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Effects of whole-body vibration on quadriceps and hamstring muscle strength, endurance, and power in children with hemiparetic cerebral palsy: a randomized controlled study

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Abstract

Background: Hemiplegic cerebral palsy (CP) enormously affects the quadriceps and hamstring muscles. It causes weakness in the affected lower-extremity muscles in addition to muscle imbalance and inadequate power production, especially in the ankle plantar-flexor and knee extensor muscles. It also causes anomalous delayed myoelectrical action of the medial hamstring. A whole-body vibration (WBV) exercise can diminish muscle spasticity and improve walking speed, muscle strength, and gross motor function without causing unfavorable impacts in adults suffering from CP. Thus, the aim of this study is to investigate the impacts of WBV training associated with conventional physical therapy on the quadriceps and hamstring muscle strength, endurance, and power in children with hemiparetic CP.

Results: The post-intervention values of the quadriceps and hamstring muscle force, endurance, and power were significantly higher than the pre-intervention values for both groups (p = 0.001). The post-intervention values of the study group were significantly higher than the control group (quadriceps force, p = 0.015; hamstring force, p = 0.030; endurance, p = 0.025; power, p = 0.014).

Conclusion: The 8 weeks of WBV training that was added to traditional physical therapy was more successful in improving the quadriceps and hamstring muscle strength, endurance, and power in children with hemiparetic CP when compared to traditional physical therapy alone.

Keywords: Cerebral palsy, Endurance, Force, Power, Vibration

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Background

Cerebral palsy (CP) is a developmental disorder of movement and posture. It causes non-progressive disturbances of the brain, which prompts movement impediments and conversely influences sensation, perception, cognition, behavior, and communication. Furthermore, there are spasticity, dyskinesia, and hyperreflexia which disturb motor control of walking, reaching, and accuracy of grasping objects [1].

Results of the meta-analysis study of Spittle et al. [2] revealed that the pervasiveness of CP was 14.6% in extremely preterm children, 6.2% in very preterm children, and 0.7% in the moderate to late preterm when compared with 0.11% in term-born children. Such result can be divided on the basis of the motor effects it has on the individual; these can incorporate pyramidal/spastic CP or extrapyramidal/non-spastic CP [3, 4]. It was shown that the most widely recognized sort of CP was the pyramidal or spastic CP which is combined with tight or contracted muscles [4, 5]. CP is frequently subdivided according to the affected parts of the body into monoplegia, hemiplegia or hemiparesis, paraplegia or paraparesis, diplegia, and quadriplegia or quadriparesis [6]. Children with CP have weak muscle strength and control, which limits the functional activities such as standing and walking [7]. Also, the quadriceps and hamstring muscles are affected in hemiplegic CP that may cause a remarkable change in the functional activities such as sit-to-stand activities, stairs climbing, and controlling upright posture during walking [8].

The whole-body vibration (WBV) exercise is conducted with the subject's body on an oscillating platform which vibrates horizontally at a frequency ranged from 10 to 25 Hz [9]. This stimulates the primary endings of muscle spindles and actuates the motor neurons to produce muscle contraction, similar to the tonic vibration reflex [10]. Its low-frequency training diminishes the muscle tone in contrast to high frequencies (40 Hz), which expands the muscle tone [11]. Therefore, WBV has positive effects on muscle performance [12]. In WBV training, the participant stands on a platform that produces vertical vibrations which invigorate the muscle spindles resulting in reflexive muscle contraction [13].

Muscle strengthening training is a significant strategy to prepare frail muscles responsible for debilitated walking capacity like quadriceps muscle in spastic kids. WBV is currently a quickly evolving procedure that is utilized to improve muscle strength in spastic conditions [14, 15]. WBV exercise builds muscle strength and force that could prompt enhancements in the nature of the neuromuscular capacities. Furthermore, when it is compared with other common resistance training programs, a study revealed that it requires some less rehabilitation time [16]. WBV has been acknowledged as a treatment for patients with spastic CP. Tupimai et al. [7] figured out a decrease in the spasticity of the hip adductor, quadriceps, hamstrings, and soleus muscle of the stronger leg just as the soleus of the weaker leg after passive muscle stretching (PMS) associated with the use of oscillating WBV in children with spastic CP when compared with PMS alone.

