8週全身律動對於腦性麻痺病童下肢肌肉張力以及功能的影響

Effects of an eight-week whole body vibration on lower extremity muscle tone and function in children with cerebral palsy

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簡述內容：

腦性麻痺是嬰幼兒或孩童由於尚未成熟的腦部受到非進行性、非暫時性之腦部神經損傷，造成動作及姿勢發展上的障礙，進而導致活動上及日常生活的限制，而這種損傷會導致運動失衡無法運動，需要復健及被動性的全身運動，研究顯示經由八週的垂直律動可以協助腦性麻痺孩童的走路功能，減少雙膝的痙攣、增加肌肉力量、改善運動功能。

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Effects of an eight-week whole body vibration on lower extremity muscle tone and function in children with cerebral palsy

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ABSTRACT

The aim of this study was to evaluate the effect of an eight-week whole body vibration (WBV) on lower extremity spasticity and ambulatory function in children with cerebral palsy with a complete crossover design. Sixteen participants aged 9.2 (2.1) years participated in this study. Half of the participants received a 10-min WBV, 3 times a week for 8 weeks. Then a 4-week washout period followed, after which they received a sham WBV 3 times a week for 8 weeks. The other half received the intervention in a reversed order. The participants were evaluated via variables measuring range-of-motion, muscle tone, and ambulatory function before, immediately after, 1 day after, and 3 days after each intervention. Repeated-measures analyses revealed significant beneficial effects on most variables expect the passive range-of-motion measurement. Significant correlations were found between timed up-and-go and relaxation index, and between timed up-and-go and six-minute walk test. The results suggested that an 8-week WBV intervention normalized muscle tone, improved active joint range and enhanced ambulatory performance in children with cerebral palsy for at least 3 days. These indicated that regular WBV can serve as an alternative, safe, and efficient treatment for these children in both clinical and home settings.

1. Introduction

Cerebral palsy (CP) is the most common childhood disabilities which affect individual's posture and movement (Koman, Smith, & Shilt, 2004). Compared to the typically developed children, these children have impaired sensation and increased muscle tone therefore they have trouble voluntarily controlling their muscles. About seventy to eighty percent of children with CP demonstrate spastic clinical features (Krigger, 2006). Traditionally spasticity is managed via anti-spastic medication

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or injection. Several disadvantages are associated with these treatments. First, not all patients achieve satisfactory results, and not all parents are comfortable with long-term medication use or invasive injection. In addition, there are side effects such as general weakness that in turn affect their functional performance. As a result, there is a need for alternative or additional treatment options.

Other than spasticity, poor muscle strength is also an important factor that leads to movement dysfunction in CP (Damiano, Martellotta, Sullivan, Granata, & Abel, 2000). The weak quadriceps in this population inevitability impaired their walking performance (Damiano, Kelly, & Vaughn, 1995). These days whole body vibration (WBV) has become popular in local gym and fitness centers, and it was found to offer fitness and health benefits, including flexibility and muscle strength (Dolny & Reyes, 2008; Kosar, Candow, & Putland, 2012; Rittweger, 2010). Recently, it seems to reach satisfactory results in managing spasticity and muscle strength among participants with upper motor neuron syndrome (Ahlborg, Andersson, & Julin, 2006; Chan et al., 2012; Ness & Field-Fote, 2009).

Whole body vibration (WBV) is a training method which exposures the whole body of an individual to low frequency, low amplitude mechanical stimuli via a vibrating platform. The vibration stimulate the muscle spindles, sending nerve impulses to initiate muscle contractions according to the tonic vibration reflex (Cardinale & Bosco, 2003). Its effects on enhancing health and fitness in general population have been studied extensively; however, little was done with special groups, for example children with CP. Ruck, Chabot, and Rauch (2010) examined the effects of a 9-min WBV program on children with CP and found their mobility improved (Ruck et al., 2010). In this particular study, the only indicator for mobility was the change in self-selected walking speed (Ruck et al., 2010). Unger, Jelsma, and Stark (2013) investigated the vibration on trunk muscle strengthening and found beneficial effects onto posture and gait. Other than the postural related measurements, there was only one gait parameter, the 1-min walk test, assessed (Unger et al., 2013). Furthermore, the direct effect on spasticity was never evaluated.

Ahlborg et al. (2006) performed a comprehensive survey of spastic, strength, and walking variables after an 8-week WBV or an 8-week resistance training in adult with CP (Ahlborg et al., 2006). They found WBV was more effective in decreasing spasticity of the knee extensors compared to the resistance training. Leg muscle strength increased in both groups. On the other hand, the ambulatory parameters did not change significantly. Although this study demonstrated an extensive investigation on the effects of WBV on CP, there were aspects that can be improved. First, findings of the study were gathered from adults with CP, not children. Children usually demonstrate a better potential in functional improvement, therefore studies with children as subjects are of great needs. Second, this study had no control group. A control group provides true baselines for all testing variables, and this becomes substantially important when dealing with children. Third, when isokinetic strength was measured before ambulatory parameters, the muscle exertion would hinder the effects of WBV on ambulation. Last, the study only measured immediate influences, no lasting effects were evaluated.

Therefore, the aim of this study was to evaluate the immediate and lasting effects of WBV on lower extremity spasticity and ambulatory function in children with CP. It was hypothesized that upon the completion of this 8-week program, the spasticity among these CP children would decrease significantly and their ambulatory function would improve.

