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Combined effects of functional task training with electrical stimulation on motor abilities and balance in children with diplegia

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Abstract

Background Children with spastic diplegic cerebral palsy (CP) often demonstrate gluteus medius weakness that causes balance deficits and frequent falling during walking.

Purpose The aim of the study was to evaluate the combined effects of functional task training with electrical stimulation of bilateral hip abductor muscles on motor abilities (standing and walking) and balance in children with spastic diplegic CP.

Methods Thirty children with diplegic CP of both sexes whose ages ranged from 7 to 10 years were assigned randomly into two equal groups. For both groups, motor abilities were assessed by gross motor function measure (GMFM), and balance (static and dynamic) was assessed by the humac balance system before and after the study. The control group received a functional training program focusing on standing walking and balance exercises. While children in the study group received the same functional training program with bilateral electrical stimulation of gluteus medius muscles for 50 min. The treatment program for both groups was conducted for 3 sessions/week for 8 weeks.

Results There were statistically significant differences between the control and study group post-treatment in GMFM as well as the center of pressure test and weight shift test in favor of the study group ($p < 0.05$).

Conclusion Using functional task training with electrical stimulation for treatment of children with spastic diplegic CP have significant effects on improving their motor abilities and balance that suggests using it in rehabilitation for these children.

Keywords Balance, Diplegic cerebral palsy, Functional electrical stimulation, Motor abilities

Introduction

Cerebral palsy (CP) is a common neurodevelopmental disorder caused by non-progressive lesions of the immature brain. The clinical signs and characteristics of spastic CP include motor deficits and postural abnormalities, increased muscle tone, and limited range of motion. Children with CP usually have balance problems due to neuromuscular, musculoskeletal, and sensory system deficits resulting in walking impairment [1]. The problems of gait are instability in ambulation and a higher incidence of falls. It is due to spasticity, difficulty of initiation of activity, reduced voluntary movement performance, enhanced walking cost efficiency, and early fatigue [2]. Diplegia is the most prevalent form of spastic CP, which manifests as symmetrical involvement of both lower limbs. It makes up 35% of the CP population [3]. Children who suffer from spastic diplegia may display clumsiness and fall frequently during regular motor activities. They may also have difficulty standing up on their own and walking

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abnormalities as a result of balance, motor control deficiencies, and spasticity [4]. Complex integration of multiple body systems such as the vestibular, visual, proprioceptive, and higher-level premotor systems, is required to achieve balance [5]. Impaired motor control is one of the most common neuromuscular deficits in children with spastic CP and often occurs in combination with muscle weakness and spasticity [4].

Numerous musculoskeletal deformities, such as pelvic malalignment, non-synchronization between the trunk and lower limbs, lack of proprioception, and muscle imbalance can cause numerous functional difficulties in children with spastic diplegia. Otherwise, spasticity causes difficulty in initiation movement, decreased performance of voluntary movement increased cost efficiency of gait. A healthy gait pattern requires good coordination between the pelvis and lower extremities [6].

There are numerous strategies of treatment for CP: pharmacological and surgical options, as well as physiotherapy approaches. Physiotherapy approaches that are currently available for the treatment of CP are neurodevelopmental therapy, proprioceptive neuromuscular facilitation, constraint-induced movement therapy, functional task training program, and functional electrical stimulation [7].

The purposes of the functional-task training program were to create and enhance a wider range of movement patterns, with a focus on strengthening muscles. Also, this exercise program was used to enhance postural adaptation, increase postural control, and give opportunities for age-appropriate abilities and performance [5].

The functional task training program is a potential neurological rehabilitation technique for the enhancement of functional performance in children with CP. This program included both walking and non-walking exercises like getting up from a seated position, getting on and off a bench, climbing up and down stairs; and walking on ramps as well as flat surfaces [8].

Functional electrical stimulation (FES) is used for stimulation during voluntary and functional movements. This is accomplished by providing electrical stimulation to muscles that, during contraction, lead to suitable and functional movement [9]. It is frequently used to increase the range of motion, decrease muscle stiffness, strengthen muscles, improve upper extremity function, and increase walking speed [10]. NMES is applied via surface electrodes. It is a non-invasive approach that is generally well tolerated [11]. In addition, it has been demonstrated that when muscle training is implemented within functional activities, the gains of performance are faster compared with training isolated from the functional activities [12].

