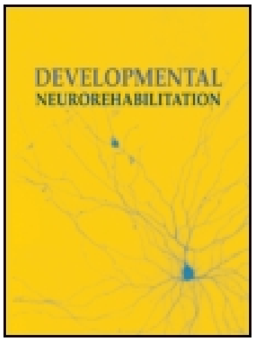

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Effect of a trunk-targeted intervention using vibration on posture and gait in children with spastic type cerebral palsy: A randomized control trial

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Abstract

Aim: This study aimed to determine whether strengthening trunk muscles using vibration can improve posture and gait in children with spastic-type cerebral palsy (STCP).

Methods: A total of 27 children (6–13 years) participated in a single-blinded pre–post crossover experimental trial. The 1-Minute Walk Test, 2D-posturography, ultrasound imaging and sit-ups in one minute were used to assess effect on gait, posture, resting abdominal muscle thickness and functional strength.

Results: Significant increase in distance walked ($p < 0.001$), more upright posture, an increase in sit-ups executed ($p < 0.001$) and an increase in resting thicknesses of all the four abdominal muscles – transversus abdominis ($p = 0.047$), obliquus internus ($p = 0.003$), obliquus externus ($p = 0.023$) and the rectus abdominis ($p = 0.001$) was recorded. Strength and posture were maintained at 4-weeks post-intervention.

Conclusion: A trunk-targeted intervention using vibration can improve posture and gait in children with STCP without any known side effects. It is recommended that vibration and specific trunk strengthening is included in training or rehabilitation programmes. Effects of vibration on force generation and spasticity need further investigation.

Keywords: *CP, abdominal muscles, strengthening, whole body vibration, posture and gait*

Introduction

Several researchers maintain that the underlying postural problems and range of ambulation and upper limb activity limitations in children with cerebral palsy (CP) are due to poor postural control [1]. Poor abdominal muscle activation is evident in many children with CP and is often accompanied by an excessive lumbar lordosis and anterior pelvic tilt. If the pelvis is not stabilised, the muscle action around the hip is impeded by sub-optimal length–tension relationships [2]. For example, if the pelvis is tilted forward the iliopsoas, muscle is placed in a shortened position and is unable to contract strongly enough to flex the femur forward without compensatory movements of the trunk. Similarly, the hip extensors placed in a lengthened position are unable to generate optimal force needed for forward propulsion. It is hypothesised that providing a more stable base of support will allow for more controlled and directed movement, and therefore strengthening the trunk or core musculature should be one of the primary focus areas for improving motor performance [3, 4]. Despite evidence supporting this, therapeutic interventions often primarily target the limbs and seldom make specific reference to targeting the core or trunk musculature.

There are studies that have reported on the impact of interventions directed at strengthening or targeting the trunk musculature for improving postural control and/or balance in children with CP. However, these have generally been at a lower level of evidence and the results have often not been conclusive with regard to the impact on posture and function. Electrical stimulation applied to the abdominal and extensor back muscles in 6–18-month-old infants reported improved sitting balance and trunk control [5], while another case series in six children aged 2–7 reported acquisition of independent sitting following a seating intervention [6]. Interventions such as therapeutic horseback riding have also reported improved short-term posture and balance in children with CP [7, 8]. More rigorous

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studies aimed at improving standing balance in older children [9–11] did not specifically report on the various factors or components (such as abdominal muscle functioning) contributing to the total outcome, i.e. balance. A randomised control trial investigating the effect of an 8-week progressive resisted exercise programme in adolescents with spastic-type CP (STCP) included abdominal and back extensor exercises [12] reported that inclusion of the trunk in their exercise programme did not result in 'better' gait performance compared to outcome reported in studies investigating only lower limb targeted strengthening programmes, despite apparent increase in abdominal muscle strength.

