases with the distance of the feet from the centre line of the vibrating board. Two positions are indicated on the Galileo System's vibrating board, marked 1 and 2, corresponding to peak-to-peak displacements of 1 mm and 2 mm. Training intensity was increased throughout the 3-week training period by increasing the vibration amplitude (1 mm for training sessions 1–4, 2 mm for sessions 5 and 6). The goal was to increase vibration frequency to 24 Hz and peak-to-peak displacement to 2 mm (as determined for the middle toe of each foot); these target settings correspond to a peak acceleration of approximately 3.8 g. Each WBV training session consisted of 3 minutes of vibration stimulation and 3 minutes of rest (during which participants were asked to stand upright), performed twice, followed by a final 3 minutes of vibration. In total, each participant underwent 9 minutes of vibration.¹⁴

Outcome measures

Variables for motor function observation included proprioceptive sense (knee and ankle), balance (balance distribution between the two feet), and several gait variables. Participants were evaluated before treatment and three weeks after treatment.

Joint-position sense

We evaluated joint-position sense (JPS) of the knee and ankle by estimating the position–reposition error of the dominant leg. Joint angle was measured using Tiltmeter, an iPhone application with an interrater reliability of 0.96 and concurrent validity of 0.83.¹⁵ The therapist manually moved the participant's knee flexion angle from 90° to 100° or from 90° to 80°, where it was maintained for 5 seconds, and then brought the knee passively back to 90°; the participant was then asked to reposition the knee at the previously positioned angle as accurately as possible, and the therapist measured the difference between the two repositionings.⁶ Position–reposition error of the ankle was assessed in a similar way, with ankle movement starting at a neutral position and then repositioned to either 10° plantar flexion or 10° dorsiflexion.

Postural balance test

We used the Tetrax Interactive Balance System (Tetrax System, Jerusalem, Israel) to assess changes in vertical pressure under the feet while the participant remained standing, using two different conditions: solid surface, eyes open, and solid surface, eyes closed. The system's

reliability has been confirmed,¹⁶ allowing the system to be widely used for both assessment and rehabilitation in different groups in previous studies.¹⁷ Interactive posturography was assessed by vertical pressure fluctuations produced while standing upright on four independent pressure-sensitive platforms. Participants were asked to look at a fixed target placed 1 m in front of them.

The Tetrax device also measures a parameter called general stability. The concept of postural stabilization is characterized by body oscillations, reflected by centre-of-mass horizontal acceleration, which changes continuously. Posture is not a stationary phenomenon; it can alternate phases on the basis of changing postural performance indexes. These indexes are correctly, objectively, and efficiently measurable by means of computerized posturography. The stability index (SI), an indicator of overall steadiness, measures the participant's ability to control postural balance and is independent of the participant's weight and height. A low SI value indicates high stability.

Gait analysis

Our gait analysis used the two-dimensional OptoGait System (Bolzano, Italy), a rectangular opto-electrical measurement system consisting of transmitting and receiving bars that create a two-dimensional measurement area. Each bar is 1 m long and contains 100 LEDs that transmit continuously to one other so that any break in the connection can be measured and timed. Walking pattern was monitored at 1000 Hz to allow us to collect both spatial and temporal gait data. The OptoGait System has demonstrated high discriminant and concurrent validity with a validated electronic walkway (GAITRite, Sparta, NJ), in both orthopaedic patients and healthy controls.¹⁸ Participants wore their own footwear while walking at a self-selected speed along an instrumented 10 m walkway, beginning and ending each walk a minimum of 2 m beyond the walkway to allow sufficient distance for acceleration and deceleration. Each participant performed three trials; we analyzed three-trial averages for gait speed, step length, and step width.

Statistical analysis

We used the Kolmogorov–Smirnov test to test for normal distribution among all measured variables, and independent-samples *t*-tests to compare baseline values for each dependent variable between the control and WBV groups (JPS ankle, $p = 0.014$; speed, $p = 0.005$; step length, $p = 0.021$; step width, $p = 0.002$; but not JPS knee or SI).

