SPORT TK-EuroAmerican Journal of Sport Sciences

https://revistas.um.es/sportk Online ISSN: 2340-8812

Received: **10/02/2022.** Accepted: **14/03/2022.** Published: **21/06/2022**

Comparative effect of different treatment approaches on lumbar hyperlordosis, respiratory muscle strength, and balance in diplegic children: A randomized controlled clinical trial

Rasha A. Mohamed[1]*, Abeer M. Yousef [2], Elsayed H. Mohamed[3]

[1] Department of Physical Therapy for Growth and Developmental Disorders in Children and its Surgery, Faculty of Physical Therapy, Cairo University, Egypt.

[2] Department of Basic Sciences, Faculty of Physical Therapy, Cairo University, Egypt.

[3] Physical Therapy Department, Buraydah Private Colleges, Saudi Arabia.

* Correspondence: Rasha A. Mohamed; dr.rashapt@gmail.com

ABSTRACT

The aim of this study was to compare the effect of different treatment approaches (pressure biofeedback training of the abdominal drawing-in maneuver with and without prone hip extension, whole-body vibration, and core stability exercises) on lumbar hyperlordosis, respiratory muscle strength, and balance in children with diplegic cerebral palsy. Forty-five children, ranged in age from 8 to 12 years, were randomly allocated into three groups (A, B, C). All children underwent a specialized exercise program for one hour, three days/ week for three successive months. In addition, group A received pressure biofeedback training, group B underwent the whole-body vibration, and group C underwent the core stability exercises. The lumbar lordotic angle, active lumbar and hip range of motion, respiratory muscle strength, and balance were measured before and after three months of treatment. We found a significant decrease in lumbar lordotic angle along with a significant increase in active lumbar and hip range of motion of group A and group C post-treatment ($p < 0.001$) in favor of group A, while non-significant change was found in group B ($p > 0.05$). A significant improvement was recorded in the three groups' respiratory muscle strength and stability indices in favor of group B ($p < 0.001$). Pressure biofeedback training and core stability exercises are the best adjunctive to traditional physical therapy to improve lumbar hyperlordosis, respiratory muscle strength, and balance together in children with diplegic cerebral palsy. Moreover, whole-body vibration is the best adjunctive to improve respiratory muscle strength and balance.

KEYWORDS

Biofeedback; Core stability; Respiratory muscles; Postural balance; Vibration.

1. INTRODUCTION

Cerebral palsy (CP) is a non-progressive, neuro-motor disorder in the developing brain that leads to chronic movement and posture disorders restricting multiple functions (Rosenbaum et al., 2007). CP describes a pool of disorders of movement and posture that causes limitation (Kwon & Lee, 2015). Therefore, cerebral palsy is a disorder of muscle control that results from some damage to part of the brain.

There is a significant weakness in the trunk muscles spasticity of the extremities with mild motor impairment of the upper extremities than the lower ones (Tang-Wai et al., 2006). Children with diplegic CP have anterior pelvic tilt, lumbar lordosis, hip adduction, hip internal rotation, knee flexion, equinovalgus, and toe-in deformity (Tecklin, 2014), which affects their ability to perform most everyday tasks as well as recreational activities. Spasticity decreases muscle strength, flexibility, and range of motion (ROM) (Dickin et al., 2013).

The abdominal muscle (AM) weakness often leads to an anterior pelvic tilt and lumbar hyperlordosis in CP children (Kim et al., 2006), especially in the rectus abdominis muscle (Vaz G et al; 2002). An anterior pelvic tilt stretches the transverse abdominis (TA) and rectus abdominis muscles resulting in inhibition of their stretch reflex and maintaining a neutral pelvis (Roussouly et al., 2005). In addition to this, an increased lumbar lordosis and anterior pelvic tilt are the most frequently postural compensation patterns associated with the restriction in the extension of the hip joint (Lee et al., 1997). The tightness in the hip flexors further increases the anterior tilt of the pelvis thereby preventing hip extension (Bilgili et al., 2012). Gluteus maximus (GM) is the prime mover for hip extension, and its weakness could result in pelvic imbalance and dysfunction in the hip joint (Lewis et al., 2007). Lumbar hyperlordosis leads to limitation of spinal ROM and weakness of the hip extensors (Jang et al., 2013).

The pulmonary function is also compromised in children with CP to a great extent. The low pulmonary functions in CP children might be attributed to the reduced strength of the respiratory muscle. Reduced muscle strength of the respiratory muscles is a provocative factor for chest infection in CP children. Hence, clearance of the airway by coughing is very essential to prevent pulmonary infections. (Boel et al., 2019).

The central nervous system's integration and processing of sensory inputs are considered the primary basis for balance control (Chiba et al., 2012). Standing balance may be affected by even a slight shift in the body posture (Bottaro et al., 2005). Poor movement strategy and balance impairment occur in CP children due to impaired postural and equilibrium reactions and weakness in diplegic children (Marjorie & Anne, 2005).

Exercises that lengthen hip flexors and back extensors while strengthening AM and hip extensors will help in the correction of hyperlordosis (Kendall et al., 2005). The abdominal drawing-in maneuver (ADIM) is usually recommended for activating abdominal muscles and trunk stabilization training (Kisner & Colby, 2018). Hip extension exercises increase the lumbar lordotic angle and pelvic tilt because of lumbar and pelvis instability and muscle imbalance in the surrounding areas. Therefore, ADIM with hip extension movement stabilizes the lumbar and pelvic regions and prevents abnormal movements (Oh et al., 2007). A previous study was conducted in which the authors investigated the efficacy of ADIM with a hip extension on the trunk and hip extensor muscles and the degree of anterior pelvic tilt. They reported a significant the strength of hip extensors and reduction in the pelvic tilt (Oh et al., 2007).

Biofeedback (BF) promotes motor learning values (Arpa & Ozcakir, 2019). An individual may use BF to identify muscle activity by converting signals into visual and/or auditory signals. As a result, they can monitor and regulate their own muscle movement, which is usually uncontrollable due to the injury in the brain (Li et al., 2014). A pressure biofeedback training (PBFT) was used to evaluate and train the function of the abdominal muscle (Mills et al., 2005).

A mechanical oscillation f whole-body vibration (WBV) produces forces with varying amplitudes and frequencies (Ali S et al., 2019). It improves muscular strength, bone density, and balance (Marin & Rhea, 2010; Ko et al., 2016), stimulates the muscle spindles and the Golgi tendon (Ko et al., 2016), modulates the muscle tone (Elshafey et al., 2021), and triggers the proprioceptive response in the body (Banky et al., 2017).

The core stability area looks like a box with the anterior section of the AM's, and the posterior section includes the spinal muscles and gluteal muscles. The diaphragm and pelvic girdle muscles form their roof and the floor (Miyake et al., 2013). Postural control greatly depends on the abdomen, pelvic, and shoulder muscles (Briggs et al., 2004). Lumbar stabilization exercises are used to balance the abdomen and trunk extensor muscles, which is crucial for stabilizing the spine and performing the movements in the upper and lower extremity (Willson et al., 2005). Core stabilization exercises could improve balance and stability and diminish muscle tone (Dodd et al., 2002).

Previous studies have been conducted in which authors investigated the efficacy of hip extension strengthening and stretching of the hip flexors on lumbar hyperlordosis in adults (Oh et al., 2007; Malai et al., 2015). In another study, the authors established the efficacy of hip flexors and functional stretching exercises on hyperlordosis in infants (Czaprowski et al., 2013). To the best of researcher’s knowledge, no studies were found on the various methods and approaches to correct hyperlordosis in children with diplegic CP. Hence, the researcher identified the need and conducted a study with the prime objective to compare the effect of different treatment approaches (PBFT of the ADIM with and without hip extension, WBV, and core stability exercises) on lumbar hyperlordosis, respiratory muscle strength, and balance in children with diplegic CP.

2. METHODS

The present study was a parallel group randomized controlled trial with a planned duration of three successive months (Figure 1). The study was conducted in the outpatient clinic of Al-Qassim University, Saudi Arabia. The study was registered in the clinical trial registry with the registration number as UMIN000044103. Since the study was conducted on human beings hence the researchers followed the Code of Ethics of the World Medical Association (Declaration of Helsinki). The study's intent, assessment and treatment protocols were informed to all parents. Before the children participated, their parents had to sign a consent form.

