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Original Research

The Effect of Vibration Therapy on Walking Endurance in Children and Young People With Cerebral Palsy: Do Age and Gross Motor Function Classification System Matter?

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KEYWORDS
Cerebral palsy;
Child;
Rehabilitation;
Vibration;
Walk test

Abstract *Objective:* To investigate the effect of age and Gross Motor Function Classification System (GMFCS) level on walking endurance after 20 weeks of vibration therapy in children and young people with cerebral palsy (CP).
Design: The study was a clinical trial without control group comparing baseline and postintervention outcomes within participants.
Setting: Vibration therapy was performed at school or at home. Assessments took place in a clinical research unit.
Participants: Children and young people (N=59) with CP, aged 5-20 years, GMFCS level II, III, or IV, recruited through schools, physiotherapy services, and District Health Board clinics, Auckland, New Zealand.
Interventions: Participants performed side-alternating whole-body vibration therapy (WBVT) at 20 Hz and 3-mm amplitude, 9 minutes per day, 4 times per week for 20 weeks.
Main Outcome Measures: Distance walked in the 6-minute walk test (6MWT) was recorded before and after the intervention.
Results: Participants baseline results for the 6MWT were lower, independent of age or GMFCS, when compared to non-CP literature. On average, participants walked 12% further in the 6MWT after the intervention ($P<.001$). There was significant improvement in 6MWT distance in all age groups (5-10y: 16%, $P<.001$; 11-15y: 10%, $P=.001$; 16-20y: 13%, $P<.001$) and all GMFCS levels

List of abbreviations: 6MWT, 6-minute walk test; BMI, body mass index; CP, cerebral palsy; GMFCS, Gross Motor Function Classification System; WBVT, whole-body vibration therapy.

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(level II: 10%, $P<.001$, level III: 40%, $P=.013$, level IV: 57%, $P=.007$). There was a greater percentage improvement in the distance walked in those with GMFCS level III and level IV than level II ($P=.049$ and $P<.001$, respectively).
Conclusions: WBVT had a beneficial effect on walking endurance in children and young people with CP, independent of age and GMFCS.
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Cerebral palsy (CP) is a group of nonprogressive neurologic disorders affecting movement and posture. It results from damage to the developing central nervous system occurring before birth or during early infancy and is the leading cause of serious physical disability in children.[1] Symptoms include spasticity, muscle weakness, and ataxia, ranging in severity, depending on the location and extent of the brain damage.[1] CP has a prevalence rate of approximately 2 in 1000 live births.[2]

A key aim of therapy is to prevent or delay the development of secondary health problems, with severity and type of symptoms affecting the feasibility of some therapies. Management of musculoskeletal tissue often includes physiotherapy to strengthen weak muscles and improve joint range of motion, combined with invasive interventions such as Botox injections and orthopedic surgeries.[1] Although >90% of children with CP reach adulthood,[3] therapy is typically focused on early childhood. Despite this, motor function tends to deteriorate over the lifespan of patients with CP.[3] Although some degree of functional deterioration is expected among elderly people, in the CP population this deterioration occurs much earlier in the lifespan, from adolescence and early adulthood.[4]

A declining ability to perform functional activities such as walking results in a loss of exposure to gravitational load, compromising bone health and contributing to reduced bone mineral density. This reduction affects approximately 85% of adults suffering from medium to severe CP and can result in frequent fractures.[3] Reduced walking ability and activity can also adversely affect overall body composition, with increase weight gain and further loss of muscle mass which has negative health implications.[5,6] Therefore, efforts to improve muscle function to maintain mobility throughout the lifespan are of key importance. There are, however, barriers to implementing physical activity in individuals with physical disability, including a lack of appropriate programmes, inadequately trained professionals, and negative societal attitudes toward disability.[7]

Treatment to reach the common goal of independent walking is tailored by clinicians and health professionals based on the Gross Motor Function Classification System (GMFCS), which describes the severity of patients' motor symptoms.[8] The scale has 5 levels with GMFCS level I representing those with a mild level of disability where walking is relatively unaffected, whereas level V reflects a severe level of impairment where self-mobility is very limited.