2. Materials and methods

A crossover repeated measures design was employed in this study. Sixteen children with CP were randomly divided into two groups. One group received an 8-week WMV intervention followed by an 8-week control condition, with a 4-week rest in between; the other group began their treatment sequence with the control condition to counterbalance the order effects (Fig. 1). The outcome variables included active and passive range-of-motion (AROM and PROM) of both knees, relaxation

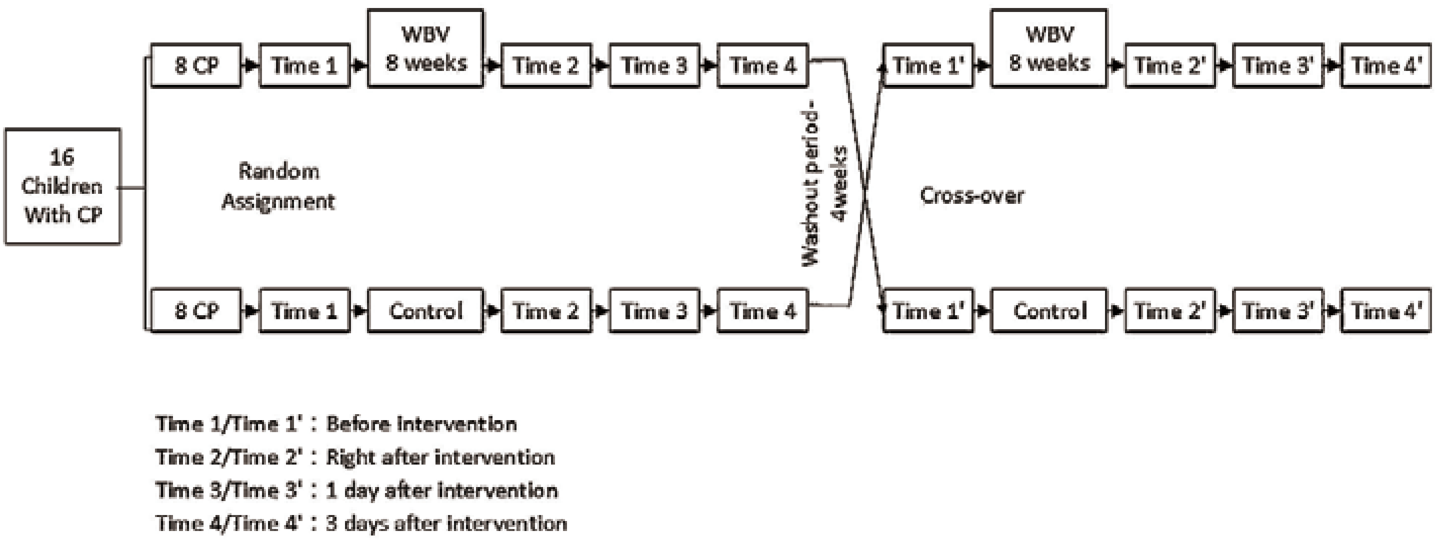

Fig. 1. Flow chart of the crossover design.

index (RI) assessed by the Wartenburg Pendulum test, modified Ashworth scales (MAS) for bilateral knee extensors, timed up-and-go (TUG) and 6-min walk test (6WMT).

2.1. Participants

Sixteen children with CP, eight boys and eight girls, aged 9.2 (2.1) years with diagnoses of either spastic diplegia ($N = 11$) or spastic quadriplegia ($N = 5$) were recruited from a local hospital and a special education school. The inclusion criteria were: (1) add-up MAS scores of bilateral lower extremity greater than two; (2) ability to walk for at least 6 min with or without walking aids; and (3) ability to comprehend commands. Criteria which would affect their muscle tone and ambulatory performance were excluded. The exclusion criteria were: (1) the presence of any progressive disorder or a severe concurrent illness not typically associated with CP; (2) lower extremity surgery within the past 6 months; (3) nerve block or botulinum toxin injection within the past 3 months; (4) a limitation of knee joint range-of-motion over 10°; (5) epilepsy. One of the authors performed the selection process. Most participants walked independently without walking aids except four, who used 4-wheeled walkers for ambulation. The Institutional Review Board for Human Studies of Chang Gung Memorial Hospital approved this protocol. Written informed consents were obtained from all participants and their legal guardians.

2.2. Equipment

The equipment utilized in this study included electrogoniometers (SG110, Biometrics, Ltd, Cwmfelinfach, Gwent, UK) and a WBV platform (AV-001A, Body Green, Taipei, Taiwan). The electrogoniometers, taped on the lateral sides of the knee joints, were used to measure the degree of flexion and extension. A data acquisition unit (MP150, Biopac Systems Inc., Santa Barbara, CA, USA) was used for signal registration. The WBV platform could provide vertical vibrations with frequencies and amplitudes ranging from 8 to 40 Hz and 0.4 to 2.0 mm, respectively.

2.3. Protocol

The vibration platform located in a quiet room with the environment set up for variable measurements. Subject was transferred to the room via wheelchair to avoid any fatigue prior to the testing. All participants underwent a series of outcome measurements in the order of AROM and PROM for knee joints, Pendulum test, MAS, TUG, 6MWT. Variables measured before the intervention (Time1) were the baseline scores. These measurements were administered again immediately after 8-week intervention (Time2), 1 day after (Time3), and 3 days after (Time4) the 8-week period. The test-retest reliability for each variable was evaluated from two consecutive days before intervention with ten children with spastic cerebral palsy, aged 9.7 (1.7) years. Change scores (Diff2-1/Diff3-1/Diff4-1) were used to show the improvement of each dependent variable measured in time 2, 3 and 4 compared to the baseline. The duration of each assessment was about 45 min.

Each subject performed both the WBV and control conditions in a counterbalanced order on two separate days, one week apart. The subject was instructed to adhere to the daily routines. Prior to the first experimental trial, the participant was requested to stand on the vibration platform with the knees slightly flexed at about 30 degrees from full extension. Anterior knee stops and a pelvic belt were used along with the WBV machine for securing their knees and pelvis to provide external support while standing. The participants were instructed to avoid holding on to the supported rail if possible however they were allowed to hold onto the rail if necessary (Ness & Field-Fote, 2009). They were asked to focus on standing with equal weights on both legs, and keep body movements to a minimum. Passive vibration was then delivered at 20 Hz with a vertical displacement of 2 mm. The WBV was given for 10 min. For the control condition, participants followed the same procedure instead that the vibration machine was not turned on. After the intervention, the participants were moved to the assessment area in wheelchairs to avoid any physical activity on their feet.