In the present study, forty-five children diagnosed as diplegic cerebral palsy, both males and female (male = 23 and females = 22), children falling within the age group of 8 to 12 years were recruited as the participants for the study. Children graded at level II of Gross Motor Function Classification Scale (GMFCS), with grade 1^+ and 2 level of spasticity based on Modified Ashworth Scale, having lumbar hyperlordosis with lumbar lordotic angle (LLA) ranged from 40°-45°, dynamic shortening of hip flexors, the strength of quadriceps, hamstring, and calf muscles was at least grade 3 according to Kendall et al. (2005), abled to walk independently without walking aids, and had the adequate intellect and were able to comprehend instructions were eligible to participate in the study.

However, children diagnosed with any genetic or metabolic disorders, who had undergone any previous surgery, who had taken Botox injection of the lower limbs (LL_s) during the previous 6 months, with any visual or auditory problems, obesity, uncontrolled seizures, cardiopulmonary disorders, blood diseases, leg length discrepancy, congenital heart diseases, and difficulty to cope with the tests and intervention protocols during the familiarity session were excluded from the study.

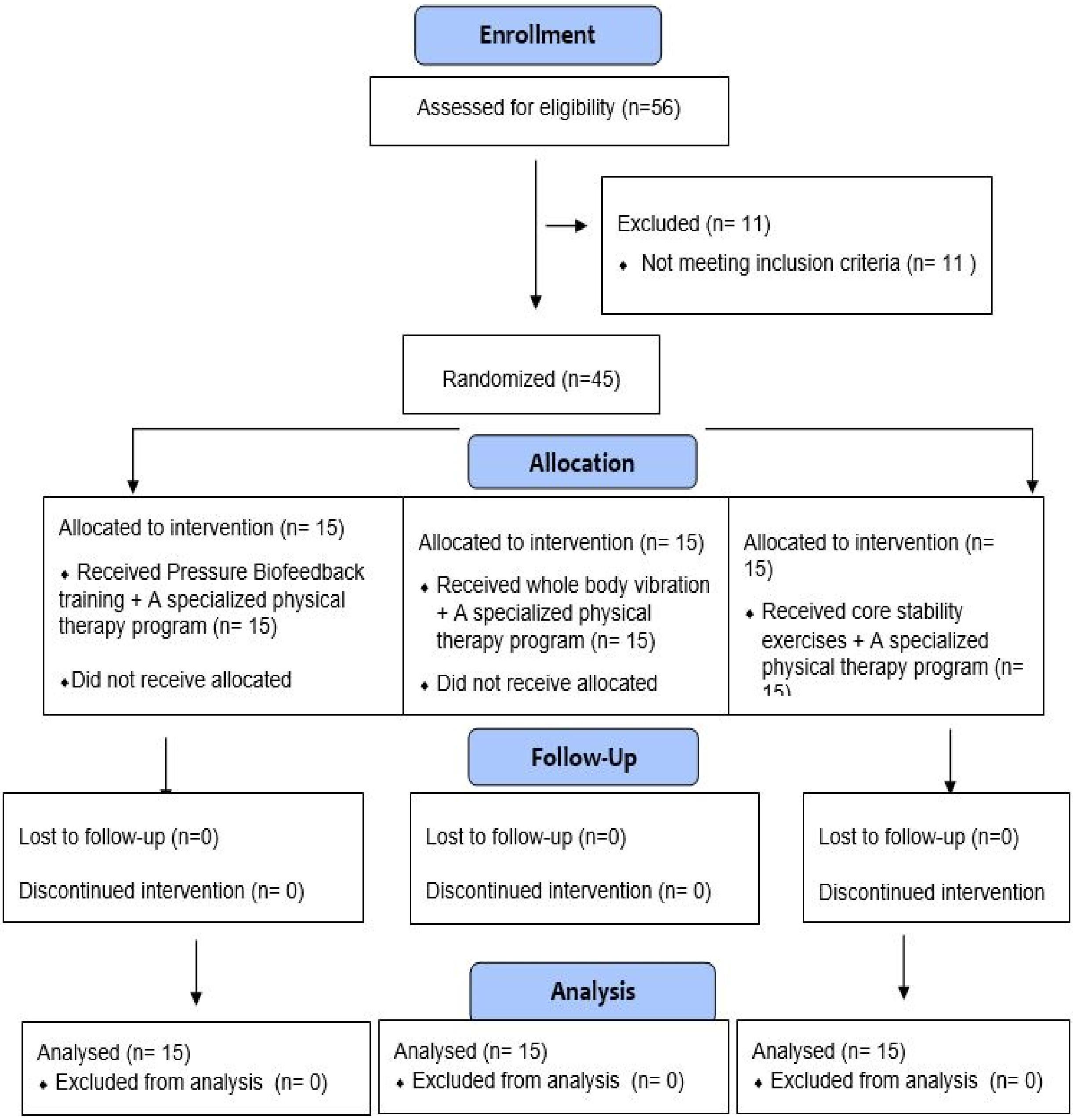

Figure 1. CONSORT Flow Diagram showing the experimental design of the study

2.1. Sample size calculation

Sample size for the present study was calculated using G*POWER statistical software (version 3.1.9.2; Universitat Kiel, Germany). Prior to this study, a pilot experiment was conducted on LLA, in which 10 children were included as the sample participants, with n=05 in each group. The data of LLA from this pilot study was used to calculate the sample size (Alpha= 0.05, power 80%, and effect size 0.48). The sample size of the present study was 45 with n=15 in each group.

2.2. Randomization, allocation, and blinding

All patients were scheduled for regular outpatient physical therapy sessions in the Outpatient-Clinic of Al-Qassim University, Saudi Arabia. A total of 56 children were screened for the study by a research coordinator. Out 0f 56 children, 10 children did not fulfill the selection criteria and were excluded from the study. A total of 45 children were recruited as the participants for the study. All the participants were randomly allocated into three groups i.e. group A, group B and group C, with n=15 in each group. Based on a computer-generated randomization schema with blocks of randomly varied sizes, the allocation ratio was 1:1:1 of equal numbers n = 15. Followed by this, the group allocation was revealed exclusively via computer software (CleanWeb) to the non-blinded physiotherapist, who was not involved in the study. An off-site independent statistician constructed the randomization list prior to the start of the study. In this study no drop outs were reported. Figure 1 represents the participants' flow chart through the study and timeline of assessments and interventions according to the CONSORT guidelines (Moher et al., 2012).

2.3. Outcome measures

Anthropometric measurements were done in which the height (cm) and weight (kg) of each participant were measured using the weight and height scale (health scale 70, made in China). The researcher who was blinded to allocation and intervention completed pre-intervention and post-intervention assessments of all the participants under similar conditions before and after successive three months of treatment. All the participants underwent familiarity sessions of outcomes measures to make them understand the purpose and methods of tests in an appropriate manner.The primary outcomes in this study were LLA, active lumbar ROM, and active hip ROM while the secondary outcomes were respiratory muscle strength and balance.

2.3.1. Lumbar lordotic angle assessment

Plain radiography of the lumbar region was performed to measure LLA using Cobb's angle. LLA assessment was done by measuring the angle between two lines. The first line was parallel to the top of the first lumbar vertebra, and the second line was parallel to the bottom of the vertebral body where kyphosis to the sacral vertebrae begins (Cho et al., 2015).

2.3.2. Lumbar range of motion assessment

Active lumbar ROM was measured using the baseline bubble inclinometer (Model 10602, Fabrication Enterprise Inc., USA). Initially, reference points were marked on the specific landmarks on the participant’s body which included the 1st sacral and the 12th thoracic spinous process for measuring the range of motion of flexion and extension of the lumbar spine. Two bubble inclinometers were used simultaneously for measuring the range of motion of flexion and extension of the lumbar spine in the standing position. The participant was asked to bend forward and then backward. The actual lumbar ROM was calculated by subtracting the degrees obtained by the lower and upper inclinometers (Magee & Manske, 2020).

2.3.3. Hip joint range of motion measurement

An electrogoniometer was used for the measurement of the range of motion of the hip joint. The electrogoniometer was connected to the TeleMyo900 transmitter via the NorAngle control box in a supine posture with the contralateral hip and knee in full flexion. The stability and mobility arms of the goniometer were placed parallel to the pelvis and thigh using double-faced adhesive tape. The greater trochanter and lateral margin of the knee joint were marked as the reference point for the measurement of ROM of flexion and extension of the hip joint. The ROM measurement for hip joint flexion and extension was done by taking the participant into supine lying and prone lying positions respectively (Behrens et al., 2006).