The therapeutic use of whole-body vibration therapy (WBVT) as a rehabilitation tool to improve motor function in CP populations has increased.[9] However, very few studies have investigated the effect of WBVT on walking endurance as per the 6-minute walk test (6MWT)[10] across ages and different GMFCS levels. In children with typical development, 6-minute walk distance is influenced by age, sex, height, weight, developmental stage, and ethnic background[11,12] and average distance ranges from 470 to 677 m.[13]

The data available demonstrate that 8-20 weeks of vibration therapy can improve walking endurance in a 6MWT by 8%-67% in children and young people with CP and GMFCS levels I-III.[14-16] However, there is a great variety in protocols and demographic of participants in these studies making it difficult to identify which subgroups benefit the most from WBVT. Therefore, the primary aim of this study was to investigate changes in walking endurance in children and young people with CP after 20-week WBVT and to identify if any age-related or GMFCS level-related effects are present.

Methods

Participants were recruited between 2012 and 2018 through schools, physiotherapy services, and district health board clinics in the Auckland region of New Zealand. Participants had mild to moderate CP, corresponding to GMFCS level II, III or IV, and were aged 5-20 years old. Data from participants aged 11-20 years with GMFCS II and III were extracted from a previous study by this research group.[14] Ethics approval was granted by the Northern A Health and Disability Ethics Committee (NTX/11/05/042). Written informed consent was obtained from the legal guardians, as well as written or verbal consent from all able participants.

Exclusion criteria included having had a fracture within 8 weeks of enrolment, pregnancy, acute thrombosis, muscle or tendon inflammation, nephrolithiasis, discopathy, or arthritis. Other exclusion criteria were the use of anabolic agents, glucocorticoids (other than asthma inhalers), bisphosphonates, or growth hormone. In addition, potential participants were also excluded if they displayed cognitive or physical impairment sufficiently severe that would hinder fulfilment of study protocol or clinical assessments.

WBVT was performed using a side-alternating Galileo basic vibration plate[a] 4 times per week for 20 weeks. The length and intensity of sessions began with three 1-minute bouts at 12 Hz; this was then gradually increased over the first 4 weeks to reach the target level: three 3-minute bouts of therapy, performed at 20 Hz, amplitude 2-3 mm, with at

Table 1 Participant characteristics, compliance rate, and baseline anthropometric measures by age category and GMFCS level

Data	All	Age Category (y)			GMFCS Level		
		5-10	11-15	16-20	II	III	IV
n	59	15	24	20	44	6	9
Women:men	26:33	10:5	7:17	9:11	17:27	5:1	4:5
Age (y)	13.8±4.3	7.4±1.8	14.4±1.3	17.9±0.1	13.7±4.3	15.9±4.5	12.9±4.1
Compliance (%)	77±24	88±17	76±19	69±31	80±23	62±32	71±23
Height (cm)	149.0±20.1	121.0±9.7	154.8±10.2	163.1±12.9	152.1±20.9	146.3±9.9	135.7±15.9
Weight (kg)	46.3±17.8	23.8±6.1	47.6±12.0	61.7±10.8	48.7±18.7	43.7±11.4	36.6±14.4
BMI (kg/m^2)	19.9±1.4	16.0±2.2	19.6±3.3	23.3±3.4	20.1±4.0	20.1±3.5	19.4±5.2

NOTE. Values are mean ± SD.

least 3-minute rests between bouts. During treatment, participants stood barefoot on the plate with knees slightly bent and feet apart. A frame was available to enable participants to support themselves if they were unable to balance at the start of the study. Those with GMFCS level IV were able to use their own frames or hoist to assist with stabilization during therapy. Training was performed in school or home environments, depending on family preference. School WBVT sessions were all supervised by an experienced physiotherapist, with 4 years of experience in this treatment, whereas home sessions were monitored once per week. Parents were also provided feedback or support to enable appropriate supervision of the home sessions. To monitor compliance with study protocol, participants and their families were asked to maintain a WBVT diary. Full compliance (100%) was defined as completion of all 80 sessions at the required time (min) and intensity (Hz).