Previous research has shown the effectiveness of the combination of a functional task training program and functional electrical stimulation on the gastrocnemius muscle to improve motor capacity [12]. Therefore, the purpose of the current study was to evaluate the combination of functional task training with electrical stimulation of bilateral hip abductor muscles and its effects on motor functions (standing, walking) and balance in children with spastic diplegia.

Study design

This prospective randomized clinical trial was carried out in the outpatient clinic of Itay Elbaroud General Hospital and Health Insurance Hospital; it was conducted from January 2023 to September 2023.

Ethical consideration

This trial was approved by the Research Ethical Committee of the Faculty of Physical Therapy, Cairo University (P.T.REC/012/004508). The current study was registered on the Clinical Trials Protocol Registration and Results System (NCT06234215).

Sample size calculation

G*POWER statistical software (version 3.1.9.2; Universitat Kiel, Germany) was used to carry out sample size calculation relying on the finding of El-Shamy and El Kafy 2021; and suggested that the required size of each group is 15 subjects. The calculations were made using $\alpha = 0.05$, power = 80% and effect size = 1.1, and allocation ratio N2/N1 = 1.

Subjects

Thirty children with spastic diplegic CP of both sexes were recruited in this trial. Children aged 7 to 10 years with Modified Ashworth Scale scores of 1 to 1+ of spasticity were included [13]. Based on the Gross Motor Function Classification system, their motor functions were at levels I and II [14]. Participants demonstrated cooperation and were able to follow study instructions. Children with epilepsy, musculoskeletal deformities in the upper, and lower extremities or spine, vision or hearing issues, injection of botulinum toxin, or orthopedic surgery during the previous 6 months or during the research period were excluded.

Children were assigned by simple randomization via closed sealed envelopes into two groups (control and study). The control group included 15 children and they received the functional training program. The study group included 15 children. They received the same functional training program and electrical stimulation during exercise for about 50 min. The treatment program was conducted for both groups for successive 8 weeks.

Recruitment and randomization

Forty-one children had their eligibility evaluated for participation in this trial. Four children were taken out because their parents refused to participate in the study, while seven other children were excluded because they did not match the criteria for inclusion. Using closed sealed envelopes, the randomization procedure was carried out after the baseline outcomes measurements. The researcher produced 30 closed sealed envelopes, one inside each that included a card labeled "study group" or "control group". Then, each child was instructed to draw one sealed envelope that contained whether he/she was allocated to the control group or the study group.

Materials

A Materials for selection

1 - Modified Ashworth Scale (MAS).

It was utilized to evaluate the level of spasticity of the affected lower limbs to ensure baseline similarity of all participating children [13].

2 - Gross Motor Function Classification System (GMFCS).

The GMFCS categorizes the gross motor function of participants with CP from 2 to 18 years of age into 5 different levels [14]. It was used to select participating children at levels I and II.

B Materials for evaluation

All participating children in both groups were evaluated pre and post-treatment programs (8 weeks).

1. Gross Motor Function Measure (GMFM):

   The GMFM is a standardized observational instrument designed and validated to measure change in gross motor function over time in children with CP [15]. It was used to evaluate the motor functions of each child.
2. Humac balance system:
   The humac balance system (503746) is a tilting system connected with a static force plate which allows measurements of both dynamic tilt and static force.
3. Weight and height scale: A valid and reliable weight and height scale was used; this data was required for humac administration.

C Materials for treatment

For both groups physical therapy tools (mat, wedge, balance board, inclinator, parallel bar, stepper, shifter, and stairs) were used. For the study group (EV-906) Digital TENS/EMS neuromuscular stimulator device was used.

Procedures

I) For evaluation

All parents became aware of all goals and study technique without any risk before participation of their children. Before the testing session, each child was given instructions regarding the evaluative procedures after agreeing to a written consent form. This was done to ensure that all of the children were aware of the device and the steps involved in the evaluation process. Before and after 8 weeks of the procedure, assessments were given to each child in both groups in a quiet, warm environment.

