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Original Article

Plyometric exercises: subsequent changes of weight-bearing symmetry, muscle strength and walking performance in children with unilateral cerebral palsy

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Abstract

Objective: To evaluate the subsequent effects of plyometric training on weight-bearing symmetry, muscle strength, and gait performance in children with unilateral cerebral palsy. **Methods:** Thirty-nine children with spastic hemiplegia (age 8-12 years) were randomly divided into either the PLYO group (*n*=19, received a 30-minute plyometric exercise program plus the traditional physical rehabilitation, twice/week for eight consecutive weeks) or Non-PLYO group (*n*=20, received the traditional physical rehabilitation only). The weight-bearing symmetry index (WB-SI), maximum isometric muscle strength (MIMS) of quadriceps and hamstring muscles, and spatial-temporal gait parameters were assessed pre and post-intervention. **Results:** From pre- to post-intervention, changes of WB-SI among PLYO and Non-PLYO groups did not differ significantly (P=.81; hindfoot and P=.23; forefoot). MIMS of quadriceps and hamstring muscles at 90° knee flexion (P=.008 and .013 respectively) increased significantly in PLYO compared to Non-PLYO group. Walking speed (P=.033), stride length (P=.002), and step time (P<.001) improved markedly in PLYO group more than in Non-PLYO group. The proportion of single leg support (P=.14) among PLYO and Non-PLYO groups did not differ significantly. **Conclusion:** Addition of plyometric exercises to the physical rehabilitation programs of children with unilateral CP could achieve greater improvement in muscles strength and walking performance, but not in WB-SI.

Keywords: Spastic Hemiplegia, Strength Training, High-Impact Resistive Exercises, Body Weight-Support, Gait

Introduction

Cerebral palsy (CP) is a diversified group of developmental disorders secondary to a static immature brain injury that primarily results in persistent nonspecific impairment of movement and posture[1]. Approximately 25% of all CP cases experience disturbance of motor function with unilateral spasticity pertaining to the upper and lower extremities contralateral to the affected cerebral hemisphere and categorized as spastic hemiplegia[2]. Some asymmetry might be noted when hemiplegic children are attempting to perform motor activities. In supported standing, hemiplegic children may stand preferentially on their more functional side and exhibit postural malalignments that impair the ability to transfer body weight on the affected lower extremity[3]. Muscle weakness has been long recognized as a pervasive symptom in CP children that directly related to the impairment of motor function. They can generate only 52% or less of the maximal anticipated contractile force in the lower extremity muscles in relation to the typically developed counterparts[4,5]. The extent of weakness across the lower extremity muscles does not follow a homogenous pattern, some groups are particularly more affected than others, often with the distal muscles are being more involved[4-6]. Although children with spastic hemiplegia are ambulatory and show high functional levels, they have weakness in the major muscle groups of the affected side compared with their able-bodied counterparts[4].

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The majority of the ambulatory children with CP including those who are hemiplegic demonstrate an inefficient walking performance and show an abnormal walking pattern[7,8].

Strength training has been increasingly evidenced as an effective therapeutic intervention for improving muscle strength and increasing motor function in children with CP[9,10]. Previously, strength training was cautiously prescribed for CP believing that the huge effort would proportionally worsen muscle spasticity[11]. Subsequently, growing evidence from the most recent observations has reported non-harmful effects of the training induced-strength on spasticity[12,13]. Further, it has been indicated that their muscles may positively react to the training[14,15]. Plyometric exercises are a specific pattern of resistive strength training in which the muscle starts to contract eccentrically followed by rapid concentric contraction of the same muscle. It can jointly generate high-velocity dynamic movements and high-impact force on the muscles and bones[16,17].

Currently, a limited number of studies have analyzed the efficacy of the plyometric training on CP or any other disabling health conditions in children. Preliminary studies have demonstrated the ameliorative effect of plyometric exercises for the gross motor function in boys with unilateral CP[18], distant jumping and motor performance skills in children with neurofibromatosis[19], acquisition of bone mass and increasing lean body mass in young people with Down syndrome[20,21]. Although plyometric training is likely a beneficial intervention, its effect on CP children has not been sufficiently appraised. The purpose of this study was to evaluate the effect of plyometric training on weight-bearing symmetry, muscle strength and walking performance in children with hemiplegic CP.