Clinical assessments were performed at the Maurice and Agnes Paykel Clinical Research Unit (Liggins Institute, University of Auckland) by an experienced physiologist, with >10 years of experience in these assessments. Participants' height was measured using a Harpenden stadiometer. Body mass was obtained using whole-body dual-energy x-ray absorptiometry.[b] Body mass index (BMI) was calculated as weight in kilograms divided by height in meters squared. Walking endurance was assessed before and after the 20-week intervention using the 6MWT,[10] where participants were instructed to walk as fast as possible for 6 minutes along a straight 25-m indoor track with turning points marked with cones. Participants were familiar with the 6MWT prior to this study, because it was part of their health care assessments. Standardized phrases of encouragement were used during the test.[10] The total distance covered was recorded, rounded to the nearest centimeter.

Participants were divided into subgroups by age category (5-10, 11-15, 16-20y based on complete years of age) and GMFCS level (II, III, IV). Age-based centiles for height, weight, and BMI were calculated. Paired sample *t* tests were performed to compare outcome measures pre and posttreatment for each subgroup. IBM SPSS Statistics[c] was used to perform 1-way analysis of variance to compare baseline results, absolute improvement, and percentage improvement in distance walked between age categories and between GMFCS groups. Tukey post hoc test for multiple comparisons was used to assess pairwise differences. For all analyses, statistical significance was defined as $P<.05$, and results were summarized as mean ± SD.

Results

Sixty participants were recruited with 59 completing the assessments. Data from 1 participant were not used on analysis due to inability to obtain postintervention 6MWT. Participant characteristics are summarized in table 1. Overall, 25% of participants were aged 5-10 years, 41% were 11-15 years, and 34% were 16-20 years. Most of the participants were within GMFCS level II (75%), 10% were level III, and 15% were level IV. Within each age category, all GMFCS levels were represented.

The average rate of compliance with WBVT was 77% (see table 1). Compliance did not differ significantly between GMFCS levels, but rates were significantly higher for ages 5-10 years, than ages 11-15 years ($P=.048$), and ages 16-20 years ($P=.026$).

Anthropometry

On average, participants were below age expected height (29th centile) and weight (41st centile) at baseline (table 2). Height and weight were also below average across all age groups and all GMFCS levels. There was an inverse relation between GMFCS level and both height centile and weight centile. Although overall BMI was on the 55th centile, there were a large number of participants at each extreme (14% <10th centile and 15% >90th centile).

Overall, participant's centiles for height, weight, and BMI did not significantly change with 20 weeks of WBVT (see table 2). This trend remained similar across all age groups and GMFCS levels except for a 16% increase in BMI centile in the 5-10 years of age group ($P=.020$).

Walking endurance

As shown in fig 1, all age groups scored below the average expected distance.[13] At baseline, there was no significant difference in 6MWT scores between age groups. The increase in the 6MWT distance after 20 weeks of WBVT was significant for all age categories (table 3). On average, participants were able to walk 12% further and mean

Table 2 Centiles for anthropometric measures before and after WBVT, by age category and GMFCS level

Data	Height			Weight			BMI		
	Pre	Post	*P* Value	Pre	Post	*P* Value	Pre	Post	*P* Value
All	29±28	29±28	.80	41±31	41±31	.89	55±31	57±32	.10
Age (y)									
5-10	37±29	36±29	.27	42±32	46±34	.06	47±30	54±34	.020*
11-15	25±25	23±24	.19	36±29	35±30	.47	51±33	52±35	.39
16-20	27±31	29±32	.19	47±33	45±30	.53	67±28	66±27	.41
GMFCS level									
II	35±28	36±28	.72	48±31	47±31	.50	57±32	57±32	.53
III	12±17	11±15	.09	22±19	23±20	.16	50±27	53±27	.08
IV	8±17	6±13	.24	19±22	24±28	.28	53±36	60±38	.12

NOTE. Values are mean ± SD.
* $P<.05$.

improvement by age group ranged from 10% to 16% (see table 3). There were no significant differences between age categories in the absolute improvement or percentage improvement after WBVT.

At baseline, there were significant differences in distance walked between GMFCS levels ($P<.001$) in line with GMFCS definitions where a higher GMFCS level represents a lower level of mobility (fig 2). The baseline distance walked differed significantly between all GMFCS levels (II vs III: $P<.001$, II vs IV: $P<.001$, III vs IV: $P=.437$). After WBVT, all GMFCS levels increased the distance walked. There were significant differences in the percentage improvement between GMFCS levels ($P<.001$), but not in absolute values. Mean improvement by GMFCS level ranged from 10% to 57% (see table 3). The percentage improvement was significantly greater for GMFCS level IV versus level II ($P<.001$), and for level III versus level II ($P=.049$) but did not differ between levels III and IV ($P=.14$).