2.3.4. Measurement of respiratory muscle strength

The maximal inspiratory pressure (MIP) and maximal expiratory pressure (MEP) were assessed using Respiratory Pressure Meter (Microhard System, Porto Alegre, Globalmed). The participant was asked to attain a sitting position. The maximal inspiratory pressure (MIP) measurement was done by asking the participant to exhale to the residual volume and to inhale intensively as long as possible for atleast 1sec to 3 seconds. Maximal expiratory pressure (MEP) measurement was done by asking the participant to inhale to the maximal lung capacity and then forcefully exhale as long as possible for 1-3 s. Each participant was provided with five consecutive attempts. The best out of all was recorded (Mohamed et al., 2021).

2.3.5. Balance assessment

The balance assessment was done using the Biodex Stability System (BSS; Biodex, Inc., Shirley, NY). The BSS is a dynamic balance platform that enables simultaneous movements in medial-lateral and anterior-posterior axes. It is used to measure a medial-lateral stability index (MLSI), anterior-posterior stability index (APSI), and overall stability index (OSI). It consists of eight levels of stability, ranging from level 1(the least stable) to level 8 (the most stable level). In this study, the stability indices were measured at level 8 because, during familiarity sessions, the children had trouble keeping their equilibrium below this level. The test was repeated three times, and the average score of the three attempts was documented.

2.3.6. Interventions

In the present study, all three groups underwent a specialized exercise program. The exercise program was implemented as one hour /session, three days a week for a total of three successive months. In addition to this, the participants of groups A, B and C underwent PBFT of the ADIM with and without prone hip extension, WBV, and core stability exercises. A specialized exercise program included (hot fomentation for 10 min, hold-relax stretching of the iliopsoas, hamstring, and calf muscles (held the position for 20 sec followed by relaxation for 10 sec, repeated 5 times, followed by a 1-min rest), balancing and gait training exercises.

During the course of the study, the researcher ensured that the eligible children did not participate in any other activities and did not undergo any injections or medications. The researchers monitored and verified the compliance during the treatment sessions. Prior to the start of the intervention, familiarity sessions were conducted by the researcher to make them understand the correct method of intervention. The adherence rate of the participants was approximately 97 %. The attendance record of each participant was calculated by the number of the prescribed visits attended. The completeness of the exercises was calculated by the percentage of the exercises completed to the author's satisfaction. The record of the completeness of the exercises/ intervention was maintained by using the template for Intervention Description and Replication (TIDieR) checklist and guide (Hoffmann et al., 2014). The participants failing to complete 90% of the exercises were considered drop outs of the study.

2.4. Pressure biofeedback training

The PBFT of ADIM with and without prone hip extension was conducted using the PBF unit (PBFU) (Chattanooga Group, Hixson, TN). The PBFU is widely used and has a high level of validity and reliability (Lima et al., 2012). It included ADIM with hip extension followed by ADIM without hip extension. Each maneuver was performed for 10 minutes with a total duration of 30 minutes. In this, the rest period was not counted against the duration of exercises.

2.4.1. The abdominal drawing-in maneuver

Each participant was instructed to lie in the supine lying position on a stable surface with bilateral knee bent to 90 degrees of flexed position with the feet flat on the stable surface. The PBFU was placed under the fifth lumbar vertebra. The child was instructed to tighten the umbilicus upward and backward towards the lumbar, press on the airbag, tighten the buttocks to allow the pointer to reach a specified value, and prevent the pointer from floating. The participants were asked to keep their spine stable during the training. The researcher ensured that PBFU was not leaking. Before training, the PBU was inflated to 40 mmHg. The participants were encouraged to to reach 180 mmHg during the training. The movement was performed for 15 sec with relaxation for 5 sec between the movements (Xu C et al., 2021). The exercise was performed as 3 sets × 10 repetitions, with two min break between each set with a total of 10 min (Richardson et al., 2004).

2.4.2. Abdominal drawing-in maneuver with prone hip extension

Abdominal drawing-in maneuver with prone hip extension was initiated by placing a target bar on the wall at the level of 10° hip extensions. Each child was instructed to lie down in a prone position. A PBFU was positioned between the therapeutic table's pad and the child's lower abdomen to control the action of AM. The bag of PBFU was inflated to 70 mmHg and the participant was instructed to pull his/her abdomen in and to hold that position. Followed by this, the child extended the hip without bending the knee until the popliteal area touched the target bar. During hip extension, the participant was directed to maintain a pressure of 60 mmHg using visual input from an analog pressure gauge. The hip extension end-range movement was kept for 5 secs (Oh et al., 2007). The exercise was performed in 3 sets with 10 repetitions/set for a total of 10 minutes with 3 minutes rest intervals between consecutive sets.

2.5. Whole body vibration

WBV training was conducted using the Galileo System vibration unit (Novotec Medical, Pforzheim, Germany). It was applied in two positions; squatting and in the standing position with the knee joint in a semi-flexed position, with a duration of 7 min for each position and 1 min rest in between. Semi -squat position was used to focus energy on the lower extremities (Park et al., 2018). Han et al. (2019) recommended WBV with 18-20 Hz, which was more effective because higher frequencies made the child fatigued and required a long time to recover the muscle. So, the overall duration of training was 15 min at a frequency of 20 Hz and amplitude of 2 mm. each participant was instructed to maintain his/her position.

2.6. Core stability exercises

The participants of group C underwent core stability exercises for 30 min per session. The core stability program had three levels. Each exercise was performed at each level for 5 min according to a set of sequences. The first (simple) level included the exercises as supine abdominal draw-in, abdominal draw-in with both knees to the chest, and supine twist. In the second level participants performed pelvic bridging (5 repetitions) and twisting with a medicine ball (2 sets × 10 repetitions) and in the third level participants performed bridging with the head on a physioball (held for 5 s, followed by relaxation) and prone bridging. In all the levels, 2 sets of exercises were performed with 10 repetitions /set (Lahatinen et al., 2007).

2.7. Statistical analysis

ANOVA-test for numerical data and by Chi-squared test for categorical data was conducted to compare the participants' characteristics among the three groups. Shapiro-Wilk test was used to check the normal distribution of data for all variables. Levene's test was used for establishing the homogeneity of variances between groups. Mixed model MANOVA was performed to compare within and between-group effects on LLA, active lumbar ROM, active hip ROM, MIP, MEP, and stability indices. For subsequent multiple comparisons, post-hoc analysis was done using the Bonferroni correction. The level of significance was set at $p < 0.05$. All statistical analysis was performed through the statistical package for social studies (SPSS) version 25 for windows (IBM SPSS, Chicago, IL, USA).

3. RESULTS

3.1. Participants' characteristics

Table 1 showed participant characteristics A total of Forty-five children, diagnosed with diplegic CP participated in this study. Non-significant difference was found between all the groups with respect to age, weight, height, sex, and spasticity grades distribution with $p > 0.05$.

Table 1. Participants' characteristics

		Group A	Group B	Group C	*p*-value
		Mean ± SD	Mean ± SD	Mean ± SD	
Age (years)		9.83 ± 1.35	9.7 ± 1.27	9.8 ± 1.44	0.96
Weight (kg)		29.36 ± 3.15	29.53 ± 3.88	28.82 ± 3.64	0.85
Height (cm)		135.06 ± 7.21	134 ± 7.1	134.86 ± 8.09	0.91
Degree of spasticity					
1^+		7 (47%)	6 (40%)	8 (53%)	0.76
2		8 (53%)	9 (60%)	7 (47%)	
Sex	Boys	7 (47%)	7 (47%)	9 (60%)	0.71
	Girls	8 (53%)	8 (53%)	6 (40%)	

**SD, standard deviation; p-value: level of significance; *Significant at p< 0.05*

3.2. Effect of treatment on lumbar lordotic angle, lumbar ROM, hip ROM, MIP, MEP, and stability indices

There was a significant interaction of treatment and time with F = 45.28, $p = 0.001$, and $\eta^2 = 0.93$), a significant main effect of time with F = 937.51, $p = 0.001$, and $\eta^2 = 0.99$, and a significant main effect of treatment with F = 21.83, $p = 0.001$, and $\eta^2 = 0.86$.

