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The effect of reciprocal electrical stimulation on handgrip and pinch grip strength in spastic hemiplegic cerebral palsy child

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Abstract

Background

In hemiplegic spastic cerebral palsy (CP) patients, the affected hand can present with a combination of spasticity, weakness, and dystonia. Electrical stimulation is a part of a physical therapy program that is used for improving hand function, and one of the methods of electrical stimulation is reciprocal electrical stimulation (RES). RES mimics the neuromuscular-stimulation procedure for alternate activation of agonist and antagonist muscle groups. Also, RES has been reported to decrease the cortical excitability of the spastic muscle and to improve neural drive through stimulation of sensory receptors and sensory neurons of agonist and antagonist muscles. Our study aims to evaluate the effect of RES on handgrip strength and pinch grip strength on spastic CP children.

Patients and methods

In total, 60 hemiplegic spastic CP children were randomly assigned into two groups, the study group comprised 30 participants and 30 participants in the control group. The study group received an exercise program combined with RES, while the control group received an exercise program joined with faradic stimulation for wrist extensors. Participants in both groups have been evaluated for their handgrip strength and pinch grip strength at baseline and after 12 weeks of physical therapy training.

Results

Statistically significant differences were found when comparing pre-evaluation and postevaluation results for handgrip strength and pinch grip strength in both the control and the study groups. Significant differences were found between the improvement in the control group and the study group.

Conclusion

Both wrist extensor faradic stimulation and RES have affected the improvement of grip strength and pinch grip strength when added to an exercise program. However, this study result suggests that RES is more beneficial than faradic wrist extensor stimulation.

Keywords: Cerebral palsy, cortical excitability, reciprocal electrical stimulation

Introduction

Cerebral palsy (CP) is the leading cause of disability in children. It occurs in ~1.5–2.5 out of every 1000 live births [1]. Motor impairment and functional abilities vary in severity and type according to the etiology [1]. CP is a collection of chronic disorders that impair movement development and limit activity. These include nonprogressive abnormalities of the developing fetal or infant brain that result in CP [2]. CP may be associated with various comorbid conditions, including epilepsy, musculoskeletal problems, intellectual disability, feeding difficulties, visual abnormalities, hearing abnormalities, and communication difficulties [3].

Spasticity is a motor disorder characterized by increased resistance to passive muscle stretch and hyperactivity of stretch reflexes that are velocity and acceleration dependent [4].

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Spastic CP is defined by hyper-deep-tendon reflexes, hypertonic muscle tone, muscle weakness, and gait abnormalities [5]. Around 70–77% of people with CP have spastic CP [5]. There are numerous physical intervention techniques available to help individuals overcome motor spasticity. For example, standing, progressive resistance exercise, passive movement, stretching, and active movement are all examples of neuromuscular electrical stimulation (NMES) with its most common technique [6]. The dynamometer was developed by American neurologists for diagnostic purposes and became widely used in the late nineteenth century. It is still used in a variety of ways in clinical settings as a diagnostic and prognostic tool [7]. The JAMAR (JLW Instruments-Chicago, IL 60607-USA, Version 18.0. Chicago: SPSS Inc., USA) handgrip dynamometer is typically used to assess hand and pinch grip strength in children with CP [8].

CP is caused by abnormal brain development or damage to the fetal or infant's brain. The insult/injury to the brain that results in CP is not progressive ('static') and can occur during the prenatal, perinatal, or postnatal periods [9]. Frequently, the etiology of a single patient is complex. Congenital brain malformations, intrauterine infections, intrauterine stroke, and chromosomal abnormalities are among the prenatal causes, while hypoxic–ischemic insults, central nervous system (CNS) infections, stroke, and kernicterus are among the perinatal causes [10]. Finally, postnatal causes include accidental and deliberate trauma, CNS infections, stroke, and anoxic insults [11]. Prematurity plays a significant role in the development of CP [1]. Numerous prematurity-related complications, such as periventricular leukomalacia, intraventricular hemorrhage, and periventricular infarcts, can result in CP [9]. Multiple gestations, intrauterine growth restriction, maternal substance abuse, preeclampsia, chorioamnionitis, abnormal placental pathology, meconium aspiration, perinatal hypoglycemia, and genetic predisposition are additional risk factors for CP [1,9]. Hemiplegia occurs when the CNS is disrupted, resulting in impairment on one side of the body. Affected hands may exhibit a combination of spasticity, weakness, and dystonia [12].

