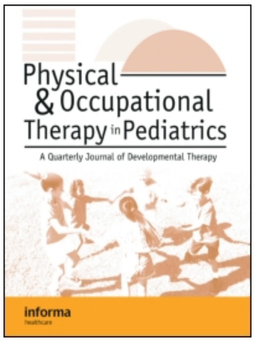

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Effectiveness of a Multi-Modal Exercise Program Incorporating Plyometric and Balance Training in Children With Hemiplegic Cerebral Palsy: A Three-Armed Randomized Clinical Trial

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ABSTRACT

Aim: To evaluate the effectiveness of a multimodal exercise program incorporating plyometric and balance training on muscle strength and postural stability in children with spastic hemiplegic cerebral palsy (SHCP).

Methods: A total of 57 children with SHCP were enrolled in the study and randomly allocated into three treatment-based groups: plyometric exercises (PLYO group; $n = 19$), balance exercises (BAL group, $n = 19$), and combined plyometric and balance exercises (PLYO-BAL group; $n = 19$). The maximum isometric muscle strength (IMS_{max}) and postural stability [anterior-posterior stability index (AP-SI), mediolateral stability index (ML-SI), and overall stability index (O-SI)] were measured pre- and post-intervention.

Results: By applying the intention-to-treat analysis, the PLYO-BAL group showed greater post-treatment IMS_{max} than the PLYO and BAL groups for the quadriceps ($p = .03$ and $p = .0002$ respectively), hamstrings ($p = .018$ and $p < .0001$ respectively), and dorsiflexors ($p = .006$ and $p < .0001$ respectively). Also, the PLYO-BAL group achieved better post-intervention stability scores as compared to PLYO and BAL groups regarding AP-SI ($p < .0001$ and $p = .0001$ respectively), ML-SI ($p = .001$ and $p = .015$ respectively), and O-SI ($p = .011$ and $p = .04$ respectively).

Conclusions: Incorporation of plyometric and balance exercises in a multimodal rehabilitation program could be an important consideration for enhancing muscle strength and boosting postural stability in children with SHCP.

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KEYWORDS
Cerebral palsy; stretch-shortening cycle exercises; balance exercises; maximum voluntary contraction; postural control

Cerebral palsy (CP) is a group of persistent neurological disorders that impair movement and posture, because of an unprogressive lesion that occurs in the immature brain

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during fetal development or at birth (Rosenbaum et al., 2007). Prevalence estimates of CP range from 1.5 to 2.5 in every 1,000 live births or children of a defined age-range (Oskoui et al., 2013). Motor impairments in CP are dependent on several factors that include spasticity, muscle weakness, loss of selectivity, postural instability, and incoordination (Elnaggar, 2021, Elnaggar, 2020a; Graham, Rosenbaum, Paneth, Dan, & Lin, 2016). Around 33% of children with CP have spastic hemiplegia (SHCP), where the brain lesion is unilateral and leads to spasticity and paresis on the contralateral side of the body (Mewasingh et al., 2004). Although children with SHCP confront challenges with higher motor skills, most of them can walk without constraints (Gorter et al., 2007), and are often integrated into community schools and leisure activities. Thus, they are in need to carry out the same activities alongside their peers with typical development, like schoolyard playing or walking at school outings. Due to their motor impairments, children with SHCP may experience trouble keeping up with peers in the aforementioned activities (Bax et al., 2007).

Muscle weakness is a key aspect of the activity limitations in children with SHCP (Ferland et al., 2012). The paretic lower extremity muscles can only produce a maximum projected contractile force of 36% to 82% as compared to children with typical development (Dallmeijer et al., 2017). Even though the pattern of weakness across lower-extremity muscles is heterogeneous, where distal muscles are particularly more affected than proximal muscles, it is generally contributing to limitations in activities and participation (Damiano & Abel, 1998). Another aspect of activity limitation in children with SHCP is the impaired postural control (Kenis-Coskun et al., 2016). Children with SHCP demonstrate limitations in postural control that restrict their capacity to respond to unanticipated postural perturbations, which can also limit the activity performance and social participation (Elnaggar, 2020b; Kenis-Coskun et al., 2016). On that premise, there may be a need to develop improved, clearly effective rehabilitation protocols to remedy impairments of body functions and structures, which can then mitigate activity limitations and increase participation (Wright et al., 2008).