While each of the four abdominal muscles works independently from one another and have predominant mover and/or stabilizer functions, it is the collective effort of the trunk musculature that provides efficient trunk stability and movement [13–15]. It is hypothesised therefore that the type of exercise may be responsible for the varied outcome seen in the above studies. Typically, 'trunk strengthening' exercises in rehabilitation programmes demand mainly isotonic activity, with not enough emphasis on isometric and eccentric components of muscle work. Furthermore, as Stackhouse et al. [16] suggested, because children with CP demonstrate large deficits in voluntary muscle activation, using voluntary contractions for strength training may not produce forces sufficient to cause muscle hypertrophy and recommended adjuncts such as enhanced feedback and neuromuscular electrical stimulation may be more helpful for strengthening muscles that cannot be sufficiently recruited with voluntary effort alone.

The use of vibration as an adjunct to exercise was first introduced by scientists investigating interventions effective for reducing muscle atrophy. Although studies investigating effects of vibration on motor performance have reported varying benefits associated with vibration training [17, 18] using it, is gaining favour in the field of rehabilitation. Training using vibration platforms, has shown to be effective in increasing strength [19, 20] resulting in improved balance and coordination [19–22]. Vibration effectively provides perturbation of the gravitational field during the course of the intervention [23, 24] and the principle upon which it works lies in the laws of motion and one can improve stability, strength or power by either applying more mass or more acceleration to the body. Many forms of training and conditioning use mass such as weight machines and free weights while vibrating machines, instead, applies acceleration to the body, while keeping mass the same – increase the gravitational load of up to 14 g (where $g = 0.98\,\mathrm{m\,s^{-2}}$) [25]. The effect of the mechanical action on the musculoskeletal system is to produce fast and short changes in the length of the muscle-tendon complex which can elicit a tonic muscle contraction via the tonic vibration reflex. The stretch and H-reflex are inhibited during exposure, while post-exposure the stretch reflex displays increased potentiation. Recorded electromyography (EMG) activity of the biceps while exercising with vibrating dumbbells was 200% higher than when performing elbow flexion with a dumbbell with a mass of 5% of the subject's body mass [26].

There is paucity in the literature regarding evidence for the safe and effective use of vibration intervention in children with or without pathology. An earlier investigation focussed on the effect of vibration on bone mineral density in children with 'disabling' conditions and the device used allowed for stationary standing on a vibrating platform only [27]. A more recent pilot trial in 6–13 year-old children with CP suggests vibration may also be effective for improving mobility function [28]. One study in adults with CP [22] reported whole body vibration (WBV) to increase strength and improve motor performance and did neither appear to increase spasticity nor result in any other detrimental adverse effects. The use of vibration in other areas of neurological pathology in adults has been studied and a systematic review which included persons with multiple sclerosis, Parkinson's disease and CP [29] suggest WBV therapy to be effective in improving balance and gait function and reducing risk of falling in the elderly.

There is some evidence for the impact of targeting the abdominal muscles on function in adults, however in children and within the population of CP, the evidence is limited to few studies with small sample sizes and varying outcome. The use of vibration to facilitate muscle contraction seems to be a safe and appropriate choice of intervention for supplementing a strengthening exercise programme targeting the abdominal muscles in children with CP because these muscles are poorly activated and are deeply situated rendering typical manual facilitation techniques inadequate. This study aimed to establish whether an intervention specifically targeting the abdominal muscles in children with STCP using WBV would improve posture and impact lower limb activity and function.

Methods

A single-blinded experimental pre–post crossover study design with random assignment was used to investigate the effect of a trunk-targeted intervention in children with STCP (Table I). A large standard

Table I. Experimental crossover study design.

Group 1	M1	Intervention (4 weeks)	M2	No intervention (4 weeks)	M3
Group 2	M1	No intervention (4 weeks)	M2	Intervention (4 weeks)	M3

Note: M1, measurement at baseline; M2, measurement at 4 weeks and M3, measurement at 8 weeks.

deviation (SD) was expected within the sampled group for the primary outcome (distance walked in one minute) and the availability of only a limited number of potential subjects motivated the selection of the current design. This design allowed for comparison with a control group (M1–M2) as well as preliminary investigation into the medium-term effects following withdrawal of the intervention.