Nordlund and Thorstensson [17] detailed that WBV training improved life quality and person satisfaction. Likewise, it has useful outcomes of lower-extremity muscle strength, back pain, and bone mineral density. In addition, Wren et al. [18] indicated critical improvement in the lower-limb muscle function in children with diminished mobility. Studies revealed that WBV enhanced the muscle strength and decreased spasticity of the quadriceps muscles in grown-ups with spastic diplegic CP [19]. Additionally, it expanded the power force, velocity, and jump performance following one session of WBV training [20, 21]. Torvinen et al. [22] deduced that WBV improves isometric strength of the quadriceps muscle and vertical jump performance in youthful sound subjects.

Puthoff and Nielsen [23] mentioned that the impedances in lower-extremity muscle performance (strength, endurance, and power) took place due to functional deficiency and inability. Along these lines, keeping up and improving lower-extremity strength and force are fundamental factors to diminish the functional impediments and incapacity. Duquette et al. [24] indicated in their review study that WBV may enhance spasticity, muscle strength, and coordination in children suffering from CP. Similarly, it was effective in improving muscle strength and the force limit of humans [9]. Be that as it may, no investigations have explored the impact of vibration incitement on the muscle strength, endurance, and force of the lower limbs in children with hemiparetic cerebral palsy. Thus, this study explored the impact of WBV training related to customary-used physical therapy on the quadriceps and hamstring muscle strength, endurance, and force in children with hemiparetic CP.

Methods

This randomized controlled study was conducted between September of 2019 and February of 2020. Forty-four children, diagnosed as having spastic hemiparetic CP (boys and girls), participated in the study. They were selected from the Faculty of Physical Therapy clinic, Cairo University, and National Institute of Neuromotor System. Their age went from 4 to 8 years sequentially, and somewhere in the range of 16 and 20 months, they achieved a development as per Denver developmental screening scale, to limit motor variability. The participants' demographic data are shown in Table 1.

Table 1 Demographic characteristics of the participants

	Study group, *n* = 20	Control group, *n* = 20	*p* value
Age, year	6.05 ± 1.5	5.85 ± 1.46	0.672
Weight, kg	18.95 ± 3.76	19 ± 6.31	0.976
Height, cm	110.60 ± 8.31	111.40 ± 11.94	0.807
BMI, kg/m^2	15.36 ± 1.68	14.89 ± 2.06	0.439
Boys/girls	12/8	10/10	0.523
Affected side, right/left	12/8	9/11	0.342
Spasticity grades, 1/1+	14/6	12/8	0.507
GMFCS level, I/II	7/13	9/11	0.519

Data are presented as mean ± standard deviation, *significantly ($p < 0.05$), *BMI* body mass index, *spasticity grades* modified Ashworth scale, *GMFCS* Gross Motor Function Classification System

The incorporation standards of the study were (1) spasticity went from 1 to 1+ evaluation as per the modified Ashworth scale [25]; (2) levels I and II, as per Gross Motor Function Classification System (GMFCS) [26]; (3) ready to comprehend and adhere to verbal orders and guidance included in both assessment and treatment; (4) resilient to stand alone and walk forward and backward without assistive device; (5) the CP diagnosis was conducted by a pediatric neurologist; and (6) each one of the children was 1 m tall or more so that they can stand on the WBV device and grasp the hand rails. Children with both hearing and visual impairments, fixed deformities in either one of the lower extremities, a history of convulsions, and children receiving anti-spastic drugs who had undergone surgeries in the lower-limb musculoskeletal system were excluded from the study. The protocol of this study was approved by the ethical committee of the Faculty of Physical Therapy, Cairo University, Egypt (No: P.T.REC/012/ 002581), and was retrospectively registered by the Pan African Clinical Trial Registry (PACTR202006704135699). Following an explanation of the experimental protocols, written informed consent was obtained from all participants' parents.