Various approaches have been employed to increase strength in children with CP, and progressive resistance exercises were the most frequently used approach (Park & Kim, 2014). Although the muscle strength improved, it was less effective because it was not always transferred to activity performance and participation (Franki et al., 2012). It has been proposed that strength training should be performed at higher and more functional movement velocity than progressive resistance training to get functional improvement in children with CP, especially since they have reduced capacity to rapidly generate forces (Moreau et al., 2012). Based on that, functional power training has been developed for children with CP, where they are learned to induce fast movement related to daily activities, with added load instead of the slow repetitive single-joint movements (Van Vulpen, De Groot, Rameckers, Becher, & Dallmeijer et al., 2017; Van Vulpen et al., 2018).

Plyometric exercises are a type of power training that comprises quick, powerful movements involving a system of reactive exercises and an eccentric contraction, followed immediately by an explosive concentric contraction (Johnson et al., 2011). Plyometric exercises are built upon various scientific principles (stretch-shortening cycle, optimizing sarcomere length, and stretch reflexes) that can help to boost the power output (Davies et al., 2015). The repeated cycle of the expeditious muscle-contraction in plyometric exercises results in an increased rate of force development, which enhances the reactive muscle strength and explosive power (Elnaggar, 2020b; Elnaggar & Abd El-Nabie, 2021). Previous investigations showed significant improvement in muscle strength, postural control, weight-bearing symmetry, agility, and gross motor function in children with SHCP following plyometric training (Elnaggar, 2020b; Elnaggar et al., 2019; 2021; Johnson et al., 2014).

The clinical implications of the unimodal use of balance training in children with CP have been upheld in earlier studies. Specifically, balance training led to an improvement in the ability of children with CP to recover postural stability in face of a balance-threat (i.e., reactive balance control) (Shumway-Cook et al., 2003). Besides, balance rehabilitation training has been proved to allow faster muscle activation, reduce abnormal co-contractions, improve multiple-muscle sequencing, and improve the directional specificity of postural muscles (Woollacott et al., 2005). Further, balance training has been suggested to improve gross motor function (Abd El-Kafy & El-Basatiny, 2014).

Bearing in mind that balance and strength training produce neuromuscular adaptations (Behrens et al., 2014; Martin Behrens et al., 2015), combining these therapeutic approaches could probably intensify the effects of the underlying neuromotor adaptations. The aim of this study was to evaluate the effect of a multimodal exercise program incorporating plyometric and balance training on muscle strength and postural stability in children with SHCP.

Methods

Design

This was a three-armed, single-blinded randomized clinical study carried out between January 2019 and February 2020 at the Physical Therapy Out-patient Clinic of Prince Sattam Bin Abdulaziz University (PSAU), Al-Kharj, Saudi Arabia. This research was approved by the Research Ethics Committee at PSAU (Protocol No: RHPT/0019/0071), and procedures were conducted in accordance with the ethical principles of the Declaration of Helsinki adopted in 1964 and the most recent iteration in 2013. Parents/duly-appointed guardian signed a consent form.

Sample Size Determination

A preliminary power analysis was performed, before data collection, through the PASS software, V 14.0.15 (NCSS, Kaysville, UT, USA). In an analysis of covariance study, a group-sample of 16 participants, was obtained for each of the 3 groups. The covariate had an R^2 of 0.40. The total sample of 48 participants achieves a power (1-β) of 91% to detect differences among the means versus the alternative of equal means using an F test with a significance level set at ($\alpha = .05$). Premised on findings from a pilot study, the size of the difference between the study groups in the maximum isometric strength of quadriceps was represented by their standard deviation under the alternative hypothesis, which was 2.05 newtons. The common within-group standard deviation was

