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Original Article

Assessment of Respiratory Function in Children with Cerebral Palsy after Using Combined Plyometric Exercise and Sensorimotor Program: A Randomized Controlled Trial

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Abstract:

Purpose: Cerebral palsy [CP] is one of the major causes of motor disability among children. This research was implemented to determine whether combining plyometric and sensorimotor activities would enhance the respiratory function of children and adolescents with CP. **Methods**: 40 children from both genders suffering from spastic hemiplegic CP aged from 8-14 years, 20 children [assigned as experimental group: EG] received combined plyometric exercises and sensorimotor program [SP], and 20 children CP [assigned as control group: CG] received sensorimotor program only. Both groups were treated for successive 6 weeks. Respiratory function was measured before and after treatment by forced expiratory volume in one second [FEV1], forced vital capacity [FVC], and FEV1/FVC. **Results**: comparing children with spastic hemiplegic CP in the EG as well as the CG, plyometric training showed a significant beneficial effect on the parameters above in favor of the experimental group. In contrast, in the control group, there was a small improvement in FVC and FEV1 with no improvement in FEV1/FVC. **Conclusion**: Children with CP should closely monitor their pulmonary function and participate in greater plyometric exercise [PE] throughout treatment to improve their respiratory capacities.

Keywords: Cerebral palsy, Pulmonary function, Sensorimotor program, and Plyometric exercise.

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1. Introduction:

CP is the most prevalent childhood motor disability **[1].** Children with CP are more likely to have pulmonary disorders than their healthy peers. They frequently experienced such health problems as chronic obstructive pulmonary disease, sleep apnea, recurrent chest infections, as well as bronchiectasis **[2].**

Reduced pulmonary function is reported in children with spastic CP due to several factors, including decreased chest wall movement, weak respiratory muscles, differences from normal chest wall anatomy **[3],** decreased airway clearance, respiratory muscle weaknesses, impaired lung mechanics, and inefficient cardiovascular fitness as well as chest mobility **[4-6].**

Pulmonary function testing [PFT] is a non-invasive method to test how lungs function efficiently. The data that has been fully examined and interpreted offers objective data on the patient's present respiratory status and can be applied to the patient's follow-up care **[7].** Training of the respiratory muscles gets little attention in physical therapy programs for cerebral palsy. Former studies **[8, 9]** have assessed the effects of respiratory muscle training in CP children in GMFCS levels I–IV and investigated their parameters of lung functions. Keles, Elbasan **[10] fou**nd that after inspiratory muscle training [IMT], ambulated children with CP improved in the six-minute walk test [6MWT]. Benefits in the standing and walking dimensions of gross motor function assessments were noted in another study by Unnithan, Katsimanis [**11]** in children in GMFCS levels I–III following strengthening and aerobic exercises **[12].**

PE are high-velocity, extraordinary-impact exercises that include hopping, jumping, throwing, and bounding. This resisted strengthening exercise involves an eccentric contraction followed by a quick concentric contraction of the same muscle to indirectly strengthen the respiratory muscles involved in performing gross motor tasks **[13**]. Few studies have examined the effects of PE on children with CP or other debilitating health problems. Plyometric exercises have improved gross motor function in boys with unilateral CP **[14]**, distance jumping, and motor performance abilities in children with neurofibromatosis **[15].**

However, the impact of plyometric exercise on pulmonary function in children with mild CP has not yet been examined **[16, 17],** even though it has the potential to improve motor function. Consequently, this study aimed to compare the impact of a 6-week PE program combined with the same timeline of SP for children with CP in terms of pulmonary function.

2. Materials and Methods:

2.1. Experimental Design:

Using a single-blind methodology, a randomized control trial was conducted between September 2022 and September 2023 in the pulmonary functions lab and physical therapy clinic at Egyptian Chinese University **[ECU]** in Cairo, Egypt. The study protocol has the Research Ethical Committee, Pediatric Department, Cairo University ID: P.T.REC/012/003787 and has the identifier NCT05506527 from ClinicalTrial.gov, where it was registered.