Enclosing assignment in sequentially numbered, opaque, sealed envelopes was used for the allocation concealment. An external independent person performed the envelopes' opening process, who was unaware of the group allocation until data analyses were complete. Besides, he was not aware of the treatment technique and had no contact with the participants. A group of 63 children with CP were examined to be sure that the basic requirements were met. It was revealed that 19 children out of the total number did not meet the consideration standards. The remaining 44 children were divided randomly into two groups (n = 22 per group). A control group received a traditional physical therapy program and a study group received the same physical therapy program combined with WBV training.

The G Power was used to calculate the sample size. Effect size (ES) was calculated with basis on α value and power of the test. With ES (1), α (0.05), and power of the test (0.85), the total sample size was estimated to reach 38 children. Figure 1 shows the recruitment and treatment allocations of the participants. After 8 weeks of intervention, the measured outcomes were accessible for 20/22 patients in the study group and 20/22 in the control group.

Procedure

The children were evaluated for quadriceps and hamstring muscle performance, including strength, endurance, and power before and after the intervention. Strength is the ability to exert force, while power is precisely defined as the time rate of accomplishing work, where work is the result of the force exerted on an object and the distance the object moves in the direction in which the force is exerted. Furthermore, both variables reflect the ability to exert force at a given velocity. Power is a direct mathematical function of force and velocity [27].

A Lafayette hand-held dynamometer (HHD) [Model-01163, Lafayette Instrument Company, USA] is a convenient portable tool that can be easily applied in the clinic for strength assessment. A study indicated moderate to excellent test-retest reliability (interclass correlation coefficients in the range of 0.56 and 0.97 of strength estimations got with a HHD for various muscle groups, pathologies, and application techniques) [28].

Quadriceps muscle force assessment

HHD was utilized to evaluate the muscle strength while the child extends and flexes the knee. The participants sat on a standard treatment table, when the quadriceps muscle was allowed to contract to a degree not more than 85° of knee flexion. The child could stabilize the trunk and pelvis by grasping the table edge. The child carried out three trials with a tangible exerted effort that developed from 50%, 75%, and reached ultimately to