3.2.1. Within group comparison

Within group comparison of LLA and hip ROM in group A and group C revealed a significant reduction in LLA, and a significant increase in active lumbar and hip ROM with $p<0.001$. Within group comparison of group B revealed non-significant changes with $p > 0.05$. Within group comparison of MIP and MEP revealed a significant decrease in APSI, MLSI, and OASI in all the three groups with $p<0.001$ (Table 2).

3.2.2. Between group comparison

In the present study, between group comparisons revealed significant decrease in LLA. There was a significant decrease in LLA of group A compared with that of group B and group C with $p < 0.01$), and a significant decrease in group C compared with that of group B with $p < 0.001$ (Table. 3).

There was a significant increase in the lumbar flexion of group A compared with that of group B and group C with $p < 0.001$, and a significant increase in group C compared with that of group B with $p < 0.01$. There was a significant increase in the lumbar extension of group C compared with that of group A and group B with $p < 0.001$, and a significant increase in group A compared with that of group B with $p < 0.01$ (Table 3).

Table 2. Pre and post-treatment mean values of lumbar lordotic angle, lumbar ROM, hip ROM, MIP, MEP and stability indices

	Group A					**Group B**					**Group C**				
	Pre	**Post**				**Pre**	**Post**				**Pre**	**Post**			
	M±SD	**M±SD**	***MD***	***% of change***	***p***	**M±SD**	**M±SD**	***MD***	***% of change***	***p***	**M±SD**	**M±SD**	***MD***	***% of change***	***p***
LLA (degrees)	42.13 ± 1.68	33 ± 1.13	9.13	21.67	**0.001***	41.86 ± 1.55	41. 26± 1.62	0.6	1.43	**0.07**	41.66 ± 1.44	35.06 ± 1.53	6.6	15.84	**0.001***
Lumbar flexion (degrees)	41.8 ± 1.69	52.07 ± 1.16	10.27	24.57	**0.001***	42.06 ± 1.79	42.8± 2.42	0.74	1.76	**0.1**	42.53 ± 1.45	48 ± 1.73	5.47	12.86	**0.001***
Lumbar extension (degrees)	17.4 ± 1.12	22.13± 1.55	4.73	27.18	**0.001***	17.46 ± 0.91	18. 2± 1.85	0.74	4.24	**0.08**	17.33 ± 1.23	24.26± 1.27	6.93	40	**0.001***
Hip flexion (degrees)	65.13 ± 3.09	80.13 ± 3.5	15	23.03	**0.001***	64.66 ± 2.66	66.53 ± 3.66	1.87	2.89	**0.09**	65.46 ± 3.02	75.33 ± 2.91	9.87	15.08	**0.001***
Hip extension (degrees)	6.06 ± 0.7	10.06 ± 1.09	4	66.01	**0.001***	5.86 ± 0.74	6.2 ± 0.67	0.34	5.8	**0.08**	5.8 ± 0.77	8.6 ± 0.82	2.8	48.28	**0.001***
MIP (cmH$_2$O)	43.93 ± 2.15	47.86 ±1.95	3.93	8.95	**0.001***	44.06 ± 2.18	55.4 ±1.72	11.34	25.74	**0.001***	43.26 ± 1.94	51.13 ± 2.26	7.87	18.19	**0.001***
MEP (cmH$_2$O)	40.93 ± 0.79	52.66 ± 3.22	11.73	28.66	**0.001***	41.26 ± 1.03	44.4 ± 1.84	3.14	7.61	**0.001***	41.66 ± 1.54	57.33 ± 2.12	15.67	37.61	**0.001***
APSI	1.67 ± 0.01	1.31 ± 0.07	0.36	21.56	**0.001***	1.68 ± 0.01	1.23 ± 0.04	0.45	26.79	**0.001***	1.66 ± 0.02	1.15 ± 0.09	0.51	30.72	**0.001***
MLSI	1.91 ± 0.05	1.56 ± 0.06	0.35	18.32	**0.001***	1.93 ± 0.06	1.35 ± 0.05	0.58	30.05	**0.001***	1.92 ± 0.05	1.52 ± 0.07	0.4	20.83	**0.001***
OVSI	1.98 ± 0.09	1.57 ± 0.07	0.41	20.71	**0.001***	1.96 ± 0.03	1.4 ± 0.6	0.56	28.57	**0.001***	1.97 ± 0.05	1.49 ± 0.06	0.48	24.37	**0.001***

**Notes: SD, standard deviation; APSI, anterior-posterior stability index; LLA, lumbar lordotic angle; MEP, Maximal expiratory pressure; MIP, Maximal inspiratory pressure; MLSI, medial-lateral stability index; OSI, overall stability index; ROM, range of motion; p-value, level of significance; SD, standard deviation; *Significant at p< 0.05.*

Table 3. Comparison of post-treatment mean values of lumbar lordotic angle, lumbar ROM, hip ROM, MIP, MEP, and stability indices among the three groups.

	A vs. B **MD (*p*-value)**	**A vs. C** **MD (*p*-value)**	**B vs. C** **MD (*p*-value)**
LLA (degrees)	8.26 (0.001)	2.06 (0.001)	6. 2(0.001)
Lumbar flexion (degrees)	9.27 (0.001)	4.07 (0.001)	5.2(0.003)
Lumbar extension (degrees)	3.93 (0.98)	2.13(0.002)	6.06(0.001)
Hip flexion (degrees)	13.6 (0.001)	4.8 (0.001)	8.8 (0.001)
Hip extension (degrees)	3.86 (0.001)	1.46 (0.001)	2.4 (0.001)
MIP (cmH$_2$O)	7.54 (0.001)	3.27 (0.001)	4.27 (0.001)
MEP (cmH$_2$O)	8.26 (0.001)	4.67 (0.001)	12.93 (0.001)
APSI	0.08 (0.01)	0.16 (0.001)	0.08 (0.02)
MLSI	0.21 (0.001)	0.04 (0.19)	0.17 (0.001)
OVSI	0.17 (0.001)	0.08 (0.02)	0.09 (0.002)

**Notes: SD, standard deviation; APSI, anterior-posterior stability index; LLA, lumbar lordotic angle; MEP, Maximal expiratory pressure; MIP, Maximal inspiratory pressure; MD, mean difference; MLSI, medial-lateral stability index; OSI, overall stability index; p-value, level of significance; SD, standard deviation; vs., versus; *Significant at p< 0.05.*

There was a significant increase in the hip flexion and extension ROM of group A compared with that of group B and group C with $p < 0.001$ and a significant increase in group C compared with that of group B with $p < 0.001$ (Table 3).

There was a significant increase in MIP of group B compared with that of group A and group C with $p < 0.001$ and a significant increase in MIP of group C compared with that of group A with $p < 0.001$. There was a significant increase in MEP of group C compared with that of group A and group B with $p < 0.001$ and a significant increase in group A compared with that of group B with $p < 0.001$. (Table 3).

There was a significant decrease in APSI of group C compared with that of group A and group B with $p < 0.05$ and a significant decrease in APSI of group B compared with that of group A with *p*

< 0.01. There was a significant decrease in MLSI of group B compared with that of group A and group C with $p < 0.001$ while there was no significant difference between group A and C with $p > 0.05$. There was a significant decrease in OASI of group B compared with that of group A and group C with $p < 0.01$ and a significant decrease in OASI of group C compared with that of group A with $p < 0.05$ (Table 3).

4. DISCUSSION

The primary objective of the study was to compare the effect of different treatment approaches (PBFT of the ADIM with and without prone hip extension, WBV, and core stability exercises) on lumbar hyperlordosis, respiratory muscle strength, and balance in children with diplegic CP.

The researcher attributed the significant improvement in LLA, lumbar and hip ROM to the combined effect of the physical therapy program together with PBFT or core stability exercises. It is usually recommended to improve trunk control and abdominal muscle strength in diplegic children with lumbar hyperlordosis (Roussouly et al., 2005; Unger et al., 2006). A sufficient amount of literature is available in support of strengthening of AM and GM in minimizing the lordotic angle in the lumbar region, improving the lumbar ROM and balance (Oh et al., 2007; Radziszewski, 2007). Contraction of TA muscle increases internal abdominal pressure and tension in the thoracolumbar fascia which stabilizes the region (Kibler et al., 2006). The thoracolumbar fascia is also a proprioceptor that provides feedback regarding feedback about the position of the trunk (McGill, 2002). Abdominal bracing exercises leads to significant increases in the isometric trunk extension and hip extension (Tayashiki et al., 2016). Increased abdominal pressure by ADIM in the individuals with hyperlordosis caused decreased muscle activity in lumbar erector spinae (LES) and increased activity of the GM. Moreover, LES muscle activity was reduced by increasing internal stability (Kim & Kim, 2015).