2.4. Outcome variables

2.4.1. Measurement of joint range-AROM & PROM

The AROM measures the range of movement through which the subject can actively move a joint using the adjacent muscles, whereas the PROM measures the amount of motion at a given joint when the joint is moved by an external force. Electrogoniometers were secured on the lateral sides of the knees for signal registration. For the AROM measurement, the subject was first asked to actively move the knee to full extension and then full flexion. Subject was asked to maintain full extension and flexion for 3 s each and the median angles of the two 3-s intervals were used for AROM calculation. For the PROM condition, their knees were passively moved by an examiner to the end range. The intraclass correlation coefficients (ICCs) for AROM and PROM were 0.73 and 0.79, respectively.

2.4.2. Measurement of spasticity—Wartenburg Pendulum test

The Pendulum test evaluated muscle tone by using gravity to provoke stretch reflexes of knee extensors during passive swinging of the lower limb. The oscillatory movements of the lower leg were captured by electrogoniometer at the lateral knee. The relaxation index (RI) was then calculated as follows: RI = (starting angle − first angle)/(starting angle − resting angle) × 1.6 (Burridge et al., 2005). The ICC calculated for RI was 0.72. In case of spasticity, the oscillatory amplitudes were significantly less as compared to those with normal muscle tone.

2.4.3. Measurement of spasticity-MAS

The MAS scale is widely used method for measuring spasticity. A score of 0–4 was used to assess the resistance of knee extensors to passive movement. The children lay supine with the lower leg hanging freely over the edge and the knee passively extended by the examiner. The examiner moved the subject's knee to a position of maximal flexion over 1 s. A score was then given based on the classification by Bohannon and Smith (Bohannon & Smith, 1987). The MAS scores of both legs were added up to represent the muscle tone of the subject's lower extremities. The ICC calculated for MAS was 0.92.

2.4.4. Functional measurement-TUG

TUG is a test used to assess a person's mobility. TUG measured the time required for an individual to stand up from a chair with armrests, walk 3 m, turn, walk back to the chair, and sit down. The subject walked with their regular footwear at their preferred speed with or without walking aids. The examiner stayed with the participants to protect their safety at all times. High test–retest reliability (ICC = 0.94) and adequate validity (spearman $r = -0.77$) for the TUG in children with CP have been reported (Zaino, Marchese, & Westcott, 2004).

2.4.5. Functional measurement-6MWT

Six-MWT measured the distance walked within 6 min. A 7-m walkway was marked on a level floor. The subject was asked to walk continuously along this walk way, turn around at the end, and continue to cover as much ground as possible over 6 min. The examiner spoke standardized phrases to the patient to avoid improper encouragement and enthusiasm. High test–retest reliability (ICC = 0.98) for the 6MWT in children with CP was revealed (Maher, Williams, & Olds, 2008).

2.5. Statistics

Data were analyzed using the statistical analysis software SPSS (version 17.0, SPSS Inc., Chicago, IL, USA). Descriptive statistics were used to calculate participants' demographics. A two-way repeated measures analysis of variance (ANOVA) (condition(2) × change scores of time (3)) was performed for all variables. The alpha level was set at 0.05. Multiple comparisons between pairs of means were used to determine where the differences existed with Bonferroni adjustments of alpha level. The relationship between functional improvements and changes in spasticity were examined by correlation analysis.

3. Results

The initial spasticity measurements for MAS and RI were 4.61 (0.95) and 0.59 (0.07), respectively. The initial measurements for TUG and 6MWT were 13.53 (2.30) s and 201.33 (17.51) m, respectively.

Descriptive and inferential statistics for outcome analyses are presented in Table 1. Significant differences were found in change scores between the treatment and control condition for variables including MAS, RI, and 6MWT. Multiple comparisons revealed that differences existed between change scores Diff2-1 and Diff4-1 only for MAS ($p = 0.036$) and RI ($p = 0.022$); and between change scores Diff2-1 and Diff3-1 ($p = 0.006$), Diff2-1 and Diff4-1 ($p = 0.012$), but not Diff3-1 and Diff4-1 ($p = 0.907$), for 6MWT. For AROM and TUG, significant differences were found in condition only. However, no difference was found in PROM.

Correlation of scores was performed to reveal the relationship between functional improvement and changes in muscle tone. Correlation results revealed that change in TUG was significantly correlated with change in RI ($r = -0.526$, $p = 0.036$),

Table 1
Descriptive and inferential statistics for outcome analyses.

Variables	WBV condition			Control condition			$P_{condition}$	$P_{change\ score}$
	Change_score[a]			Change_score[a]				
	Diff2-1	Diff3-1	Diff4-1	Diff2-1	Diff3-1	Diff4-1		
AROM (°)	5.74 (3.46)	4.35 (2.05)	3.34 (2.73)	0.24 (2.29)	0.61 (2.39)	0.22 (2.13)	0.000**	0.154
PROM(°)	1.13 (2.04)	−0.75 (2.88)	0.48 (2.02)	0.25 (1.23)	0.09 (1.23)	0.33 (1.26)	0.892	0.118
RI	0.13 (0.06)	0.09 (0.06)	0.09 (0.06)	0.00 (0.04)	0.02 (0.04)	−0.00 (0.30)	0.000**	0.030*
MAS	−1.43 (1.05)	−1.20 (1.11)	−0.50 (0.73)	−0.17 (0.25)	−0.13 (0.34)	0.03 (0.46)	0.000**	0.033*
TUG (s)	−2.49 (1.56)	−2.79 (1.68)	−2.39 (1.52)	−0.39 (1.28)	−0.52 (1.37)	−0.54 (1.18)	0.000**	0.416
6MWT (m)	16.89 (8.01)	6.96 (6.74)	7.66 (6.46)	−0.20 (7.50)	−1.70 (9.31)	0.57 (4.25)	0.000**	0.005**

Values are expressed as mean ± SD.