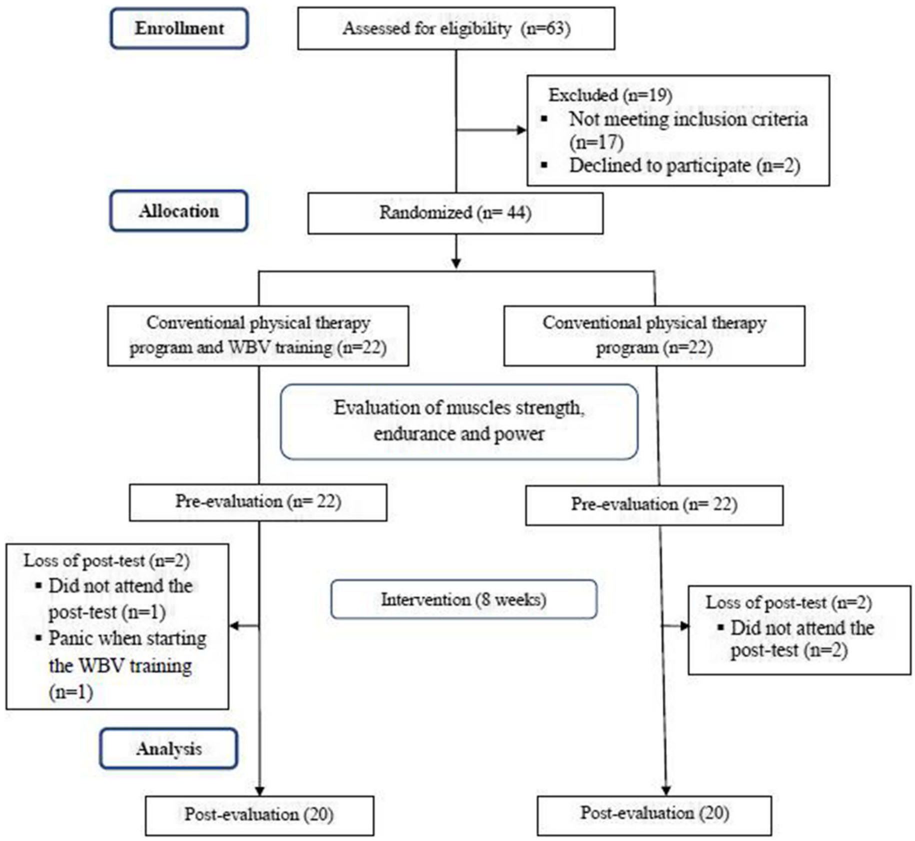

Fig. 1 Flowchart of the study processes. WBV indicates whole-body vibration

100%. Then, he did three maximal contractions, which went on for 5 s, with rest intervals of 60 s. The therapist set the device sensor only proximal to the ankle joint and balanced out the position of the HHD in relation with the shank, without giving counterforce. The peak force of every trial was recorded in pounds (lbs) [29].

Hamstring muscle force assessment

After the child has finished four contraction trials of the hamstring muscle against HHD, data showed that the exercise was accomplished with a gradual progress as follows: 25%, 75%, until reached to 100% of maximal effort on the last trial. All contraction trials were conducted while the child lay prone with the knee flexed to 90° [30]. When the child accepted this position, the assessment of the hamstring muscle force was acted as per the strategy of Rheault et al. [31]. A static hamstring contraction was carried out against the HHD which was put on the back side of the lower leg, two inches proximal to the lateral malleolus. At that point, the examiner requested that the child apply a steadily expanded power until reaching to the maximal contractile force, which was kept up for around 5 s to accomplish the peak force result, while the examiner balanced out the pelvis and held the HHD device to record the force esteem. While performing the test, the child was told to pull against the device, "pull as hard as you can, pull harder, relax." [32].

Muscle endurance: six-minute walk test (6 MWT)

This is a sub-maximal exercise test used to evaluate the aerobic capacity and muscular endurance [33] that was utilized to assess the muscle endurance. The recommendations of the American Thoracic Society [34] indicated that it is a practical test that requires 100 ft (30 m) passage to measure the distance that an individual can walk rapidly in a time of 6 min. The therapist identified the starting point and asked the child to walk the entire passage in 6 min; he followed him/her to protect him from falling. Then, he measured the specific distance walked quickly in 6 min by utilizing a stopwatch. The child was told to cover the longest distance as possible without running. When the child completed walking for 6 min, he was asked to stop walking and the therapist stopped the stopwatch. Subsequently, the total distance was determined [35].

Muscle power: vertical jump height (VJH) test

The vertical jump height test gives a significant index of muscular power. It was utilized to estimate the muscle power by determining the distance between the two marks (the first mark is rated when the child stands next to the chart, lifting his hand, while the other one is rated after the child jumped and touched the chart). Then, the Lewis formula [36] was employed to compute the average muscle power [average power (Watts) = 4.9 × body mass (kg) × VJH (m) × 9.81].

Intervention

The control group got the traditional physical therapy program for the rehabilitation of such children that incorporates (1) stretching activities to keep up muscle elasticity particularly Achilles tendon, hamstring muscles, hip flexors and adductors, shoulder internal rotators, elbow and wrist flexors, pronators, and ulnar deviators; (2) strength training to hip flexor, knee extensor, and ankle dorsiflexor; (3) facilitation of postural responses to ameliorate the mechanisms of posture control through the utilization of an assortment of activities including a ball and a balance board through inclining it forward, backward, and sideways; (4) stimulate the joint mechanoreceptors to control spasticity by utilizing proprioceptive exercise training (approximation) which is applied in a slow and rhythmic way for upper and lower extremities and trunk from a semi-leaned back and quadruped positions; (5) facilitation of single limb support; (6) balance training on the mat and tilting board, from quadruped, kneeling, half kneeling, and standing position; (7) facilitate the parachute reactions by pushing the child from sitting on a roll and from a standing posture to boost the child to take protective steps either forward, backward, or sideways to get back his/her balance [37]; (8) gait training exercises through walking on different floor surfaces (mat, floor, carpets) that will improve also the body balance [38].