A significant improvement was observed in the group that underwent PBFT. The researcher attributed this to the improvement in motor control through the greater effect of BF on neural plasticity and cortical reorganization. Feedback is very much essential for monitoring errors and improving corrections in the motor program. Though the neural damage disrupts the control of the muscle tone but the affected individuals may have specific pathways that are unaffected. With the help of BF, Patients will be able to learn the use of these retained pathways and this regulation may result in muscle function recovery (Woodford & Price, 2007).

Motor learning requires information from the external environment, exteroceptors, and proprioceptors. Basmajian (1963) has demonstrated that individuals could control the recruitment and frequency of discharge of motor units through auditory and visual feedback. Visual stimuli have been found to elicit potentials in specific areas of the cerebellum. The cerebellum is essential in adapting, learning, and executing motor actions. PBFU provides external visual feedback to the patients regarding their task performance.

Motor behavior in the affected individuals could be improved with the BF training and by reinforcing the affected individuals to reach goal-oriented behavior (O'Leary et al., 2007). The BF monitors the information, from the exteroceptors in the skin and proprioceptors in the joint and muscles, concerning the length of the muscle, the amount of tension, and tactile sensation. The BF may increase the muscle force by increasing motor unit recruitment or by increasing the firing rate of motor units. Repetitive and concentrated practice plays an essential role in brain plasticity (Wolf et al., 2002). In addition to this, the additional effect of reciprocal inhibition of the iliopsoas and hamstring muscles also occurred during the training of AM and GM (Ruas et al., 2018).

Core stability exercises improve the quality of spinal muscle contraction and upper and lower extremity muscle strength through the length-tension relationship (Unayik & Kahiyan, 2011). The core stability exercises activated the abdominal and back muscles to reach the level of optimal muscle strength (Ali et al., 2019). The researcher attributed this significant effect to the improved neuromuscular system that enhances the optimal appropriate muscular balance, proximal stability, lumbar-pelvic-hip chain mobility, and function (Norris, 2001), resulting in strengthening the LLS muscles and controlling the movement (Gribble & Hertel, 2003).

In the present study, a non-significant effect of WBV with physical therapy program was found on LLA, lumbar ROM, and hip ROM. These results of the study were consistent with the previous studies in which authors concluded that WBV in diplegic CP children did not affect the hip joint ROM (Lee & Chon SC, 2013; Tupimai et al., 2016; Ahmadizadeh et al., 2019). Few authors have also reported in their respective studies to correct the Hyperlordosis in CP children, by strengthening of AMs' and hip extensors with stretching of hip flexors and back extensors (Kendall et al., 2005).

The non-significant improvement recorded in lumbar and hip ROM explained the non-significant improvement in lumbar Hyperlordosis in this group. To the best of the researcher's knowledge, the previous studies have reported that WBV is a promising approach to increasing the strength in the muscles through tonic vibration reflexes (Bryant et al., 2013), while other authors have reported no improvement in the muscle strength (Gloeckl et al., 2012). Previous studies recorded an increase in the thickness of AM (Ali & Abd el-aziz, 2020) without measuring its strength and lumbar ROM. Therefore, the effect of WBV on hip and trunk muscles could not be sufficient to produce a significant improvement in the LLA and lumbar ROM.

In the present study, a significant improvement was found in the stability indices of the three groups with a higher effect on WBV. The findings of the present study were in accordance with a study conducted by Ali et al. (2019), in which authors compared the effect of core stability exercises and WBV on children with spastic CP and they concluded that WBV is more effective in improving balance.

The significant improvement in the stability indices due to the effect of WBV has also been confirmed in the previous literature (Mohamed et al., 2019; Gloeckl et al., 2021). The researcher attributed this significant improvement to the combined effect of sensory stimulation through WBV and a designed exercise program. WBV worked at the various external and internal inputs like visual, vestibular, and proprioceptive inputs (muscle spindle, tendon organs, Pacinian, and Meissner corpuscles) resulting in modulation of muscle tone (Elshafey et al., 2021).WBF worked on the enhancement of the relationship between motor and sensory systems, improving the sensorimotor integrative processes (Costantino et al., 2018), the synchronization of the motor units firing, and also improved co-contraction of synergist muscles (Abbasi et al., 2017). In addition to this, the significant effect of WBV might be a result of enhancing ankle strategy through improving ankle ROM (Ahmadizadeh et al., 2019), although it has not been confirmed in the current study.

The significant improvement in the stability indices in the groups that underwent PBFT and core stability exercises in the favor of core stability might be a result of the decrease in the LLA, improvement in the lumbar ROM and hip ROM, which could result in moving the center of mass of the back to its normal location, and an increase in the lumbopelvic stability (Liebenson et al., 2009). The strengthening exercises of the trunk and pelvic muscles could improve the postural and equilibrium reactions in children with CP (Sterba et al., 2002). Core stability exercises modify the load transfer and lead to efficient weight distribution, which results in improving the balance of the individual (Roelants et al., 2006).

The feed-forward system gets stimulated by the core stability program, which leads to postural activity in the upper and lower extremities and improved coordination between the upper extremities and trunk (King, 2011). The core stability exercises also improve the feedback mechanism because the spine's stability depends on muscle strength and accurate sensory signals from the environment and body interactions that are delivered to the central nervous system for continuous feedback and movement refinement (Akuthota et al., 2011).

The statistical analysis of the present study also revealed a significant improvement in MIP and MEP of the three groups with a higher effect on WBV. Increased MEP during respiration might assist in the discharge of secretions and foreign substances from the airway, preventing pneumonia and other pulmonary disorders, which are common in CP children.

The improvement was recorded in MIP and MEP in groups undergoing PBFT and core stability exercises, with a higher effect of PBFT than the core stability exercises. Previous studies have reported the significant effect of core stabilization exercises on various respiratory parameters, muscle strength, and physical fitness in different populations other than children (Cavaggioni et al., 2015; Oh & Park, 2016; Park et al., 2017; Mustafaoglu et al., 2019). The researcher attributed the significant effect of PBFT and core stability exercises to the activation of AM muscle. The AM pulls the ribs and costal cartilage caudally, thereby assisting the forced expiration.

The contractions of the abdominal muscles cause an increase in the intra-abdominal pressure and a decrease in the intrathoracic pressures that help in increasing the airflow (Key, 2013). In addition to this, the abdominals create a push towards the diaphragm upward into the thoracic cage, increasing the speed and volume of exhalation. The passive stretch to the costal fibers of the diaphragm help in increasing the inspiration phase of respiration (Starr et al., 2011). In addition, the core stability muscles improve the strength of the upper spinal musculature. Core exercises also increase trans-diaphragmatic pressure, which is the maximal force generated by the diaphragm at functional residual capacity, which stimulates it (Strongoli et al., 2010).

To the best of the researcher’s knowledge, very few studies have been conducted to investigate the effect of WBV on MIP and MEP. The statistical analysis of the present study revealed significant improvement in MIP and MEP. The findings of this study were found to be in accordance with the previous literature (Pessoa et al., 2017). WBV induces a reflex sensitization of the muscle spindles, enhancing the strength of the diaphragm muscle and accessory muscles of respiration of the scapular girdle (Pessoa et al., 2017) as well as an increase in the involuntary respiration by neural inspiratory stimulation (Sumners et al., 2008).

The researcher has highlighted the key strengths of the study. In the current study, no dropout was reported, the baseline data was homogenous with a lack of any discrepancies. However, some drawbacks were also reported. Even though the sample size was calculated according to a previous statistical estimate, increasing the sample size might have increased the power of the results. Hence, the researcher emphasized the need to conduct the large sample prospective trials along with frequent follow-up periods to determine the long-term effects of the training.

