

**Authors:**

Shamekh Mohamed El-Shamy, PhD

**Affiliations:**

From the Department of Physical Therapy for Disturbance of Growth and Development in Children and its Surgery, Faculty of Physical Therapy, Cairo University, Giza, Egypt.

**Correspondence:**

All correspondence and requests for reprints should be addressed to: Shamekh Mohamed El-Shamy, Department of Physical Therapy for Disturbance of Growth and Development in Children and its Surgery, Faculty of Physical Therapy, Cairo University; 7 Ahmad Alzayat St., Bain Elsarayat, Giza, Egypt.

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**ORIGINAL RESEARCH ARTICLE**

# Effect of Whole-Body Vibration on Muscle Strength and Balance in Diplegic Cerebral Palsy

## A Randomized Controlled Trial

**ABSTRACT**

El-Shamy SM: Effect of whole-body vibration on muscle strength and balance in diplegic cerebral palsy: a randomized controlled trial. *Am J Phys Med Rehabil* 2014;93:114–121.

**Objective:** The purpose of this study was to investigate the effects of whole-body vibration training on muscle strength and balance in children with diplegic cerebral palsy.

**Design:** Fifteen children were assigned to the experimental group, which received whole-body vibration training (9 mins per day, 5 days per week). Another 15 were assigned to the control group, which participated in a traditional physical therapy exercise program for 3 successive months. Baseline and posttreatment assessments were performed using the Biodex isokinetic dynamometer to evaluate the knee extensors peak torque at 60 degrees per second and 90 degrees per second and using the Biodex balance system to evaluate stability index.

**Results:** The children in the experimental group showed a significant improvement when compared with those in the control group ( $P < 0.001$ ). The peak torque at 60 degrees per second and 90 degrees per second after treatment was  $28.8 \pm 0.45$  and  $47.5 \pm 0.7$  N · m and  $30.9 \pm 0.68$  and  $54.2 \pm 1.7$  N · m for the control and the experimental group, respectively. The overall stability index after treatment was 2.75 and 2.2 for the control group and the experimental group, respectively.

**Conclusions:** Whole-body vibration training may be a useful tool for improving muscle strength and balance in children with diplegic cerebral palsy.

**Key Words:** Whole-Body Vibration, Diplegia, Muscle Strength, Balance

**C**erebral palsy (CP) has been defined as “a group of permanent disorders of the development of movement and posture, causing activity limitation, that are attributed to non progressive disturbances that occurred in the developing fetal or infant brain.”<sup>1</sup> The motor impairment in CP is multifactorial, and it includes problems such as spasticity, dystonia, muscle contractures, bony deformities, coordination problems, loss of selective motor control, and muscle weakness.<sup>2</sup>

Impaired postural control limits a child’s reactive balance control, which is the ability to recover from unexpected threats to stability. Impaired postural control in children with CP results from multiple factors. Musculoskeletal problems, including contractures, reduced range of motion, and shifts in initial alignment, all affect reactive balance control in children with CP. Other motor components of CP include the disruption of spatial and temporal aspects of postural muscle responses during the recovery of stability after an unexpected external perturbation.<sup>3</sup>

One factor contributing to impaired walking ability in CP is muscle weakness.<sup>4</sup> Muscle weakness is commonly associated with abnormal bone development, which leads to increased susceptibility to fractures.<sup>5</sup> A recent task force of experts in CP identified the prevention and the treatment of secondary conditions, such as muscle weakness and bone fragility, as critical areas of future research in CP.<sup>6</sup>

Muscle strengthening is likely to be useful for improving both motor function and bone development in children with CP. One method for muscle strengthening that is increasingly used in a variety of clinical situations is whole-body vibration (WBV).<sup>7-9</sup> WBV has been defined as standing or exercising on a vibrating platform that transmits vertical sinusoidal oscillations to the entire body via the feet.<sup>10</sup>

WBV improves intermuscular and intramuscular coordination by inducing high-frequency muscular contractions of agonists and antagonists in the neuromuscular system.<sup>11</sup> This effect mainly improves power in individuals with motor impairment. Ward et al.<sup>12</sup> applied high-frequency vibration therapy with low amplitude to improve trabecular bone density in children affected with neuromuscular diseases. Negative side effects were not reported after 6 mos of vibration therapy. This positive experience raised the hope that vibration therapy may improve physical ability in children with motor impairment.<sup>13</sup>