Materials and methods

Study design

A two-arm single-blinded randomized controlled study approved by the Research ethics committee (Protocol No. RHPT/2017/019) at Prince Sattam bin Abdulaziz University (PSAU). The study procedures were in accordance with the Declaration of Helsinki. The study was conducted at the research laboratories and the Physical Rehabilitation Clinic, College of Applied Medical Sciences, PSAU, KSA. Each outcome measure was assessed at the baseline and immediately after training by the same investigator who was blinded to treatment allocation.

Participants

We included a convenient sample of 39 ambulatory cerebral palsied children (24 boys and 15 girls) who were attending the Physical Rehabilitation Clinic, College of Applied Medical Sciences, PSAU, KSA. Participants were included if they were determined as a spastic unilateral CP by their pediatric neurologist, 8-12 years of age, independent ambulators, categorized as level I according to Gross Motor Function Classification System (GMFCS)[22], mild spastic (hypertonia less than 1+ grade as being measured by the Modified Ashworth Scale)[23], able to understand and follow instructions. Children were excluded if they undergone orthopedic or neuromuscular surgery in the past year, used neuromuscular blockers for tone management in the past six months, were suffering from cardiopulmonary disorders, and if they had severe mental or physical co-morbidities that may result in activity limitation. All children and their parents were invited to sign a consent form after they have approved to participate in the study.

Randomization and allocation

Eligible children were allocated randomly to either the plyometric (PLYO) training or non-plyometric (Non-PLYO) training groups. The randomization process was accomplished by a researcher who did not participate in sample recruitment. Initially, randomization codes were created using Microsoft Excel software (Microsoft Corporation, Redmond, WA). Then, the allocation was hidden in sealed non-transparent envelopes with consecutive numbers. Eligible children were then referred to a researcher overseeing the treatment who randomly allocated them to one of the study groups.

Outcome measures

Weight-bearing symmetry

Assessment of weight-bearing symmetry on both lower limbs was basically carried out by using a Tekscan HR Mat™ pressure measurement system (South Boston, Massachusetts, USA) and Foot Mat™ Software for Researchers. The system has been identified to be a moderate to a good reliable system for measurement of plantar pressure peaks with low variability[24]. The Foot Module was chosen to capture the plantar surface area (cm^2) and the static forefoot (FF) and hindfoot's (HF) pressure (kilopascals). The system was calibrated to the weight of each child and data were collected at 60 Hz. After familiarization, each child was instructed to stand barefooted bipedally with each foot almost 20 cm away from the other, to look straight ahead with both arms in a laterally outstretched position and to stand as naturally and quietly as possible for 20 seconds. Thereafter, the feet were captured, and the plantar pressure template was created by a rectangle enclosing the area of observed pressure under the heel (HF pressure) and another rectangle enclosing the area of observed pressure under the metatarsal heads and the metatarsophalangeal joints (FF pressure). The pressure values from the sensors within these rectangles were aggregated into a standardized mask to represent the selected foot region. Values from three trials were picked up, and the average scores of foot contact area and plantar pressures peaks (PP) from the involved (IS) and uninvolved (US) sides were used for statistical analysis. Finally, the weight-bearing symmetry index (WB-SI) was calculated and reported as percentages by dividing the absolute differences between pressure peaks of the involved (PPIS) and uninvolved (PPUS) sides by the sum of the pressure peaks of both sides:

$$SI\ (\%) = \left(\frac{PPUS - PPIS}{PPUS + PPIS}\right) X\ 100$$

Higher values of WB-SI indicate more weight bearing asymmetry, whereas the lower values close to zero% indicate symmetrical weight-bearing distribution on both lower extremities.

Muscle strength

Each child underwent an assessment of the maximum isometric muscle strength (MIMS) of two muscle groups in the affected lower extremity using a digital dynamometer (MIE Medical Research Ltd., Leeds, UK) and 50 Hz sampling frequency. The "make test" where each child could gradually develop an isometric contraction (within 5 sec) at a constant joint angle to avoid the reflex action was employed[25]. The measured muscles were the quadriceps muscle at two knee flexion angles of 60° and 90°, and the hamstring muscle was assessed only at 90° of knee flexion.