Han and Eyvazzadeh [13] concluded in 2020 that hemiplegia could present with various symptoms, depending on its severity. Muscle weakness or stiffness on one side, muscle spasticity or permanently contracted muscle, poor fine motor skills, difficulty in walking, poor balance, and difficulty in grasping objects are all possible symptoms.

Hemiplegic children may take longer than their peers to reach developmental milestones. They may play with only one hand or keep one hand in a fist [1].

From infancy onward, children with hemiplegic CP frequently exhibit significant hand involvement, with excessive thumb adduction and flexion and limited active wrist extension. Aberrant plasticity following lesion can result in progressive abnormalities of the developing motor system. For example, somatosensory, visual, and developmental deformity impairments all contribute to difficulties with hand use. Progressive soft-tissue and bony changes may occur, resulting in contractures that further impair function, creating a vicious cycle that necessitates early intervention to break [14].

Typically, hemiplegic CP children report difficulties with hand function, motor control, sensibility, and sensory processing, in addition to the persistence of the primitive grasp reflex [15]. Simple hand movements with hand splinting have been shown to improve hand function in children with CP by stimulating the redistribution of brain activity associated with regaining hand function; this results in a reduced motor deficit. Increases in active range of motion and grip strength were observed [15].

To effectively manage CP, an interprofessional approach is necessary. Interventions should prioritize the maximizing quality of life and minimizing disability burden [16]. Benzodiazepines, baclofen, dantrolene, tizanidine, cyclobenzaprine, botulinum toxin, and phenol are all used to treat spasticity [1]. Additionally, NMES is a common physiotherapy modality for reducing muscle spasticity and activating weakened muscles [2]. Reciprocal electrical stimulation (RES) is distinguished from NMES in that it replicates the typical firing sequences of muscle groups using electromyographic patterns obtained from healthy volunteers during functional movement or activity [17]. To simulate voluntary movement, the stimulation pattern of RES treatment is converted into a sequence of contractions of the agonist muscle, the antagonist muscle, and the agonist's muscle again. This rhythmic pattern was expected to enhance neural drive by stimulating muscle stretch receptors and sensory neurons in both flexor and extensor motor neurons, which have been shown to replicate spinal changes observed during locomotion [1,18].

The purpose of this study was to determine the effect of RES on the handgrip and pinch grip strength in children with spastic CP.

The hypothesis

RES is an innovative application of electrical stimulation (ES) that can be used for neuromuscular requalification and performance improvement. The RES is more valuable than faradic wrist extensor stimulation when added to an exercise program in spastic hemiplegic children with CP.

Patients and methods

Study design

A randomized clinical trial on spastic hemiplegic CP children of both sexes, from the outpatient clinics at the National Institute of Neuromotor System and Faculty of Physical Therapy, Cairo University in Cairo, Egypt. A total of 60 hemiplegic children aged from 11 to 14 years old were divided equally into study and control group, 33 patients were grade 1, and 27 were grade 1+ according to modified Ashworth scale (MAS) for spasticity assessment. The ethical committee approved the study (No. 012/003062), Cairo University, Faculty of Physical Therapy. Group I, the control group, included 30 patients with 14 males and 16 females, and group II, the study group with 17 males and 13 females.