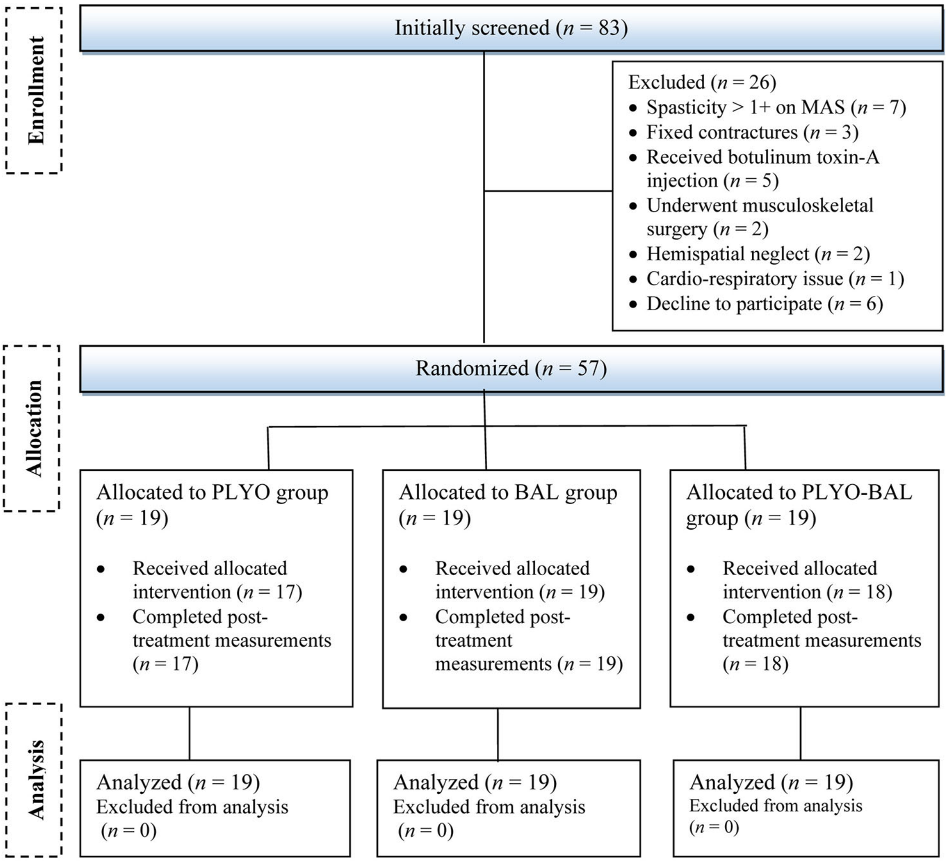

Figure 1. A diagram showing the participants' flow and retention through the study.

assumed to be 4.87 newtons. The sample was increased to 57 participants to account for the possible dropout.

Participants

Fifty-seven participants were recruited from the University Hospital, Physical Therapy Out-patient Clinic of PSAU , and a tertiary referral hospital Al-Kharj, Saudi Arabia. The pre-defined criteria for inclusion included a verified diagnosis of SHCP (Rosenbaum et al., 2007), age between 8 to 12 years, motor function level I or II according to Gross Motor Function Classification System (Palisano et al., 1997), spasticity grade varying between 1 and 1+ as specified by Modified Ashworth Scale (Ansari et al., 2008), as measured through the hip adductor, knee flexor and extensor, and ankle plantar flexor muscles, and cognitive capacity to follow guidance on evaluation and training. Exclusion criteria included fixed contractures, botulinum toxin injection to any of the lower extremity muscles through the past six months, or musculoskeletal surgery in the past year, motor neglect (i.e., reduced movement amplitude, unreasonable slowness in the execution of movement, and delayed movement initiation of the paretic side in response to a stimulus even though strength and coordination are preserved) (Zielinski et al., 2014), and cardio-respiratory disorders expecting to interfere with exercises performance.

Eligible Participants were randomly assigned into three intervention arms by an independent researcher as follows: plyometric exercises (PLYO group; $n = 19$), balance exercises (BAL group, $n = 19$), and combined plyometric and balance exercises (PLYO-BAL group; $n = 19$). Permuted block randomization method, with different block-size, was implemented to balance groups and ensure the equal probability of participants' assignment. A sequence of numerated, sealed opaque envelopes was created in each random permuted block. Upon the formal entry of each participant in the study, the researcher unlocked the next envelope in that sequence.

A diagram showing participants' flow and retention through the study is demonstrated in Figure 1. Out of 83 potentially eligible children, 57 fulfilled the inclusion criteria. Three children (5.3%) were lost (two from the PLYO group did not complete for unknown causes and one child from the PLYO-BAL group was hospitalized due to a medical problem that was irrelevant to the treatment, thus missed the post-treatment assessment). However, as an intention-to-treat analysis, the data of these three children were included in the analyses.

Outcome Measures

Muscle Strength

Maximal isometric muscle strength (IMS_{max}) of quadriceps, hamstrings, and ankle dorsiflexors were assessed using a hand-held dynamometer (Manual Muscle Tester, model 01163; Lafayette® Instrument Company, Lafayette, Ind., USA). The protocol used to assess IMSmax was performed based on a method described by Berry et al, which demonstrated good to high-reliability metrics for isometric force measurements in children with CP (Berry et al., 2004). A "make" test was applied, in which the muscle length kept constant to mitigate provoking a reflex while testing (Bohannon, 1988), where children were asked to push their limbs against the dynamometer that was rigidly held perpendicular to the limb segment by the examiner until the maximum force was reached (Andrews et al., 1996). Testing positions, stabilizations, and dynamometer placement were similar to those outlined earlier (Bohannon, 1988; Hislop & Montgomery, 2007).

