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ORIGINAL RESEARCH ARTICLE

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Functional progressive resistance exercise versus eccentric muscle control in children with hemiplegia: a randomized controlled trial

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Abstract

Background: Historically, strength exercise in children with CP is not recommended, because it may develop spasticity, which results in difficulty with walking. But, recently increasing studies and systemic reviews have reported that strength exercise can promote muscle strength in children with CP with no negative impact on spasticity. The study is aiming to compare the effect of functional resistance exercise and functional eccentric training on dynamic balance and functional ability in children with hemiplegia. For this purpose, forty participating children diagnosed with spastic hemiplegia were included and their ages ranged from 6 to 13 years. They were randomly allocated into two groups: functional resistance exercise (group I) or eccentric muscle control exercise (group II). The training was conducted three times a week for 6 weeks for both groups. Each group received one of the interventions in addition to designed physical therapy programs. Functional ability and dynamic balance were measured before and after 6 weeks of the intervention by gross motor function measure and functional reach test.

Results: Comparison between the two groups before treatment revealed no significant difference in all values of functional ability and dynamic balance. But comparison after treatment in values showed significant improvement in both groups with greater improvements in favor of group I ($p < 0.01$).

Conclusion: Adding both functional resistance exercise and eccentric muscle control exercise is beneficial for improving functional ability and dynamic balance with more recommendation for adding functional resistance exercise that showed more significant improvement than eccentric muscle control in children with hemiplegia.

Keywords: Dynamic balance, Functional resistance exercises, Eccentric muscle control, Spastic hemiplegia

Background

Hemiplegia is a common type of spastic cerebral palsy caused by a lesion to the sensorimotor cortex that controls one side of the body resulting in impairment to limbs, trunk, and neck on one side of the body [1]. Approximately 25% of CP cases experience a change in motor function in which the affected side of the brain has unilateral spasticity of the opposite upper and lower part of the hemisphere and is classified as spastic hemiplegia [2]. Some asymmetry can be seen when hemiplegic children attempt functional activities. In assisted standing, hemiplegic children prefer to stand on their most functional side and ignore the affected side; they have a postural imbalance that affects the ability to shift the weight of the affected lower limb [3].

A common consequence of muscle weakness is delayed postural balance or abnormal development and delayed motor development which is common in all types of CP; due to spasticity, initiation of postural muscle activity in these children is delayed resulting impaired postural mechanisms [4]. Furthermore, impairment has been observed in multiple muscle sequences resulting in increasing the level of co-activation of agonist and

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antagonist muscles in the joint lead to decrease balance [5].

Functional progressive resistance exercise (FPRE) can improve lower limb muscle strength and function in children with CP with no adverse effect on spasticity [6]. Furthermore, it can improve lower limb co-contraction and allows agonist and antagonist muscles to work together efficiently, resulting in reducing muscle tone in the lower extremity [7].

On the other hand, eccentric muscle control exercise (EMCE) of the affected limb in children with hemiplegia improved muscle strength, cadence, velocity, and weight shifting on the affected limb during gait [8]. Furthermore, for a given muscle force, they need less motor unit activation and utilize less oxygen and energy than concentric contractions [9].

Although the literature suggests that FPRE and EMCE are effective in the treatment of children with hemiplegia, there is no study conducing to date to compare the effect the of two interventions. Thus, the purpose of this study was to compare the effects of FPRE versus EMCE on dynamic balance and functional ability in the treatment of children with hemiplegia.

Methods

Design

This randomized controlled trial was approved by the Ethical Committee for Human Research at the faculty of Physical therapy, Cairo University. The study was registered at the Pan African Clinical Trials Registry with registration No. PACTR202111663993438. Participants' parents/legal guardians provided written informed consent before the study was conducted.