The previously mentioned physical therapy intervention in addition to a WBV training session, by using a WBV platform (Galileo Med. L Plus model 2000, Novotech Medical GmbH, Germany), was conducted to the study group. The WBV program comprises various positions such as the child stands in an erect position, stands on one leg, and stands facing hand rails according to Ibrahim et al. [39] on a vibrating platform (Fig. 2). This platform vibrates horizontally at a frequency ranged from 10 to 25 Hz incrementing gradually with amplitude of 2 mm [40]. The participants had to carry out each position for 2 min in the first month, and then it was increased to 3 min in the second month. The rest period between each position was 1 min in the first month, then it became half a minute in the second month. The duration of the vibration exposure was 10 min. Manual mode was selected for maximum efficiency of exercising and to prevent accommodation.

The same physical therapist conducted the treatment program for both groups (3 times/week for 2 successive months, 1 h each session). None of the participants received less than 24 sessions. During the study period, participants received no physical therapy treatment rather than that scheduled in the study protocol.

Statistical analysis

The data were analyzed by using SPSS for Windows version 20.0 (SPSS, Inc., Chicago, IL). Before data analysis, the normality test (Shapiro-Wilk) showed that it was normally distributed ($p > 0.05$). This test was essential before conducting the parametric data analysis. An independent t test was used to investigate the significant difference between both groups regarding age, weight, height, and BMI, and the chi-square test was used to examine the significant difference between both groups regarding gender, affected side, spasticity grade, and GMFCS level. A two-way mixed analysis of variance (ANOVA) was used to investigate the difference between the quadriceps and hamstring forces, VJH, 6 MWT, and

Fig. 2 Child positions during whole-body vibration training

power of both groups. The Bonferroni was used as a confidence interval adjustment to compare main effects with the significance level set at 0.05 for all tests.

Results

Table 1 shows no significant difference in age, height, weight, and BMI of both groups (p = 0.672, 0.976, 0.807, 0.439 respectively). Moreover, there was no noteworthy distinction between both groups in gender, affected side, spasticity grades, and GMFCS level (p = 0.523, 0.342, 0.507, 0.519 respectively). Descriptive statistics of the quadriceps and hamstring muscle force are shown in Table 2. The values of 6 MWT, VJH, and lower-extremity power before and after the intervention are illustrated in Table 3.

In general, there was a significant between-subjects effect (groups, p = 0.001) and significant within-subjects effect (time, p = 0.001) and intervention effect (time × group, p = 0.001). Subsequently, multiple pairwise comparison tests were conducted to identify the source of significance regarding the group interaction (study versus control) and time (pre versus post) factors.

The investigation result shows that there was no critical distinction between both groups in respect to their pre-estimations of the quadriceps and hamstring muscle power, as it was (p = 0.741, 0.665 separately). However, there were noteworthy increments in the post-estimations of the two groups when compared with their pre-estimations (p = 0.001). The study group's post-values were altogether higher than the post-estimations of the control group (p = 0.015, 0.030 individually), as explained in Table 2.

For the pre-values of 6 MWT, VJH, and muscle power, there was no critical distinction between both groups (p = 0.585, 0.893, 0.855 respectively). There were significant increases in the post-values of both groups compared to their pre-values (p = 0.001). The study group's post-values were significantly higher than the post-values of the control group (p = 0.025, 0.001, 0.014 respectively), as illustrated in Table 3. No harmful events were recorded in both groups.

Discussion

The current study revealed that adding the WBV training to the traditional physical therapy program increased the strength, endurance, and power of quadriceps and hamstring muscles in children with hemiparetic CP more than traditional physical therapy alone. Performance of quadriceps and hamstring muscles is important for ambulation as the activation of quadriceps immediately after initial contact can reduce the energy needed for heel strike and hamstring muscle activated during the swing phase of the gait cycle to flex the knee joint [41].

Overactivity of the hamstring muscle is a basic finding in an electromyographic pattern during gait in children with CP. These muscles have antagonistic action to hip flexor and knee extensors and result in a reduction in sagittal plane motion of the hip and knee joints [14]. The medial hamstring muscle showed abnormal prolonged electrical activity during gait in CP children [42].

There was a significant increase in the post-values of the quadriceps and hamstring muscle force and power of the control group compared to pre-values. This improvement could be a result of exercises that enhance muscle performance, which comes into agreement with Unger et al. [43] who reported that the resistive exercise has been broadly used as a treatment protocol to improve muscle strength and endurance. Lee et al. [44] added that strengthening exercises could be a useful method to improve gait abilities of children with spastic CP. Furthermore, strengthening exercises enhance the muscle power and flexibility. It also improves the postural balance, activity of daily living, and functional activities like walking and running of those children [45].