Inclusion criteria

(1) A medical diagnosis of spastic hemiplegic CP was made by pediatricians and pediatric neurologists where children with spasticity grades ranged from 1 to 1+ according to MAS [19].
(2) Children were able to recognize and follow verbal orders and commands included in both test and training techniques.
(3) Children aged from 11 to 14 years.
(4) Only children with medically approved CP.
(5) Parents' approval of informed consent.

Exclusion criteria

(1) Children had a permanent deformity (bony or soft-tissue contractures).
(2) Children had undergone a previous surgical intervention to wrist and hand.
(3) Children had visual or auditory defects.
(4) Children had intelligence quotient less than 70 [20].

Evaluation procedures

Both study and control groups were evaluated for the degree of spasticity, their weight, and height, handgrip strength, and pinch grip strength at baseline. Then handgrip strength and pinch grip strength were reevaluated at the end of 12 weeks of the physical therapy program. Changing in handgrip strength and pinch grip strength was measured by subtracting pre-evaluation results from postevaluation results:

(1) MAS was used to measure the degree of spasticity by passive movement from the supine position to enroll patients in the study.
(2) Digital weighing scale was used to measure body weight.
(3) Paper-height scale divided in cm and fixed to the wall to measure body height
(4) Grip dynamometer (Jamar hydraulic hand dynamometer): the data-collection protocol was modified for children aged 6–19 years and included the use of a calibrated Jamar hydraulic hand dynamometer, as recommended in this study. Each participant sat (in height-appropriate chairs and tables) with their shoulders adducted and rotated, with the shoulder between 50 and 70° flexed, the elbow ~90° flexed, and the forearm in a neutral position. The wrist was extended between 0 and 30°, and ulnar deviation was between 0 and 15°. Throughout the test, the participant's untested hand remained in his lap. The dynamometer was placed on the table, and the research assistant held the top in place while the participant squeezed. Three grip measurements were taken with a 30-sec rest period in-between. As a strong measure, the highest of three readings was used.
(5) Pinch meter: the finger grip strength was determined with a calibrated core manometer using key pressure, defined as the placement of the first digit plate against the radial side of the second digit, between the distal and proximal IP joints. The key was pinch because this pressure is most frequently used by children with spasticity. The participant was seated (using height-appropriate chairs and tables), with the shoulder adducted, rounded, and neutrally rotated, the elbow flexed between 50 and 70°, and the forearm in a neutral position. The wrist was extended between 0 and 30°, and ulnar deviation was between 0 and 15°. Throughout the test, the participant's untested hand remained in his lap. Three lateral measurements were taken, separated by a 30-sec rest period. The highest of three readings was used to determine the strength.

Intervention

The control group received a traditional conventional physical therapy program that consisted of an exercise program for 60 min and ES to wrist extensor of spastic hand for 20 min, while the study group received an exercise program for 60 min and ES to wrist flexor and extensor for 20 min. Both groups received three-session weekly for 12 weeks.

Exercise program

(1) For 20 min, apply hot compresses to the wrist muscles to improve blood circulation and relax the muscles (as a warm-up for exercise and for wrist flexor-muscle relaxation).
(2) Facilitating antispastic muscles (wrist extensors): tapping followed by movement, rapid stretching, triggering mass flexion, biofeedback, weight-bearing, toe clenching, compression on bony prominence, rapping the muscle, approximation, vibration, irradiating weak muscles with strong muscles, and brief ice application.
(3) Prolonged stretching of the wrist muscles for 20 min using techniques such as position, night splint, reflex inhibiting pattern, and Bobath technique.
(4) Passive stretching of highly tense muscles (wrist flexors) to break down muscle adhesions and sheath adhesions. Gentle, gradual stretching that does not stretch excessively should be used, holding for 20 s, and then relaxing for 20 s 3–5 times per session. After the 2-h session, maintain the new range of motion with an adjustable wrist splint and then release the hand to perform daily tasks activities of daily living (ADL).
(5) Active progressive exercises for the upper-extremity muscles.
(6) Training to walk with aids in a closed environment by incorporating obstacles, side walking, and side walking again to stimulate the hand's protective reaction.
(7) Balance training program incorporating static and dynamic exercises.
(8) Weight-bearing and adduction exercises to strengthen the hands and facilitate reaching, grasping, and releasing in accordance with the child's abilities.