Sampling

A sample of convenience was used in that all children between the ages of six and 13 years with spastic-type diplegic or hemiplegic CP attending a local special school were invited to participate in the study. The names of those who agreed to participate and provided written informed assent and parental consent were randomly assigned to the different intervention groups using excel generated random numbers (Table I). A sample size calculation was done using MacDowell's 1-minute fast walking test [30] of total distance walked in one minute. The following parameters were entered: mean 90 m before treatment and 97.5 m post-treatment, a SD of 10 m before and after treatment, a significance level of 0.05 and a power level of 80%. As the small number of subjects available was unable to support a comparison independent *t*-test design, the sample size was calculated using a dependent *t*-test (Statistica version 9). This suggested a sample size of 29 subjects. To be included in the study, subjects had to be in good general health, ambulant – with or without walking aids, with or without orthoses, i.e. classified as levels I, II or III according to the Gross Motor Function Classification Scale (GMFCS). Subjects were excluded from the study if they presented with any other motor dysfunction or condition affecting motor performance (e.g. ataxia, spina bifida, muscular dystrophy), had any orthopaedic surgery or spasticity-altering procedures in the previous 12 months or had a body mass index (BMI) $> 25\,\mathrm{kg\,m^{-2}}$ as too much adipose tissue renders ultrasound (US) imaging difficult and effects reliability [31].

Instrumentation

The 1-Minute Walk Test and 2-D (two-dimensional) photographic posture analysis was used to assess the effect of an abdominal muscle re-education and strengthening intervention on gait and posture. Resting abdominal muscle thickness was also recorded using US imaging as it is hypothesised that an increase in strength may be accompanied by an increase in the size of the muscle [32]. As the exercise programme was a strengthening intervention, the measurement of the total number of sit-ups in one minute was also recorded to estimate the impact on abdominal muscle strength. All the measurements were taken at the school during school hours and were conducted over a two-day period in no specific order to ensure sufficient rest between tests. All measurements were taken by the same tester at baseline (M1), four weeks (M2) and again at eight weeks (M3) who was blinded as to which subjects participated in either of the two arms of the study. Baseline demographic variables – age and GMFCS level of functioning, use of walking aids and or orthoses – were recorded onto an excel spread sheet. Height was measured using a standard tape measurement fixed to a wall. Wearing only shorts and T-shirts, children stood with their backs to the wall while height was recorded using a spirit-level. Weight was measured using a calibrated digital SALTER Personal Fitness Plus Scale (UK; model 9191).

The 1-Minute Walk Test. The fast 1-Minute Walk Test as described by McDowell et al. [30] was used as a measurement of functional ability and measures the distance a child is able to walk in one minute. Participants were asked to walk as fast as they can on a marked oval level course for exactly one minute. Participants using splints and or walking aids were permitted to use them during this test. A trial run was done with a 5–10 minutes rest before the main trial commenced.

Digital photographic 2-D postural analysis. A high-speed digital camera (Canon 40D) was used to capture static standing and seated posture as viewed from the side (Figure 1). Wearing only under garments, 11 reflective markers (from the VICON Motion Analysis System) were placed on the following bony points on the tempero-mandibular joint, C6, the superior border of the manubrium, mid-point on the lateral border of the acromion, posterior superior iliac spine, anterior superior iliac spine, the sacrum, greater trochanter, lateral epicondyle, lateral malleolus and lateral aspect of the head of the fifth metatarsal bone. Subjects were asked to stand or sit as upright as possible and lateral images, from the right only or in children with left-sided hemiplegia, from the left only, were captured. Images were downloaded to a PC and using Image J software (http://rsbweb.nih.gov/ij/download.html) the degree