Additionally, the control group's muscle forces and walking abilities might be brought about by the facilitator impact of the conventional physical therapy program, which improved the normal erect posture. This concurred with Kern et al. [46] who reported that the conventional treatment protocol of children with CP focuses on the accomplishment of the typical succession of development milestones, thus promotes the normal movement patterns. Comerford and Mottram [47] pointed

Table 2 The values of quadriceps and hamstring muscle force before and after the intervention

		Study group, n = 20	Control group, n = 20	p value
Quadriceps force, lbs	Pre	4.27 ± 1.45	4.09 ± 1.86	0.741
	Post	9.50 ± 1.64	5.07 ± 1.88	0.015*
	p value	0.001*	0.001*	
Hamstring force, lbs	Pre	3.25 ± 0.98	3.11 ± 1.05	0.665
	Post	5.07 ± 1.63	3.96 ± 1.48	0.030*
	p value	0.001*	0.001*	

Data are presented as mean ± standard deviation, *significantly (p < 0.05)

Table 3 The values of 6 MWT, VJH, and power before and after the intervention

		Study group, n = 20	Control group, n = 20	p value
Six-minute walk test, cm	Pre	169.95 ± 35.11	189.85 ± 45.74	0.585
	Post	249.95 ± 42.12	215.55 ± 51.00	0.025*
	p value	0.001*	0.001*	
Vertical jump height, cm	Pre	7.35 ± 2.83	7.48 ± 3.02	0.893
	Post	17.60 ± 2.78	9.73 ± 3.16	0.001*
	p value	0.001*	0.001*	
Average power, watts	Pre	111.78 ± 38.55	114.59 ± 56.08	0.855
	Post	173.80 ± 44.15	130.86 ± 59.55	0.014*
	p value	0.001*	0.001*	

Data are presented as mean ± standard deviation, *significantly ($p < 0.05$)

out that muscles have three major functions: static control of posture and alignment of joints, dynamic movement control, and providing a proprioception afferent information into the central nervous system. Consequently, the coordination between different muscle groups ensures the correct joint loading and correct alignment occurs [48].

Although there were significant increases in the post-values of the quadriceps and hamstring muscle force of the control group, however, the remarkable increments in the post-values of the study group were significantly higher than the post-values of the control group when compared with their pre-values, which comes in concurrence with the outcomes of Delecluse et al. [49] who concluded that WBV training increases the strength of knee extensors through creating a reflexive muscle contraction in untrained participants. They emphasized that these results are not the result of a placebo effect.

Rittweger et al. [50] discovered that the improvement achieved by the study group is coincident. He pointed out that WBV training employs the stretch reflex to facilitate muscle contraction as it activates 90% of the body muscles, and these are considered as the advantages of WBV training, whereas the traditional resistance training employs 40–50% only of the muscles and it has a direct stimulation of the nervous system. This emphasizes that WBV training improves the communication between the brain and the muscles. Consequently, it leads to quicker, proficient, and precise muscle contractions, which in turn creates the muscle power and strength development. Also, the WBV training improves the circulatory system by increasing the oxygen transfer capabilities to the contracted muscles. Furthermore, Rittweger et al. [50] demonstrated that vibration training increases human growth hormone levels, while, at the same time, decreases cortisone. These two hormones, in addition to other things, assume a function in the breakdown and the build-up of muscle tissue (referred to as anabolism and catabolism). With these two hormones in better balance, the muscles are maintained in a healthy and strong state.

The post-values of the study group were altogether higher than the post-values of the control group in respect to vertical jump height that is compatible with the outcome of Bosco et al. [51] who detailed that there was a noteworthy improvement in the jumping performance for children having daily vertical sinusoidal vibrations at a frequency of 26 Hz following 10-day of the training program. Moreover, WBV training improved equilibrium, deftness agility, and power [52], and the concentric torque of quadriceps muscles [53], and this in turn underpins the remarkable improvement in lower-extremity muscle strength and VJH of the study group.

