BALNEO RESEARCH Balneo and PRM Research Journal
English Edition
e ISSN 2734 - 8458 p ISSN 2734 - 844X ROMANIAN ASSOCIATION OF BALNEOLOGY

Research article

Effectiveness of Passive Movement Training in Patients with Cerebral Palsy: A Comparative Analysis of Robot-Assisted Therapy and Electrical Stimulation in Hand Rehabilitation

Corina Sporea [1,2,*], Maria Veronica Morcov [1,2,*], Mirela Morcov [2], Andrada Mirea [1,2]

1 University of Medicine and Pharmacy "Carol Davila", 37 Dionisie Lupu Street, 020021 Bucharest, Romania; corina.sporea@gmail.com (C.S.); averopsi@yahoo.com (M.V.M.); andrada.mirea@gmail.com (A.M.)

2 National University Center for Children Neurorehabilitation "Dr. Nicolae Robanescu", 44 Dumitru Minca Street, 041408 Bucharest, Romania; morcov.mirela@recuperarecopii.ro (M.M.)

* Correspondence: corina.sporea@gmail.com; averopsi@yahoo.com

Citation: Sporea C., Morcov M.V., Morcov M., Mirea A. - Effectiveness of Passive Movement Training in Patients with Cerebral Palsy: A Comparative Analysis of Robot-Assisted Therapy and Electrical Stimulation in Hand Rehabilitation *Balneo and PRM Research Journal* ***2023**, 14(4): 623*

Academic Editor(s):
Constantin Munteanu

Reviewer Officer:
Viorela Bembea

Production Officer:
Camil Filimon

Received: 15.11.2023
Accepted: 04.12.2023
Published: 20.12.2023

Reviewers:
Ana Cristea
Mariana Rotariu

Abstract: Background: Cerebral palsy is a non-progressive neurodevelopmental condition that results in varied degrees of disability, with upper limb functioning affected in over 80% of cases. The objective of this study was to investigate the impact of passive movement train-ing of the hand (PMT) with robot-assisted therapy (RAT) compared to PMT with function-al electrical stimulation (FES). Methods: Fifty-eight patients diagnosed with CP, aged be-tween 7 and 14 years, participated in a two-week rehabilitation program involving physi-cal therapy (PT) combined with either RAT or FES. Post-rehabilitation, we assessed the evolution of cylinder grip, finger extension, pinch grips, lateral grip, and three-point grip in each therapy group to determine the more effective passive movement training. Results: Both the RAT group ($p < 0.001$) and the FES group ($p < 0.01$) demonstrated a statistically significant improvement in all parameters. Patients who received PT and FES exhibited more significant improvement in each movement, except for the pinch index grip, where the RAT group showed superior results. Conclusions: Our findings indicate the positive effects of both PMTs on hand function rehabilitation. We recommend incorporating both therapies into rehabilitation programs for enhanced outcomes.

Keywords: cerebral palsy; hand function; passive movement training; robot-assisted therapy; electrical stimulation

Introduction

Cerebral palsy (CP), a neurological condition that profoundly impacts movement and posture, delves into a complex realm of challenges that extend far beyond its definition. Originating from damage to the developing brain, often occurring before birth, during childbirth, or shortly after that, CP presents a heterogeneous landscape of symptoms and manifestations. As the primary cause of physical impairment in children, the prevalence of CP has been a subject of epidemiological scrutiny, with estimations placing it affecting approximately 17 million individuals worldwide [1]. The reported prevalence has seen a decline from 2.1 per 1000 live births in 2013 [2] to 1.6 per 1000 in 2022 [3], exhibiting considerable heterogeneity between low- and middle-income countries (2.3-3.7 per 1000) and high-income countries (1.5 per 1000). This condition presents various physical and developmental challenges, including muscle coordination, balance, and motor skills. With a spectrum ranging from mild to severe, individuals with CP exhibit varying levels of independence and functional abilities. Within the expansive spectrum of CP, upper limb disorders emerge as a critical facet, demanding nuanced attention and targeted interventions. Research indicates that more than 80% of individuals with CP experience upper limb impairment, characterized by various challenges that significantly influence hand functionality [4]. This high prevalence underscores the pivotal role of understanding and addressing hand impairment in spastic CP.