At first, the procedure was fully described and a pretest trial to familiarize each child with the procedure was performed. Before each test, the dynamometer was calibrated. Children underwent three 5-seconds testing-trials with 30-second rest-intervals and the average IMS_{max} for each muscle group was reported. The assessor urged children verbally to do as much effort as possible. The quadriceps and hamstring muscles were assessed from sitting with hip and knee flexed to 90°. The dynamometer was positioned anteriorly on the lower leg, above the malleoli such that knee extension could be resisted to evaluate quadriceps IMS_{max} and placed posteriorly on the lower leg in such a way that knee flexion was resisted to measure hamstrings IMS_{max}. Ankle dorsiflexors were assessed from supine with hip and knee flexion at 90° and ankle held in the neutral position. The dynamometer was positioned at tarsal bones on the dorsal aspect of the foot; thus, dorsiflexion could be resisted.

The reliability of IMS_{max} measurement has also been undertaken in the present study to ensure repeatability of the measurements and that no biases are associated with the test arrangements. Based on the data collected through a single operator, two consecutive days' precision test from the first 10 children enrolled in the study, the intraclass correlation coefficient (95% CI) were 0.98 $(92-99)$ for the quadriceps, 0.97 $(0.90-0.98)$ for the hamstring, and 0.96 $(0.93-0.99)$ for the dorsiflexors. The coefficient of variation from duplicate measurements was 2.18%, 2.21%, and 2.56%, respectively, for the quadriceps, hamstring, and dorsiflexors.

Postural Stability

Postural stability was measured using the Biodex Stability System (Biodex Inc., Shirley, NY). The system employs a circular platform (diameter; 55 cm) that is freely movable, simultaneously in the anterior-posterior and medial-lateral axes. The platform stability varies from 1 to 8, where 1 is the most unstable and 8 is the most stable. The system allows the platform to tilt up to 20^{o} and calculates three different stability indices (SI) reflecting fluctuations around the zero-point that is defined while the platform is stable, before measurement (Schmitz & Arnold, 1998). The test measures, in degrees, the anterior-posterior SI (AP-SI; platform tilt in the sagittal plane), medial-lateral SI (ML-SI; platform tilt in the frontal plane), and an overall SI (O-SI; aggregate platform deviation from the horizontal plane). A higher AP-SI, ML-SI, or OSI score indicates poor stability. Prior analysis of measures obtained across repeated trials indicated that the Biodex stability system produced reliable measures. The intraclass reliability was ($R = 0.95$) for the AP-SI, ($R = 0.93$) for the ML-SI, and ($R = 0.94$) for the O-SI (Cachupe et al., 2001). In another study, the intratester reliability of the Biodex stability system has been reported to be 0.80 for the AP-SI, 0.43 for ML-SI, and 0.82 for the O-SI (Schmitz & Arnold, 1998).

Many familiarization test sessions were dedicated to children before the assessment process. Testing-protocol was a two-leg stance, with eyes opened, 20-seconds test duration, and stability level starting at level 8 and ending at level 4. Children stood on a locked platform. Next, the platform was released to identify feet-position co-ordinates and establish the ideal feet position for assessment. Children were instructed to adjust their feet such that they could keep the platform stable. Then, the platform was locked. Throughout the testing session, foot-position coordinates were kept constant. The test started when the platform was unlocked for a 20-second trial and children were instructed to preserve upright posture and keep the center-of-pressure in the smallest concentric ring (A-zone) shown on the display panel of the system. Three attempts were permitted, and the average value was calculated (Elnaggar & Elbanna, 2019).

Intervention

Plyometric Exercises

Plyometric exercises were given in 45-minute sessions, twice weekly for a total of 16 sessions over eight weeks, and were closely overseen by a pediatric physical therapist, with a 1:1 therapist-to-child training ratio. Exercises were the same as that we have developed in an earlier study (Elnaggar et al., 2019)—details of exercises are described in the Supplementary document S1. Children attended a pre-training session to clarify the proper execution of exercises. Exercises were specifically concerned with enhancing the lower limb strength and were undertaken in conformity with the guidelines issued by the National Strength and Conditioning Association (NSCA) (Faigenbaum et al., 2009). The entire program was composed of a warm-up phase (stretching and submaximal aerobic exercises), workout phase (10 plyometric exercises), and cool-down phase (stretching and low-intense exercises).

The workout load was increased in two training paradigms: the first geared toward horizontal exercises and the second toward vertical exercises. Exercises were progressed by increasing the number of repetitions, in two training-blocks, each lasted four weeks. The number of repetitions, children started with, in the first block, was determined through a preliminary test of children's performance, in a sample of six participants. Repetitions were performed sequentially without breaks, while 2-minutes rest-intervals were given between exercises. All exercises were conducted on a rubber floor, while children using sports-footwear.