Participants

A sample of participating children with spastic hemiplegia was recruited from the Outpatient Clinic of Faculty of Physical Therapy, Cairo University, and National Institute for Neuromuscular System. They were evaluated by the examiner and included if they were diagnosed as spastic hemiplegia, their ages ranged from 6 to 13 years, according to gross motor function classification system-extended and revised (GMFCS-ER), they were at a level of motor function between I and II [10], and able to understand and follow instructions given in exercise program. Participants were excluded if they had significant mental or behavioral disorders, any associated disorders such as visual or auditory problems, fixed deformities of the lower extremities any musculoskeletal surgery, or injection by botulinum toxin in the lower limbs in the past 6 months before intervention [11] and unstable seizures.

Randomization

Before starting the intervention, 40 children were randomly assigned to one of both groups process using sealed opaque envelopes. The examiner prepared 40 sealed envelopes, each including a card identified as group I or II. Each legal guardian of child was asked to choose a closed envelope to determine whether he/she was allocated into group I ($N=20$, 13 boys and 7 girls) or group II ($N=20$, 10 boys and 10 girls). Children in group I received functional resistance exercise program, while those in the group II received eccentric muscle control exercise program.

Procedures

Weight and height were recorded for each child; then, each child's functional ability and dynamic balance were evaluated individually before and after 6 weeks of treatment by the same examiner who was blinded in terms of group assignment.

Functional ability evaluation

Functional ability was assessed by gross motor function measure (GMFM) which is a five-level classification system. It is valid in assessing the child's current motor functions and consists of 88 items related to gross motor abilities divided into five dimensions: lying and rolling (17 items); sitting (20 items); crawling and kneeling (14 items); standing (13 items); and walking, running, and jumping (24 items) [12]. It was used to assess the child's motor performance before and after treatment. Among the 5 domains, total scores in the domain (gait, running, and jumping) were assessed in this study. The examiner explained each item for each child and his parent. The tasks were done according to the instructions illustrated in the GMFM manual. The child began to perform each item while the examiner was observing the child's ability to perform the task then gave him a score that ranged from 0 to 3 where 0 = could not do, 1 = initiated (˂ 10% of the task), 2 = partially completed (10 ˂ 100%of the task), and 3 = task completion. After completing all tasks, the examiner calculated the score for each child by dividing the total score by 72. Evaluation of each child took from 20 to 30 min.

Dynamic balance evaluation

Functional reach test was used to assess dynamic balance. It was performed with a leveled yardstick that was attached to the wall at the level of the patient's acromion of the unaffected arm while sitting in a chair [13]. The forward reach test is as follows: the child was seated next to but not touching the wall. The examiner instructed the child to raise his arm forward until it was parallel to the

floor, and then the examiner gave the child verbal instructions and demonstrations to reach forward without touching the yardstick. The initial reach was measured with the upper extremity flexed to 90° using the placement of the third metacarpal along the meter stick [14]; then, the examiner measured the distance in centimeters from the tip of the acromion process to the tip of the middle finger. After the child took the starting position, the examiner instructed him to reach as far as he could forward without falling while maintaining a fixed base of support. The side reach test is as follows: the examiner instructed the child to raise his arm lateral until it was parallel to the floor. The initial reach was measured with the upper extremity abducted to 90° using the placement of the third metacarpal along the meter stick; then, the examiner measured the distance in centimeters from the tip of the acromion process to the tip of the middle finger. After the child took the starting position, the examiner instructed him to begin leaning as far as possible laterally without rotation while maintaining a fixed base of support. The examiner measured the maximum distance the child reached in centimeters. Scores were determined by calculating the difference between the start and end position of the reach.

Intervention

The treatment was conducted by an experienced physical therapist. Children in both groups received 3 sessions per week for 6 weeks. In the remaining 3 days of the week, the mothers of included children were instructed to perform a home routine program, and a diary was kept to follow the application leaving a day off for rest.

Group I: Children in this group received a designed physical therapy program in addition to functional progressive resistance exercise. The designed physical therapy program focused on (1) facilitation of postural stability and balance in form of stimulation of righting and equilibrium reactions to improve the postural mechanism by balance bar, single leg balance with bar and walking in a stride line, (2) closed and open environment gait training as overcoming obstacles and walking in different floor styles, and (3) walking up and downstairs [15], in addition to functional progressive resistance exercise which consists of sit to stand, half-kneeling standing, and side step up. Children in that group were trained three times per week for 6 weeks. The session starts with warm-up exercise (range of motion, mobilization, stretching) which was done for 3 min, then resistive exercise for 25 min, and finally cooling down exercise (range of motion, mobilization, stretching) which was done for 2 min. All exercises were performed in 1–3 sets of 8–12 repetitions, with a 30-s to 1-min rest in between the sets. According to each subject's performance, both weight and repetition were increased and progressed.