In exploring the intricacies of hand impairment within the realm of spastic CP, it is essential to delve into the specific manifestations and consequences faced by individuals with this condition. Spasticity, a hallmark feature of spastic CP, manifests as increased muscle tone, leading to stiff and rigid muscles, significantly impacting hand movements, and impairing fine motor skills, precision, and overall dexterity [5,6].

One of the critical manifestations of hand impairment in spastic CP is diminished hand control. The intricate interplay between the nervous system and musculature, disrupted by the underlying neurological damage, contributes to challenges in executing precise hand movements. This lack of control extends beyond the physical realm, influencing the ability to manipulate objects, perform daily tasks, and engage in activities that demand coordinated hand movements.

Moreover, the development of contractures adds another layer of complexity to hand impairment in spastic CP. Contractures involve the permanent shortening of muscles and tendons, leading to a restriction in joint movement. In the context of hand impairment, contractures can result in deformities and malalignments, further hindering the functional capabilities of the hand. Addressing contractures becomes a crucial aspect of rehabilitation programs aimed at improving hand functionality in individuals with spastic CP.

The consequences of hand impairment reverberate throughout various facets of an individual's life. Abnormal postures adopted due to compromised hand control and the presence of contractures can lead to secondary musculoskeletal issues. These issues, in turn, contribute to a cycle of challenges, impacting not only hand abilities but also overall independence, participation in daily activities, and the quality of life of individuals with spastic cerebral palsy [7].

Recent studies have shed light on the profound correlation between upper limb functionality and independence in both activities of daily living and instrumental activities of daily living [8–10]. Thus, the critical importance of targeted interventions addressing hand impairment in spastic CP is not only for the immediate enhancement of hand functionality but also for fostering independence and improving the overall quality of life for affected individuals.

The impact of CP extends beyond the individual diagnosed with the condition and profoundly affects the entire family. The challenges posed by activity limitations and participation restrictions often create a ripple effect, encompassing emotional, financial, and social dimensions and the overall quality of life for the individual and his family [11,12].

The multifaceted nature of hand impairment in spastic CP necessitates a holistic approach to rehabilitation. Recognizing the diverse challenges faced by individuals with CP, especially concerning hand functionality, rehabilitation programs aim to address a myriad of goals. These encompass the maintenance and improvement of joint range, prevention of adhesion, contracture, and damage caused by immobilization, reduction of pain, edema, and hypertonia, proprioceptive stimulation, improved metabolism of joints, and lymphatic and blood circulation, maintenance of functional afference and perception of one's body, increased coordination, dexterity, and functional independence, augmented grasping and pinching strength, and improved visual-spatial and attentive capacities.

Understanding hand impairment in spastic CP goes beyond recognizing the physical challenges; it extends to embracing the intricate interplay of neurological, musculoskeletal, and functional aspects. A comprehensive exploration of hand impairment necessitates an appreciation for the individualized experiences of those affected, recognizing the unique journey each person traverses in navigating the complexities of living with spastic CP. As we delve deeper into the realm of hand impairment, we uncover not just challenges but also resilience, adaptability, and the potential for transformative interventions that can significantly enhance the lives of individuals grappling with the multifaceted impact of spastic CP on hand functionality.

Physical therapy (PT) is pivotal in the comprehensive rehabilitation of individuals with CP, particularly in addressing hand impairment [13,14]. The primary goal of PT in this context is to enhance and optimize hand functionality, allowing individuals to achieve greater independence, improved quality of life, and increased participation in daily activities. PT in CP hand rehabilitation is a comprehensive and dynamic process that targets specific impairments and considers individuals' holistic needs and goals. By addressing the unique challenges presented by hand impairment in CP through a tailored and evolving rehabilitation plan, PT contributes significantly to improving hand functionality and enhancing the overall quality of life for individuals living with CP [15].