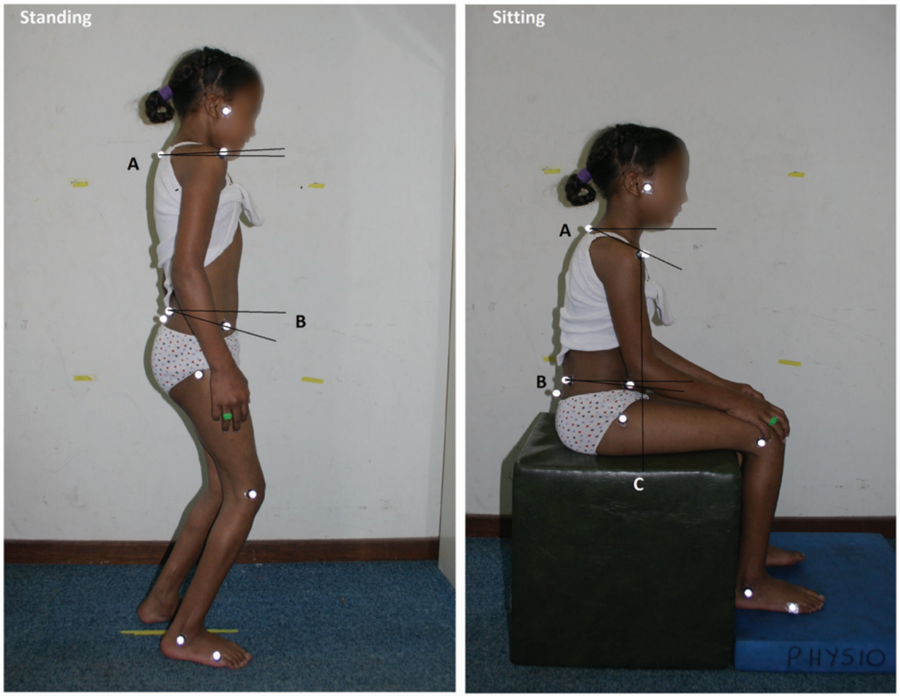

Figure 1. Standing and sitting positions for 2-D photographic imaging.
Note: A, a–p angle; B, a–p pelvic tilt and C, shoulder-to-seat-height.

of antero–posterior pelvic tilt – the angle formed between a line which runs through the posterior and anterior superior iliac spines and the horizontal (Figure 1); and forward trunk sway (or antero–posterior (a–p) angle) – the angle between lines drawn from the marker positioned on C6 posterior and the sternum anterior and a horizontal line from C6 – was measured; as well as shoulder-to-sitting height – the distance from the marker on the acromion to the seating surface (sitting; Figure 1). Although the information obtained using 2-D analysis is limited, stringent standardization of the procedure did produce reliable measurements (Table I) to determine kinematic variables [33].

For the a–p angle, it is assumed that the smaller the angle, the more upright the posture in relation to the pelvis (i.e. less crouched or less forward leaning) and a negative value is indicative of an over extended upper trunk. Similarly, for the pelvic tilt measurement, the smaller the angle, the more neutral the pelvis is positioned and a negative value suggests a posterior pelvic tilt. In sitting a more neutral pelvis suggest a more upright posture. This study hypothesised that an increase in abdominal muscle strength will result in a reduced anterior tilt (typically seen in children with STCP) which in turn will allow for a more upright posture.

US imaging. Using the same procedure as described by Unger [34], US imaging was used to record and measure the thickness of the four abdominal muscles – transversus abdominis (TrA), obliquus internus (OI), obliquus externus (OE) and the rectus abdominis (RA) – using a Siemens® Accusonic X150 US imaging machine.[1] Real-time images of the right side in children with diplegia and the affected side in children with hemiplegia of the four abdominal muscles were captured. Participants were positioned in supine with their arms resting along their sides on a plinth with their knees supported on a cushion, keeping their hips in ±20–45° of flexion ensuring in as far as it was possible a neutral lumbar curvature. A resting image was captured on end-inspiration as observed by the tester. The average of three thickness measurements (i.e. the distance between facia boundaries) at 10, 15 and 20 mm from a fixed point [34] for all four abdominal muscles during rest and during activity was calculated (mm).