2.2. Participants:

- Forty children who have spastic hemiplegic cerebral palsy of both genders took part in this study once their parents signed a consent form that the institution accepted. They were chosen from the outpatient clinic of the Faculty of Physical Therapy at Egyptian Chinese University. The study had the following inclusion criteria: Children in the study aged from 8 to 14 years old, all had spastic hemiplegic CP [grade 2 spasticity on Tardieu Scale before treatment], were selected based on their scores on the Levels I, II Gross Motor Function Classification System **[GMFCS]**, and were able to follow basic verbal instructions. Children with severe oromotor difficulties, severe chest infections, significant visual impairments, or recent surgeries were excluded.

2.3. Sample Size Calculation

The sample size for this study was calculated using a power analysis conducted with G*Power 3.1 software. A pilot study was initially conducted with three participants in each group. In the pilot study, the mean FVC for the EG

was 2.36 L [SD = 0.42 L], while the CG had a mean FVC of 1.92 L [SD = 0.31 L]. Based on the effect size observed in the pilot study and with the desired significance level [α] set at 0.05 and desired power [1 - β] of 0.95, a sample size of 20 participants in each group was chosen for the main study. This sample size calculation was specifically tailored to the primary outcomes of FVC, FEV1, and the FEV1/FVC ratio, which are central to the study's objectives.

2.4. Study randomization:

The study population was randomly divided into two groups; EG had a selected SP combined with PE, and CG had SP only. Before starting this study, the opaque and sealed envelopes approach was employed with both colored and uncolored cards to make sure that the children were allocated equally across the groups. Colored cards were assigned to EG, while uncolored ones were assigned to CG

2.5. Protocol:

Outcome measures:

Before the rehabilitation program, all subjects [EG and CG] were assessed by a Micromedical Gold standard fully computerized portable auto spirometer used to measure pulmonary functions test in the form of FEV1, FVC as well as FEV1/FVC after EG received plyometric exercise in the form of a vertical training paradigm and sensorimotor program three times each week for six weeks. While CG had received only a sensorimotor program as EG.

Pulmonary function test:

Every subject was seated and asked to close his mouth tightly around a mouthpiece to prevent air leakage and to wear nose clips to stop breathing via their nose. The participants received instructions to take in as much air as possible and exhale as much as possible against the resistance. Three measurements were taken in total, and the best value was selected. All measurement variables were noted and subjected to statistical analysis.

Plyometric exercise:

The plyometric exercise program was developed according to the guidelines of the National Strength and Conditioning Association **[18]**. The EG received plyometric exercises in the form of:

Vertical training paradigm: were stride jumping [Take a stride standing and alternately step forward with each foot], squat jumping [take a squat position and try to jump as high as possible], tuck jumping for 10 repetitions for each exercise while step jumping [stand behind stepper and make jump up and down alternatively with right and left feet] for 15 repetitions for each side.

The frequency of plyometric training is three sessions /week. Each session should last 30 minutes, including 5 minutes of warm-up, 20 minutes of plyometric training, and 5 minutes of cool down.

Sensorimotor Program:

(1) Stretching exercises to keep muscles flexible, especially in the hamstrings, hip flexors and adductors, shoulder internal rotators, forearm pronators, and ulnar deviators; [2] training exercises that strengthen the knee extensors, hip flexors, and ankle dorsiflexors; [3] proprioceptive neuromuscular facilitation for the upper and lower limbs [4] applying a variety of tasks, such as moving a ball and a balancing board, to develop the mechanisms of posture control by facilitating postural reactions; [5] positioning the child in a quadruped, semi-leaning back position and doing gentle; [6] facilitation of single-limb support; [7] performing balance exercise on a mat and tilting board while standing, kneeling, half-kneeling, or quadruped; [8] and forcing the child when they are sitting on a roll and then when they are upright to perform defensive actions [either forward, backward, or sideways] to achieve biomechanical equilibrium **[19]**.

The treatment program conducted for 3times/week for 6 successive weeks:

- For EG: had 30 minutes PE and 45 minutes SP
- For CG: had 45 min SP

Statistical Analysis:

This study examines the effect of PE on pulmonary function in cerebral palsy patients. The primary outcome measures encompass FVC, FEV1, and the FEV1/FVC ratio. A total of 40 CP patients were randomized into either the EG [n = 20] or CG [n = 20]. Extensive patient characteristic assessments were conducted at baseline, including age, weight, height, body mass index **[BMI]**, GMFCS level, and Tardieu Scale. Pulmonary function measurements were obtained before and following the intervention period. The statistical analyses employed a battery of tests, such as chi-square tests, Mann-Whitney U tests, and independent samples t-tests, to ensure robustness.