Prior to the assessment, children were familiarized to the dynamometer, a measurement trial was undertaken to get oriented to the procedure. After calibration of the dynamometer, each child was adopted to the standardized position for strength measurement according to Hislop and Montgomery[26]. For the quadriceps, each child assumed sitting position with the hip in 90° flexion and the pelvis cautiously secured to minimize the potential compensatory movements. The ankle cuff was applied distally above the malleoli, and the dynamometer was fixed to a stationary point so that resistance could be offered to the quadriceps muscle. The maximum isometric strength of the quadriceps was then measured twice with the knee in 90° and 60° flexion. The hamstring was also assessed from the same position as for the quadriceps, but the dynamometer was adapted to a fixed position to resist the hamstrings at 90° of knee flexion. The joint angle verified using a goniometer before each test trial. The lever arm from the lateral femoral condyle to the ankle cuff was measured and multiplied by force to calculate the torque in Newton meters (Nm). Three trials with strong verbal encouragement were allowed for each muscle, and the highest generated force was included in the analysis.

Walking performance

Three-dimensional gait analysis was implemented. Spatial-temporal characteristics of the gait were measured using a 12-infrared camera Vicon-motion capture system (Vicon 612, Vicon Motion Systems Ltd., Oxford, UK) at a sampling rate of 100 Hz. connected to a workstation with Vicon Clinical Manager software for acquisition, processing, and analysis of data in a Plugin-Gait model. After camera volume set up and system calibration, retroreflective markers were precisely secured to both lower extremities. Configuration and alignment of the markers were conducted according to the specification by Davis et al[27]. Afterward, children were instructed to walk with a self-preferred speed along a 10-meter walking path five times. Then, walking speed, stride length (SL), step time, and proportion of single limb support (%SLS) were calculated from a full completed gait cycle.

Intervention

All participants, both in the PLYO and the Non-PLYO group received 16 sessions of the traditional physical rehabilitation care that was basically designed to meet each child's individual needs. The overall treatment goals were to maintain flexibility, improve balance and postural control, build strength, develop coordination, improve gait performance, and to optimize the functional skills. They received two sessions per week for eight consecutive weeks. Each session lasted almost for one hour and included; 1) static and dynamic flexibility exercises, 2) advanced balance training, 3) postural correction exercises, 4) progressive strength training of the lower extremity muscles, 5) coordination exercises, 6) and Functional ambulation exercises. The treatment was carried out by three licensed pediatric physical therapists who had more than 10-years' experience in pediatric rehabilitation.

Participants who were allocated to the PLYO group received an additional 30 minutes of a closely overseen and monitored plyometric exercises. A rest period of 15 minutes was allowed between the usual physical rehabilitation care and plyometric exercises.

Plyometric training

The plyometric training program basically focused on lower extremity strength training and was developed according to the guidelines of the National Strength and Conditioning Association[28]. The exercise load was progressively increased in two practice paradigms; the first paradigm gave priority to the horizontal exercises while the second paradigm focused on the vertical exercises. The treatment was conducted twice/week in non-sequential days under direct surveillance by the therapist for two months. The program was delivered in accordance with the protocol described by Johnson et al.[18] with minimal adaptation. Exercises were conducted in 2 blocks; each block lasted for one month as described in Table 1. For safety and optimal performance, each session commenced with a pre-workout warming up for five minutes by the mean of static and dynamic stretching and moving through the exercises planned for each day's workout at a lower intensity. Thereafter, 10-explosive exercises were administered during the workout stage. Eventually, a set of cool down exercises to stretch and relax the entire body was considered after the workout for another five minutes.

Data processing and statistical analysis

Levene's test for equality of variances and Kolmogorov-Smirnov test of normality permitted the use of parametric statistical analysis to test the significance. The mean and standard deviation were computed for each variable. Two-way mixed ANOVA test was used to compare the mean values of the measured variables (weight-bearing symmetry, muscle

Table 1. Plyometric training program.