In a randomized controlled trial, Ruck et al.<sup>14</sup> studied the effects of WBV on children with CP. WBV increased the average walking speed in a 10-m walking test. WBV had a significant effect on bone

mineral density, muscle force, and gross motor function in children with bilateral spastic CP. This study serves as a basis for future research on evidence-based pediatric physiotherapy.<sup>15</sup>

WBV training seems to increase muscle strength,<sup>16</sup> which may lead to improvements in walking and mobility parameters, including gait speed, stride length, cycle time, and ankle angle. The therapeutic principle is based on the activation of proprioceptive spinal circuits. The proprioceptive organs detect a change in body position by detecting a change in the length of muscles and tendons and induce a contraction of the antagonist stabilizing the system because of the spinal reflex.<sup>11</sup>

The aim of this study was to evaluate the effect of 3 mos of WBV training on muscle strength and balance in children with spastic diplegic CP. The main hypothesis was that the treatment would improve muscle strength and postural control in these patients.

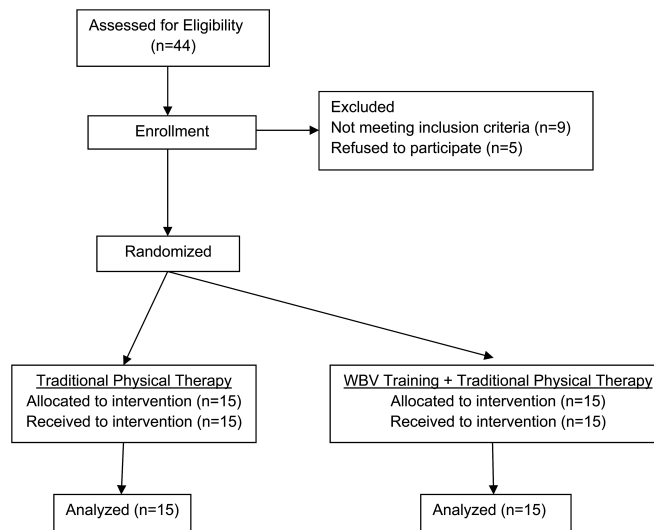
## MATERIALS AND METHODS

### Subjects

Thirty children who were diagnosed with spastic diplegic CP were included in this study. To avoid a type II error, a preliminary power analysis (power = 0.87,  $\alpha = 0.05$ , effect size = 0.5) determined a sample size of 30 for this study. The criteria for inclusion in this study were age between 8 and 12 yrs, ability to walk with or without walking aids, a degree of spasticity between 1+ and 2 according to the modified Ashworth Scale, and ability to understand and follow simple verbal instructions. The exclusion criteria were dyskinetic CP, medication changes that could affect muscle strength or tone, cardiac or respiratory conditions that are affected by exercise, and the occurrence of unstable seizures or lower limb orthopedic surgery in the preceding 12 mos or botulinum toxin injections in the previous 6 mos. The children were identified from the outpatient clinic at the Faculty of Physical Therapy, Cairo University, Egypt. Written informed consent was obtained from all participants. The parents of potential participants were contacted by a researcher, who gave further oral explanations and answered questions as needed. This study was approved by the ethical committee of the Faculty of Physical Therapy, Cairo University.

### Randomization

For this study, 44 children were identified as potential participants. Nine children were excluded because they failed to fulfill the inclusion criteria,



**FIGURE 1** Flow diagram showing the children participating in this study.

and parents of five children refused to participate in this study.

Randomization was performed using sealed envelopes. The investigator prepared the sealed envelopes, which contained a piece of paper indicating whether each participant was in the experimental group (WBV) or the control group (traditional treatment). Allocation occurred before the initial assessment. The experimental design is shown as a flow diagram in Figure 1.