We implemented the minimum training frequency (twice/week) and dosage (eight weeks) per the NSCA recommendations on the following basis:

1. The relatively intense nature of plyometric workout. Plyometric training, unlike traditional strength-building exercises, is very stressful. Stress comes from the mechanical impact demands placed on muscles and joints, and the ability of the nervous system to respond rapidly to these quickly applied forces. So, it was imperative to give enough time for recovery of the musculoskeletal system and facilitate favorable neuromuscular adaptations, while reducing the risk of injury.
2. The study sample that comprises children with SHCP who are relatively weaker than children without motor impairments.
3. Fatigue avoidance, where we thought that higher frequency and dosage may induce fatigue and affect the performance and compliance to treatment.
4. Previous evidence on plyometric exercises in children with SHCP that demonstrated significant improvement in muscle strength following an 8-week program.

Balance Exercises

The balance training program applied for 45 minutes/session, twice/week over eight successive weeks. The program included different balance activities emphasizing subsystems that influence balance behavior (i.e., visual, vestibular, and somatosensory systems) and muscle strength. The training was configured with an increasing level of difficulty within the session (i.e., moving from stable and wide supporting surface to relatively unstable and narrower surfaces), and the same sequence was followed throughout the treatment course. Throughout the treatment, each child received a 1:1 therapist-to-child training ratio. Each session commenced with a 5-10 minutes stretching phase followed by eight balance exercises: *1) Static balance:* children stood with feet shoulder-width apart, arms outstretched, and held for 20-30 seconds with eyes open and closed. *2)*

Stand on a line or stick: stand with hands-on-hips (eyes open and closed) on a line for as much time as possible. *3) Balance board activities:* children tried to maintain balance for 30-seconds without letting the board's edges touching the ground; held a ball and tried to balance a bean bag on the head. *4) Walking between two parallel lines:* children attempted to walk 10-steps forth and back without the lines being crossed; walk while balancing a bean bag on the head, walk while bouncing a ball between lines, with the line width progressively reduced. *5) Balance beam activities:* children traveled along the beam picking up objects from side-to-side; walked forward, sideways, and backward; walked and pivoted 90 and 180° on the beam, walked, stooped, and picked an object up and threw at a particular goal; went back and forth on an inclined beam. *6) partner balance:* child and therapist were partners. With hands placed together, children tried to rock forth and back or push their partner off balance, without feet movement. *7) Surfing*: children placed one foot ahead of the other, balance on the Bruininks balance beam, and tried to lean the trunk down to reach the floor while preserving equilibrium. *8) Switching from one knee to the other in position:* children placed the right knee on the mat with the left leg straight back, squat, and then tried to switch the left forward and kneel on that knee and draw the right leg backward (Senisi, 1994).

Combined Intervention

Children in the PLYO-BAL group received 90-minute training sessions (45 minutes for balance exercises and 45 minutes for plyometric exercises), twice per week, for a total of 16 sessions over eight weeks. A rest-interval of at least 15 minutes was permitted in-between. The training initiated with the balance exercises followed by plyometric exercises for two reasons. First, to make use of the "pre-conditioning" effect of balance exercises that were expected to enhance muscle capacity to generate greater force during strength training (Bruhn et al., 2006). Second, to avoid the onset of fatigue that may result if children commenced with the plyometric exercises during which the lower limb muscle exert huge effort, therefore, could adversely affect children's performance during the balance training.

Treatment Adherence

There was no difference between the study group regarding the adherence-to-treatment rate ($p = .09$). The children in the PLYO group participated in 91.8% (range: 75% − 100%) of the scheduled treatment sessions. The children in the BAL group participated in 92.4% (range: 81.3 − 100%) of the treatment sessions. The children in the PLYO-BAL group attended 95.7% (range: 87.5% − 100%) of the scheduled sessions.

Data Analysis

The intention-to-treat analysis was applied for comparing the study groups. A multiple imputation procedure (multiple regression model) was implemented to handle missing data. D'Agostino–Pearson omnibus test was used to compute the skewness and kurtosis of all data. The analysis of co-variance (ANCOVA) was applied to calculate post-

Table 1. The baseline demographic and clinical characteristics.