Sit-ups in one minute. The total number of sit-ups executed in one minute was selected to measure effect on abdominal muscle strength. Although not a standardised outcome measure, this field performance measure is well used in research to reflect possible strength gains in the abdominal musculature [35]. In the crook lying position with the feet supported by the research assistant, subjects had to sit-up or curl-up to 90° hip flexion without arm support and return to the almost flat (flat hand)

Table II. Intra-tester reliability of: distance walked in 1 min, number of sit-ups in 1 min and degree of pelvic tilt, a–p angle and shoulder-to-floor height measurements (2-D imaging), ICC ($n = 10$).

Outcome measurement	ICC	95% Confidence interval	SEM
1-Min Walk Test (s)	0.979	0.910; 0.994	2.403
Number of sit-ups in 1 min	0.990	0.972; 0.997	1.085
Degree of a–p pelvic tilt (°)	0.982	0.939; 0.994	0.749
a–p angle (°)	0.947	0.843; 0.983	2.394
Shoulder-to-floor height (mm)	0.905	0.738; 0.968	17.04

Table III. Trunk-targeted exercise programme.

Dosage: time (s)	Frequency (Hz)	Activity
1 × 45	35	Warm-up: standing
3 × 30	35–40	Various sit-up exercises in supine on a cushion (crunches, cycling, hand behind head and table top)
1 × 30	35–40	Hip and lumbar extension exercise in four point kneeling or prone over a ball
2 × 30	35–40	Side lying crunches
1 × 30	35–40	Plank

supine position as many times as they could in one minute.

Reliability

All the above outcome measures have proven validity and were selected for the clinical feasibility. Reliability of US imaging for measurement of abdominal muscle thickness in children was shown by Unger [34] while tester reliability for the 1-Minute Walk Test, sit-ups in one minute and the angle measurements for the 2-D photographic imaging for the posture analysis were conducted on 10 randomly selected participants from the control group. Repeated measurements by the same tester either on the same day or between days were conducted as described in the testing procedures below for each of the above measures. Table II presents a complete listing of the intra-class correlation coefficient (ICC) scores for all variables measured in this study.

Intervention

A selective trunk-targeted exercise programme using the WBV was used to activate and strengthen the abdominal musculature in this study. Although it is a novel form of exercise in this population, the underpinning theory regarding involuntary capacity to activate weak or dormant muscle, it was deemed appropriate to use vibration to target the abdominal muscles. Further benefits for using vibration is the ‘ease’ of use – no external resistance, i.e. no heavy weights necessary and only one set of repetitions are required versus 3–10 repetitions recommended in the strengthening or weight training (PRE) literature [32], allowing for a short 5–10 minutes workout session. All the exercises including the warm-up were conducted on the vibrating platform. As the exercise programme was a novel approach to trunk-targeted intervention, children with STCP – those not selected for participation in this study, i.e. older children or those who had undergone surgical procedures in the 12 months prior to the study – assisted the researchers to pilot the exercise regime that was followed in this study.

Procedure

Approval was obtained from the Human Research Ethics Committee at Stellenbosch University and from relevant institutional heads. All the measurements were taken at the school during school hours. Tests were conducted over a two-day period in no specific order – two tests on day 1 and the remaining two outcomes measured on day 2. This was to ensure sufficient rest between tests and to limit time out of the classroom.