Sit-to-stand bilateral exercises were performed from sitting on a chair (no armrests, no backrest) with the hips at 90° and knees at 90° flexion (thigh parallel to the floor) and feet flat on the floor. The therapist used weight on the child's pelvis to add resistance. From the starting position, the therapist instructed the child to stand up slowly from the chair.

- Half kneeling standing: the child was seated in a half-kneeling position without any external support. The therapist used weight distally at the child's ankle on the affected side. From this starting position, the therapist instructed the child gradually to push his affected leg forward to stand up while the weight is shifted forward on the front leg
- Side step-up exercise: the starting position of the child was standing; the therapist used weight distally at child's ankle on the affected leg as resistance. The therapist asked the child to raise his affected leg and climb up a 15-cm staircase sideways [16]

Exercise repetition (i.e., set) was five times in the first 2 weeks then increased to 10 times in 3–4 weeks and 15 times in 5–6 weeks. Weight was increased according to subject's participation, 5% weight in 1–2 weeks, 10% weight in 3–4 weeks, and 35% weight in 5–6 weeks, based on their body weight.

Group II: Children in this group received a designed physical therapy program in addition to eccentric muscle control exercise that included 4 exercises:

- Standing to sit: the child stood erect with the neck in a neutral position, back extended, hand beside the body, knee extended, and feet flat on the floor. The therapist asked the child to sit on a chair slowly with back, knees, ankle flexed at 90 angles.
- Standing and shifting weight anterior: the child stood erect; the therapist asked the child to shift weight anteriorly slowly
- Sitting and returning to crock lying: the child was positioned sitting on matt with the neck in a neutral position, back erect, knee extended. The therapist asked the child to return to the crock lying position gradually
- Standing and kicking a large ball: the child was positioned in front of a mirror; then, the therapist asked the child to kick a large ball backward slowly on a specific target then return to starting position. Each exercise was done 5 times, and 10 sets were performed with rest in between sets

Data analysis

Unpaired *t*-test was conducted for comparison of subject characteristics between groups. Chi-squared was carried out for comparison of sex distribution between groups. Mann–Whitney *U* test was conducted for comparison of GMFCS between groups. Normal distribution of data was checked using the Shapiro–Wilk test for all variables. Levene's test for homogeneity of variances was conducted to test the homogeneity between groups. Unpaired *t*-test was conducted to compare the functional reach distance and GMFM-88 between groups. Paired *t* test was conducted for comparison between pre- and post-treatment in each group. The level of significance for all statistical tests was set at $p < 0.05$. All statistical analysis was conducted through the Statistical Package for Social Studies (SPSS) version 25 for Windows (IBM SPSS, Chicago, IL, USA).

Results

Subject characteristics

Table 1 showed the subject characteristics of groups I and II. There was no significant difference in age, weight, height, BMI, and sex distribution between groups ($p > 0.05$)

Effect of treatment on functional reach test and Gross Motor Function Measure 88

Within-group comparison

There was a significant increase in forward and sideward functional reach distance and GMFM-88 scores post-treatment compared with pre-treatment in both groups ($p < 0.001$). The percent of change in forward and sideward functional reach distance and GMFM-88 in group I was 27.19, 55.26, and 12.02% respectively, while that in group II was 22, 31.02, and 8.59%% respectively (Table 2).