5. CONCLUSION

Based on the obtained results, the researcher concluded that PBFT of the ADIM with and without prone hip extension and core stability exercises are the best adjunctive to the traditional physical therapy to improve lumbar hyperlordosis, respiratory muscle strength, and balance together in children with diplegic CP. Moreover, WBV is the best adjunctive for improving respiratory muscle strength and balance.

6. REFERENCES

1. Abbasi, E., Kahrizi, S., Razi, M., & Faghihzadeh, S. (2017). The effect of whole-body vibration training on the lower extremity muscles' electromyographic activities in patients with knee osteoarthritis. *Medical journal of the Islamic Republic of Iran, 31,* 107. https://doi.org/10.14196/mjiri.31.107
2. Ahmadizadeh, Z., Khalili, M. A., Ghalam, M. S., & Mokhlesin, M. (2019). Effect of whole body vibration with stretching exercise on active and passive range of motion in lower extremities in children with cerebral palsy: A randomized clinical trial. *Iranian Journal of Pediatrics, 29*(5), e84436.
3. Akuthota, V., Ferreiro, A., Moore, T., & Fredericson, M. (2008). Core stability exercise principles. *Current sports medicine reports, 7*(1), 39-44. https://doi.org/01.CSMR.0000308663.13278.69
4. Ali, M. S., & Abd El-Aziz, H. G. (2021). Effect of whole-body vibration on abdominal thickness and sitting ability in children with spastic diplegia. *Journal of Taibah University Medical Sciences, 16*(3), 379-386. https://doi.org/10.1016/j.jtumed.2020.11.006
5. Arpa, S., & Ozcakir, S. (2019). Does electromyographic biofeedback improve exercise effects in hemiplegic patients? A pilot randomized controlled trial. *Journal of Rehabilitation Medicine, 51*(2), 109-112. https://doi.org/10.2340/16501977-2513

6. Banky, M., Ryan, H. K., Clark, R., Olver, J., & Williams, G. (2017). Do clinical tests of spasticity accurately reflect muscle function during walking: A systematic review. *Brain Injury, 31*(4), 440-455. https://doi.org/10.1080/02699052.2016.1271455
7. Behrens, R., Gregoire, C., Mathern, T., & Pederson, J. L. (2006). An Electromyographic and Electrogoniometric Study of Stair Climbing with and without the Use of the Ez-Step[a] and the Quad-Step[a]. *Physical Therapy Scholarly Projects, 42.* https://commons.und.edu/pt-grad/42
8. Bilgili, F., Temelli, Y., & Akalan, N. E. (2012). Assessment of the hip and knee flexion contractures in cerebral palsy patients with crouch gait. JAREM. *Journal of Academic Research in Medicine, 2*(2), 33. https://doi.org/10.5152/jarem.2012.11
9. Boel, L., Pernet, K., Toussaint, M., Ides, K., Leemans, G., Haan, J., ... & Verhulst, S. (2019). Respiratory morbidity in children with cerebral palsy: an overview. *Developmental Medicine & Child Neurology, 61*(6), 646-653. https://doi.org/10.1111/dmcn.14060
10. Bottaro, A., Casadio, M., Morasso, P. G., & Sanguineti, V. (2005). Body sway during quiet standing: is it the residual chattering of an intermittent stabilization process? *Human movement science, 24*(4), 588-615. https://doi.org/10.1016/j.humov.2005.07.006
11. Briggs, A. M., Greig, A. M., Wark, J. D., Fazzalari, N. L., & Bennell, K. L. (2004). A review of anatomical and mechanical factors affecting vertebral body integrity. *International Journal of Medical Sciences, 1*(3), 170. https://doi.org/10.7150/ijms.1.170
12. Bryant, E., Pountney, T., Williams, H., & Edelman, N. (2013). Can a six-week exercise intervention improve gross motor function for non-ambulant children with cerebral palsy? A pilot randomized controlled trial. *Clinical Rehabilitation, 27*(2), 150-159. https://doi.org/10.1177/0269215512453061
13. Cavaggioni, L., Ongaro, L., Zannin, E., Iaia, F. M., & Alberti, G. (2015). Effects of different core exercises on respiratory parameters and abdominal strength. *Journal of physical therapy science, 27*(10), 3249-3253. https://doi.org/10.1589/jpts.27.3249
14. Chiba, R., Takakusaki, K., Ota, J., Yozu, A., & Haga, N. (2016). Human upright posture control models based on multisensory inputs; in fast and slow dynamics. *Neuroscience research, 104*, 96-104. https://doi.org/10.1016/j.neures.2015.12.002
15. Cho, I., Jeon, C., Lee, S., Lee, D., & Hwangbo, G. (2015). Effects of lumbar stabilization exercise on functional disability and lumbar lordosis angle in patients with chronic low back pain. *Journal of physical therapy science, 27*(6), 1983-1985. https://doi.org/10.1589/jpts.27.1983

16. Costantino, C., Petraglia, F., Sabetta, L. L., & Giumelli, R. (2018). Effects of single or multiple sessions of whole body vibration in stroke: is there any evidence to support the clinical use in rehabilitation? *Rehabilitation research and practice, 2018,* 8491859. https://doi.org/10.1155/2018/8491859
17. Czaprowski, D., Leszczewska, J., Kolwicz, A., Pawłowska, P., Kędra, A., Kriščiūnas, A., ... & Kowalski, I. M. (2013). The influence of self-stretching based on postisometrical relaxation, static stretching combined with stabilizing exercises, and stabilizing exercises only on the flexibility of one-joint and two-joint hip flexors. *Medicina, 49*(10), 69. https://doi.org/doi.org/10.3390/medicina49100069
18. Dickin, D. C., Faust, K. A., Wang, H., & Frame, J. (2013). The acute effects of whole-body vibration on gait parameters in adults with cerebral palsy. *Journal of Musculoskeletal and Neuronal Interactions, 13*(1), 19-26.
19. Dodd, K. J., Taylor, N. F., & Damiano, D. L. (2002). A systematic review of the effectiveness of strength-training programs for people with cerebral palsy. *Archives of physical medicine and rehabilitation, 83*(8), 1157-1164. https://doi.org/10.1053/apmr.2002.34286
20. Elshafey, A., Mahgoub, S.A. & Mohamed, M. (2021). Effect of whole-body vibration on spastic diplegic children. *European Journal of Molecular & Clinical Medicine, 8*(2), 1025.
21. Gloeckl, R., Heinzelmann, I., Baeuerle, S., Damm, E., Schwedhelm, A. L., Diril, M., ... & Kenn, K. (2012). Effects of whole body vibration in patients with chronic obstructive pulmonary disease–a randomized controlled trial. *Respiratory medicine, 106*(1), 75-83. https://doi.org/10.1016/j.rmed.2011.10.021
22. Gribble, P. A., & Hertel, J. (2003). Considerations for normalizing measures of the Star Excursion Balance Test. *Measurement in physical education and exercise science, 7*(2), 89-100. https://doi.org/10.1207/S15327841MPEE0702_3
23. Han, Y., Lee, S. & Yun C. (2019). The immediate influence of various whole-body vibration frequency on balance and walking ability in children with cerebral palsy: A pilot study. *Journal of Exercise Rehabilitation, 15*(4), 597-602. https://doi.org/10.12965/jer.1938318.159
24. Hoffmann, T. C., Glasziou, P. P., Boutron, I., Milne, R., Perera, R., Moher, D., ... & Michie, S. (2014). Better reporting of interventions: template for intervention description and replication (TIDieR) checklist and guide. *BMJ, 348*. https://doi.org/10.1136/bmj.g1687