	PLYO group ($n = 19$)	BAL group ($n = 19$)	PLYO-PAL group ($n = 19$)	*P*-value
Age, year	9.95 ± 1.35	9.32 ± 1.45	10.05 ± 1.31	.21[a]
Gender (b/g), *n* (%)	12 (63.2) / 7 (36.8)	10 (52.6) / 9 (47.4)	14 (73.7) / 5 (26.3)	.46[b]
Weight, kg	35.21 ± 3.75	36.05 ± 3.01	34.63 ± 4.59	.52[a]
Height, m	1.31 ± 0.06	1.33 ± 0.08	1.32 ± 0.05	.56[a]
BMI, kg/m^2	20.50 ± 1.82	20.34 ± 1.49	19.93 ± 1.90	.59[a]
GMFCS (I/II), *n* (%)	15 (78.9) / 4 (21.1)	13 (68.4) / 6 (31.6)	16 (73.7) / 3 (26.3)	.63[b]
MAS (1/1+), *n* (%)	14 (73.7) / 5 (26.3)	10 (52.6) / 9 (47.4)	11 (57.9) / 7 (42.1)	.49[b]
Paretic side, (RT/LT), *n* (%)	7 (36.8) / 12 (63.2)	4 (21.1) / 15 (78.9)	8 (42.1) / 11 (57.9)	.46[b]
Muscle strength, Newton				
Quadriceps	62.05 ± 8.10	63.58 ± 7.82	65.43 ± 5.17	.35[a]
Hamstrings	56.32 ± 8.22	57.44 ± 9.83	58.40 ± 6.37	.74[a]
Dorsiflexors	47.81 ± 7.61	49.36 ± 6.29	50.65 ± 6.66	.49[a]
Postural stability indices, degree				
AP-SI	3.16 ± 0.55	2.99 ± 0.48	3.33 ± 0.51	.15[a]
ML-SI	3.11 ± 0.35	2.98 ± 0.44	3.17 ± 0.35	.33[a]
O-SI	3.23 ± 0.40	3.13 ± 0.31	3.07 ± 0.34	.39[a]

Notes: Continuous data expressed as mean ± SD and categorical data shown as frequency (%).
PLYO, plyometric; BAL, balance; PLYO-BAL, combined plyometric and balance; BMI, body mass index; b/g, boys/girls; GMFCS, gross motor function classification system; MAS, modified Ashworth scale; AP-SI, anteroposterior stability index; ML-SI, mediolateral stability index; O-SI, overall stability index.
[a]1-way AVOVA test.
[b]Fishers' exact test.

treatment differences among treatment-groups, using the pretreatment values as co-variates. The Tukey's honest significance test was employed for pairwise comparison. All analyses were conducted via the Minitab statistical software, version 19.2 (Minitab Inc., State College PA, USA), with a *P*-value of 95%.

Results

Baseline Characteristics

The baseline demographic and clinical characteristics are presented in Table 1. There were no significant between-group differences with respect to age, anthropometric (weight, height, and body mass index), or clinical (motor function level and spasticity grade) variables ($p > .05$). Also, there were no significant pretreatment differences between study groups concerning muscle strength and postural stability variables ($p > .05$).

Post-Treatment between-Group Differences

Differences as per the ANCOVA analysis are shown in Table 2. There was a statistically significant post-treatment difference between study groups concerning quadriceps [$F_{(2,53)} = 9.37$, $p = .0003$] hamstring [$F_{(2,53)} = 10.69$, $p = .0001$], and dorsiflexor [$F_{(2,53)} = 17.58$, $p < .0001$] strength adjusted to the pretreatment scores of these variables. Also, there was a statistically significant post-treatment difference between study groups regarding AP-SI [$F_{(2,53)} = 20.76$, $p < .0001$], ML-SI [$F_{(2,53)} = 7.94$, $p = .0009$], and O-SI [$F_{(2,53)} = 5.34$, $p = .008$] adjusted to the pretreatment scores of each variable.

Results of Tukey's post-hoc analyses are presented in Table 3. For muscle strength, the PLYO-BAL group achieved greater strength than the PLYO and BAL groups for

Table 2. Summary of ANCOVA analysis—post-treatment between-group differences, controlled for pretreatment values.

	PLYO group ($n = 19$)	BAL group ($n = 19$)	PLYO-BAL group ($n = 19$)	P-value	η^2p
Muscle strength, Newton					
Quadriceps	64.68 ± 8.52	64.24 ± 7.31	70.64 ± 4.93	.0003*	0.26
Hamstrings	59.66 ± 6.56	58.44 ± 9.17	64.77 ± 6.26	.0001*	0.29
Dorsiflexors	51.94 ± 6.63	50.05 ± 6.70	58.39 ± 7.26	<.0001*	0.40
Postural stability indices, degree					
AP-SI	2.87 ± 0.37	2.58 ± 0.46	2.36 ± 0.56	<.0001*	0.44
ML-SI	2.78 ± 0.42	2.64 ± 0.44	2.37 ± 0.26	.0009*	0.23
O-SI	2.96 ± 0.40	2.84 ± 0.42	2.48 ± 0.47	.008*	0.17

NOTES: All data are presented as mean ± SD. * significant at $P < 0.05$, η^2p: the effect size for significant ANCOVA test. PLYO, plyometric; BAL, balance; PLYO-BAL, combined plyometric and balance; AP-SI, anteroposterior stability index; ML-SI, mediolateral stability index; O-SI, overall stability index.