### Procedures

Baseline and posttreatment assessments were performed for all children by a single blinded examiner. Knee extensor strength was evaluated using the Biodex isokinetic dynamometer (Biodex Medical System, Shirley, NY) linked to the IBM personal computer software. Each child was seated, and his/her position was stabilized with a restraint strap over the mid thigh, the pelvis, and the trunk in accordance with the Biodex Advantage operating manual. All children were familiarized with the Biodex test in a similar manner. First, the administrator of the test demonstrated the procedure. Second, the test procedure was explained to the children. Third, the children were allowed to warm up and practice the actual movement by performing three repetitions without a load. More repetitions were not allowed to prevent the onset of fatigue. The anatomic axis of the knee joint was aligned with the mechanical axis of the dynamometer before the test. After three submaximal warm-up repetitions, each child was instructed to generate maximum voluntary concentric torque via a verbal command to

push as hard and fast as he/she can, then relax. The test procedure included three attempts at the maximum concentric contraction of the quadriceps muscle, with a rest period of 30 secs between attempts. The mean peak torque (newton meter) of the three tests was recorded.

Balance and postural stability were evaluated using the Biodex Balance System. This device is used to assess neuromuscular control by quantifying the ability to maintain dynamic postural stability on an unstable surface. The Biodex Balance System consisted of a high-resolution color touch screen, support rails, and 12 levels of platform control. The Biodex Balance System allows for 12 stability levels, which range from stability level 1 to stability level 12.

Each child was asked to achieve a centered position on a slightly unstable platform by shifting his/her foot position until it was easy to keep the cursor (representing the center of the platform) centered on the screen grid while standing in a comfortable upright position. Once the participant was centered and the cursor was in the center of the display target, he/she was asked to maintain his/her foot position until the platform was stabilized. The test began after introducing foot angles and heel coordinates into the Biodex system. The child was instructed to focus on the visual feedback screen directly in front of him/her, hold both arms at the side of his/her body without grasping the handrails, and attempt to maintain the cursor in the middle of the bull's-eye on the screen. The duration of the test was 30 secs, and the mean of three repetitions was determined. At the end of each test, the results were printed. These results included the overall stability

**TABLE 1** Mean (standard deviation) of the general characteristics of the participants

Characteristics	Control ( <i>n</i> = 15)	Experimental ( <i>n</i> = 15)	<i>P</i> (Two-Tailed)
Sex (boy/girl), <i>n</i>	11/4	12/3	0.66
Age, yrs	9.93 (1.1)	9.66 (1.2)	0.54
Weight, kg	32.43 (0.70)	32.23 (0.45)	0.36
Height, m	1.34 (0.40)	1.34 (0.51)	0.24
GMFCS level			
I	6	7	
II	9	8	0.72

GMFCS indicates Gross Motor Function Classification System.

index, the anteroposterior stability index, and the mediolateral stability index. Higher values indicate that the child had difficulty balancing.

## Treatment

The participants were allocated to either the experimental group (WBV training) or the control group (traditional physical therapy program). Both treatment groups received traditional physical therapy training, which included neurodevelopmental techniques, muscle stretching, strengthening exercises, proprioceptive training, and balance training, for 3 mos (1 hr per day, 5 days per week).

The experimental group underwent additional WBV training using the Vibraflex Home Edition II WBV device (Orthometrix Inc, White Plains, NY). Outside North America, the brand name Galileo Basic is used for this equipment. This device has a motorized board that produces side-to-side alternating vertical sinusoidal vibrations around a fulcrum in the midsection of the plate. The user can select the frequency of the vibrations. The patient stands on the board with each foot placed at an equal distance from the center of the board. The peak-to-peak displacement to which the feet are exposed increases with the distance of the feet from the center line on the vibrating board. Three positions are indicated on the vibrating board as 1, 2, and 3, which correspond to peak-to-peak displacements of 2 mm, 4 mm, and 6 mm.

The treatment schedule was adapted from published observational studies that used the same WBV system to treat children with neuromuscular diseases and bone fragility disorders.<sup>13,17</sup> Each WBV session consisted of the following schedule: 3 mins of WBV, 3 mins of rest, 3 mins of WBV, 3 mins of rest, and 3 mins of WBV. Thus, one treatment session corresponded to 9 mins of exposure to WBV.