25. Jang, E. M., Kim, M. H., & Oh, J. S. (2013). Effects of a bridging exercise with hip adduction on the EMG activities of the abdominal and hip extensor muscles in females. *Journal of physical therapy science, 25*(9), 1147-1149. https://doi.org/10.1589/jpts.25.1147
26. Jeon, I. C., & Jang, J. H. (2017). Comparison of prone hip extension exercise and prone hip extension exercise after iliopsoas stretching on lumbopelvic control and gluteus maximus activity in subjects with short iliopsoas. *Journal of Musculoskeletal Science and Technology, 1*(1), 19-25. https://doi.org/10.29273/jkema.2017.1.1.19
27. Jin, Z. H., Kibler, W. B., Press, J., & Sciascia, A. (2008). The role of core stability in athletic function. *Journal of Beijing Sport University, 12,* 39.
28. Kendall, F.P., McCreary, E.K., Provance, P.G., Rodgers, M.M. & Romani, W.A. (2005). *Muscles: Testing and function with posture and pain.* Lippincott Williams & Wilkins, Baltimore.
29. Key, J. (2013). ‘The core’: understanding it, and retraining its dysfunction. *Journal of bodywork and movement therapies, 17*(4), 541-559. https://doi.org/10.1016/j.jbmt.2013.03.012
30. Kim, H. J., Chung, S., Kim, S., Shin, H., Lee, J., Kim, S., & Song, M. Y. (2006). Influences of trunk muscles on lumbar lordosis and sacral angle. *European Spine Journal, 15*(4), 409-414.
31. Kim, T. W., & Kim, Y. W. (2015). Effects of abdominal drawing-in during prone hip extension on the muscle activities of the hamstring, gluteus maximus, and lumbar erector spinae in subjects with lumbar hyperlordosis. *Journal of physical therapy science, 27*(2), 383-386. https://doi.org/10.1589/jpts.27.383
32. King, M. A. (2000). Functional stability for the upper quarter. *International Journal of Athletic Therapy and Training, 5*(2), 17-21. https://doi.org/10.1123/att.5.2.17
33. Kisner, C. & Colby, L. (2018). *Therapeutic exercise: Foundations and techniques.* F.A. Davis Company, Philadelphia.
34. Ko, M. S., Sim, Y. J., Kim, D. H., & Jeon, H. S. (2016). Effects of three weeks of whole-body vibration training on joint-position sense, balance, and gait in children with cerebral palsy: a randomized controlled study. *Physiotherapy Canada, 68*(2), 99-105. https://doi.org/10.3138/ptc.2014-77
35. Kwon, Y. H., & Lee, H. Y. (2015). Differences in respiratory pressure and pulmonary function among children with spastic diplegic and hemiplegic cerebral palsy in comparison

with normal controls. *Journal of physical therapy science, 27*(2), 401-403. https://doi.org/10.1589/jpts.27.401

36. Lahtinen, U., Rintala, P., & Malin, A. (2007). Physical performance of individuals with intellectual disability: A 30-year follow-up. *Adapted physical activity quarterly, 24*(2), 125-143. https://doi.org/10.1123/apaq.24.2.125
37. Lee, B. K., & Chon, S. C. (2013). Effect of whole body vibration training on mobility in children with cerebral palsy: a randomized controlled experimenter-blinded study. *Clinical Rehabilitation, 27*(7), 599-607. https://doi.org/10.1177/0269215512470673
38. Lee, L. W., Kerrigan, D. C., & Della Croce, U. (1997). Dynamic implications of hip flexion contractures1. *American journal of physical medicine & rehabilitation, 76*(6), 502-508.
39. Lewis, C. L., Sahrmann, S. A., & Moran, D. W. (2007). Anterior hip joint force increases with hip extension, decreased gluteal force, or decreased iliopsoas force. *Journal of biomechanics, 40*(16), 3725-3731. https://doi.org/10.1016/j.jbiomech.2007.06.024
40. Li, Y., Chen, X., Zhang, X., & Zhou, P. (2014). Several practical issues toward implementing myoelectric pattern recognition for stroke rehabilitation. *Medical Engineering & Physics, 36*(6), 754-760. https://doi.org/10.1016/j.medengphy.2014.01.005
41. Liebenson, C., Karpowicz, A. M., Brown, S. H., Howarth, S. J., & McGill, S. M. (2009). The active straight leg raise test and lumbar spine stability. *PM&R, 1*(6), 530-535. https://doi.org/10.1016/j.pmrj.2009.03.007
42. Lima, P. O., Oliveira, R. R., Moura Filho, A. G., Raposo, M. C., Costa, L. O., & Laurentino, G. E. (2012). Concurrent validity of the pressure biofeedback unit and surface electromyography in measuring transversus abdominis muscle activity in patients with chronic nonspecific low back pain. *Brazilian Journal of Physical Therapy, 16,* 389-395. https://doi.org/10.1590/S1413-35552012005000038
43. Magee, D.J. & Manske, R.C. (2020). *Orthopedic physical assessment.* Saunders Publication, Philadelphia.
44. Malai, S., Pichaiyongwongdee, S., & Sakulsriprasert, P. (2015). Immediate Effect of Hold-Relax Stretching of Iliopsoas Muscle on Transversus Abdominis Muscle Activation in Chronic Non-Specific Low Back Pain with Lumbar Hyperlordosis. *Journal of the Medical Association of Thailand, 98,* S6-11.
45. Marín, P. J., & Rhea, M. R. (2010). Effects of vibration training on muscle power: a meta-analysis. *The Journal of Strength & Conditioning Research, 24*(3), 871-878. https://doi.org/10.1519/JSC.0b013e3181c7c6f0

46. McGill, S. (2002). *Low back disorders: evidence-based prevention and rehabilitation.* Champaign, IL, Human Kinetics.
47. Mills, J. D., Taunton, J. E., & Mills, W. A. (2005). The effect of a 10-week training regimen on lumbo-pelvic stability and athletic performance in female athletes: a randomized-controlled trial. *Physical Therapy in Sport, 6*(2), 60-66. https://doi.org/10.1016/j.ptsp.2005.02.006
48. Miyake, Y., Kobayashi, R., Kelepecz, D., & Nakajima, M. (2013). Core exercises elevate trunk stability to facilitate skilled motor behavior of the upper extremities. *Journal of bodywork and movement therapies, 17*(2), 259-265. https://doi.org/10.1016/j.jbmt.2012.06.003
49. Mohamed, R. A., Abd El Aziz, A. S., & El Sayed, H. M. (2019). Effect of Whole Body Vibration versus Suspension Therapy on Balance and Functional Capacity in Children with Diplegic Cerebral Palsy. *Journal PharmTech, International Journal, 12*(1), 80-89.
50. Mohamed, R. A., El Sayed, H. M., Habshy, S. M., & Aly, S. M. (2021). Impact of two different pulmonary rehabilitation methods in children with down syndrome. *Journal of Bodywork and Movement Therapies, 27*, 512-521. https://doi.org/10.1016/j.jbmt.2021.04.009
51. Moher, D., Hopewell, S., Schulz, K. F., Montori, V., Gøtzsche, P. C., Devereaux, P. J., ... & Altman, D. G. (2012). CONSORT 2010 explanation and elaboration: updated guidelines for reporting parallel group randomised trials. *International journal of surgery, 10*(1), 28-55. https://doi.org/10.1016/j.ijsu.2011.10.001
52. Mustafaoglu, R., Demir, R., Demirci, A. C., & Yigit, Z. (2019). Effects of core stabilization exercises on pulmonary function, respiratory muscle strength, and functional capacity in adolescents with substance use disorder: Randomized controlled trial. *Pediatric pulmonology, 54*(7), 1002-1011. https://doi.org/10.1002/ppul.24330
53. Norris, C. M. (2001). Functional load abdominal training: part 1. *Physical Therapy in Sport, 2*(1), 29-39. https://doi.org/10.1054/ptsp.2000.0032
54. Oh, D. S., & Park, S. E. (2016). The effect of lumbar stabilization exercise on the pulmonary function of stroke patients. *Journal of Physical Therapy Science, 28*(6), 1896-1900. https://doi.org/10.1589/jpts.28.1896
55. Oh, J. S., Cynn, H. S., Won, J. H., Kwon, O. Y., & Yi, C. H. (2007). Effects of performing an abdominal drawing-in maneuver during prone hip extension exercises on hip and back

extensor muscle activity and amount of anterior pelvic tilt. *Journal of orthopaedic & sports physical therapy, 37*(6), 320-324. https://doi.org/10.2519/jospt.2007.2435