Demographic data was collected, analyzed, and summarized for continuous variables using the mean and standard deviation. Gender distribution between groups was assessed using the Chi-square test. Data was screened before the final analysis to meet assumptions necessary for parametric testing. The Shapiro-Wilk test for normality, Levene's test for homogeneity of variance, and detecting outlier scores are all part of this process.

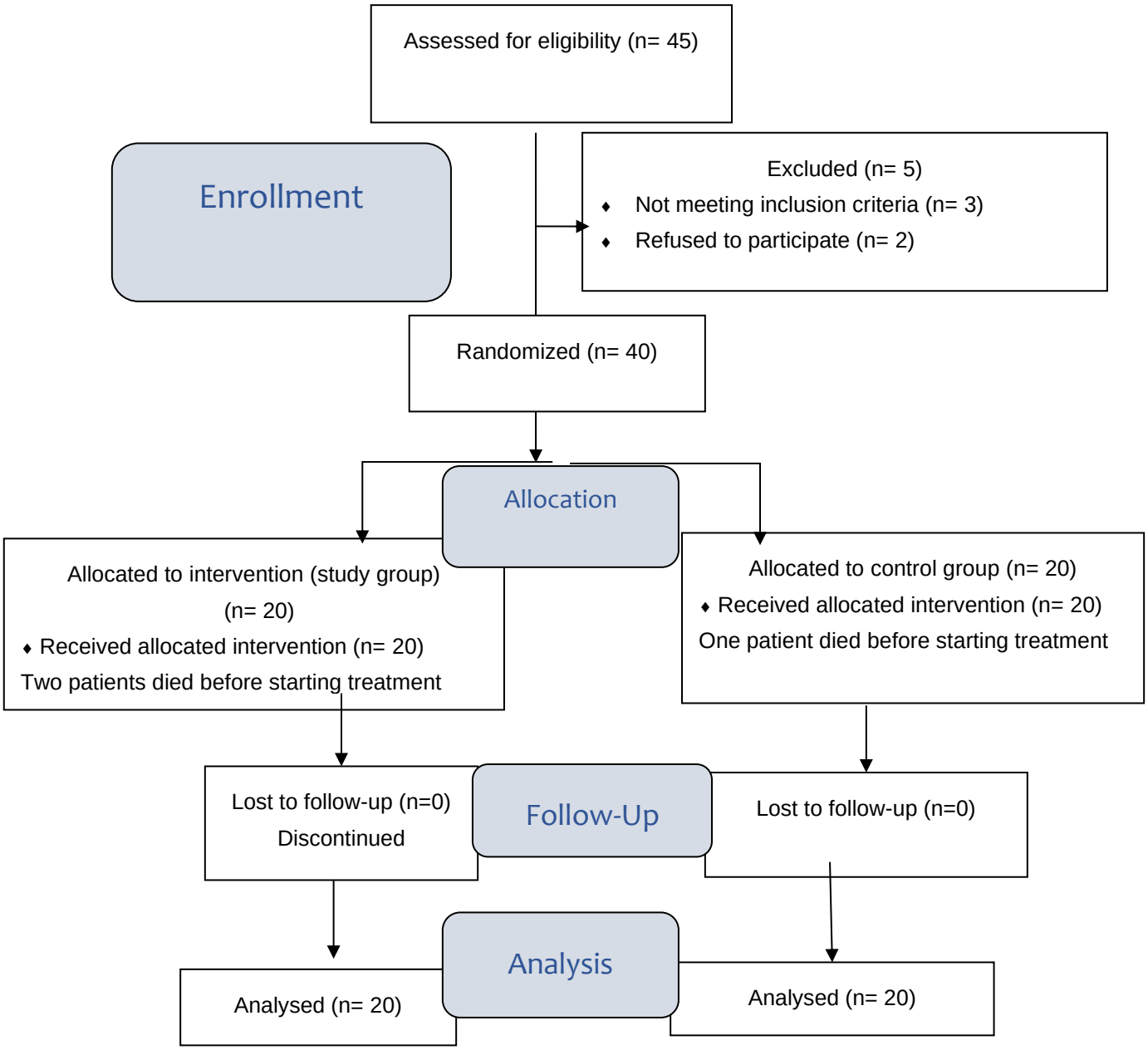

Figure [1]: Study flow chart

3. Results:

3.1. Characteristics of Patients in the Experimental and Control Groups:

Patients' baseline characteristics in the control and experimental groups are shown in **Table 1**. Gender [p = 0.749], age [p = 0.925], weight [p = 0.871], height [p = 0.749], body mass index [BMI] [p = 0.787], GMFCS level [p = 0.358], and Tardieu Scale [p = 0.752] did not differ significantly between groups. This indicates that the groups were well-matched at baseline.

Table 1: Characteristics of patients in the experimental and control groups.

Qualitative variables	Experimental group [N = 20]	Control group [N = 20]	p-value
	Mean ± SD [Median]	Mean ± SD [Median]	
Gender [M/F] [a]	9/11	8/12	0.749
Age [year] [b]	10.83 ± 1.78	11.025 ± 1.06	0.925
Weight [Kg] [b]	32.61 ± 6	32.94 ± 4.48	0.871
Height [Cm] [c]	1.33 ± 0.14	1.35 ± 0.16	0.749
BMI [Kg/m2] [b]	18.31 ± 2.27	18.43 ± 3.41	0.787
GMFCS [b]	2.05 ± 0.89	1.8 ± 0.77	0.358
Tardieu Scale [b]	1.2 ± 0.25	1.23 ± 0.26	0.752
FVC_Pre [Liter] [c]	1.84 ± 0.27	1.81 ± 0.26	0.760
FEV1_Pre [Liter] [c]	1.45 ± 0.25	1.49 ± 0.31	0.682
FEV1/FVC Ratio_Pre [%] [c]	0.79 ± 0.05	0.82 ± 0.08	0.228

Values are presented as mean ± SD. [a] Chi-Square Tests. [b] Mann-Whitney U-test. [c] independent samples t-test.