Table 3. Tukey's pairwise comparisons.

	PLYO vs BAL		PLYO vs PLYO-PAL		BAL vs PLYO-PAL	
Variable	MD	P-value	MD	P-value	MD	P-value
Muscle strength, Newton						
Quadriceps	1.78	.35	3.03	.03*	4.81	.0002*
Hamstrings	2.09	.28	3.49	.018*	5.58	< .0001*
Dorsiflexors	3.20	.036*	4.07	.006*	7.27	< .0001*
Postural stability indices, degree						
AP-SI	0.18	.25	0.63	< .0001*	0.45	.0001*
ML-SI	0.09	.99	0.44	.001*	0.35	.015*
O-SI	0.07	.13	0.40	.011*	0.33	.04*

NOTE: PLYO, plyometric; BAL, balance; PLYO-BAL, combined plyometric and balance; MD, mean differences; AP-SI, anteroposterior stability index; ML-SI, mediolateral stability index; O-SI, overall stability index.
*Significant at $P < 0.05$.

quadriceps ($p = .03$ and $p = .0002$ respectively), hamstrings ($p = .018$ and $p < .0001$ respectively), and dorsiflexors ($p = .006$ and $p < .0001$ respectively) muscles. No significant post-treatment differences were observed between PLYO and BAL groups except for dorsiflexor strength, where the PLYO group achieved greater strength ($p = .036$). For postural stability, the PLYO-BAL group achieved better stability scores as compared to PLYO and BAL groups regarding AP-SI ($p < .0001$ and $p = .0001$ respectively), ML-SI ($p = .001$ and $p = .015$ respectively), and O-SI ($p = .011$ and $p = .04$ respectively). No significant post-treatment differences were noted between the PLYO and BAL groups for stability indices (all $p < .05$).

Discussion

The findings demonstrate that combining plyometric and balance exercises is an effective rehabilitation strategy for enhancing muscle strength and postural control in children with SHCP. Previous studies into traditional strength training in children with CP, although demonstrated an increase in muscle strength, their conclusions were inconsistent regarding the implication of improved strength for activity performance and participation (Franki et al., 2012). In the present study, we employed a type of explosive power training (i.e., plyometric exercises), which is quite different from the traditional strength training. The main difference is related to the specificity of strength training since power training incorporates higher and more functional movement velocity that deem helpful to increase children capacity to generate rapid force directly related to activity performance (Moreau et al., 2012). Prior studies on the effect of unimodal power training in children with CP demonstrated meaningful enhancements in explosive and isometric muscle strength, dynamic balance, gross motor function, and walking capacity (Kara et al., 2019; Oudenhoven et al., 2019; Van Vulpen et al., 2017). Plyometric exercises, as a specific form power training, have also been proven beneficial for children with SHCP. A randomized clinical trial conducted by Elnaggar et al. (2019) found that an 8-week plyometric training program primarily focusing on lower limbs has the potential to enhance muscle strength, equate weight-bearing on lower limbs, and improve walking performance in children with SHCP. Also, a multiple-baseline, single-subject study by Johnson et al. (2014) found that plyometric training for 8 – 14 weeks can effectively improve gross motor function, strength, and agility in children with SHCP. Further, a pre-, posttest control-group study by Elnaggar (2020b) concluded that incorporation of plyometric exercises into physical rehabilitation improved muscle-activation strategies and enhanced balance capacity in children with SHCP over 12 weeks.

Evidence on the effect of the single-mode balance training in children with CP have been reported. Shumway-Cook et al. (2003) demonstrated that balance training increased the ability of children with SHCP to recover stability as indicated by lesser center-of-pressure displacement and shorter time-to-stabilization after balance perturbation. Woollacott et al. (2005) reported that balance training in children with CP enhanced postural control that was attributed to improvements in specific neural factors that contribute to postural control such as directional specificity of response, the amplitude of agonist/antagonist muscle activity, the sequence of muscle contraction, and velocity of muscle activation. Abd El-Kafy and El-Basatiny (2014) provided evidence that balance training improved postural stability and gait parameter in children with CP.