Test sessions:

- Demographic data including child's name, age, and gender were collected and reported in the evaluation sheet.
- Assessment of GMFM: items of both standing and walking domains were assessed for each child and the sum of all scores was recorded.
- Assessment of balance: the HUMAC Balance System is a balance board combined with the HUMAC balance Software to offer a powerful assessment tool for static and dynamic balance. The device was fed specific settings. Child's weight, height, birthdate, and feet position on the board. The HUMAC Balance System assesses static balance via a center of pressure test (COP) and dynamic balance via a weight shift test. During the COP test each child was asked to keep the movable point in the center of the circle on the visual feedback screen while he/she was standing. While the weight shift test was used to assess dynamic balance, each child was asked to put the movable point on the bright spot on the visual feedback screen by shifting body weight (mediolateral and anteroposterior) without moving feet.

The testing time lasted for 60 s for every child, and the average of the three repeats was recorded. After completion of the test, a printout was obtained.

II) For treatment

All participating children received treatment sessions of 50 min each session 3 times per week, for 8 weeks [12].

Control group

This group received a functional training exercise program for 50 min 3 times per week, for 8 weeks. Each session includes exercises focusing on standing, walking, and balance [8] such as.

- Facilitation of standing and single limb stance facing stand bar by using blocks.
- Stride standing on the mat with a light push by the therapist.
- Step up and down using a stand bar.
- Balance training from standing and walking on the mat and tilting board.
- Weight shifting exercises.
- Gait training activities include sideway and forward walking using a stepper, toe-heel walking in straight line, walking in an open environment, and walking on an inclinator.
- Up and down stairs.
- Jumping.

Study group

Children in this group received the same training program combined with neuromuscular electrical stimulation by using (EV-906 digital TENS/EMS) on the gluteus medius muscle bilaterally for 50 min [12].

The treatment plan was clarified to the child and his/her parents. Two active electrodes spaced 2 cm apart and parallel to the muscle fibers were stuck bilaterally on the gluteus medius muscle [16].

Parameters

After optimizing the positioning of the electrodes, the electric current characteristics are 300 μs pulse width that was symmetrical in nature. Pulse intensity ranged from 17 to 33 mA and the stimulation frequency ranged from 26 to 30 pps, to achieve a noticeable muscle contraction [12].

Statistical analysis

Unpaired *t* test was utilized to make a comparison between groups regarding the group's age, weight, and height between groups. The Mann–Whitney test was utilized to make a comparison between groups' GMFCS levels. The chi-square test was utilized to make a comparison between groups regarding sex and the distribution of spasticity. The Shapiro–Wilk test was conducted to test the normal distribution of data. To evaluate the homogeneity between groups, Levene's test for homogeneity of variances was used. A paired *t* test was used to compare each group's pre- and post-treatment periods, while an unpaired *t* test was used to compare the GMFM scale, COP, and weight shift between the groups. The level of significance was set at $p < 0.05$. The statistical software for social sciences (SPSS) version 25 for Windows (IBM SPSS, Chicago, IL, USA) was used for all statistical analysis.

Results

Baseline characteristics

The *baseline* characteristics of children involved in control and study groups are illustrated in (Table 1). There was no significant difference between groups in age, weight, height, GMFCS, sex, and spasticity grade distribution ($p > 0.05$).

Effect of treatment on GMFM, COP, and weight shift

Within group comparison

There were significant improvements in standing and walking domains of GMFM post-intervention compared with pre-intervention in both groups ($p > 0.001$). The percent of change of standing and walking GMFM in the control group was 17.37 and 33.90% respectively and that in the study group was 42.27 and 55.74% respectively (Table 2).

There were significant improvements in COP and weight shift post-intervention compared with pre-intervention in both groups ($p > 0.001$). The percent of change of COP and weight shift in the control group was 12.17 and 28.50% respectively and that in the study group was 21.14 and 93.02% respectively (Table 3).

Table 1 Baseline characteristics of participants in both control and study groups

	Control group mean ± SD	Study group mean ± SD	*t* value	*p* value
Age (years)	8.33 ± 1.29	8.66 ± 1.49	−0.65	0.51
Weight (kg)	26.20 ± 6.96	28.93 ± 8.01	−0.99	0.33
Height (cm)	121.33 ± 9.53	126.53 ± 14.61	−1.15	0.25
GMFCS, median (IQR)	2 (2–1)	2 (2–1)	(*U* = 105)	0.71
Sex, *n* (%)				
Girls	8 (53%)	6(40%)	(χ^2 = 0.53)	0.46
Boys	7 (47%)	9 (60%)		
Spasticity grades, *n* (%)				
Grade I	7 (47%)	8 (53%)	(χ^2 = 0.13)	0.71
Grade I+	8 (53%)	7 (47%)		