3.2. Pulmonary function parameter within and between group comparison:

Table 2 provides a detailed comparison of pulmonary function parameters at baseline and following the intervention in both the experimental and control groups, as well as the p- p-values for within-group [by paired t-test] and between-group comparisons [by independent t-test].

Variable	Experimental group [N = 20]				Control group [N = 20]				Between groups comparison [P value]
	Pre	Post	Variation	p-value [within the group]	Pre	Post	Variation	p-value [within the group]	
Variable 1	1.84 ± 0.27	2.28 ± 0.33	0.44 ± 0.22	< 0.001 [a]	1.81 ± 0.26	1.96 ± 0.31	0.15 ± 0.24	0.011 [a]	0.005 b
	1.45 ± 0.25	1.94 ± 0.31	0.49 ± 0.23	< 0.001 [a]	1.49 ± 0.31	1.6 ± 0.27	0.12 ± 0.21	0.022 [a]	0.001 b
Variable 2	0.79 ± 0.05	0.85 ± 0.04	0.06 ± 0.06	< 0.001 [a]	0.82 ± 0.08	0.82 ± 0.06	0 ± 0.08	0.978	0.034 b

Values are presented as mean ◎ SD; ap◎ 0.05 between pre-test and post-test; bp◎ 0.05 between experimental and control groups.

Statistical analysis:

Employed independent samples t-tests for intergroup comparisons and paired t-tests to examine changes within groups. Significantly improvements were observed within EG post-intervention, with FVC increasing from 1.84 ± 0.27 L to 2.28 ± 0.33 L [$p < 0.001$] and FEV1 increasing from 1.45 ± 0.25 L to 1.94 ± 0.31 L [$p < 0.001$]. In CG, FVC and FEV1 showed smaller improvement; FVC increased from 1.81 ± 0.26 L to 1.96 ± 0.31 L [$p = 0.011$], and FEV1 increased from 1.49 ± 0.31 L to 1.60 ± 0.27 L [$p = 0.022$], Between-group comparisons confirmed statistically significant differences in FVC [$p = 0.005$] as well as FEV1 [$p = 0.001$].