Exercise	Description	Repetitions in 1st Mo.	Repetitions in 2nd Mo.
Horizontal training paradigm			
Bounding	Exaggerated foot to foot forward movement	1set / 10 R	1set / 15 R
Forward jumping	Double-footed forward jump to maximum achievable distance preceded arm swing	1set / 5 R	1set / 10 R
Forward hopping	Hop forward as far as possible between marked points without pause in both directions	1set (5 RT and 5 LT) / 5 R	1set (5 RT and 5 LT) / 10 R
Counter jumping	Double-footed side to side jump as far as possible	1set / 5 R	1set / 10 R
Lateral leaping	Stretch out one side and hop off the other in a lateral motion landing on one foot	1set / 5 R	1set / 10 R
Vertical training paradigm			
Stride jumping	From stride stance, interchangeably move each foot forward between jumps	1set / 5 R	1set / 10 R
Squat jumping	Squat down and spring upward as high as achievable	1set / 5 R	1set / 10 R
Tuck jumping	Jump high moving knees toward the chest	1set / 5 R	1set / 10 R
Step jumping	Stand behind a step, jump up onto and down a step and switch RT and LT feet.	1set / 10 RT and 10 LT	1set / 15 RT and 15 LT
Step hopping	While facing a step, hop up and down and switch RT and LT feet	1set / 10 RT and 10 LT	1set / 15 RT and 15 LT

- Children were instructed to perform consecutive repetitions without pausing and were encouraged to exert their maximum efforts during each exercise.
- The number of repetitions in the 1st month was set based on observation of children's performance at the baseline.
- Children were given 1-2 minutes rest between exercises.
- The standard step height is 5 inches.
- Abbreviations: R, repetitions; RT, right; LT, left.

strength, and walking performance) among the PLYO and Non-PLYO groups across the time from pre to post-intervention and to identify whether an interaction exists between treatment and time. When there was a significant interaction, one-way repeated measure ANOVA test was used to report the changes within each group. To quantify the standardized differences between means, the appropriate effect size was calculated by using partial Eta-squared ($\eta^2_{Partial}$) formula ($\eta^2_{Partial}$=0.01 considered a 'small' effect size, $\eta^2_{Partial}$=0.09 a 'medium' effect size, and d $\eta^2_{Partial}$=0.25 a 'large' effect size). The level of significance was set at p<.05. We used SPSS (V 24.0, Armonk, NY, USA) in all statistical analysis.

Study power and sample size

Power analysis to estimate the appropriate sample size was conducted using PS software (version 3.1.2). Estimates of mean difference and common standard deviation for quadriceps muscle strength at 90° (MD=10.42, common SD=8.49) were collected from eight children who took part in a pilot study and received the same intervention, independent sample t-test, a type I error of .05, and power of 95 %. Based on these presumptions, a total of 36 children were needed for the current study (18 children for PLYO group and 18 for Non-PLYO group). The sample size was increased by approximately 20% to account for the dropout rates.

Results

Quantitative and baseline data of the participants

As shown in participants' flow chart (Figure 1), out of 58 children who were potentially eligible, 44 children met the inclusion criteria and took part in the randomization phase (22 children were allocated to each group), but only 39 children completed the study and their data were analyzed (19 children in PLYO group and 20 children in Non-PLYO group).

Participant's details at the baseline are presented in Table 2. There were no statistically significant differences between the PLYO and Non-PLYO groups with respect to the demographic and anthropometric characteristics. Also, no statistically significant between-group differences were determined for the foot contact area, plantar PP, WB-SI, muscle strength, and walking performance measures.

Weight-bearing symmetry

Details of the changes in weight-bearing symmetry measures from pre- to post-intervention among the study groups are shown in Table 3. The changes of foot contact area of the IS (*P*<.001), HF (*P*=.002) and FF (*P*<.001) pressure peaks among the PLYO and Non-PLYO groups were not equivalent across the time from the pre- to post-