[a] Different score Diff2-1: difference between measurements "Time2" & "Time1". Diff3-1: difference between measurements "Time3" & "Time1". Diff4-1: difference between measurements "Time4" & "Time1".

* $p < 0.05$.

** $p < 0.01$.

but not with change in MAS ($r = -0.129$, $p = 0.633$). Six-minute walk test was significantly correlated with change in TUG only ($r = -0.713$, $p = 0.002$), but not with changes in RI or MAS. No other correlations were significance.

4. Discussion

This study is the first to implement a crossover repeated measures design for measuring the effects of an 8-week WBV protocol on children with CP. The results were consistent with our hypothesis that spasticity (MAS and RI) would reduce, and ambulatory function (TUG and 6MWT) would improve significantly after the WBV intervention. These effects could last up to 3 days after the intervention. These benefits would facilitate children to actively engage in daily activities, exercise trainings and therapeutic interventions.

The benefits of the 8-week WBV program are manifolds. First, it can suppress spasticity in children with CP. This finding was in line with previous research (Ahlborg et al., 2006; Chan et al., 2012; Liepert and Binder, 2010; Miyara et al., 2014; Ness & Field-Fote, 2009). Using an electrophysiological approach, Liepert and Binder (2010) revealed the vibration effects on target muscles (Liepert and Binder, 2010). Vibration effects are mediated through the activation of muscle spindles and transmission by Ia fibers, which enhances cortical excitability of the vibrated muscle. The vibration stimuli simultaneously reduce activity in antagonistic muscles via reciprocal inhibition and supraspinal inhibition, therefore reducing antagonistic muscle hyperactivity. A more balanced interaction between flexors and extensors can then be achieved. In addition, WBV can induce presynaptic inhibition. Previous studies demonstrated that a vibratory stimulus applied directly to a muscle will induce the presynaptic inhibition of Ia afferents (Schieppati, 1987) and is likely to reduce the release of neurotransmitters to the motoneurons (Katz, 1999), thereby decreasing the monosynaptic reflex excitability.

Second, it significantly improved the AROM in the knees. The vibration delivered directly to the soles of feet, and went all the way up to the subject's body, especially to the lower extremities. These mechanical vibrations stimulated skin receptors and muscle spindles, enhancing the cortical excitability of the vibrated muscle and therefore increasing joint AROM (Katusic, Alimovic, & Mejaski-Bosnjak, 2013). On the other hand, no such improvements occurred in PROM. Clinically, measurement of PROM is assessed by passively moving a joint to its extreme position. This movement is slow and should not elicit reflex activity. This indicated that the value of PROM cannot be interfered with spasticity. Rather, the limitation of PROM is mainly originated from the mechanical constraints, such as the length of musculature surrounding the joint, the flexibility of joint capsule, and the contour of bones.

Third, it can improve walking performance. TUG was significantly improved immediately after and 30-min after the WBV intervention. The improvement on 6MWT was also significant but it attenuated over time after the cease of the intervention. Previously a correlation was found between muscle tone, functional gait parameters and a more normal electromyography pattern (Hesse et al., 1996), indicating that a reduction in spasticity might lead to improvements in motor function and walking ability. Another study also found patients with measurable spasticity showed reduced knee angular velocity during walking since their muscles were rather stiff (Tuzson, Granata, & Abel, 2003). As a consequence, the ambulation function improved as the spasticity decreased. In addition, results from the current study also revealed significant correlation between change in TUG and change in RI. The improvement in RI remained during follow-up period of 30 min, which paralleled with the improvement in TUG. Unlike TUG, 6MWT might require better endurance which could not be acquired from this intervention. Thus the improvement on 6MWT might fade faster in this protocol.

Vibrations are believed to initiate muscle contractions by stimulating muscle spindles and alpha motor neurons, resulting in an effect similar to that of conventional resistance training (Delecluse, Roelants, & Verschueren, 2003). In the current study the WBV was performed on a vibrating platform during supported standing. It is a form of muscle and proprioceptive training that is largely independent of the motivation of the participant (Rauch, 2009). Children with young ages are usually less motivated since they do not understand well the link between therapeutic training and health benefits. Therefore WBV can serve as a substitute for traditional resistance training and rehabilitation programs.

Based on the subjective reports of the participants, negative side-effects seldom occur with the WBV intervention. One participant reported stiff legs and one reported back muscle soreness in the first two sessions of WBV intervention. Still, attentions need to be paid. Vibrating platform might threaten participants' balance and cause their feet to slide off. Close supervision is needed especially for those with physical/sensory disabilities and those with young ages.

There are still limitations in this study. First, results from this study revealed the effects of WBV intervention in decreasing spasticity and improving walking function, but whether the effects of WBV are comparable to those provided by oral medication or muscle injection are still questionable. Future studies should directly compare the antispastic effects of vibration to those of antispastic agents. Second, participants in this study did not cease their regular therapeutic activities. The WBV program was added to their daily routines. The authors controlled the possible influences via crossover design. Even that, the effects from their physical exercises or school activities cannot be completely removed.

5. Conclusion

To sum up, WBV program can be a suitable approach to control spasticity and improve walking function in children with CP, particularly it is non-invasive, easy to apply, relatively safe and requires little efforts. It may also serve as a routine addition or substitute for other anti-spastic agents with future supporting studies. Performed before the rehabilitation session, it serves as a spasticity reducing protocol and gets the individual ready for advanced exercise trainings. Previous studies also revealed other benefits of WBV on various physiological measures, including the oxygen consumption, muscle temperature, skin blood flow, muscle power, muscle strength, balance, and bone density (Cochrane, Stannard, Sargeant, & Rittweger, 2008; Lohman Iii, Petrofsky, Maloney-Hinds, Betts-Schwab, & Thorpe, 2007; Rauch, 2009). These together support the potential clinical application of WBV in CP rehabilitation.