The EG did exhibit a little improvement in the FEV1/FVC Ratio, increasing from 0.79 ± 0.05 to 0.85 ± 0.04 [p ⊚ 0.001], while the CG's ratio remained relatively stable [0.82 ± 0.08 to 0.82 ± 0.06, $p = 0.978$]. Comparison between groups indicated a significant difference in the FEV1/FVC Ratio [$p = 0.034$].

These results demonstrate that plyometric exercise substantially positively impacted pulmonary function parameters [FVC, FEV1, and the FEV1/FVC ratio] within EG compared to CG.

4. Discussion:

The most common cause of morbidity and mortality in children with CP is respiratory complications. So, treating CP patients should include interventions to improve respiratory function **[20].** Because previous studies have shown that children with CP often have both restrictive and obstructive lung disease, the present study used tests of FEV1, FEV1/FVC, and FVC to evaluate pulmonary function **[6].**

Interestingly, our outcomes of the six-week plyometric exercise showed a significant improvement in EG's FEV1 and FVC. Improved respiratory muscle strength from plyometric exercise might explain these increased results. Also, there is an increase in blood circulation, heart rate, arterial blood pressure, oxygen demand, and rate and depth of breath caused by accessory respiratory muscles getting in action, leading to changes in muscular, cardiovascular, and pulmonary systems, increasing individual tolerance capacity **[21].**

In prior studies, plyometric exercises have improved upper or lower body power and strength. For example, Luebbers, Potteiger **[22]** studied the impact of 7 weeks of plyometric training on vertical jumping and anaerobic capacity in physically active college-aged men. They found no difference in effectiveness between a 4-week and 7-week plyometric training, provided both were followed by a 4-week recovery period **[22].** Fernandez-Fernandez, Saez de Villarreal **[23]** studied the outcomes of an 8-week plyometric training program. They found that young tennis players who engaged in plyometric training significantly improved their ability to perform explosive movements **[23].**

The impacts of 8 weeks of lower body plyometric exercise with constant volume and duration on the vertical jumping height and pulmonary functions in male and female collegiate volleyball players were studied by Usman and Shenoy **[24],** and the results showed significant improvements in both measures. They reported that the increase in respiratory muscle strength and improved lung mechanics gained by plyometric exercises and the active lengthening of the muscles, immediately followed by active muscle shortening, are the primary causes of the observed improvement. The physiological fact of stretch-shortening cycle movement of muscles in plyometric exercises maximizes force production during the concentric contraction by increasing muscle recruitment. Additionally, it was discovered that physical training enhances the respiratory muscles, resulting in a considerable increase in FEV1 and FVC **[24].**

The findings of our study were consistent with the work of **[21].** They implemented their research on high school students aged 14-18 years and assigned them to a cycling group [$n = 30$] and a jump roping group [$n = 30$]. Each group did the exercises three times a week for 12 sessions and measured chest wall expansion [at the axillary and xiphoid levels], vital capacity [VC], expiratory reserve volume, forced VC, and forced expiratory volume in one second. Finally, the authors reported that chest wall expansion and respiratory capacity increased after plyometric exercises such as jump roping **[21].**

This current study reported that 6 weeks of plyometric exercise in addition to the Sensorimotor program had a positive effect on pulmonary function parameters [FVC, FEV1, as well as the FEV1/FVC ratio] within the experimental

group in comparison with the control group that encourages to involve the plyometric training exercises in the rehabilitation programs for all CP children to decrease associated airway complications.

5. Conclusions:

In conclusion, the present study shows the beneficial impact of plyometric exercises on pulmonary function in CP children and recommends that they be involved in their rehabilitation programs.

Conflicts of interest:

The authors declare no conflicts of interest.

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List of abbreviations:

6MWT	Six-Minute Walk Test
BMI	Body Mass Index
CG	Control Group
CP	Cerebral Palsy
ECU	Egyptian Chinese University
EG	Experimental Group
FEV1	Forced Expiratory Volume in One Second
FVC	Forced Vital Capacity
GMFCS	Gross Motor Function Classification System
IMT	Inspiratory Muscle Training
PE	Plyometric Exercise
PFT	Pulmonary Function Testing
SP	Sensorimotor Program
VC	vital capacity

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