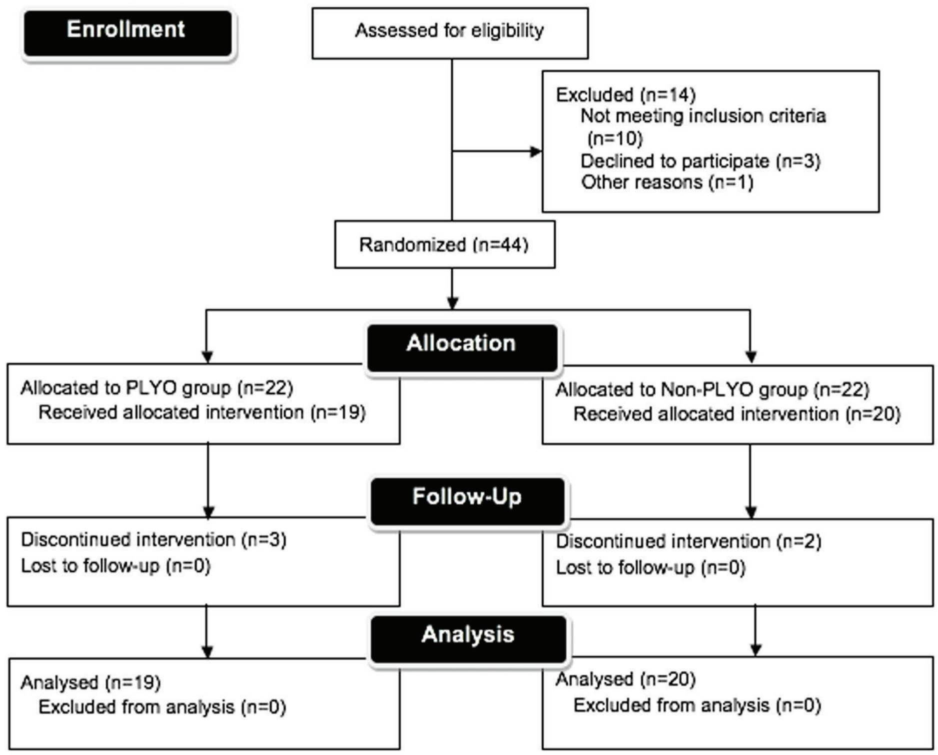

Figure 1. Participants' flow chart.

Table 2. Participants' baseline characteristics.

	PLYO	Non-PLYO	*P*
Age, *years*	9.47 ± 1.43	10.30 ± 1.38	.07
Weight, *Kg*	34.63 ± 4.55	33.90 ± 5.57	.65
Hight, *m*	1.34 ± 0.09	1.36 ± 0.08	.63
BMI, *kg/m²*	19.24 ± 1.70	18.38 ± 2.08	.17
Gender, *n* (b/g)	13/6	11/9	.39
Side involved, *n* (D/ND)	4/15	5/15	.77

D: dominant, ND: nondominant, P: significance level at P<0.05.

Table 3. Differences of changes in weight-bearing symmetry measures from pre- to post-intervention among PLYO and Non-PLYO groups.

Variable		PLYO		Non-PLYO		Group x Time interaction	
		Pre	Post	Pre	Post	*P*	$\eta^2_{Partial}$
Foot contact area, *cm²*		39.53 ± 11.58	75.47 ± 16.72¥	41.30 ± 12.59	55.30 ± 15.51¥	<.001*	0.49
PP, *Kilopascal*	HF	44.12 ± 12.93	89.26 ± 9.46¥	42.20 ± 12.09	76.25 ± 11¥	.002*	0.23
	FF	90.89 ± 6.99	76.42±7.92¥	88.40 ± 5.95	84.95 ± 5.90¥	<.001*	0.54
WB-SI *(%)*	HF [WB-SI]	36.04 ± 16.36	6.48 ± 3.96	37.26 ± 13.03	8.76 ± 7.79	.81	-
	FF [WB-SI]	5.03 ± 3.32	6.17 ± 4.23	5.73 ± 3.96	5.08 ± 3.34	.23	-

*Descriptive statistics are presented as mean ± SD, P: level of significance, $\eta^2_{Partial}$: Effect size of the difference, PP: pressure peak, HF: hindfoot, FF: forefoot, WB-SI: weight-bearing symmetry index, *: changes from pre- to post-intervention among PLYO and Non-PLYO groups are significant at P<.05, ¥: Significant.*

Table 4. Summary of differences of changes in maximum isometric muscle strength (Nm) from pre- to post-intervention among PLYO and Non-PLYO groups.

Variable	PLYO		Non-PLYO		Group x Time interaction	
	Pre	Post	Pre	Post	*P*	$\eta^2_{Partial}$
Quad. 60°	45.13 ± 9.97	50 ± 6.71	41.31 ± 8.88	43.78 ± 7.12	.276	-
Quad. 90°	47.09 ±10.46	56.15 ± 9.13¥	44.13 ± 9.36	45.65 ± 7.06	.008*	0.17
Hams. 90°	32.90 ± 8.37	40.49 ± 6.31¥	29.02 ± 8.86	31.35 ± 5.82	.013*	0.15

*Descriptive statistics are presented as mean ± SD, P: level of significance, $\eta^2_{Partial}$: Effect size of the difference, Quad: Quadriceps muscle, Hams: Hamstring muscle, *: changes from pre- to post-intervention among PLYO and Non-PLYO groups are significant at P<.05, ¥: Significant within-group changes.*

Table 5. Differences of changes in walking performance measures from pre- to post-intervention among PLYO and Non-PLYO groups.