SD standard deviation, *IQR* interquartile range, *U* Mann–Whitney test value, χ^2 chi-squared value, *p value* probability value

Table 2 Mean values of standing and walking for GMFM scale pre- and post-treatment of both control and study groups

GMFM scale	Pre-treatment	Post-treatment				
	Mean ± SD	Mean ± SD	MD	% of change	*t* value	*p* value
Standing						
Control group	25.67 ± 3.56	30.13 ± 3.88	−4.46	17.37	−10.26	0.001
Study group	24.27 ± 4.61	34.53 ± 5.50	−10.26	42.27	−11.66	0.001
MD	1.4	−4.4				
t value	0.93	−2.52				
	p = 0.36	*p = 0.01*				
Walking						
Control group	35.40 ± 5.96	47.40 ± 6.56	−12	33.90	−22.54	0.001
Study group	33.60 ± 6.10	52.33 ± 3.63	−18.73	55.74	−16.74	0.001
MD	1.8	−4.93				
t value	0.81	−2.54				
	p = 0.42	*p = 0.01*				

SD standard deviation, *MD* mean difference, *p value* probability value, *GMFM* Gross Motor Function Measure

Table 3 Mean values of COP and weight shift pre- and post-treatment of both control and study groups

	Pre-treatment	Post-treatment				
	Mean ± SD	Mean ± SD	MD	% of change	*t* value	*p* value
COP						
Control group	66.80 ± 7.24	74.93 ± 5.36	−8.13	12.17	−13.03	0.001
Study group	65.60 ± 8.45	79.47 ± 4.10	−13.87	21.14	−8.36	0.001
MD	1.2	−4.54				
t value	0.41	−2.6				
	p = 0.68	*p = 0.01*				
Weight shift						
Control group	11.93 ± 6.72	15.33 ± 6.68	−3.4	28.50	−10.14	0.001
Study group	12.47 ± 5.27	24.07 ± 6.09	−11.6	93.02	−18.61	0.001
MD	−0.54	−8.74				
t value	−0.24	−3.73				
	p = 0.81	*p = 0.001*				

SD standard deviation, *MD* mean difference, *p value* probability value, *COP* center of pressure test

Between groups' comparison

There were no significant differences between groups pretreatment ($p > 0.05$).

There were significant improvements in standing and walking for GMFM, COP, and weight shift of the study group compared with that of the control group post-treatment ($p < 0.01$) (Tables 2 and 3).

Discussion

The present study included the spastic diplegic type of CP which is the most common type of spastic CP [3]. Children with spastic diplegic CP face a variety of troubles including poor balance, walking disturbances, and frequent falls. Balance problems that are common in children with spastic diplegia may be partially explained by these children's impairments in the postural control system [1]. Children with CP are often unable to stand up straight, and some may need assistance. Muscle strength is clearly necessary for achieving gross motor activities, but it is unknown if the development of standing capacity depends on it or if there are other factors affecting the ability to develop standing in CP [17]. Therefore, the purpose of this study was to determine how functional task training and electrical stimulation of bilateral hip abductor muscles affect standing, walking, and balance in children with diplegia.

Children between the ages of 7 to 10 years were recruited in this study. It comes in agreement with Shumway-Cook and Woollacott [18] who stated that postural control is practically developed as an adult in 6–10 years of age. The study's age selection was matched with Hallemans et al. [19] who emphasized that at this age, standing and walking have completely matured and resemble an adult's pattern, so the developmental issue as a factor affecting the gait in these children can be excluded. It was reported that lack of hip flexion, extension, and adductor spasticity in the legs can cause delays in independent standing and walking in people with spastic diplegia lasting up to 6 years of age [20]. A previous study by Usama et al. [21] stated that children aged between 5 and 12 years old, had a good performance like adults during balance assessment using humac system. So, children aged from 7 to 10 years were selected as they understand orders, cooperate with humac balance system administrations, and perform functional task training.

The selected children with GMFCS Level I and II were recruited to participate in this study. They can perform better in functional task training program that consists mainly of standing and walking activities. Level I children can walk alone but speed, balance, and coordination are limited. Long-distance walking and balancing on uneven or inclining terrain may be challenging for them. Level II Children need physical help when walking. Children's gross motor skills, such as running and jumping, are very limited [22].