Discussion

This study highlights the effect of side-alternating WBVT on walking endurance in the 6MWT in a large sample of children and adolescents with CP. The results indicate that 20 weeks of WBVT can improve walking endurance in those with CP across the included age and GMFCS groups. Improvement in 6MWT distance after WBVT is consistent with previous research.[14-16] Gusso et al,[14] who included a subset of the participants in this study, demonstrated improvement in walking endurance after 20 weeks of side-alternating WBVT in 40 adolescents and young adults (16.2±2.1y) with GMFCS levels II-III. A 67% improvement in 6MWT distance was also reported by Ibrahim et al,[15] who conducted a controlled trial involving 12 weeks of side-alternating WBVT in 15 children (9.6±1.4y) with spastic diplegia. In addition, Cheng et al[16] noted significant improvements in the 6MWT when comparing 8 weeks of vertical WBVT with a sham treatment using a crossover design in 16 children (9.0±2.3y) with spastic diplegia or spastic quadriplegia. Thus, WBVT may result in substantial improvements in quality of life through increased functional mobility and independence for these individuals.

Baseline 6MWT scores in this cohort were lower than the expected values for children with typical development, but similar to values for those with CP.[13,17-19] Altered walking ability in children with CP is associated with musculoskeletal impairments including altered muscle tone, muscle weakness, and reduced selective motor control,[20,21] as well as somatosensory deficit.[22] These factors affect joint forces and result in structural abnormalities in the bones and surrounding soft tissue, causing inefficiencies in movements such as walking.[13]

In addition, children and adolescents in this study were shorter than average for their age (27th centile), but because they were also lighter, their BMI was relatively typical (55th centile). Similar trends have been observed in other cohorts, showing that compared to children with typical development, those with moderate to severe CP have poor growth.[3,23,24] Despite average BMI being within the 50th centile, there were a larger number of participants at each extreme than would be expected for the general population. This is in line with evidence presented by Odding et al,[2] where >50% of children with CP were either over or underweight. This highlights again the need for interventions that aim at increasing mobility in this

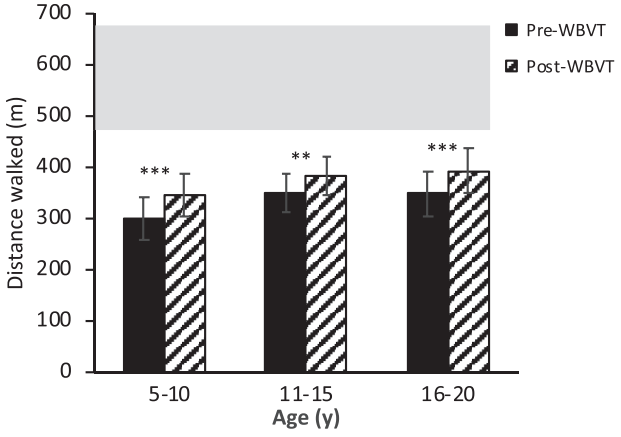

Fig 1 Distance walked in the 6MWT pre- and post-WBVT by age category. Shaded area shows approximate expected distance walked for typical development.[15] Error bars show SE.

Table 3 Distance walked in 6MWT before and after WBVT, by age category and GMFCS level

Data	Preintervention	Postintervention	Difference (m)	Change (%)	*P* Value
All	335±180	376±181	41±39	12	<.001*
Age (y)					
5-10	298±160	344±163	46±28	16	<.001*
11-15	347±185	382±183	34±44	10	.001*
16-20	348±194	392±197	44±40	13	<.001*
GMFCS					
Level II	424±105	467±97	43±43	10	<.001*
Level III	110±43	154±50	44±28	40	.013*
Level IV	49±31	77±38	28±23	57	.007*

NOTE. Values are mean ± SD.
* $P<.05$.

population in an attempt to improve body composition and minimize its health-related complications.

All GMFCS groups in this study increased their 6MWT scores after WBVT by a similar absolute amount, resulting in a significantly greater percentage improvement for GMFCS levels III and IV than level II, due to differing baseline mobility. The results indicate that WBVT can potentially be used to improve walking endurance in those who are not able to walk independently (without assistive devices) as well as those who can walk independently, and that the relative improvement appears to be greatest for those who are least mobile at baseline. However further research is required to confirm our finding.