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全身律動對於腦性麻痺病童
痙攣現象及下肢功能的影響

Effects of whole body vibration on spasticity and lower extremity function in children with cerebral palsy

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簡述內容：

痙攣型腦性癱瘓的狀況為肌肉僵硬和運動困難，當雙腿均受到影響(痙攣型雙癱)時，患兒可能難以行走，因為臀部和腿部的繃緊肌肉導致雙腿向內轉動，並在膝關節處形成交叉(即剪刀腿)；其他患者僅有一側身體受影響（痙攣性偏癱），往往手臂受到的影響比腿更為嚴重，而最嚴重的類型是痙攣型四肢癱，為患者四肢及軀幹都受到影響，往往伴有控制口和舌的肌肉受影響，且通常具有智力低下及其他疾病；一般來說因痙攣型腦性癱瘓對於自主性復健刺激相當困難，本研究顯示採用全身垂直律動的刺激誘發肌肉收縮伸張，進而讓無法自主運動者也能經由被動式訓練進一步獲得控制與改善，且確實獲得明顯效益。

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Effects of whole body vibration on spasticity and lower extremity function in children with cerebral palsy

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ABSTRACT

Aim: The aim of this study was to evaluate the effect of whole body vibration (WBV) on lower extremity spasticity and ambulatory function in children with cerebral palsy (CP) with a complete cross-over design.
Method: Sixteen participants aged 9.8(2.3) years received a 20-min WBV and a control condition in a counterbalanced order on two separate days. Change scores of each outcome variable were used to show the improvement.
Results: Repeated-measures analyses revealed significant differences in condition scores among variables including active range-of-motion (active ROM, increased), relaxation index (RI, increased), Modified Ashworth Scale (MAS, decreased), timed up-and-go (TUG, decreased), and Six Minute Walk Test (6MWT, increased). Significant differences were also found in time change scores for MAS

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and 6MWT. Correlation results revealed that TUG was significantly correlated with RI ($r = -.512$, $p = .042$), and 6MWT ($r = -.700$, $p = .003$).
Interpretation: This study suggested that WBV intervention can control the spasticity, enhance ambulatory performance and increase active ROM. Along with previous results, data from this study revealed the potential use of WBV in clinical rehabilitation in children with CP. Future investigations should focus on finding the combination of treatment frequency and duration to achieve an ideal result.

1. Introduction

Cerebral palsy (CP), which occurs in 2–3 of every 1000 individuals, is one of the leading causes of movement and posture disorders (Koman, Smith, & Shilt, 2004). Spasticity is a frequent-observed phenomenon after upper motor neuron lesion, including stroke, head injury, spinal cord injury and CP, etc. About seventy to eighty percent of children with CP demonstrate spastic clinical features (Krigger, 2006). These children are affected by neuromuscular symptoms such as impaired sensation and increased muscle tone, and therefore demonstrate a decreased ability to voluntarily control their muscle activities. As a result, a wide range of movement dysfunction can occur.

The goals of spasticity management are to improve flexibility and movement ability. Clinically, other than the medication and injection treatments, muscle stretching and functional training have been considered an integral part of patient's daily management of spasticity. Our group has performed a series of studies investigating the benefits of repetitive passive movements onto spasticity control, sensory normalization and functional improvement (Cheng, Ju, Chen, Chang, & Wong, 2013; Cheng, Ju, Chen, & Wong, 2012; Ju, Lin, Cheng, Cheng, & Wong, 2013; Ju, Liu, Cheng, & Chang, 2011). Repetitive passive movements decrease spasticity via decreasing stiffness of the mechanical component, especially the muscle–tendon-unit (Cheng et al., 2013). These changes also arouse muscle spindle in detecting its fascicle length (Ju et al., 2013). Consequently, the motor function of the participants improves.

However, research increasingly shows that spasticity and abnormal sensation are not the sole culprits in producing motor dysfunctions such as impaired ambulation in children with CP (Damiano, Martellotta, Sullivan, Granata, & Abel, 2000; McLaughlin et al., 2005). Poor muscle strength is also an important factor that leads to movement dysfunction. Recently, vibratory stimulation was proposed as a new therapeutic modality for the treatment of spasticity and muscle strengthening in participants with upper motor neuron syndrome (Ahlborg, Andersson, & Julin, 2006; Chan et al., 2012; Ness & Field-Fote, 2009). Whole body vibration (WBV), for which the participant stands on a vibrating platform, delivers low-frequency, low-amplitude mechanical stimuli that enter the human body via the feet. The vibrations stimulate the muscle spindles, sending nerve impulses to initiate muscle contractions according to the tonic vibration reflex (Cardinale & Bosco, 2003). Compared to the repetitive passive movement, this WBV protocol adds a muscle strengthening component to the anti-spastic effects.

To date, little research examined the effects of WBV on the lower extremity spasticity and ambulatory function with clinical indicators in children with CP. A recent study examined the effects of a 9-min WBV program on children with CP. The mobility in these children improved, however the only indicator for mobility was the change in self-selected walking speed. No spasticity measurement was performed (Ruck, Chabot, & Rauch, 2010). Another study investigated the vibration effects onto posture and gait (Unger, Jelsma, & Stark, 2013). The vibration used in that study aimed at trunk muscle strengthening. Besides, other than the posture-related measurements, only one gait parameter, the 1-Minute Walk Test, was assessed. The direct effect on spasticity was not evaluated.