Functional Electrical Stimulation (FES) is an innovative and promising approach in CP hand rehabilitation. This technique involves the application of electrical impulses to stimulate targeted muscles or nerves, aiming to improve motor function and enhance overall hand functionality in individuals with CP [16]. FES can target specific muscles in the hand that may be weakened or underused due to CP. FES activates these muscles by delivering controlled electrical impulses, facilitating contractions, and improving strength [17]. FES interventions also enhance muscle coordination, promoting more controlled and purposeful movements in the hand. They can be tailored to stimulate muscles involved in grasping and pinching movements to enhance the precision and strength of these essential hand functions [18–21]. FES also has the potential to reduce spasticity by providing sensory input and promoting more controlled muscle activity. It is often used to facilitate active movement in individuals with limited voluntary control over specific muscles. Through repetitive and task-specific FES interventions, individuals with cerebral palsy may experience positive changes in neural pathways, promoting motor learning. FES can be considered an adjunctive tool in CP hand rehabilitation. By addressing specific challenges related to muscle weakness, coordination deficits, and spasticity, FES contributes to a holistic approach to enhancing hand functionality and improving the overall quality of life for individuals living with CP.

Robot-assisted therapy (RAT) using Gloreha Sinfonia represents an advanced rehabilitation therapy based on a device designed to aid in hand rehabilitation for various neurological conditions, including CP [22–25]. The device offers a personalized and engaging approach to support individuals in their journey towards improved hand functionality and greater independence through its features, such as adjustable intensity, task-specific training, and monitoring capabilities. This device provides targeted and controlled passive movement training for the hand and supports various hand movements, including gripping, releasing, and fine motor skill exercises. It assists individuals with limited voluntary control or range of motion in their hands due to CP, facilitating active movement by providing mechanical support and encouraging individuals to engage in purposeful hand exercises. It supports task-specific training, enabling individuals to practice activities relevant to daily life, and improves the transfer of skills learned during rehabilitation to real-world situations. Through repetitive and task-specific training, the device encourages motor learning and the formation of new neural pathways, and through controlled and guided movements, it contributes to improving hand coordination and dexterity. Gamification-incorporated elements turn the rehabilitation sessions into enjoyable activities that encourage participation and ultimately lead to greater independence in daily activities.

We delved into a comprehensive examination and measurement of the impacts of FES and RAT when used in conjunction with PT. We aimed to pinpoint the enhancements achieved by each of these therapies regarding the patient's hand's range of motion, muscle strength, and coordination within the context of cerebral palsy. Despite scrutinizing the existing body of literature, we found a noticeable absence of articles that undertook comparative studies to elucidate the distinct advantages offered by these two therapeutic approaches.

2. Results

The study group comprised 58 patients divided into the Robot-Assisted Therapy (RAT) and Functional Electrical Stimulation (FES) groups. The RAT group included 42 patients, 26 girls and 16 boys aged between 7 and 14 years. All were diagnosed with spastic cerebral palsy, with 28 having hemiplegia, 2 with quadriplegia, and 12 with diplegia, all presenting impaired hand functionality. The FES group consisted of 16 girls aged between 12 and 14 years, with 14 having hemiplegia and 2 with tetraplegia.

According to the origin environment, 27 patients came from urban areas and 31 from rural ones (Figure 1).