ES

A specialized programmable electrostimulator was used (Phyaction 787; Uniphy, Eindhoven, the Netherlands). The device has two channels that can stimulate two opposing groups of muscles alternatively (reciprocate). During ES, the child sits in a chair with his treated forearm resting on a pillow placed on the bed in front of him.

Faradic electrical stimulus

Faradic electrical impulses have been applied for wrist extensors to stimulate wrist extension. The mother or researcher's assistant was asked to support the wrist by extension during ES for 20 min. The electrodes are placed over the dorsum of the forearm as follows: the active electrode is placed over the common extensor origin, while the inactive electrodes are placed on the motor point of extensor pollicis longus, abductor pollicis longus, and extensor indices.

RES technique

The electrodes are placed as follows: channel 1 (stimulates wrist and hand extensors) electrodes placed over the dorsum of the forearm as follows: the active electrode is placed over the common extensor origin, while indifferent over the motor point of extensor pollicis longus, abductor pollicis longus, and extensor indices. Channel 2 (stimulates wrist and hand flexors) electrodes placed on the palmar side of the forearm are as follows: the negative electrode is placed between the finger flexors and wrist flexors. The positive electrode is placed over the tendon portion of the forearm.

Statistical analysis

Sample size calculation

We estimate the mean for handgrip strength from a previous study conducted by Azzam [15]. With a power of 80% and α=0.05, a total of 60 individuals were divided equally to 30 in each group. The sample size was calculated from UCSF [21].

SPSS statistics v. 18 was used for the analysis of data. Pre-evaluation of age, body weight, and body height were analyzed using an independent *t*-test to detect the difference between study and control groups. Crosstabs were used to show categorical data. Handgrip strength and pinch grip strength were tested by dependent *t*-test for pre-evaluation results and postevaluation results in both groups. Changing in handgrip strength between control and study groups was tested by an independent *t*-test. A *P* value of less than 0.01 was considered statistically significant.

Results

No significant statistical differences were found between both the study and the control groups in the pre-evaluation results as regards the body weight, body length, and sex, degree of spasticity, pinch grip strength, and handgrip strength. Both groups received a traditional conventional physical therapy program consisting of a 60-min exercise program. The control group received ES of the spastic wrist extensors for 20 min, while the study group received ES of the wrist flexors and extensors for 20 min. Both groups received three-weekly sessions for 12 weeks.

Table 1 shows the distribution of males and females within our 60 study participants (31 males and 29 females). Table 2 shows the degree of spasticity within the participants according to the MAS where 33 of them were grade 1 (13 in the control group and 20 in the study group), and 27 of them were grade 1+ (17 in the control group and 10 in the study group), with no significant difference between study and control groups.

Table 1: Male and female distribution in control and study groups

	Sex		Total
	Male	Female	
Group			
Control group	14	16	30
Study group	17	13	30
Total	31	29	60

Table 2: Degree of spasticity modified Ashowrth scale in control and test groups

	Degree of spasticity modified Ashowrth scale		Total	*P*
	1	1+		
Group				
Control group	13	0.069	30	0.069
Study group	20	10	30	
Total	33	27	60	

χ^2 test for significance. *P*<0.01 is considered significant.

Table 3 illustrates no significant differences found between both groups in age, height, weight, handgrip strength, and pinch grip strength.

In Table 4, the results from comparing preassessment and postassessment of handgrip strength and pinch grip strength within the studied groups reveal a significant improvement in the pinch grip strength and handgrip strength detected in the control group ($P < 0.001$). A significant improvement was found in the pinch grip strength and handgrip strength in the study group ($P < 0.001$).