Table 1 Comparison of subject characteristics between groups I and II

	Group I (FPRE)	Group II (EMCE)			
	Mean ± SD	Mean ± SD	MD	*t*-value	*p*-value
Age (years)	8.75 ± 2.15	8.65 ± 1.87	0.1	0.15	0.87
Weight (kg)	22.15 ± 3.51	22 ± 3.24	0.15	0.14	0.88
Height (cm)	122.9 ± 4.3	123.3 ± 4.34	− 0.4	− 0.29	0.77
BMI (kg/m^2)	14.57 ± 1.37	14.38 ± 1.58	0.19	0.41	0.67
Sex, *n* (%)					
Girls	7 (35%)	10 (50%)		($\chi^2 = 0.92$)	0.33
Boys	13 (65%)	10 (50%)			

SD standard deviation, *MD* mean difference, χ^2 chi-squared value, *p value* probability value

Between groups comparison

There was no significant difference between groups pre-treatment ($p > 0.05$). Comparison between groups post-treatment revealed a significant increase in forward and sideward functional reach distance ($p < 0.01$) and GMFM-88 scores ($p < 0.001$) in favor of group I (Table 2)

Discussion

The current study aimed to test the effect of adding functional progressive resistance exercise versus eccentric muscle control exercise to physical therapy program on functional ability and dynamic balance, and the results of the study reported that 6 weeks of progressive exercise in addition to a designed physical therapy exercise produced better improvement in all measured variables than 6 weeks of eccentric exercise and a designed physical therapy exercise.

The results of the study were supported by a number of studies that have conducted the effectiveness of functional progressive resistance exercise in children with hemiplegia [17–21].

The findings of the presents study were supported by Cho HJ and Lee BH [17], who conducted a randomized controlled trial applied on 13 children with spastic cerebral palsy, measured the functional ability and dynamic balance after functional progressive resistance exercise, and found its effect in children with cerebral palsy and also concluded that FPRE had a positive effect on lower extremity strength, morphology of quadriceps muscle, decreasing muscle tone, and improving dynamic balance and functional ability in children with spastic CP. Therefore, they suggest that in children with CP, FPRE has been shown to be an effective, safe, and convenient intervention that can be applied in a 6-week period.

Our results came in line with Verschuren et al. [22] who used GMFM to measure motor ability in standing and found a significant effect, whereas Dood et al. [23] who used GMFM to measure motor ability in walking, jumping, and running reported a significant improvement after a strengthening intervention program. On the other hand, Taylor et al. [24] and Crompton et al. [25] found that the GMFM-66 overall total score showed no significant improvement Also, Lee et al. [26] reported no significant improvement in GMFM-88 total score after a progressive resistance exercise in children with cerebral palsy. Additionally, improvement in our study in functional ability came in line with Eagleton et al. [27], and Blundell et al. [28] reported that the increased muscle strength resulted in a better gait pattern with less crouch, faster speed, and improved gross motor ability (standing, sit-to-stand, walking, running, jumping activities). Also, Blundell et al. found that

Table 2 Mean functional reach distance and GMFM-88 pre and post-treatment of the groups I and II

	Group I (FPRE) Mean ± SD	Group II (EMCE) Mean ± SD	MD	*t*-value	*p* value
Forward reach distance (cm)					
Pre treatment	21.15 ± 1.81	20.45 ± 1.87	0.7	1.19	**0.23**
Post treatment	26.9 ± 2.57	24.95 ± 2.37	1.95	2.49	**0.01**
MD	− 5.75	− 4.5			
% of change	27.19	22			
***t*-value**	− 16.94	− 24.32			
	***p* = 0.001**	***p* = 0.001**			
Sideward reach distance (cm)					
Pre treatment	11.4 ± 3.71	10.8 ± 4.43	0.6	0.46	**0.64**
Post treatment	17.7 ± 4.48	14.15 ± 4.47	3.55	2.51	**0.01**
MD	− 6.3	− 3.35			
% of change	55.26	31.02			
***t*-value**	− 17.68	− 22.33			
	***p* = 0.001**	***p* = 0.001**			
GMFM-88					
Pre treatment	60.3 ± 2.12	59.4 ± 2.81	0.9	1.14	**0.26**
Post treatment	67.55 ± 1.87	64.5 ± 2.3	3.05	4.58	**0.001**
MD	− 7.25	− 5.1			
% of change	12.02	8.59			
***t*-value**	− 16.68	− 13.31			
	***p* = 0.001**	***p* = 0.001**			

SD standard deviation, *MD* mean difference, *p-value* level of significance

task-specific strength training triggers reorganization cortical areas of the brain used with a task. In other words, it entails more than simply increasing muscle force-producing capacity.