Variable	PLYO		Non-PLYO		Group x Time interaction	
	Pre	Post	Pre	Post	*P*	$\eta^2_{Partial}$
Speed, *m/sec*	1.18 ± 0.08	1.29 ± 0.06¥	1.21 ± 0.09	1.25 ± 0.05¥	.033*	0.12
SL, *m*	1.24 ± 0.05	1.3 ± 0.05¥	1.18 ± 0.06	1.21 ± 0.06¥	.002*	0.24
Step time, *Sec*	0.71 ± 0.05	0.55 ± 0.05¥	0.73 ± 0.07	0.68 ± 0.06¥	<.001*	0.41
% SLS	28.37 ± 3.95	32.47 ± 3.22	26.90 ± 3	29.70 ± 2.89	.14	-

*Descriptive statistics are presented as mean ± SD, P: level of significance, $\eta^2_{Partial}$: Effect size of the difference, SL: stride length, %SLS: proportion of single limb support, *: changes from pre- to post-intervention among PLYO and Non-PLYO groups are significant at P<.05, ¥: Significant.*

intervention, as the children in the PLYO group showed greater improvement in these variables compared to those who are in the Non-PLYO group. But, the changes in HF [WB-SI] (*P*=.081) and FF [WB-SI] (*P*=.23) were similar across the time for both groups. The repeated measure analysis revealed that the foot contact area of the IS and HF pressure peaks increased significantly in PLYO and Non-PLYO groups (*P*<.001), and the FF pressure peaks reduced significantly in both groups (PLYO; *P*<.001, and Non-PLYO; *P*=.008).

Muscle strength

Summary of the differences in the changes in muscle strength among both groups is demonstrated in Table 4. The changes of MIMS of the quadriceps of the IS at 60° of knee flexion (*P*=.276) from the pre- to post-intervention did not differ significantly among PLYO and Non-PLYO groups. In contrary, the changes of MIMS of quadriceps and hamstring muscle of the IS at 90° of knee flexion (*P*=.008, *P*=.013 respectively) from pre- to post-treatment were significantly different among the PLYO and Non-PLYO groups, where the children in the PLYO group showed greater improvement. The within-group analysis showed that MIMS of quadriceps and hamstring muscles of the IS at 90° increased significantly in PLYO group (*P*=.002, *P*<.001 respectively), but did not change significantly in Non-PLYO group (*P*=.211, *P*=.135 respectively).

Walking performance

The walking performance measures are displayed in Table 5. The changes in walking speed (*P*=.033), SL (*P*=.002), and step time (*P*<.001) among the PLYO and Non-PLYO groups were significantly different across the time from the pre- to post-intervention, where the children in the PLYO group showed favorable effects. However, the changes in %SLS (*P*=.14) among both groups were not significantly different. The within-group analysis revealed that walking speed (*P*<.001, *P*=.015 respectively), SL (*P*<.001, *P*=.028 respectively), and step time (*P*<.001, *P*=.002 respectively) changed significantly in PLYO and Non-PLYO groups.