In Table 5, a comparison of hand-grip and pinch grip strength between both groups reveals an improvement in pinch grip strength and handgrip strength in the study group compared with the control group.

Discussion

Worldwide, CP has been estimated by 1 to nearly 4 per 1000 live births or per 1000 children [22]. Although it is more common in developing countries, according to the World Health Organization (WHO), CP comprised only 0.2–0.3% of the total population in developing countries [23]. In Egypt, 52 out of 25,540 children in one governorate were diagnosed with CP with a prevalence of 2.04 per 1000 live births [24]. In 2021, Bass's study has revealed that spastic hemiplegia is caused by injury to the brain, particularly of the motor cortex, or dysfunction, which can occur in many different ways [25].

The disorder of spastic hemiplegia is sometimes caused by injuries before, during, or shortly after birth.

CP is characterized by several intellectual and motor deficits. The motor dysfunction includes irregular-movement patterns, delayed motor skills, such as sitting, standing, and walking. Also, abnormalities of muscle tone, particularly spasticity or hypotonia [26–28].

In 2012, Azzam's study mentioned that grip strength is frequently used in clinical trials and has been shown to be a sensitive indicator of disease activity [15]. Grip strength is a composite measure and may be influenced by dysfunction of the muscles, tendons, and any small joints of the hand and wrist [15]. In addition, in our study, pretreatment and post-treatment comparisons have shown a highly statistically significant difference of *P* less than 0.001 in both groups, including handgrip strength and pinch grip strength. A statistically significant improvement was seen in the study group after applying RES with regular exercise in comparison with the control group. There was a significant improvement in pinch grip strength and handgrip strength compared with the preassessment in the control group and within the study group. This agrees with Yıldızgören *et al.* [29], who reported that active wrist range of motion, spasticity, and hand function in CP are improved using NMES in addition to conventional treatments.

Table 3: Pre-evaluation results for control and study groups

Group	*N*	Mean	SD	*P*
Age				
Control group	30	11.697	1.3668	0.550
Study group	30	11.894	1.16422	
Height				
Control group	30	133.9000	11.21068	0.866
Study group	30	134.3333	8.31423	
Weight				
Control group	30	43.9833	7.31140	0.251
Study group	30	46.0333	6.33808	
Handgrip				
Control group	30	4.1900	0.92265	0.084
Study group	30	4.3033	0.90305	
Pinch grip				
Control group	30	2.7800	0.70044	0.632
Study group	30	2.5033	0.50411	

**P* is considered significant at <0.001.

Azzam has also mentioned that hand function training should be considered in conjunction with a traditional physical therapy program to improve grip control and hand functional capabilities in children with hemiplegic CP [15]. The upgrading in both groups might be accredited to the influence of transcutaneous electrical nerve stimulation (TENS). There has been strong evidence that TENS as an adjunct therapy is effective in reducing spasticity when used for more than 30 min on a nerve or muscle in chronic stroke survivors [11]. Martins and colleagues have concluded that TENS may be an essential modality for provisionally reducing spasticity. Yet, the study has recommended future investigations with the use of a larger and more homogeneous sample to avoid underestimation of spinal excitability changes [30]. Both Kwong and colleagues and Jung and colleagues support our findings regarding the use of repeated applications of TENS as an adjunct therapy for improving walking capacity and reducing spasticity [31,32]. Task-related training combined with TENS can recover paretic muscle activity in upper limb paresis, emphasizing the benefits of somatosensory stimulation from TENS [31].

In a study conducted on 30 Egyptian children with spastic diplegic CP to assess the effect of RES on knee extensors and flexors, balance training was found more effective in improving knee functions than RES. This result agrees with our findings where RES plus regular exercise was proved to be significantly effective on hand-grip and pinch grip muscles than regular exercise alone [18].