Moreover, Dos Santos et al. [29] and Taylor et al. [21] reported that progressive resistance training is believed to influence the muscle metabolic capabilities resulting in morphological and metabolic acclimation led to increase in muscle strength. They claimed that this type of training allows for improved brain control commands as well as strength gains resulting in improved functional performance.

Finally, the significant improvement in all measured variables in favor of the group I after treatment could be attributed to the type of the exercises used, which included a variety of functional resisted exercises for several joints (loaded multi-joint). These exercises (i.e., sit-to-stand, half knee-stand and step up) were designed to include the essential tasks required for the daily living performance during walking, stair climbing, and general mobility. Previous studies stated that these exercises (sit to stand, side step-ups, front steps-up, ascending and descending stairs, high kneeling and lateral) are effective methods to reinforce motor performance, gait parameters and balance [29].

Neurophysiological adaptations and microscopic changes in muscle properties of the targeted muscles as well as neuromuscular integration and improvement of muscle strength are the underlying mechanism by which functional strength training improved motor performance and functional balance. This explanation is reported by Fowler et al. [30] who found that strength-training in children with CP causes neurophysiological changes such as increased co-activation of antagonist muscles, improved synergist muscles performance, and improved spinal cord connections and cross education bilateral effect. Those neural alterations are thought to persist with training, assisting in improve movement.

On the other hand, the improvements recorded in eccentric muscle control exercise group were in line with Park et al. [8] who investigated the effect of concentric and eccentric control training of the affected leg on balance and functional ability in children with spastic hemiplegia. They reported that gross motor function and balance ability showed significant improvement. Moreover, the study was conducted by Sayed A et al. [31] who concluded that eccentric control training improved both balance abilities and gross motor function in children with spastic diplegic cerebral palsy which resulted in improving child level of activity and participation.

Our result agreed with Siobhan et al. [32] who found that children with CP showed higher electromyography (EMG) activity in the concentric tasks than eccentric ones, particularly in the association between the angles at peak torque (80-100). Following the particular strength training program, EMG activation in the eccentric effort reduced significantly for those children with CP, probably due to greater specificity of neural recruitment pattern after eccentric tasks. The finding that eccentric muscle exercise requires less active neural control than concentric muscle exercise may be linked to the downregulation of EMG activation to normal levels. In eccentric muscle actions, decrease in motor unit recruitment may indicate greater elastic energy usage or a more favorable length–tension relationship. Exercising eccentrically may improve brain efficiency, while also improving torque production which is especially beneficial for children with spasticity.

The current study had several limitations; first is a short 6-week intervention period; second is a small sample size; and third, it is difficult to generalize the findings to all children with CP.

Conclusion

Adding functional progressive resistance exercise or eccentric muscle control exercise to conventional physical therapy program showed significant improvements in functional ability, and dynamic balance with more recommendation for adding functional progressive resistance over eccentric mu exercise showed more improvement than eccentric muscle control in children with hemiplegia. However, adding both type of exercise in rehabilitation program is recommended.

Abbreviations

GMFM: Gross motor function measure; FRT: Functional reach test; FPRE: Functional progressive resistance exercise; EMCE: Exercise muscle control exercise; GMFCS: Gross motor function classification system.

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Authors' contributions

YM prepared the content of this manuscript and shared the assessment procedure, MN performed the data analysis and interpretation. All authors read and approved the manuscript.

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Availability of data and materials

The data sets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Declarations

Ethics approval and consent to participate

This study was approved by the Ethical Committee of the Faculty of Physical Therapy, Cairo University, Egypt (No.: P.T.REC/012/003215). All parents of the participating children in this study were informed about the nature and purpose of this study. All parents signed a written consent form that allowed the children to participate.

Consent for publication

Not applicable

Competing interests

The authors declare that they have no competing interests.

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