The first treatment sessions were performed using a vibration frequency of 12 Hz with the middle toe of each foot placed 5.5 cm from the neutral axis of the vibration plate (indicated as position 1 on the WBV device). The peak acceleration exerted by vibration increases with the frequency and the amplitude of the vibration. Therefore, higher frequency and higher amplitude are likely to elicit higher musculoskeletal force in the user of the WBV device. The goal was to increase the vibration frequency to 18 Hz and the peak-to-peak displacement to 4 mm (as determined for the middle toe of each foot). These target settings correspond to a peak acceleration of approximately 2.6*g* and were based on the authors' previous experience from a small observational study, which indicated that these settings are usually well tolerated by children with CP.<sup>18</sup> The intended protocol was to increase the WBV frequency in steps of 0.5 Hz every two treatment sessions until the target frequency of 18 Hz was attained. The actual speed of the increase in WBV frequency depended on the child's ability to tolerate the vibration. The frequency was increased only if the child felt comfortable with the setting. Once a frequency of 18 Hz was reached, the feet were gradually placed wider apart until these were vertical below the hip joints. Thus, the middle toe of each foot was eventually placed between 8 cm and 11 cm from the neutral axis of the vibration plate, depending on the width of the child's pelvis. The children flexed their knees and hips between 10 and 45 degrees to prevent the vibration from extending up to the head. Guided by the study physiotherapist, the children shifted their weight from side to side or increased and decreased the knee and hip angles. Other exercises included weight shift with rotation of the trunk and alternate flexion and extension of the knees. Postural correction was encouraged through visual feedback, which was provided by performing the treatment in front of a mirror, and through verbal feedback, which was provided by the therapist's cues.

## Data Analysis

Data were analyzed using the Statistical Package for the Social Sciences software, version 16.0. Descriptive statistics of mean and standard deviation presented the children's ages, weights, heights, and functional levels. A 2 × 2 mixed analysis of variance was used to analyze the knee extensor peak torque. In this case, one factor was the treatment group (control *vs.* experimental) and the other factor was time point (preintervention *vs.* postintervention). Nonparametric tests (the Wilcoxon's signed-rank test and the Mann-Whitney test) were used to analyze the

**TABLE 2** Mean (standard deviation) of comparisons of the quadriceps peak torque within each group and between groups

Variable	Test	Control ( <i>n</i> = 15)	Experimental ( <i>n</i> = 15)	Time Effect		Group Effect	
				<i>F</i> <sub>1</sub>	<i>P</i>	<i>F</i> <sub>1</sub>	<i>P</i>
Quadriceps peak torque at 60 degrees per second, N · m	Pretest	16.03 (1.63)	16.23 (1.59)	1.7	0.0001	5.7	0.001
	Posttest	28.80 (0.45)	30.90 (0.68)				
Quadriceps peak torque at 90 degrees per second, N · m	Pretest	33.96 (1.74)	34.06 (1.65)	9.5	0.001	2.3	0.001
	Posttest	47.50 (0.70)	54.20 (1.70)				

pretreatment and posttreatment values of the stability index within and between the groups. A *P* value of less than 0.05 was accepted as significant.

## RESULTS

Thirty children (23 boys and 7 girls) with diplegic CP were included in this study. The participants were randomized to the control (*n* = 15) and experimental (*n* = 15) groups. There was a mean ± SD age of 9.93 ± 1.16 yrs and 9.66 ± 1.23 yrs for the control and experimental groups, respectively. The demographic and clinical characteristics of the participants in both groups are listed in Table 1. The data indicated that the groups had similar demographic characteristics and functional levels.

Before treatment, there were no statistically significant differences in the mean values of peak torque of the quadriceps muscle at 60 degrees per second and 90 degrees per second between the control and experimental groups, as presented in Table 2. In contrast, there was a statistically significant

difference between the mean values of the quadriceps peak torque at 60 degrees per second and 90 degrees per second obtained during the baseline and posttreatment assessments. The posttreatment values of the quadriceps peak torque at 60 degrees per second and 90 degrees per second were 28.80 ± 0.45 and 47.50 ± 0.70 N · m for the control group and 30.90 ± 0.68 and 54.20 ± 1.70 N · m for the experimental group, as described in Table 2. Two-way analysis of variance with repeated measure revealed a significant group × time effect in the knee extensor peak torque (*F*<sub>1</sub> = 5.7, *P* = 0.001; Table 2). This result indicates that the children in the experimental group showed remarkable improvement when compared with the children in the control group. The overall effect size of two-way analysis of variance with repeated measures in the knee extensors peak torque was 0.83 and 0.93 at 60 degrees per second and 90 degrees per second, respectively.