The Gluteus medius muscle was selected for the application of FES in this study as it is mainly involved in the hip strategy of balance control. There are three strategies that have an important role in balance and postural control (ankle strategy, hip strategy, and step strategy). The hip strategy is intended to be used for quick or large amplitude perturbations, or when the support surface is narrow and very minimal ankle torque can be applied. It moves the body like a double-segment inverted pendulum with counter-phase motion at the ankle and hip [23]. The Previous study by Domínguez-Navarro et al. [24] emphasized that bilateral gluteus medius muscles are important in maintaining balance. Because these muscle groups are necessary for common movements such as lateral displacements, direction changes, and single-leg balance tasks.

In the current study, there were no significant differences between both groups in demographic data concerning age, sex, weight, height, GMFMCs, and spasticity which means that both groups are homogenous to avoid selection bias.

In this study, the preintervention mean values of static and dynamic balance (center of pressure and weight shift tests) in participating children for both groups showed a significant deficiency in static and dynamic balance values. This ensures that these children have significant balance problems. Raipure et al. [25] reported that spastic diplegic children have balance problems. That has an impact on their functional level, especially when they stand and walk, which might cause atypical motor behavior.

The results of both control and study groups were statistically significant and this may be due to effects of functional task rehabilitation that involves repetition of movements. It was suggested that muscle weakness and spasticity may be reduced with repetitive motor exercise. Furthermore, it serves as the physiological basis for motor learning, and sensorimotor coupling aids in the adaptation and reconfiguration of neural networks. In addition to repeated motor performance, involvement of active cognition, functional training, and performance are essential factors to enhance motor learning [26].

Functional-task training includes a variety of exercises. These variations improve motor learning since they cause relatively long-lasting changes in movement capability which is another name for motor learning. Functional-task training has a longer-lasting effect on motor performance [27]. Active participation, skill/exercise progression, and intense, structured practice are the fundamental components of motor learning; these principles were implemented in the current study. Also, the result of functional task training programs with electrical stimulation on standing and walking domains of GMFM scores showed significant differences in favor of the study group. These results may be explained by Surana et al. [28] who stated that the aims of functional task training were improving strength, balance, and coordination deficits of the lower extremities.

Statistical analysis of the two groups' post-treatment findings showed significant enhancements in their functional ability and postural stability, which are characterized by maintaining an upright posture and good alignment of the body segments. It was expressed by improvement in humac balance system values. these results agreed with Merino-Andrés et al., [29] who studied the effect of strength training in cerebral palsy subjects in the pediatric age group and found positive effects on muscle strength of lower limbs, standing, walking, and balance abilities, with no increase of spasticity in these children, it has a great improvement in Gross Motor Function Classification System levels I and II when adequate dosage and specific principles are utilized.

The results of motor, COP, and weight shift post-intervention after successive 8 weeks of training showed a significant difference in favor of the study group; this may be due to the combined effects of functional task training with electrical stimulation. This is supported by Pool et al. [30] who demonstrated that performance improvements occur more quickly when muscle training is integrated into functional task activities as opposed to training done separately from the functional activity. Functional electrical stimulation may influence plastic changes in neuronal structures, and increased activation of primary sensory and motor areas [31]. Microvascular perfusion in the activated skeletal muscle can be increased by using NMES when combined with exercise. This improves physiological muscle function by reducing the diffusion distance in the activated muscle tissue and enhancing the flow of nutrients and metabolites between the blood and tissue. Additionally to its essential function on muscle tissue (preserving steady glucose metabolism), NMES may also enhance an individual's general quality of life at all GMFM domains [32].

Using the NMES programs for pediatric conditions with chronic neurological disorders has a beneficial effect in enhancing muscle strength, movement biomechanics, spasticity, muscle architecture, body composition, and functional mobility associated with daily living. These effects enhance child development [33].

While there were significant improvements in all measuring variables in this study, there were certain limitations to verifying these findings; the sample was limited to 30 participants of spastic diplegia with level I and II on GMFCS. It is recommended that further studies utilizing large sample sizes with different GMFCS levels in different types of CP, longer study durations, using different objective evaluative materials, and follow-up are required.

Conclusion

This prospective study demonstrated the beneficial effects of functional task training with electrical stimulation on motor function and balance in children with diplegia. Therefore, this program may be applied in their rehabilitation because it is an efficient, applicable, and noninvasive approach.