The primary investigator conducted the balance, 1-Minute fast walking test and photographic posture analysis. A research assistant conducted the US imaging and measurement. All four measurements were taken by the same tester at baseline (M1), four weeks (M2) and again at eight weeks (M3). The primary investigator was blinded as to which subjects participated in either of the two arms of the study. The exercise session was introduced as follows: twice in week 1; thrice in week 2; four to five times in weeks 3 and 4. This allowed for the recovery of possible delayed onset muscle soreness. Exercising on a vibrating platform was a novel activity for this particular group of participants and initially some experienced some muscle soreness. Exercises were progressed by increasing the time to 45 s and eventually 60 s per exercise. No additional exercises, external resistance or equipment were used. All sessions occurred during their usual therapy sessions or during break-time. All other therapy – occupational or speech – continued as per usual. The sessions were all supervised by a qualified physiotherapist.

Statistical analysis

Statistica (Version 10) was used to analyse data. A one-way analysis of variance (ANOVA) was used to test the effect of randomisation at pre-intervention using the M1 measurements of the two groups.

Table IV. Intra-group analysis – M1–M2; M2–M3; M1–M3 for distance walked in 1 min (m).

	Measurement (m)	Mean	SD	N	Difference	SD	p
Group 1	M1_distance	94.74	26.28				
	M2_distance	106.68	23.56	13	−11.95	15.43	<0.001*
Group 2	M1_distance	87.03	20.07				
	M2_distance	88.58	19.58	14	−1.556	2.74	0.613
Group 1	M2_distance	106.68	23.56				
	M3_distance	95.68	22.64	13	11.008	11.32	0.001*
Group 2	M2_distance	88.58	19.58				
	M3_distance	98.30	20.62	14	−9.709	8.07	0.003*
Group 1	M1_distance	94.74	26.28				
	M3_distance	95.68	22.64	13	−0.938	17.30	0.768

Note: *$p < 0.05$.

Kolmogorov–Smirnov tests were also done at M1 and M2 to inspect distribution of the values of all the variables measured. In cases where no normal distribution was found, the Mann–Whitney-U test was used. Using repeated-measures ANOVA – using a mixed model approach – measurements at M2 were compared to baseline measurements. The change between M2 and M3 was also examined to establish if Group 1 remained the same and whether Group 2 improved over this period. Fisher least significant (LS) difference and post hoc tests were also done to inspect the data further and to determine the level of significance at the various time points. A 5% significance level ($p < 0.05$) was used as guideline for determining significant differences. Where the time × group; LS means (ANOVA) was not significant, but where visual inspection suggested a possible effect from pre- to post-intervention within each group, two time-point ANOVA was conducted. The data of Group 1 from pre- to post-intervention (M1–M2) were combined with the data of Group 2 from pre- to post-intervention (M2–M3) and the total effect was determined.

Results

A total of 30 informed consent forms were distributed to learners at the school and 27 subjects were recruited into the study, parents of three potential subjects not consenting to participation. There were 17 males and 10 females enrolled – 15 were diagnosed with spastic diplegia, nine presented with right hemiplegia and three with left hemiplegia. The numbers relating to gender and type of CP and mobility level (levels I – 13; II – 8; III – 6) were evenly distributed between the two groups. There was a normal distribution for the values recorded for height, weight and BMI within each group. Group 1 however had a skewed distribution for age which ranged between 10.5 and 13.8 years (median = 13.1). Participants in Group 1 were significantly older and taller than participants in Group 2. Although the difference between the two groups was not significant and despite being younger and shorter, subjects in Group 2 were slightly heavier for size than subjects in Group 1.

Effect of intervention on gait. There was a significant interaction between group and time ($p < 0.001$) and the results (Table IV) indicate there was a significant increase in gait speed seen in Group 1 and similarly in Group 2 following intervention. However, a significant difference was again found in Group 1 between M2 which was higher and M3 which was lower and no significant difference between M1 and M3 in this group which indicate that the treatment effect was not sustained after the intervention was withdrawn.

Effect of intervention on posture. The effect of the intervention on posture had varied impact on the different variables measured (Table V). In sitting, the ±5° decrease in forward sway and an increase of 2.7 cm in shoulder-to-seat height was significantly more than the change seen in the control group. Similarly, a decrease forward sway in standing also suggest a more upright posture following participation in the exercise programme. These improvements were maintained four weeks after the intervention was withdrawn. While there was no significant change in a–p pelvic tilt within each group, the total group effect showed a significant decrease in anterior pelvic tilt in both the seated and standing positions.