Before treatment, there were no statistically significant differences in the mean values of the

**TABLE 3** Pretest and posttest mean values of stability index within each group and between groups

Variable		Control			Experimental			<i>Z</i> <sup>b</sup>	<i>P</i>
		Percentiles			Percentiles				
		25th	50th	75th	25th	50th	75th		
Overall stability index	Pretest	3.2	3.2	3.3	3.2	3.3	3.4	-1.38	0.20
	Posttest	2.7	2.75	2.8	2.2	2.2	2.3	-4.74	0.0001
	<i>Z</i> <sup>a</sup>		-3.42			-3.45			
	<i>P</i>		0.001			0.001			
Anteroposterior stability index	Pretest	2.6	2.65	2.7	2.75	2.8	2.8	-0.76	0.48
	Posttest	2.2	2.25	2.3	1.75	1.8	1.8	-4.8	0.0001
	<i>Z</i> <sup>a</sup>		-3.42			-3.49			
	<i>P</i>		0.001			0.0001			
Mediolateral stability index	Pretest	2.2	2.3	2.3	2.3	2.3	2.35	-0.90	0.41
	Posttest	2	2	2.1	1.6	1.65	1.65	-4.77	0.0001
	<i>Z</i> <sup>a</sup>		-3.43			-3.45			
	<i>P</i>		0.001			0.001			

<sup>a</sup>*Z* is the standard normal value corresponding to Wilcoxon's signed-rank test.

<sup>b</sup>*Z* is the standard normal value corresponding to Mann-Whitney *U* test.

stability index between the control and experimental groups ( $P > 0.05$ ), as presented in Table 3. In contrast, there was a statistically significant difference between the baseline and posttreatment values of all variables being tested: overall stability index, anteroposterior stability index, and mediolateral stability index ( $P < 0.001$ ). The overall stability index after treatment was 2.75 and 2.2 for the control and experimental groups, respectively, as shown in Table 3. The mean values of the stability index improved in both groups, but a greater improvement was observed in the experimental group than in the control group ( $P < 0.001$ ).

## DISCUSSION

The results of this study indicated that a 3-mo program of combined WBV and physical therapy increased muscle strength more than a 3-mo program of physical therapy alone (Table 2).

This study also showed that WBV improves postural control in children with CP (Table 3). In WBV therapy, the child is required to stand on an oscillating platform that generates mechanical vibration signals of varying frequency, magnitude, and duration. Because the vibration signals also constitute a form of sensory stimulation and induce reflex muscle activation,<sup>9</sup> WBV therapy is also proposed to have therapeutic effects on muscle strength and other important sensorimotor functions, such as postural control.<sup>19</sup>

These results are supported by the findings of Issurin,<sup>20</sup> who reports that WBV improves monosynaptic stretch reflexes induced by afferent signals from muscle spindles and reduces the inhibiting impact of Golgi tendon organs located at myotendinous junctions. Other possible explanations for the effects of long-term adaptation to vibration may include changes in perceived exertion,<sup>21</sup> improved motor neuron excitability,<sup>22</sup> improvements in anabolic hormone balance,<sup>23</sup> and muscle hypertrophy.<sup>24</sup>

These results are supported by the findings of Lee and Chon,<sup>16</sup> who reported that WBV training leads to an improvement in gait function as measured by speed. WBV training seems to increase muscle strength, which may underlie the change in gait speed.

The results of this study are supported by the findings of Ruck et al.,<sup>14</sup> who evaluated the effects of WBV on CP and concluded that a 6-mo trial of WBV is safe in children with CP and improves mobility function. The authors of this study did not detect a positive treatment effect of WBV on bone mineral density. These results are also consistent with the study of Stark et al.,<sup>15</sup> who concluded that WBV had

a significant effect on bone mineral density, muscle force, and gross motor function in children with bilateral spastic CP.

This study was conducted in children aged from 8 to 12 yrs in agreement with Westcott et al.,<sup>25</sup> who demonstrated that infants and young children (aged 4 mos to 2 yrs) depend on the visual system to maintain balance, children between 3 and 6 yrs of age begin to use somatosensory information appropriately, and children between 7 and 10 yrs of age resolve sensory conflicts and appropriately use the vestibular system as a reference. They added that postural control is essentially adult-like by approximately 7–10 yrs of age.