Furthermore, one study reported that WBV results in a significant decrease in spasticity in the knee extensors but not in other muscle groups. Participants also showed increased muscle strength in lower legs at a higher isokinetic knee testing speed (90°/s). However, the ambulatory parameters did not change significantly (Ahlborg et al., 2006). Moreover, these findings are from adults with CP. Data from children with CP are relatively scarce. Based on our previous research findings with regard to repetitive passive movement in CP, it is likely that children with CP could benefit from WBV training. Therefore, the aim of this study was to evaluate the effects of WBV on lower extremity spasticity and ambulatory function in children with CP.

2. Methods

A complete crossover design was employed in this study. The independent variables were the intervention (WBV or control) and time (pre-WBV = time 1; post-WBV = time 2; 30 min post-WBV = time 3). The effects of WBV were evaluated via variables including active and passive range-of-motion (AROM and PROM) for both knee and ankle joints, relaxation index (RI) assessed by the Wartenburg Pendulum test, Modified Ashworth Scales (MAS) for bilateral knee extensors, timed up-and-go (TUG) and Six Minute Walk Test (6MWT).

2.1. Participants

Sixteen children with CP, 9 boys and 7 girls, aged 9.8(2.3) years with diagnoses of either spastic diplegia ($N = 11$) or spastic quadriplegia ($N = 5$) were recruited from a local hospital and a special education school. The inclusion criteria were: add-up MAS scores of bilateral lower extremity greater than two; ability to walk for at least 6 min with or without walking aids; and ability to comprehend commands. Criteria which would affect their muscle tone and ambulatory performance were excluded. Exclusion criteria were: the presence of a progressive neurological, genetic, or metabolic disorder, or a severe concurrent illness or disease not typically associated with CP; lower extremity surgery within the past 6 months; nerve block or botulinum toxin injection within the past 3 months; knee joint range-of-motion limitation greater than 10°; and epilepsy. One of the authors performed the selection process. Twelve participants walked independently without walking aids and four used 4-wheeled walkers for ambulation. The Institutional Review Board for Human Studies of Chang Gung Memorial Hospital approved this protocol. Written informed consents were obtained from all participants and their legal guardians.

2.2. Equipment

The equipment utilized in this study included electrogoniometers (SG110, Biometrics, Ltd., Cwmfelinfach, Gwent, UK) and a WBV platform (AV-001A, Body Green, Taipei, Taiwan). The electrogoniometers, taped on the lateral sides of the knee and ankle joints, were used to measure the degree of flexion and extension. A Biopac MP150 data acquisition unit (Biopac Systems Inc., Santa Barbara, CA, USA) was used for signal registration. The WBV platform could provide vertical vibration with a magnitude of 8–40 Hz and an amplitude of 0.4–2.0 mm.

2.3. Protocol

Each subject performed both the WBV and control condition in a counterbalanced order on two separate days, one week apart. The subject was instructed to adhere to the daily routines between the two days. For the WBV condition, participants stood on the vibration platform with the knees slightly flexed at about 30° from full extension. Anterior knee stops and a pelvic belt were used along with the WBV machine for securing their knees and pelvis to provide external support while standing. The participants were instructed to avoid holding on to the supported rail if possible however they were allowed to hold onto the rail if necessary (Ness & Field-Fote, 2009). They were asked to focus on standing with equal weights on both legs. Vibration was delivered at 20 Hz with a vertical displacement of 2 mm. The

WBV was given for 20 min. For the control condition, participants followed the same procedure instead that the vibration machine was not turned on. After the intervention, the participants were moved to the assessment area in wheelchairs to avoid any physical activity on their feet that might influence the vibration effects.

2.4. Assessment

The following measurements were performed before (time 1), immediately after (time 2), and 30 min after (time 3) the intervention, in the order of active and passive range-of-motion measurements (AROM and PROM) for knee/ankle joints, Pendulum test, Modified Ashworth Scale (MAS), timed-up-and-go (TUG), and Six Minute Walk Test (6MWT). The test–retest reliability for each variable was evaluated from two consecutive days before intervention with ten children with spastic cerebral palsy, aged 9.71(1.66) years. Two change scores (Diff2–1/Diff3–1) were calculated from the three time points, with the "before (time 1)" score served as the baseline.

2.4.1. Measurement of joint range-AROM & PROM

The AROM measures the range of movement through which the subject can actively move a joint using the adjacent muscles, whereas the PROM amount of motion at a given joint when the joint is moved by an external force. To measure the flexion and extension, electrogoniometers were secured on the lateral sides of the knee and ankle joints. For the AROM measurement, the subject was first asked to actively move the knee/ankle to full extension and then full flexion. Subject was asked to maintain full extension and flexion for 3 s each and the median angles of the two 3-s intervals were used for AROM calculation. For the PROM condition, their knees/ankles were passively moved by an examiner to the end range for signal registration. The Intraclass correlation coefficients (ICCs) for AROM and PROM were 0.73 and 0.79, respectively.

2.4.2. Measurement of spasticity – Wartenburg Pendulum test

The Pendulum test evaluated muscle tone by using gravity to provoke stretch reflexes of knee extensors during passive swinging of the lower limb. The oscillatory movements of the lower leg were captured by electrogoniometers at the lateral sides of the knee. The relaxation index (RI) was then calculated as follows: RI = (starting angle − first angle)/(starting angle − resting angle) × 1.6 (Burridge et al., 2005). The ICC calculated for RI was 0.72. In case of spasticity, the oscillatory amplitudes were significantly less as compared to those with normal muscle tone.

2.4.3. Measurement of spasticity – MAS

The MAS scale is widely used for measuring spasticity. A score of 0–4 was used to assess the resistance of knee extensors to passive movement. The children laid supine with the lower leg hanging freely over the edge and the knee passively extended by the examiner. The examiner moved the subject's knee to a position of maximal flexion over 1 s. A score was then given based on the classification by Bohannon and Smith (1987). The MAS scores of both legs were added up to represent the muscle tone of the subject's lower extremities. The ICC calculated for MAS was 0.92.