Effect of intervention on functional abdominal muscle strength. No measurements for the control group were recorded at M1 due to an administrative error and pre- to post-intervention data could therefore only be analysed using a two time-point framework

Table V. Summary of the effect of intervention on static posture.

Position	Measure	Group 1 (M1–M2)	Group 1 *vs.* Group 2 (M2)	Total group effect	Group 2 (M2–M3)	Retention of effect (Group 1)
Sitting	a–p angle (°)	−4·85°*	$p < 0.05$	$p < 0.001$	−5.33°*	Maintained
	Pelvic tilt (°)	No change	No difference	No change	No change	N/a
	Shoulder-to-seat height (mm)	+27·0 mm*	$p < 0.05$	$p < 0.001$	+41.4 mm*	↑* (+34·3 mm)
Standing	a–p angle (°)	−5·58°*	$p < 0.05$	$p < 0.01$	−5.47°*	Maintained
	Pelvic tilt (°)	No change	No difference	$p < 0.001$	No change	N/a

Note: *$p < 0.05$.

which analyses the effect of the intervention as for a single group. This analysis showed that there was a significant interaction from pre- to post-intervention ($p < 0.001$) with children able to perform on average five more sit-ups in one minute (pre-mean 12.9 ± 9.8; post-mean 17.6 ± 11.8). Results for Group 1 at M2 indicated that the treatment effect was sustained after the intervention was withdrawn.

Effect of intervention on abdominal muscle thickness. Using the two time-point framework, the results suggest that all four muscles were significantly thicker post-intervention [TrA ($p = 0.047$); OI ($p = 0.003$); OE ($p = 0.023$); RA ($p = 0.001$)]. This effect was maintained for the RA and OE muscles, while the TrA and OI returned to baseline measurements after the intervention was stopped, despite maintaining the ability to execute repeated sit-ups in one minute.

Discussion

Strengthening can occur in the abdominal musculature of children with STCP following participation in a four-week trunk-targeted intervention using WBV with varying impact on posture and gait function. This was seen in that children were able to walk faster and presented with a more upright posture. Despite improved posture, the effect of stronger and possibly better coordinated abdominal muscle activity on the position of the pelvis however remains inconclusive. While some children showed a significant decrease in anterior tilt, others remained unchanged. The impact the intervention had on distance walked in one minute, however, supports the hypothesis that improved biomechanical alignment and provision of a more stable base, i.e. trunk, can significantly affect gait function in these children. This however was not maintained and at four weeks post-intervention returned to baseline status – this despite participants maintaining the more upright posture and gains achieved in abdominal muscle strength. More upright posture demands abdominal muscle activity as well as appropriate or efficient ventral and dorsal truncal co-contraction activity [36], without EMG the impact of the intervention on improved abdominal activity remains an assumption.

The findings of this study confirm that the abdominal muscles in children with STCP can be strengthened. Although counting the number of sit-ups executed in one minute is not a ‘typical’ strength measure in that it does not determine the maximal force the muscle(s) is able to generate, this measurement includes an assessment of strength, power and endurance – all components demanded from this group of muscles [37]. The reported increase in thickness in the abdominal muscles post-intervention suggests that at least in part, the strength changes which allowed for an increase in the number of sit-ups executed occurred at morphological level. As a significant increase in body mass was also seen, it was assumed that the increase in muscle thickness was in part due to an increase in muscle mass.

While the findings for resting thickness measurements of all four abdominal muscles concur with the impact the intervention had on functional muscle strength, these measurements were not maintained at four weeks post-intervention despite the continued improved ability to execute sit-ups. Why this is so is not clear. Either counting the number of sit-ups is not a valid measurement of abdominal muscle strength or as reported above, there is no direct relationship between the thickness of any of the individual muscles and the ability to do sit-ups. It is recommended that aggregated change in thickness or alternatively stated – the ability to recruit during the activity or potential range of contraction – and its contribution to the ability to execute sit-ups and gait should be further explored.