To compare the effect of training on JPS, balance, and gait parameters (gait speed, step length, and step width), we used a separate 2×2 mixed-model analysis of covariance with repeated measures, using pre-intervention values of each dependent variable as covariates. Paired *t*-tests were used to compare pre- and post-treatment

Table 2 Comparison of JPS (Degree)

Variable	Mean (SD)		Covariance (ANCOVA)				<i>p</i> -value for paired <i>t</i> -test
			Between groups		group × time		
	Pre	Post	<i>F</i>	<i>p</i> -value	<i>F</i>	<i>p</i> -value	
JPS knee			3.877	0.06	1.160	0.305	
WBV	4.05 (3.78)	2.77 (2.97)					0.30
Control	6.30 (2.81)	5.66 (2.69)					0.30
JPS ankle			1.604	0.22	0.001	0.97	
WBV	10.94 (8.34)	5.08 (3.81)					0.014*
Control	4.48 (1.82)	4.43 (1.67)					0.84

*Significant at $p < 0.025$.

ANCOVA = analysis of covariance; JPS = joint position sense; WBV = whole-body vibration.

Table 3 Balance Test Comparisons (Hertz)

SI	Mean (SD)		Covariance (ANCOVA)				<i>p</i> -value for paired <i>t</i> -test
			Between groups		group × time		
	Pre	Post	<i>F</i>	<i>p</i> -value	<i>F</i>	<i>p</i> -value	
Eyes open			0.073	0.79	0.527	0.48	
WBV	74.05 (28.61)	70.20 (29.52)					0.50
Control	56.46 (24.21)	54.81 (26.66)					0.68
Eyes closed			0.086	0.77	0.073	0.79	
WBV	87.05 (24.15)	85.36 (32.00)					0.77
Control	63.10 (27.74)	61.48 (25.21)					0.67

ANCOVA = analysis of covariance; SI = stability index; WBV = whole-body vibration.

outcome measures for each group. All statistical analyses were conducted using IBM SPSS Statistics version 15 (IBM Corp., Armonk, NY), with the threshold for statistical significance set at $p < 0.05$. However, because of concerns with multiple comparisons, the α value for the *t*-tests was adjusted to $p < 0.025$ (0.05/2 comparisons).

RESULTS

Joint-position sense (position–reposition error)

We found no significant group × time interactions in JPS of either the knee or the ankle. There was a trend toward a decrease in reposition error of the knee and ankle in both groups; however, only ankle JPS improved significantly after intervention for the WBV group ($p = 0.014$; see Table 2). The between-groups difference in magnitude of improvement in JPS did not reach statistical significance ($p > 0.05$; see Table 2).

Balance test

Static postural balance had a tendency to increase more after the WBV interventions, but the changes were not statistically significant either the WBV or the control group ($p > 0.05$; see Table 3).

Gait parameters

We found no significant group × time interactions for any gait parameters. A significant main effect by group

was observed for speed ($F_{1,21} = 5.221$, $p = 0.035$) and step width ($F_{1,21} = 4.487$, $p = 0.039$; see Table 4), which indicates that the improvement in these two gait variables was greater for the WBV group than for the control group. We found no statistically significant differences between pre- and post-intervention measures of any gait parameter in the control group, but gait speed ($p = 0.005$), step length ($p = 0.021$), and step width ($p = 0.002$) improved significantly post-intervention in the WBV group (see Table 4).

DISCUSSION

Despite a growing body of literature supporting WBV for the rehabilitation of patients with various conditions,^{6,7,19–21} its use in CP has received little attention. Our study was designed to evaluate the effectiveness of WBV training, applied in conjunction with conventional PT for 3 weeks, in producing changes in proprioception, postural balance, and gait parameters in children with CP. The results indicate that WBV treatment in addition to PT produced superior outcomes in gait speed and step width relative to conventional PT; proprioception of the ankle joint and step length improved significantly only in the WBV group.

Before intervention, the mean ankle joint–position errors of the participants with CP were 10.94° (SD 8.34°)

Table 4 Gait Variable Comparison

Variable	Mean (SD)		Covariance (ANCOVA)				<i>p</i> -value for paired <i>t</i> -test
			Between groups		group × time		
	Pre	Post	<i>F</i> _{1,21}	<i>p</i> -value	<i>F</i> _{1,21}	<i>p</i> -value	
Gait speed, cm/s			5.221	0.035*	0.931	0.35	
WBV	0.44 (0.26)	0.54 (0.29)					0.005†
Control	0.70 (0.27)	0.77 (0.21)					0.11
Step length (cm)			0.032	0.87	0.169	0.69	
WBV	32.77 (8.00)	40.89 (11.05)					0.021†
Control	38.56 (11.83)	42.08 (15.99)					0.32
Step width, cm			4.487	0.039*	0.008	0.92	
WBV	15.83 (5.89)	11.27 (5.42)					0.002†
Control	11.78 (7.17)	18.93 (13.03)					0.17

*Significant between-groups interaction (ANCOVA, $p < 0.05$).