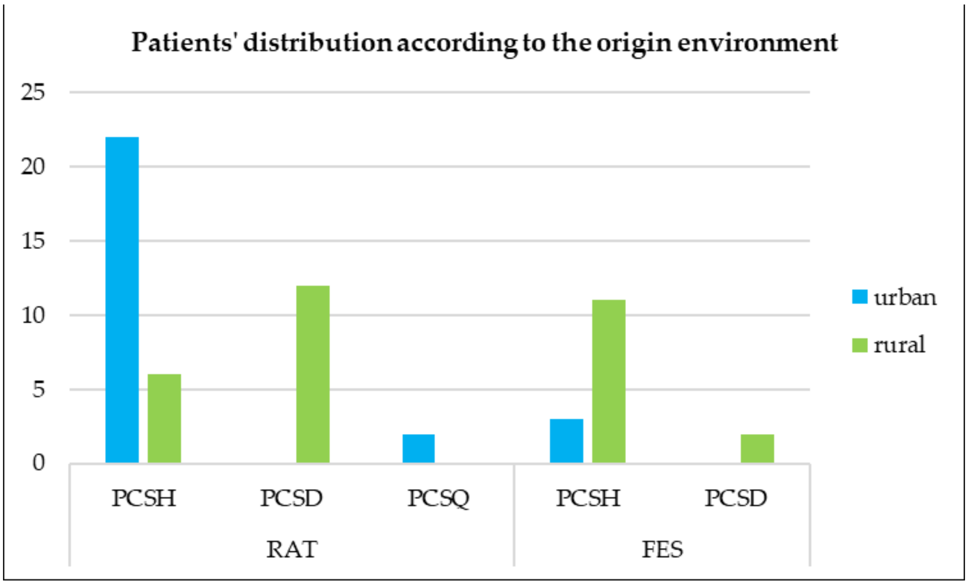

Figure 1. Patients' distribution according to the origin environment and type of CP

Regarding the affected side, 60% of the patients had the right side predominantly affected, as shown in Figure 2.

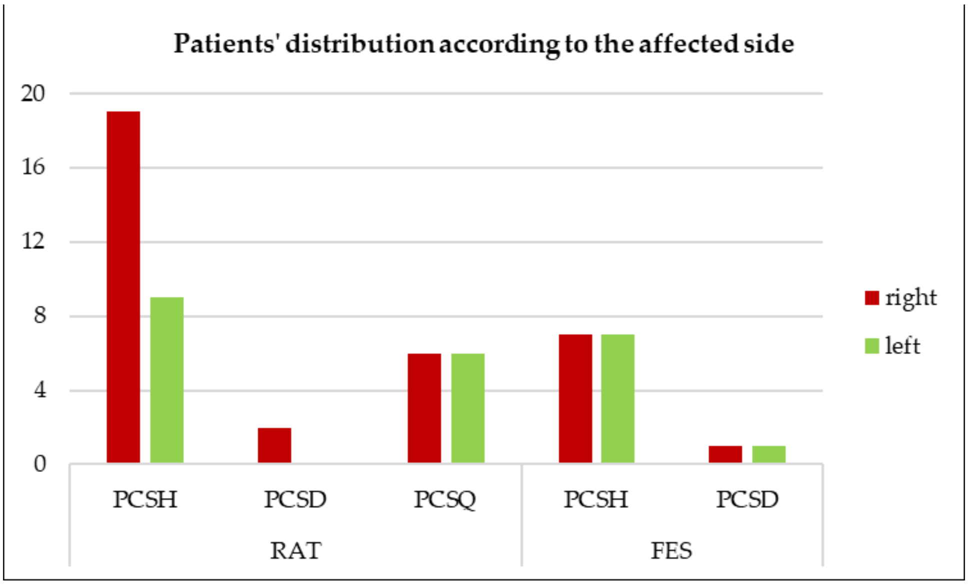

Figure 2. Patients' distribution according to the affected side and type of CP

A comparative analysis of hand movement performance parameters was conducted at admission (A) and discharge (D) using the t-test to compare paired samples (Table 1).

- Null hypothesis: No differences exist between the two sets of measurements.
- Alternative hypothesis: Differences exist between the two groups of variables expressing coordination at admission and discharge.