2.4.4. Functional measurement – TUG

TUG is a test used to assess a person's mobility. TUG measured the time required for an individual to stand up from a chair with armrests, walk 3 m, turn, walk back to the chair, and sit down. The subject walked with their regular footwear at their preferred speed with or without walking aids. The examiner stayed with the participants to protect their safety at all times. High test–retest reliability (ICC = 0.94) and an adequate validity (Spearman $r = -.77$) for the TUG in children with CP have been reported (Zaino, Marchese, & Westcott, 2004).

2.4.5. Functional measurement – 6MWT

Six-MWT measured the distance walked within 6 min. A 7-m walkway was marked on a level floor. The subject was asked to walk continuously along this walk way, turn around at the end, and continue to cover as much ground as possible over 6 min. The examiner used standardized phrases for speaking to the patient to avoid improper encouragement and enthusiasm. High test–retest reliability (ICC = 0.98) for the 6MWT in children with CP was revealed (Maher, Williams, & Olds, 2008).

2.5. Statistics

SPSS version 17.0 statistical software (SPSS Inc., Chicago, IL, USA) was used to analyze the data. Descriptive statistics were used to calculate participants' demographics. A two-way repeated measures analysis of variance (ANOVA) (condition (2) × change score (2)) was performed for all variables. Change scores were used to show the improvement of each dependent variable measured at time 2 and 3 compared to the baseline (time 1). The alpha level was set at 0.05. The relationship between functional improvements and changes in spasticity were examined by correlation analysis.

3. Results

Descriptive statistics for the outcome variables in the two conditions on the three measurement times are presented in Table 1. Descriptive and inferential statistics for the change scores are given in Table 2. Significant differences were found in change scores between the treatment and control condition for variables including knee and ankle AROM ($p = .000$), RI ($p = .000$), MAS ($p = .001$), TUG ($p = .001$) and 6MWT ($p = .000$). For MAS ($p = .007$) and 6MWT ($p = .049$) significant differences were also found between the time change scores (2–1) and (3–1). No difference was found in PROM.

The relationships between functional improvements and changes in spasticity were investigated via the correlation of change scores. The results revealed that change in TUG was significantly correlated with change in RI ($r = -.512$, $p = .042$), but not with change in MAS ($r = -.150$, $p = .580$). Change in distance at the Six Minute Walk Test was significantly correlated with change in TUG ($r = -.700$, $p = .003$), but not with change in RI or MAS. No other correlations were significant.

4. Discussion

This study evaluated the effect of WBV on lower extremity spasticity and ambulatory function in children with CP. The results revealed that spasticity, measured via the Wartenburg Pendulum test and MAS, decreased. The ambulatory function, tested with TUG and 6MWT, improved significantly after the WBV. The AROM of both knee and ankle joints also increased. Findings of this study demonstrated that the WBV is an effective intervention for controlling spasticity and improving ambulation.

Table 1
Descriptive statistics for outcome variables.

Variables	WBV condition			Control condition		
	Time 1	Time 2	Time 3	Time 1	Time 2	Time 3
KAROM (°)	93.08 (10.29)	98.71 (10.64)	97.41 (10.52)	94.08 (11.03)	93.97 (9.81)	93.37 (8.43)
AAROM (°)	26.98 (6.48)	37.58 (5.30)	37.67 (5.46)	26.98 (6.48)	27.65 (6.43)	27.19 (6.46)
KPROM (°)	104.39 (11.05)	105.32 (10.72)	103.69 (11.23)	104.20 (11.09)	104.21 (10.65)	104.05 (10.53)
APROM (°)	48.82 (7.11)	48.76 (4.69)	49.82 (4.35)	48.82 (7.11)	48.53 (6.91)	48.70 (7.02)
RI	0.59 (0.07)	0.71 (0.07)	0.68 (0.09)	0.59 (0.07)	0.60 (0.08)	0.61 (0.08)
MAS	4.63 (0.96)	3.13 (1.09)	3.56 (1.09)	4.88 (0.96)	4.50 (0.73)	4.75 (0.86)
TUG (s)	13.31 (2.45)	10.45 (1.53)	10.70 (2.47)	13.49 (2.23)	13.09 (1.94)	12.99 (2.03)
6MWT (m)	202.22 (20.63)	219.74 (22.05)	208.35 (24.80)	202.34 (20.59)	200.58 (24.40)	200.69 (20.51)

KAROM/AAROM: knee/ankle active range of motion; KPROM/APROM: knee/ankle passive range of motion; RI: relaxation index; MAS: Modified Ashworth Scale; TUG: timed-up-and-go; 6MWT: Six Minute Walk Test. Values are expressed as mean (SD).

Table 2
Descriptive and inferential statistics for outcome analyses-change scores.

Variables	WBV condition Change_score[a]		Control condition Change_score[a]		Cohen's $d_{condition}$		$P_{condition}$	$P_{change\ score}$	$P_{interaction}$
	Diff2–1	Diff3–1	Diff2–1	Diff3–1	Diff2–1	Diff3–1			
KAROM (°)	5.63(3.50)	4.33(2.05)	−0.11(2.53)	−0.71(4.57)	1.880	1.423	0.000**	0.100	0.523
AAROM (°)	10.59(4.40)	10.69(5.31)	0.67(2.45)	0.21(1.86)	2.786	2.634	0.000**	0.659	0.452
KPROM (°)	0.94(2.18)	−0.70(2.93)	0.01(1.56)	−0.15(1.54)	0.491	−0.235	0.750	0.082	0.168
APROM (°)	−0.06(6.01)	−1.00(6.70)	−0.29(1.98)	−0.12(1.90)	0.051	−0.179	0.635	0.181	0.227
RI	0.12(0.65)	0.09(0.06)	0.01(0.05)	0.02(0.04)	0.239	1.373	0.000**	0.217	0.152
MAS	−1.50(1.10)	−1.06(1.12)	−0.38(0.50)	−0.13(0.34)	−1.311	−1.124	0.001**	0.007**	0.270
TUG (s)	−2.86(2.36)	−2.61(1.82)	−0.40(1.29)	−0.51(1.37)	−1.294	−1.304	0.001**	0.826	0.457
6MWT (m)	17.52(15.98)	6.13(7.76)	−1.79(10.29)	−1.65(9.41)	1.437	0.902	0.000**	0.049*	0.025*

Values are expressed as mean(SD). $^{*}P < .05$; $^{**}P < .01$.
Cohen's d refers to effect sizes based on the differences between the change scores (2–1 and 3–1) in the WBV and control condition.
[a] Different score: Diff2–1: difference between measurements "time 2" & "time 1"; Diff3–1: difference between measurements "time 3" & "time 1".