†Significant (paired *t*-test, $p < 0.025$).

ANCOVA = analysis of covariance; WBV = whole-body vibration.

for the WBV group and 4.48° (SD 1.82°) for the control group. Compared with the joint-position error of individuals without disability reported in a previous study (0° – 3°),⁶ the participants with CP demonstrated decreased proprioceptive function, concurring with the results of previous studies that reported a deficiency in proprioception and errors in body positional sense in people with CP.^{3,19} The proprioception deficits observed in CP most likely result from primary central nervous system lesions, which affect all known proprioceptive inputs to the cortex arising from muscle spindles, Golgi tendon organs, and sensory afferent innervation of the joints and skin.³ Furthermore, because spastic muscle fibres are stiffer and sarcomeres are shorter in people with CP than in people with normal muscles, muscle changes caused by spasticity may impair JPS by shortening and stiffening muscle tissue, affecting the relationship between muscles and joints as well as disrupting muscle spindle sensitivity.²² In general, proprioceptive sense (JPS) is used to perceive the movement of the joints and plays an important role in gait and postural control.²³

In particular, ankle JPS is known to contribute significantly to gait velocity and step width, although the relationship is indirect, and people with decreased proprioception tend to walk more slowly.² Ankle JPS should be taken into account in clinical decision making about the necessity of changing gait patterns in children with CP. Clinically, patients who report not knowing where their foot is tend to walk more slowly and take smaller steps. Changes in gait patterns, including slower speed and smaller step length, have been observed in healthy people with experimentally induced proprioceptive changes around the ankle joint.²⁴ Changes in locomotor strategies, including slower walking speed, can be chosen by patients with neuropathy to compensate for sensory loss and maintain walking stability.²⁵ Following this line

of thought, long-term proprioceptive impairments may lead people with CP to develop compensatory gait changes, and improved ankle proprioception induced by WBV could contribute to better acquisition or adaptation of skilled movement.²⁶

In our study, participants in both groups showed slight and statistically non-significant improvements in balance, as measured by the SI with eyes open and eyes closed; improvement on the SI was not significantly different between the two groups. In contrast, Mikhael and colleagues²⁷ reported increases in lower extremity muscle strength and postural balance when WBV stimulation was used for geriatric patients, and Olama and Thabit's¹⁴ comparative study with people with hemiplegic CP found that balance improved in both the WBV training group and the body weight-supported treadmill training group after 6 weeks of intervention. These inconsistent findings may be partly due to differences in study populations and procedures, including frequency of vibration and duration of treatment.

However, participants in the WBV group significantly improved their gait speed and step width after a 3-week training period, whereas those in the control group showed no significant improvement. Other studies with training periods lasting 8 weeks,¹² 24 weeks,⁹ and 12 months²⁰ have found improvements in 10 m gait speed for WBV groups relative to controls. In another study with a 6-month trial period, children with cerebral palsy who had received vibration therapy increased their walking speed in the 10 m walk.²¹

Although we combined WBV therapy with traditional PT intervention for a relatively short period (3 weeks), we did observe some positive outcomes in proprioception and gait in children with CP. Therefore, we suggest WBV as a possible treatment option in physical therapy for CP. However, the small sample size and lack of

randomization are potential limitations of this study. Many of the statistically non-significant parameters in this study did not reach sufficient statistical power. Furthermore, we only included children with diplegic and hemiplegic CP with level I, II, or III gross motor function on the GMFCS; therefore, any generalization of these results beyond these CP subtypes and gross motor function levels should be undertaken with caution. Further investigation is needed to determine the most effective type and frequency of vibration for achieving improvement in gait, postural balance, and proprioception.

CONCLUSION

Three weeks of WBV training was shown to be effective in improving ankle JPS and several gait variables in CP children. Further long-term follow-up studies are needed to provide therapeutic evidence that WBV improves JPS and balance in young CP patients. This study suggests that WBV is a safe and minimally time-consuming therapy option for children with CP.

KEY MESSAGES

What is already known on this topic

Whole-body vibration (WBV) can be applied easily and safely to achieve therapeutic or physical performance goals for people with various conditions, including cerebral palsy (CP).

What this study adds

We studied the changes in strength, balance, and gait after long-term application of WBV with pediatric patients with CP. The investigation demonstrated that WBV training had a positive impact on improving ankle joint–position sense and several other gait variables. This study suggests that WBV is a safe and minimally time-consuming therapy option for children with CP.

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