56. O'Leary, S., Jull, G., Kim, M., & Vicenzino, B. (2007). Specificity in retraining craniocervical flexor muscle performance. *Journal of orthopaedic & sports physical therapy, 37*(1), 3-9. https://doi.org/10.2519/jospt.2007.2237
57. Park, S. J., Lee, J. H., & Min, K. O. (2017). Comparison of the effects of core stabilization and chest mobilization exercises on lung function and chest wall expansion in stroke patients. *Journal of physical therapy science, 29*(7), 1144-1147. https://doi.org/10.1589/jpts.29.1144
58. Park, Y. J., Park, S. W., & Lee, H. S. (2018). Comparison of the effectiveness of whole body vibration in stroke patients: a meta-analysis. *BioMed Research International, 2018*, 5083634. https://doi.org/10.1155/2018/5083634
59. Pessoa, M. F., Brandão, D. C., Sá, R. B. D., Barcelar, J. D. M., Rocha, T. D. D. S., Souza, H. C. M. D., & Dornelas de Andrade, A. (2017). Vibrating platform training improves respiratory muscle strength, quality of life, and inspiratory capacity in the elderly adults: A randomized controlled trial. *The Journals of Gerontology: Series A, 72*(5), 683-688. https://doi.org/10.1093/gerona/glw123
60. Pleguezuelos, E., Casarramona, P., Guirao, L., Samitier, B., Ortega, P., Vila, X., ... & Miravitlles, M. (2018). How whole-body vibration can help our COPD patients. Physiological changes at different vibration frequencies. *International journal of chronic obstructive pulmonary disease, 13,* 3373. https://doi.org/10.2147/COPD.S165058
61. Radziszewski, K. R. (2007). Physical exercise in treatment of patients with lumbar discopathy. *Ortopedia, traumatologia, rehabilitacja, 9*(1), 98-106.
62. Richardson, C.A., Hodges, P. & Hides, J. (2004). *Therapeutic exercise for lumbopelvic stabilization: a motor control approach for the treatment and prevention of low back pain*, Edinburgh, Churchill, Livingstone.
63. Roelants, M., Verschueren, S. M., Delecluse, C., Levin, O., & Stijnen, V. (2006). Whole-body-vibration-induced increase in leg muscle activity during different squat exercises. *Journal of strength and conditioning research, 20*(1), 124.
64. Rosenbaum, P., Paneth, N., Leviton, A., Goldstein, M., Bax, M., Damiano, D., & Jacobsson, B. (2006). The definition and classification of cerebral palsy. *NeoReviews, 7*(11), e569. https://doi.org/10.1542/neo.7-11-e569

65. Roussouly, P., Gollogly, S., Berthonnaud, E., & Dimnet, J. (2005). Classification of the normal variation in the sagittal alignment of the human lumbar spine and pelvis in the standing position. *Spine*, *30*(3), 346-353. https://doi.org/10.1097/01.brs.0000152379.54463.65

66. Ruas, C. V., Brown, L. E., Lima, C. D., Costa, P. B., & Pinto, R. S. (2018). Effect of three different muscle action training protocols on knee strength ratios and performance. *The Journal of Strength & Conditioning Research*, *32*(8), 2154-2165. https://doi.org/10.1519/JSC.0000000000002134

67. Starr, J., Dalton, D., Cynthia, C. & Pamela, K. (2011). *Joint structure and function*, FA Davis Company, Philadelphia.

68. Sterba, J. A., Rogers, B. T., France, A. P., & Vokes, D. A. (2002). Horseback riding in children with cerebral palsy: effect on gross motor function. *Developmental Medicine and Child Neurology*, *44*(5), 301-308. https://doi.org/10.1017/S0012162201002122

69. Strongoli, L. M., Gomez, C. L., & Coast, J. R. (2010). The effect of core exercises on transdiaphragmatic pressure. *Journal of sports science & medicine*, *9*(2), 270.

70. Sumners, D. P., Green, D. A., Mileva, K. N., & Bowtell, J. L. (2008). Increases in inspiratory neural drive in response to rapid oscillating airflow braking forces (vibration). *Respiratory physiology & neurobiology*, *160*(3), 350-352. https://doi.org/10.1016/j.resp.2007.10.005

71. Tang-Wai, R., Webster, R. I., & Shevell, M. I. (2006). A clinical and etiologic profile of spastic diplegia. *Pediatric neurology*, *34*(3), 212-218. https://doi.org/10.1016/j.pediatrneurol.2005.08.027

72. Tayashiki, K., Maeo, S., Usui, S., Miyamoto, N., & Kanehisa, H. (2016). Effect of abdominal bracing training on strength and power of trunk and lower limb muscles. *European journal of applied physiology*, *116*(9), 1703-1713. https://doi.org/10.1007/s00421-016-3424-9

73. Tecklin, J. (2014). *Pediatric physical therapy*, Philadelphia: Lippincott Williams &Wilkins, Wolter Kluwer.

74. Tupimai, T., Peungsuwan, P., Prasertnoo, J., & Yamauchi, J. (2016). Effect of combining passive muscle stretching and whole body vibration on spasticity and physical performance of children and adolescents with cerebral palsy. *Journal of physical therapy science*, *28*(1), 7-13. https://doi.org/10.1589/jpts.28.7

75. Unger, M., Faure, M., & Frieg, A. (2006). Strength training in adolescent learners with cerebral palsy: a randomized controlled trial. *Clinical Rehabilitation*, *20*(6), 469-477. https://doi.org/10.1191/0269215506cr961oa

76. Uyanik, M., & Kayihan, H. (2010). Down syndrome: sensory integration, vestibular stimulation and neurodevelopmental therapy approaches for children. *Stone JH, Blouin M. International Encyclopedia of Rehabilitation*, *9*.

77. Vaz, G., Roussouly, P., Berthonnaud, E., & Dimnet, J. (2002). Sagittal morphology and equilibrium of pelvis and spine. *European spine journal*, *11*(1), 80-87. https://doi.org/10.1007/s005860000224

78. Willson, J. D., Dougherty, C. P., Ireland, M. L., & Davis, I. M. (2005). Core stability and its relationship to lower extremity function and injury. *JAAOS-Journal of the American Academy of Orthopaedic Surgeons*, *13*(5), 316-325.

79. Wolf, S. L., Blanton, S., Baer, H., Breshears, J., & Butler, A. J. (2002). Repetitive task practice: a critical review of constraint-induced movement therapy in stroke. *The neurologist*, *8*(6), 325. https://doi.org/10.1097/01.nrl.0000031014.85777.76

80. Woodford, H. J., & Price, C. I. (2007). EMG biofeedback for the recovery of motor function after stroke. *Cochrane Database of Systematic Reviews*, (2). https://doi.org/10.1002/14651858.CD004585

81. Woollacott, M. H., & Shumway-Cook, A. (2005). Postural dysfunction during standing and walking in children with cerebral palsy: what are the underlying problems and what new therapies might improve balance? *Neural plasticity, 12*(2-3), 211-219. https://doi.org/10.1155/NP.2005.211

82. Xu, C., Fu, Z., & Wang, X. (2021). Effect of Transversus abdominis muscle training on pressure-pain threshold in patients with chronic low Back pain. *BMC Sports Science, Medicine and Rehabilitation*, *13*(1), 1-15. https://doi.org/10.1186/s13102-021-00262-8

LIST OF ABBREVIATIONS

AM: Abdominal muscles
ADIM: Abdominal Drawing-In Maneuver
APSI:Anterior-posterior Stability Index
BF: Biofeedback
BSS: Biodex Stability System
CP: Cerebral Palsy

GM: Gluteus maximus

LL_s: Lower limbs

LLA: Lumbar lordotic angle

MEP: Maximal Expiratory Pressure

MIP: Maximal Inspiratory Pressure

MLSI: Medial-lateral Stability Index

PBFT: Pressure biofeddback training

PBFU: Pressure biofeddback unit

OSI:Overall Stability Index

ROM: Range of Motion

TA: Transverse abdominis

WBV: Whole body vibration

AUTHOR CONTRIBUTIONS

Conceptualization, Rasha A. Mohamed and Abeer M. Yousef; Data curation, El Sayed H. Mohamed.; Formal analysis, El Sayed H. Mohamed; Methodology, Rasha A. Mohamed and Abeer M. Yousef, Software, Rasha A. Mohamed and Abeer M. Yousef; Validation, Rasha A. Mohamed and Abeer M. Yousef; Investigation, Rasha A. Mohamed, Abeer M. Yousef and El Sayed H. Mohamed.; Writing–original draft; Rasha A. Mohamed and Abeer M. Yousef; Writing–review and editing, Rasha A. Mohamed. All authors listed have made a substantial, direct and intellectual contribution to the work, and approved it for publication.

CONFLICTS OF INTEREST

The authors declare no conflict of interest.

FUNDING

This research received no external funding.

COPYRIGHT