These acute effects might promote children's active participation in exercise training and/or therapeutic interventions.

Whole-body vibration was presented to children with CP during supported standing on a vibrating platform. The vibrations are believed to initiate muscle contractions by stimulating muscle spindles and alpha motor neurons. Hence the electromyographic activity increases during WBV, resulting in an effect similar to that of conventional resistance training (Delecluse, Roelants, & Verschueren, 2003). Unlike resistance training which usually needs strong motivation of the participants, vibration therapy might serve as a form of muscle training that is largely independent of the motivation of the patient (Rauch, 2009). WBV provides a great opportunity to patients with neuromuscular disorders who often lack motivation to engage in muscle strengthening exercises.

Previous studies have reported that WBV has anti-spastic effects in patients with neuromuscular diseases (Ahlborg et al., 2006; Chan et al., 2012; Ness & Field-Fote, 2009). Modified Ashworth Scale and the pendulum test are commonly used clinical assessment tools to rate subject's spasticity. The results in this study indicated that after WBV intervention, children with CP demonstrated a decrease in spasticity, as measured with MAS and RI. An electrophysiological study of vibration therapy to local muscles has revealed its effects on spasticity (Liepert & Binder, 2010). The research suggested that vibration effects are mediated through the activation of muscle spindles and transmission by Ia fibers, which enhances cortical excitability of the vibrated muscle. At the same time, the vibration stimuli also reduce activity in antagonistic muscles via reciprocal inhibition and supraspinal inhibition. A more balanced interaction between flexors and extensors can thus be achieved. On the other hand, research on WBV pointed out that it also resulted in a decrease of spasticity (Ahlborg et al., 2006; Chan et al., 2012; Ness & Field-Fote, 2009). With spasticity, the latency of the H-reflex shortens and its amplitude increases. The WBV can facilitate presynaptic inhibition. Presynaptic inhibition of Ia-afferents reduces the release of neurotransmitters to the motoneurons, weakens the effects of Ia-afferents on motoneurons, thus resulting in a decrease of the H-reflex amplitudes. An influence of vibration on mechanical muscle fiber properties may also have contributed to the clinical effect.

The improvement on TUG was significant after WBV intervention and lasted over 30 min. On the other hand, the significant improvement on 6MWT seemed to fade gradually after the cease of the intervention. The correlation analysis revealed that the change in TUG was significantly correlated with the change in RI. The improvement in the latter variable, like the improvement in TUG, was maintained during follow-up period of 30 min. Since spastic muscles exhibit velocity-dependent hypertonic reflexes and demonstrate higher passive stiffness, patients with measurable spasticity show reduced angular velocity of the knee during walking and functional performance (Tuzson, Granata, & Abel, 2003). As a consequence, the ambulation function improves as the spasticity decreases. In addition, normalizing muscle tone can ease discomfort, thus improving walking ability and daily functioning. The results on TUG and 6MWT in our study are in line with these considerations. Unlike

TUG, 6MWT might require longer intervention than provided in our study to obtain longer-lasting improvement.

Significant improvement was also noticed in the AROM for the knee and ankle joints, both immediately and 30 min after the intervention. To the authors' knowledge, this was the first study that measured joint ROM change after WBV intervention. The improvement in range of motion can be explained by the stimulation of skin receptors, muscle spindles and the vestibular system (Katusic, Alimovic, & Mejaski-Bosnjak, 2013). In the present study vibratory stimuli were directly delivered to the soles of feet. These mechanical stimuli facilitate the activation of muscle spindles and enhance cortical excitability of the vibrated muscles, leading to joint AROM increase. No such improvements occurred in PROM. PROM is assessed by passively moving a joint to its extreme position. This movement is slow and should not elicit reflex activity. Therefore, the limitation in PROM is mainly due to mechanical constraints, such as the length of musculature surrounding the joint, the flexibility of joint capsule, and the contour of bones, rather than to spasticity.

In addition to its anti-spastic effect, other benefits of WBV are worth mentioning. According to the literature, the oxygen consumption, muscle temperature, skin blood flow and muscle power increase during vibration therapy (Cochrane, Stannard, Sargeant, & Rittweger, 2008; Lohman Iii, Petrofsky, Maloney-Hinds, Betts-Schwab, & Thorpe, 2007). If applied repetitively, positive long-term effects on muscle strength, balance, and bone density have been noted (Rauch, 2009). These results support the clinical application of WBV in CP rehabilitation. Future investigations might focus on finding the optimal combination of frequency and duration of WBV interventions.

This study suggests that a 20-min, 20 Hz WBV intervention can control the spasticity, enhance ambulatory performance and increase AROM in knee and ankle in children with CP. However, a longer follow-up period than the 30 min used in our study should be provided to investigate how long the beneficial effects of a WBV intervention are maintained. Notwithstanding this limitation, however, even on the basis of the short-term improvements demonstrated by us, clinicians might decide to apply WBV prior to exercise or other therapeutic interventions.

Finally, we would like to draw attention to the fact that WBV needs close supervision, in particular when it is offered to patients with physical and/or sensory problems, to safeguard them from losing their balance.

Conflict of interest

The authors declare that there is no conflict of interest.

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