The study group showed a notable increment in the walking distance for a time of 6 min than the control group which concurs with Torvinen et al. [22] who found an increase in the walking velocity in children with CP who were treated with WBV. In spite of the fact that the WBV training duration was short (3 weeks), Ko et al. [54] reported that the WBV training improved the ankle joint proprioception sensation and gait parameters in children with CP. Also, Torvinen et al. [55] stated that the leg extension strength and jumping performance have been improved after 4 months of vertical vibration training. They suggested that the WBV training developed a neuromuscular adaptation to the vibration stimulus in young healthy nonathletic adults. The vibratory stimulus of the WBV training intensely enacts the deep sensory receptors, which develops a reflexive muscle contraction. This mechanism may explain the higher improvement which the study group achieved in comparison with the control group [56].

Moreover, the WBV inspires the tonic vibration reflex which incorporates enactment of muscle spindles, interceded by the neural signs of Ia afferents, and lastly, actuated the muscle fibers through enormous motoneurons. Additionally, this reflex increases the motor unit recruitment through activation of muscle spindles and polysynaptic pathways [55]. This was concurrent with the discoveries of Song et al. [57] who found that the WBV training enhanced the equilibrium level, walking velocity, stride length, and angle of toe deviation. It also diminished the duration of single support and double limb support of a child with spastic CP. In addition, they concluded that the horizontal WBV training should be incorporated in rehabilitation protocols of children with CP since it can upgrade their physical performance without harmful impacts.

The improvement achieved by the study group could be clarified by the discoveries of the previous investigations which demonstrated that the WBV training increases oxygen use, muscle force, and temperature. Besides, it increases the rate of skin bloodstream [58, 59]. In the event that it is applied constantly, the practitioners will record sustained positive outcomes on postural balance, muscle strength, and bone mineral density [60]. Furthermore, Cheng et al. [61] revealed that the WBV training can improve the ambulatory level, increment joint mobility, and control the level of muscle spasticity in children with CP. In any case, Freitas et al. [62] concluded that the exposure to acute or chronic WBV training cannot create critical enhancements in body mobility, postural steadiness, and walking capacities in women with multiple sclerosis.

This investigation was limited to the following: First, the absence of follow-up on the advancement of the child's muscle strength, endurance, and force after the completion of treatment of the two groups that were critical to follow the lasting effect on the children. Second, certain secondary outcomes like gait kinematic and kinetic parameters, muscle electrical activities, spasticity, and body balance were not surveyed in the current investigation. More examinations are expected to survey the impacts of WBV on muscle performance in various sorts of children with CP. Finally, more research studies should be carried out to confirm the adequacy of WBV training on motor skills enhancement as opposed to the lower-extremity muscle performance.

Conclusion

This study showed that the addition of WBV training to the traditional physical therapy is more effective in enhancing quadriceps and hamstring muscle strength, endurance, and power in children with hemiparetic CP compared to traditional physical therapy alone. Therefore, the combination of WBV training with traditional physical therapy should be considered during designing a rehabilitation program for children with spastic CP.

Abbreviations

6 MWT: Six-minute walk test; ANOVA: Analysis of variance; CP: Cerebral palsy; ES: Effect size; HHD: Lafayette hand-held dynamometer; SPSS: Statistical Package for Social Sciences; VJH: Vertical jump height; WBV: Whole-body vibration

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Authors' contributions

All authors approved the final manuscript file. RG contributed to the conception, design of the work, acquisition and analysis of the data, interpretation of the data, and drafting the work and substantively revising it. AA contributed to the conception, design of the work, acquisition and analysis of the data, interpretation of the data, and drafting the work and substantively revising it. EE contributed to the conception, design of the work, analysis, and drafting the work and substantively revising it. YM contributed to the conception, design of the work, analysis, and drafting the work and substantively revising it.

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Availability of data and materials

The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Ethics approval and consent to participate

The study was approved by the ethical committee of the Faculty of Physical Therapy, Cairo University (P.T.REC/012/ 002581). A written consent was obtained from the parents of the children.

Consent for publication

A written consent was obtained from participants' parents.

Competing interests

The authors declare no competing interests.

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