Discussion

The present study sought to verify the effectiveness of the plyometric training on the weight-bearing symmetry, muscle strength, and walking performance in the treatment of the children with unilateral CP. The PLYO training was successful in expanding the foot contact area of the involved foot suggesting additional weight support compared to Non-PLYO training. Additionally, the PLYO training was the type of training that is more likely to provide a favorable clinical impact on weight-bearing on the HF of the affected as indicated by the increase in the HF pressure, suggesting more transfer of the body-weight on the IS. Due to the over-reliance on the uninvolved lower extremity and inability of the musculature in the involved side to adequately support the body weight during standing and walking activities, the plyometric training protocol targeted the side-to-side weight-bearing differences. Also, it gave importance to bilateral training as both lower extremities are involved in the weight-bearing activities and require maximum effort to execute these activities. However, this may explain the distinctive effect of the PLYO training on the weight-bearing symmetry. To our knowledge, no previous studies have analyzed the efficacy of PLYO on weight-bearing symmetry in children with CP. The findings of the present study may be attributed to the central and peripheral neuromuscular adaptation induced by PLYO training and enhanced proprioceptive and kinesthetic awareness. It has been suggested that the eccentric contraction phase of PLYO exercises produces repetitive mechanoreceptor stimulation and rapid changes of tendomuscular structures' length and tension. Those effects may reduce the inhibitory effect of the Golgi tendon organs and increase the sensitivity of the muscle spindle especially of the antigravity muscles. In addition, it may enhance the afferent contribution to the central nervous system regarding conscious awareness of joint position and movement[29-31]. The PLYO training-induced neural adaptation and proprioceptive modification may also contribute to the enhancement of body weight support on the involved side. Further, PLYO training has been thought to improve the musculotendinous elasticity, enhance functional stability, and increase the musculoarticular stiffness that may account for the reduction of the longitudinal retraction on the lower extremity muscles and help the transmission of the force generated by the body weight through the working extremities[32,33]. Additionally, PLYO training has been indicated to boost postural stability secondary to the improvement of muscle sequencing and intermuscular coordination[34], which could be considered as a plausible explanation as to why the body weight was disseminated on both lower extremities after training.

In this study, the authors have considered not only to assess the extent of the change in the body weight-support on the IS in response to treatment but also to determine the discrepancy between both sides, and this may explain the rationale for calculating the WB-SI. The results demonstrated that the changes in the WB-SI either for the HF or the FF across the time from the pre- to post-intervention were not similar, which means that the improvement in the body weight-support on the IS was not significant enough to equalize the weight supported on the US.

Regarding muscle strength, it has been observed that the children in the PLYO group showed a significant improvement of the MIMS of quadriceps and hamstring muscles at 90° of knee flexion from the pre- to post-intervention compared to those in the Non-PLYO group. The issue of conducting PLYO training within the context of the optimization of muscle strength in children with CP are almost non-existent in previous studies. The strength gain following the PLYO training is most likely related to the enhancement of the motor unit recruitment pattern and increased motor neuron excitability[35], better co-contraction and increased synergetic muscle activities[36]. Although they included normal children with low motor competence or athletic children, some studies are believed to support the interpretation of the results of the present study, a meta-analysis by De Villarreal et al. have reported the effectiveness of PLYO training to increase muscle strength in adult and prepubertal children[16]. Also, a study by Jonson et al. suggested that PLYO training is a safe exercise mode to improve motor performance and muscle strength in young children[17]. In addition, Ingle et al. have demonstrated a considerable improvement of the dynamic muscle strength in response to a complex PLYO and resistance training in pre- and early pubertal children[37].

The findings of the present study revealed that a 2-month PLYO training targeting the lower extremities has the potential to produce greater improvement of the walking performance from pre- to post-treatment concerning walking speed, SL, step time when compared to the Non-PLYO training. It has been reported that muscle weakness and poor balance control may account for walking problems in CP[38]. However as discussed earlier, the strength built in the lower extremity muscles and the improved agonist/antagonist coordination in addition to the kinesthetic and proprioceptive modifications might have contributed to the improved walking performance. No reports have analyzed the effect of PLYO training on walking performance in children with CP. Instead, numerous studies have reported the effect of other strength training modes of exercises on the gait function. Anderson et al. suggested a 10-week strength training to improve muscle strength, functional walking capacities and walking speed in adults with CP[39]. Eek et al. claimed that the SL tends to increase, and the cadence decreased after eight weeks of strength training in children with CP[40]. Likewise, the findings from earlier studies by Dodd et al. and Morton et al. showed significant improvement of muscle strength and walking performance in response to progressive resistance training in children with CP[10,41].

The present study was limited by the relatively small sample size and lacking follow-up. Larger experimental studies are necessary to define the subcategories of children with CP most likely to benefit from plyometric training. Also, short and long-term evaluation further away than the treatment-endpoint is likely to be required to identify the sustainability of the treatment effects. The strengths of the present study included the close supervision of PLYO training with the integration of safety precautions and accommodation for the high impact explosive exercises. In addition, the potential bias was eliminated by blinding the examiner to the intervention.

To conclude, the findings of the present study suggested that incorporation of PLYO training in the physical rehabilitation of children with unilateral CP produced significant improvement in muscle strength, and walking performance, but not in weight-bearing symmetry. The forthcoming researches should examine the long-term effect of plyometric training and may further include children with different types of CP.

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