A critical aspect in selecting a measuring procedure is its reliability. The reliability of isokinetic strength testing of the knee extensor is widely documented in the literature, especially for adult participants without CP. Testing procedures for concentric contractions of the knee extensor were reported to be highly reliable across a wide range of angular velocities.<sup>26</sup> Molnar et al.<sup>27</sup> investigated the reliability of isokinetic testing on a variety of muscle groups of the lower and upper extremities in children aged 7–15 yrs. They concluded that isokinetic testing is simple to conduct and highly reliable for typically developing children with normal intelligence, as well as children with minor learning disabilities.

The mechanical stimulus of vibration transmits to the body and stimulates muscle spindles, which activate the alpha motor neurons and initiate muscle contractions comparable with the “tonic vibration reflex.” The effect of WBV on the neuromuscular properties of skeletal muscles and spinal mechanisms is demonstrated by a decreased electromechanical delay, an increased rate of force development, and a presynaptic inhibition of skeletal muscles.<sup>28</sup> WBV also effectively induces a small degree of postactivation potentiation.<sup>29</sup>

Acute vibration training is gaining popularity as a modality for sport, exercise, and physical rehabilitation because it initiates a rapid and repeating eccentric-concentric action that evokes muscular work and elevates metabolic rate.<sup>30</sup> Strong evidence suggests that acute indirect vibration acts on muscle to enhance force, power, flexibility, balance, and proprioception. This evidence suggests that WBV also enhances neural function. Despite these findings, the neural mechanism(s) of vibration and its potentiating effect have received little attention. One proposal suggests that spinal reflexes enhance muscle contraction through a reflex activity known as the tonic vibration reflex, which increases muscle activation.

However, tonic vibration reflex is based on direct, brief, and high-frequency vibration (>100 Hz), which differs from indirect vibration that is applied at lower frequency (5–45 Hz) to the whole body or to body parts.<sup>11</sup>

Knee extensor strength improvements after WBV were associated with reflex muscle activity and not body-weight exercises.<sup>28</sup> The current study also demonstrated improvements in knee extensor strength after WBV; these gains were significantly larger than those observed in a group performing the same exercises without vibration.

The mechanisms by which WBV acts on motor control are not completely understood. Vibration applied to the muscle-tendon system elicits reflex muscle contractions and exerts effects on sensory processing. Further effects of vibration include the modification of tracking movements, increased postural sway, and the modification of gait. The parameters of vibration and the predictability of stimuli can influence the physiologic effects.<sup>31</sup> It has been suggested that deficient proprioceptive processing contributes to the progressive worsening of postural responses. Although the impact of vibration on motor performance in patients with proprioceptive deficits was reported to be lower than that observed in healthy subjects, enhancement of sensory processing through WBV remains a possible mechanism.<sup>19</sup>

The significant improvement in muscle strength and balance observed in the control group is likely caused by the fact that the physical therapy exercise program was designed to increase voluntary control of the affected muscles of the lower limbs and the trunk, to decrease unnecessary muscle activity, and to improve balance. This promoted further control of the lower limb during the concentric and eccentric activities that are required during walking. This explanation mirrors the opinion of Gage and Novacheck.<sup>32</sup> The exercise program was directed to improve muscle strength, balance, and trunk control to the level required by the task rather than to maximize motor control.

In this study, WBV demonstrated several advantages over physical therapy alone. Vibration treatment could result in a greater gain of muscle function than could walking because many more stimulation cycles are applied to the muscles. Vibration treatment is also safer than walking with walking aids because the child stands on the platform and does not actively move the limbs, which provides less opportunity for slipping, tripping, or awkward movements. In addition, one of the purported benefits of WBV training is the ability to generate improvements in muscle strength while

producing less fatigue than is present with typical exercise and resistance training.<sup>24</sup>

This study has several limitations. The small number of participants might limit the generalization of the study results. Further studies that include a larger number of children with CP and have fewer inclusion and exclusion criteria will provide results that can be more easily generalized. Further studies are also recommended to target different ages and enable comparisons of the results across different age groups. Measurement errors for the Biodex system are also high for children with CP. The total amount of training time that the two groups received was also different. This is because all children received the same amount of traditional physical therapy, whereas the children in the experimental group received additional time for WBV training. Future investigations could compare the effectiveness of different treatment schedules as well as the mechanisms underlying the effect and also provide for extended follow-up, which could be considered another limitation of the present study.

## CONCLUSIONS

WBV training in combination with physical therapy exercise program may increase the gains in muscle strength and balance in children with spastic diplegic CP.

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