Abbreviations

CP	Cerebral palsy
GMFMs	Gross Motor Functional Measure Scale
MAS	Modified Ashowrth Scale
COP	Center of pressure
NMES	Neuromuscular electrical stimulation
FES	Functional electrical stimulation
mA	MilliAmpir
pps	Pulse per second
min	Minutes
GMFCS	Gross motor function classification system

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Authors' contributions

RA performed evaluation for both groups by GMFMs and humac balance system and treatment for both groups using functional task training program but electrical stimulation for study group only, and wrote down the manuscript. WM revised the work. EE revised the work. All authors read and approved the fnal manuscript.

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Availability of data and materials

The datasets analyzed during the current study are available from the corresponding author on reasonable request.

Declarations

Ethics approval and consent to participate

The current study was conducted after approval by the local Ethical Committee at the Faculty of Physical Therapy, Cairo University (P.T.REC/012/004508) and ethical principles of the Declarations of Helsinki were followed.

Consent for publication

Signed informed consent was obtained from each child's parent regarding the participation of their children in the current study.

Competing interests

The authors declare that they have no competing interests.

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References

1. Patel DR, Neelakantan M, Pandher K, Merrick J. Cerebral palsy in children: a clinical overview. Transl Pediatr. 2020;9(S1):S125–35.
2. Woollacott MH, Shumway-Cook A. Postural dysfunction during standing and walking in children with cerebral palsy: what are the underlying problems and what new therapies might improve balance? Neural Plastic. 2005;12(2–3):211–9.
3. Honan I, Finch-Edmondson M, Imms C, Novak I, Hogan A, Clough S, Bonyhady B, McIntyre S, Elliott C, Wong S, Bink M, Badawi N. Is the search for cerebral palsy 'cures' a reasonable and appropriate goal in the 2020s? Dev Med Child Neurol. 2022;64(1):49–55.
4. Kurz MJ, Arpin DJ, Corr B. Differences in the dynamic gait stability of children with cerebral palsy and typically developing children. Gait Posture. 2012;36(3):600–4.
5. MacKinnon CD. Sensorimotor anatomy of gait, balance, and fall Handbook. Clin Neurol Elsevier. 2018;159:3–26.
6. Salphale VG, Kovela RK, Qureshi MI, Harjpal P. Effectiveness of pelvic proprioceptive neuromuscular facilitation on balance and gait parameters in children with spastic diplegia. Cureus. 2022;14(10):e30571.
7. Upadhyay J, Tiwari N, Ansari M. Cerebral palsy: aetiology, pathophysiology and therapeutic interventions. Clin Exp Pharmacol Physiol. 2020;47(12):1891–901.
8. Badaru MU, Ogwumike OO, Adeniyi AF. Effect of task-oriented exercise training program on the functional performance of children with cerebral palsy. Physiother Quart. 2021;29(3):40–8.
9. Marquez-Chin C, Popovic MR. Functional electrical stimulation therapy for restoration of motor function after spinal cord injury and stroke: a review. BioMed Eng OnLine. 2020;19(1):34.