Notably, there was no significant difference between age categories in absolute or percentage improvement after treatment, suggesting that young people aged 16-20 years with CP can benefit from WBVT to a similar degree to young children aged 5-10 years and older children aged 11-15 years (see fig 1), despite a higher rate of compliance with treatment in the 5-10 years of age group (see table 1). There is very little research into WBVT in adolescents or young adults with CP, reflecting an overall tendency in CP treatment and research to focus on children. During adolescence, physical activity declines sharply with age in the general population, correlating with behavioral changes.[25] Only 10% of New Zealand secondary school students meet minimum exercise guidelines of 60 minutes per day of moderate to vigorous activity, according to a 2012 survey of approximately 9000 school children.[26] Young people with CP are less physically active than non-CP peers, have twice the recommended amount of sedentary time and lower levels of activity than recommended by the guidelines, across all ages and levels of motor function.[27] Research indicates that being physically active as an adolescent with CP doubles the chance of being physically active as an adult.[28] The results of our study suggest that WBVT has a positive effect on walking endurance in adolescents, indicating that it could be beneficial to continue with this type of therapy beyond childhood. In addition, increasing walking endurance in adolescence may potentially facilitate increased participation in other forms of physical activity, affecting activity levels through to adulthood, improving general health, as well as attenuating CP-related bone and muscle problems.

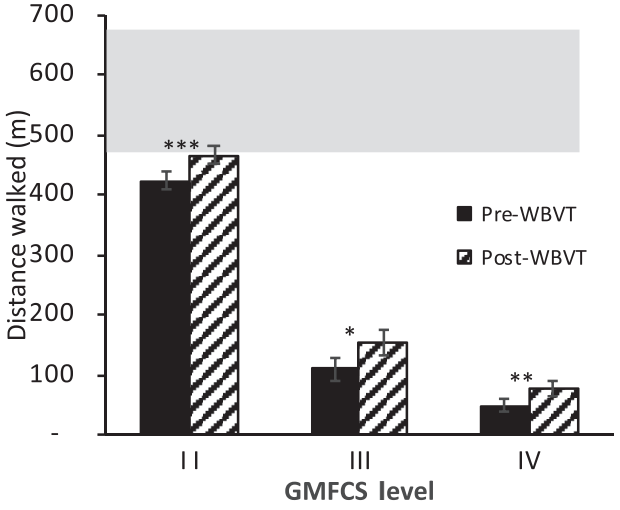

Fig 2 Distance walked in the 6MWT pre- and post-WBVT by GMFCS level. Shaded area shows approximate expected distance walked for typical development.[15] Error bars show SE.

Study limitations

This study is the largest dataset measuring walking endurance before and after side-alternating WBVT in individuals with CP and is the first to compare the effects of WBVT between GMFCS levels and age groups. However, not all GMFCS levels and age groups were included. Therefore, findings may not be generalizable to those with GMFCS level I or V, preschoolers, and adults. Furthermore, results were not analyzed by topographic subcategories such as diplegia and hemiplegia or factors such as ethnicity and socioeconomic status, all of which may affect the outcomes of therapy.

In addition, there was no control group or period to assess growth and 6MWT improvement prior to the intervention. It is possible GMFCS level and age may have contributed to different improvement patterns in the 6MWT, independent of the WBVT. Finally, no follow-up was performed to assess walking endurance after the intervention was terminated, to identify the extent to which the improvements were sustained in the weeks after therapy.

Conclusions

This study suggests that 20 weeks of WBVT can have a beneficial effect on walking endurance in children and young people, with relative improvements greatest in those with more limited mobility (GMFCS levels III and IV). This adds to the existing body of evidence on the benefits of WBVT for improving functional mobility in populations who are unable to tolerate normal levels of weight-bearing exercise. Further research is needed to clarify the mechanisms through which these improvements occur and to understand to what extent improvements are maintained after cessation of therapy.

Suppliers

a. Galileo basic vibration plate; Novotec Medical.
b. Whole-body dual-energy x-ray absorptiometry (lunar prodigy 2000); General Electric.
c. IBM SPSS Statistics (version 25.0); IBM Corp.

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