The change in performance in the study group after applying the added therapy in our findings indicates a synergistic effect of RES. In 2014, Elshafey[33] has concluded that RES used for dorsal and plantar flexor muscles after tendon Achilles' tendenotomy was a safe and effective method of treatment. It has improved balance and postural stability in children with spasticity. Although different methodologies were used, the results came in line with a previous report by Badawy and Ibrahim [18], who indicated that RES of the quadriceps and hamstrings is useful as an adjuvant physiotherapy modality for enhancing postural control during standing and walking in children with diplegia.

Moreover, alternative stimulation helps reduce cortical excitability of the spastic flexors, improves extensor strength, and improves functional performance. As well, neuromuscular

Table 4: Comparison between handgrip strength and pinch grip strength in control and study groups

		Pretreatment pinch grip strength		Post-treatment pinch grip strength		*P*	Pretreatment handgrip strength		Post-treatment handgrip strength		*P*
	N	*M*	SD	*M*	SD		*M*	SD	*M*	SD	
Control group	30	2.78	0.7	2.9	0.7	0.00	4.19	0.92	4.42	0.97	0.00
Study group	30	2.5	0.5	2.78	0.56	0.00	4.3	0.9	4.76	1	0.00
P value		0.632		0.435			0.084		0.095		

P value is considered significant if *P*<0.01. **P* is considered significant at <0.001.

Table 5: Compare improvement between control and study groups

Group	*N*	Mean*	SD	*P**
Improved pinch grip				
Control group	30	0.1314	0.06638	0.00
Study group	30	0.2843	0.05972	
Improved handgrip				
Control group	30	0.2324	0.05561	0.00
Study group	30	0.4611	0.10244	

Difference between mean of pre and post in each group. **P* is considered significant at <0.001.

adaptation and RES-induced changes in the synchronous activation pattern are learned in the brain by repeated stimulation and functionally manifested as improvement of reflex and grip [34].

Elnaggar results in 2020 agree with us and suggested that prescriptions of either RES or botulinum neurotoxin (BoNT-A) injections as an adjunct to a physical rehabilitation program are beneficial for children with diplegia [17]. Incorporating both RES and BoNT-A injections in addition to a physical rehabilitation program is likely to result in significantly positive responses [24].

Our study was conducted on 60 patients with hemiplegic CP, 31 of whom were males, and 29 were females. Children aged 10–14 years were included in the current study who can recognize and follow verbal commands and instructions involved in the testing and training techniques. Their mean age was 11.7955 ± 1.2626 years. The mean body weight was 45.0083 ± 6.86214 kg, while the mean height was 134.1167 ± 9.78773 cm. The selected children had a spasticity score between 1 and +1 on the MAS of muscle tone.

Shamsoddini and colleagues found that the degree and nature of spasticity can vary greatly, depending on the position of the head and extremities, fatigue, tension, and mood of the children. One limb may have one type of spasticity, while another may have a different pattern [35]. It came in the same line, Bass's study, where the severity of spastic hemiplegia differs with each child [25]. CP itself can range from mild to severe. Some children with spastic hemiplegic CP can walk, while others must rely on a wheelchair or other assistive devices. Others may have more muscle fatigue or pain when compared with another child, but the good idea is that, like other types and subtypes of CP, spastic hemiplegia is a nonprogressive disease because the symptoms do not get worse over time. Unfortunately, there was a lack regarding the full description of spastic hemiplegia in the concluded patients.

Shamsoddini *et al.* [35], said that spasticity management is a major challenge for the treatment team. Various methods of treatment are existing for people with CP, as well as caregivers and parents who care for someone with this disability. There is no standardized approach to managing spasticity in CP.

Conclusion

Children with hemiplegic spastic CP showed a better response to RES in combination with regular exercise. RES showed a more significant effect on improving the handgrip strength and pinch grip strength than the use of ES of the wrist extension. RES can be combined with physical therapy as an additional way to improve dysfunction in these children to enable greater integration into society.

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Conflicts of interest

There are no conflicts of interest.

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