Core stability is a complex integration of the spine, local and global spinal musculature and neural control [38]. In this study, the selected exercises aimed to activate and strengthen all four abdominal muscles – both the local and global stabilizers and movers – and included both isometric and isotonic activities. Concurrent improved pelvic tilt was recorded in standing in some children. As the impact of core stability on function is dependent on the collective functioning of all the core musculature [39], limiting the strengthening intervention to the abdominal muscles only may not be enough to overcome other 'contributing factors' and once exposure to the strength training programme ceased, this effect was lost. Similarly in the standing position, the ventral abdominal muscles cannot effectively control pelvic position without counter-activity in the posterior hip musculature/extensors [2, 38]. Inclusion of exercises targeting the hip extensors (and hip abductor and adductor for lateral tilt control) including exercises in the standing position may more effectively increase postural control in upright stance.

This study used 2-D photography to investigate posture. While an attempt was made to standardize the procedure, the results should be interpreted with caution. First, while it is generally acceptable to classify severity in children with crouch gait by measuring the degree of flexion at the knee, reference to a single variable is limiting and the contribution of hip and ankle angles are crucial when interpreting the underlying causes of crouch gait and or mechanisms involved [2]. In this study, three variables – forward sway, pelvic tilt and body length – were selected and deemed appropriate to be representative of upright posture in sitting and standing. It should be stated that an improvement in one variable did not necessarily result in a change in the other(s). Second, despite demonstrated test–retest reliability, these variables were not always stable over time. This was noted in Group 2 (which served as the control for period M1–M2) and validity of the measurement for investigating impact of intervention could be questioned. With 2-D analysis, there are limited measures for controlling rotation of the body or body parts which may account for the apparent lack of stability of selected variables and 3-D posture analysis is recommended.

Despite maintaining the improved strength, the change in gait function was however not maintained once the intervention was stopped. Similarly, the changes in thickness for two of the four muscles (both stabilizers – TrA and OI) returned to baseline measurements. Perhaps, the impact of vibration on spasticity and muscle morphology, which was not investigated in this study – cannot be ignored. The effect of the intervention on endurance was also not explored in this study. Although exercises in this study were executed in the supine and side lying positions (no standing exercises except for the 30–45 s warm-up) some participants anecdotally commented that their legs felt 'so loose' (sic) that it was 'easier to walk' (sic). An eight-week strengthening intervention using WBV in adults with CP confirms that vibration can significantly decrease spasticity [22]. This phenomenon may also have contributed to the increased walking speed seen in this study. The primary aim of most non-surgical spasticity targeting interventions is to allow for easier facilitation of movement and create a window of opportunity to strengthen the appropriate muscles. As these interventions only temporarily affect tone [40], it may be that a similar response is seen following vibration therapy and accounted for the decline in gait function seen at four weeks after exercise was stopped.

Conclusion

Targeting the abdominal muscles using WBV can in the short-term significantly improve posture and self-selected fast walking in 6–13 year-old children with STCP. The impact on gait and position of the pelvis in this study, however, was not maintained despite maintaining the gain in functional abdominal muscle strength. The maintained ability to execute sit-ups and the increase recorded in selected resting abdominal muscles thicknesses confirm this finding. Further investigation into better understanding the relationship(s) between abdominal muscle morphology and activity; and posture and function is recommended. The potential effect of exercise while standing on a vibrating platform on endurance and spasticity needs to be further investigated. The inclusion of exercises targeting all appropriate weak musculature involved in maintaining core stability is recommended.

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Note

1. Siemens® Accusonic X150 US imaging machine with a 5.5 cm wide band linear array frequency of 5 Hz B-mode (2-D).

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