In our study, the combined plyometric and balance intervention led to increases in IMS_{max} of quadriceps, hamstrings, and dorsiflexor muscles, and decreases in AP-SI, ML-SI, and O-SI, showing greater improvements in strength and stability than the single-mode intervention. As mentioned earlier, the combined effect of plyometric and balance training has not previously been studied in children with CP. There merely exists a study that evaluated the effect of classical strength training (i.e., muscles acted against manual or mechanical resistance) and balance training together in children with CP and demonstrated considerable enhancements across strength and stability variables (Auld & Johnston, 2014). The combined intervention has been demonstrated to be an effective remedy for increasing strength and enhancing postural stability

in children with Down's syndrome (Gupta et al., 2011) and children with balance deficits (Granacher et al., 2011). Also, the combined intervention has been shown superior to single-mode training in improving strength and postural control in healthy children (Chaouachi et al., 2014). Our findings for children with CP extend evidence on the effectiveness of the combined intervention.

Despite the promising results of the combined plyometric and balance intervention, the difference in therapy dosing remains arguable. Children in the PLYO-BAL group (combined intervention) received 90-minute exercise sessions compared to 45-minutes for children in either the PLYO or the BAL group, which probably led to improved outcomes, irrespective of the type of training. At the basic conceptual level, exercise programs should have preferably been matched, with respect to the amount of time accrued in a single exercise session, which is a crucial determinant of exercise dosing (Wasfy & Baggish, 2016), therefore, reaching a more robust conclusion about the comparison of the three intervention protocols. The authors' point of view was to take the advantage of both exercise approaches and maximize the benefits, especially since they target different aspects of motor function, specifically, muscle strength and postural control, which have been shown to augment each other (Bruhn et al., 2006; Damiano & Abel, 1998; Elshazly & Elnaggar, 2016). Hence, what the present experiment conclude is that combined intervention, which incorporates plyometric and balance training, has a more pronounced effect on muscle strength and postural control outcomes than either of them alone, and that these findings are likely to be important for children with SHCP, as well as for the physical rehabilitation specialists working with them to plan for combined intervention based on credible knowledge.

Favorable results of the combined intervention might be explained by the "preconditioning effect" of balance training—meaning that the neuromuscular adaptations induced by balance training might have enhanced muscles' capacity to generate greater force (Bruhn et al., 2006). Also, Balance training has been shown to enhance postural stability and reduce body sway while standing (El-Shamy & El Kafy, 2014), representing essential requirements for more efficient performance during plyometric exercises (Granacher et al., 2010). By such means, possible mal-alignments of force vectors might have been reduced and thus improved force generation. On the neuromuscular level, balance training might have contributed to an improved activation of muscles of the ankle (gastrocnemius and tibialis anterior) and knee joints (quadriceps and hamstring) (Woollacott et al., 2005), representing muscle groups that also predominantly involved in plyometric exercises, therefore enhanced treatment outcomes.

Given the relationship between muscle strength or postural control and functional ability of children with CP (Pavão et al., 2014; Pouliot-Laforte et al., 2020; Shin et al., 2016), the multimodal exercise program demonstrated in the present study, could presumably help to enhance functional performance by increasing strength and postural control. Supportive of this, are the previous reports which indicated that lower limb muscle strength is a key factor for gross motor ability and walking efficiency in children with CP (Kramer & MacPhail, 1994; Pouliot-Laforte et al., 2020; Shin et al., 2016), specifically, in children who were relatively functional, like those who participated in the present study. It has also been recognized that increasing children's ability to control posture enables them to perform anticipatory adjustments required for the execution of the functional tasks efficiently (Pavão et al., 2014).

There have been some limitations that should be considered while interpreting the results of the present study. First, participants were limited to children with SHCP with lesser physical disability relative to other types of CP (Shevell, Dagenais, Hall, & Consortium, 2009). Second, the results reported herein are limited to the examined age-group (i.e., $8-12$ years). Third, only changes in body functions and structures were measured, we did not measure whether these changes were transferred to activity performance and participation. Fourth, the results of the present study demonstrate only the short-term effect, while long-term effects remain unaffirmed. Fifth, the study lacks a standard care-based group. Therefore, there is abundant room for further research to determine to what extent the effect of plyometric training, balance exercises, or their combination are different from that of the standard care. Finally, this study cannot confirm whether improvements in the POLY-BAL group are specifically related to the intervention or the exposure to a training volume more than other groups. It is therefore important for the forthcoming studies to plan for equal training volume to draw a definitive conclusion about the intervention effects.

Conclusion

The findings suggest that a multimodal exercise program incorporating plyometric and balance training is effective in increasing muscle strength and improving postural stability in children with SHCP. A limitation is that the intensity of training in the group receiving the combined plyometric and balance intervention was twice as high as the groups receiving either plyometric or balance training. Further research is needed to determine the effects plyometric and balance training on activities and participation.

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No potential conflict of interest was reported by the author(s).

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