10. Singleton C, Jones H, Maycock L. Functional electrical stimulation (FES) for children and young people with cerebral palsy. Paediatr Child Health. 2019;29(11):498–502.
11. Mooney JA, Rose J. A scoping review of neuromuscular electrical stimulation to improve gait in cerebral palsy: the arc of progress and future strategies. Front Neurol. 2019;10:887.
12. Gonçalves RV, Fonseca ST, de Araújo PA, Souza TR, Resende RA, Mancini MC. Functional task training combined with electrical stimulation improves motor capacity in children with unilateral cerebral palsy: A single-subject design. Pedi Phys Ther. 2019;31(2):208–15.
13. Meseguer-Henarejos AB, Sánchez-Meca J, López-Pina JA, Carles-Hernández R. Inter- and intra-rater reliability of the modified Ashworth scale: a systematic review and meta-analysis. Eur J Phys Rehabil Med. 2018;54(4):576.
14. Palisano RJ, Rosenbaum P, Bartlett D, Livingston MH. Content validity of the expanded and revised gross motor function classification system. Dev Med Child Neurol. 2008;50(10):744–50.
15. Ko J, Kim MY. Reliability and responsiveness of the gross motor function measure-88 in children with cerebral palsy. Phys Ther. 2013;93(3):393–400.
16. Jeffrey RC, Glenn SK, Holtz J. Atlas for electrode placement: gluteus medius placement E Criswell, cram's introduction to surface electromyography. 2nd ed. Canada: Jones and Bartlett; 2011. p. 356.
17. McLean LJ, Paleg GS, Livingstone RW. Supported-standing Interventions for children and young adults with non-ambulant cerebral palsy: a scoping review. Dev Med Child Neurol. 2023;65(6):754–72.
18. Shumway-Cook A, Woollacott M. The growth of stability: postural control from a developmental perspective. J Mot Behav. 1985;17(2):131–47.
19. Hallemans A, Verbecque E, Dumas R, Cheze L, Hamme AV, Robert T. Developmental changes in spatial margin of stability in typically developing children relate to the mechanics of gait. Gait Posture. 2018;63:33–8.
20. MacWilliams BA, Prasad S, Shuckra AL, Schwartz MH. Causal factors affecting gross motor function in children diagnosed with cerebral palsy. Plos One. 2022;17(7): e0270121.
21. Usama M, Abdelaziem F, Rashed WM, Maher EE, Beltagy M, Zekri W. Impact of physical activity on postural stability and coordination in children with posterior fossa tumor: randomized control phase III trial. J Cancer Res Clin Oncol. 2023;149(9):5637–44.
22. Murphy KP, McMahon MA, Houtrow AJ. Pediatric rehabilitation: principles and practice. 6th ed. New York: Springer Publishing Company; 2020. p. 2–18.
23. Morasso P. Integrating ankle and hip strategies for the stabilization of upright standing: an intermittent control model. Front Comput Neurosci. 2022;16:956932.
24. Domínguez-Navarro F, Benitez-Martínez JC, Ricart-Luna B, Cotolí-Suárez P, Blasco-Igual JM, Casaña-Granell J. Impact of hip abductor and adductor strength on dynamic balance and ankle biomechanics in young elite female basketball players. Scient Reports. 2022;12(1):3491.
25. Raipure A, Kovela RK, Harjpal P. Effectiveness of neurodevelopmental treatment and sensory integration therapy on gross motor function, balance and gait parameters in children with spastic diplegia. Cureus. 2023;15(8):e43876.
26. French B, Thomas LH, Coupe J, McMahon NE, Connell L, Harrison J, Sutton CJ, Tishkovskaya S. Watkins CL. Repetitive task training for improving functional ability after stroke. The Cochrane Library 2016;(11):CD006073. https://doi.org/10.1002/14651858.CD006073.pub3.
27. Perry SIB, Nelissen PM, Siemonsma P, Lucas C. The effect of functional-task training on activities of daily living for people with Parkinson`s disease, a systematic review with meta-analysis. Complement Ther Med. 2019;42:312–21.
28. Surana BK, Ferre CL, Dew AP, Brandao M, Gordon AM, Moreau NG. Effectiveness of Lower-Extremity Functional Training (LIFT) in young children with unilateral spastic cerebral palsy: a randomized controlled trial. Neurorehabil Neural Repair. 2019;33(10):862–72.
29. Merino-Andrés J, de Mateos-Lopez García A, Damiano DL, Sánchez-Sierra A. Effect of muscle strength training in children and adolescents with spastic cerebral palsy: a systematic review and meta-analysis. Clin Rehabil. 2022;36(1):4–14.
30. Pool D, Elliott C, Bear N, Donnelly CJ, Davis C, Stannage K, Valentine J. Neuromuscular electrical stimulation-assisted gait increases muscle strength and volume in children with unilateral spastic cerebral palsy. Dev Med Child Neurol. 2016;58(5):492–501.
31. Hara Y. Brain plasticity and rehabilitation in stroke patients. J Nippon Med Sch. 2015;82(1):4–13.
32. Greve KR, Joseph CF, Berry BE, Schadl K, Rose J. Neuromuscular electrical stimulation to augment lower limb exercise and mobility in individuals with spastic cerebral palsy: a scoping review. Front Physiol. 2022;13:951899.
33. Cobo-Vicente F, San Juan AF, Larumbe-Zabala E, Estévez-González AJ, Donadio MVF, Pérez-Ruiz M. Neuromuscular electrical stimulation improves muscle strength, biomechanics of movement, and functional mobility in children with chronic neurological disorders: a systematic review and meta-analysis. Phys Ther. 2021;101(10):170.

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