Table 1. Evolution of hand movement parameters

Paired Samples Statistics						
Therapy			Mean	N	Std. Deviation	Std. Error Mean
RAT	Pair 1	cylinder_grip_D	3.9262	42	2.32170	0.35825
		cylinder_grip_A	2.4738	42	2.33082	0.35965
	Pair 2	fingers_extension_D	0.2238	42	0.19731	0.03045
		fingers_extension_A	0.0929	42	0.13324	0.02056
	Pair 3	pinch_index_D	1.0952	42	0.55346	0.08540
		pinch_index_A	0.6786	42	0.53444	0.08247
	Pair 4	pinch_middle_D	1.0429	42	0.57558	0.08881
		pinch_middle_A	0.6476	42	0.51572	0.07958
	Pair 5	pinch_ring_D	0.8690	42	0.42224	0.06515
		pinch_ring_A	0.5429	42	0.43569	0.06723
	Pair 6	pinch_little_D	0.5310	42	0.32271	0.04979
		pinch_little_A	0.2976	42	0.28412	0.04384
	Pair 7	lateral_grip_D	1.8452	42	0.81934	0.12643
		lateral_grip_A	1.3143	42	0.85784	0.13237
	Pair 8	three_point_grip_D	1.4548	42	0.82586	0.12743
		three_point_grip_A	0.9810	42	0.80886	0.12481
FES	Pair 1	cylinder_grip_D	10.0688	16	5.69862	1.42466
		cylinder_grip_A	7.4313	16	4.67058	1.16764
	Pair 2	fingers_extension_D	1.8938	16	1.05923	0.26481
		fingers_extension_A	1.4813	16	1.03552	0.25888
	Pair 3	pinch_index_D	2.3938	16	1.00695	0.25174
		pinch_index_A	2.0625	16	1.00855	0.25214
	Pair 4	pinch_middle_D	2.3438	16	1.11114	0.27778
		pinch_middle_A	1.9313	16	1.10919	0.27730
	Pair 5	pinch_ring_D	1.7375	16	0.79656	0.19914
		pinch_ring_A	1.3000	16	0.78740	0.19685
	Pair 6	pinch_little_D	0.7875	16	0.46601	0.11650
		pinch_little_A	0.5063	16	0.25682	0.06421
	Pair 7	lateral_grip_D	5.2000	16	1.60748	0.40187
		lateral_grip_A	4.3875	16	1.82716	0.45679
	Pair 8	three_point_grip_D	3.3563	16	1.29510	0.32378
		three_point_grip_A	2.7938	16	1.35424	0.33856

There is a lower value of all hand movement parameters at admission than discharge for both groups, RAT and FES.

Data analysis indicated a highly significant test ($p < 0.001$) and strong correlations between the two moments (admission and discharge) for all hand movement parameters (Table 2).

Table 2. Correlation between hand movement parameters at admission and discharge

Paired Samples Correlations					
Therapy			N	Correlation	Sig.
RAT	Pair 1	cylinder_grip_D & cylinder_grip_A	42	0.730	0.000
	Pair 2	fingers_extension_D & fingers_extension_A	42	0.712	0.000
	Pair 3	pinch_index_D & pinch_index_A	42	0.782	0.000
	Pair 4	pinch_middle_D & pinch_middle_A	42	0.765	0.000
	Pair 5	pinch_ring_D & pinch_ring_A	42	0.829	0.000
	Pair 6	pinch_little_D & pinch_little_A	42	0.841	0.000
	Pair 7	lateral_grip_D & lateral_grip_A	42	0.665	0.000
	Pair 8	three_point_grip_D & three_point_grip_A	42	0.777	0.000
FES	Pair 1	cylinder_grip_D & cylinder_grip_A	16	0.883	0.000
	Pair 2	fingers_extension_D & fingers_extension_A	16	0.971	0.000
	Pair 3	pinch_index_D & pinch_index_A	16	0.906	0.000
	Pair 4	pinch_middle_D & pinch_middle_A	16	0.887	0.000
	Pair 5	pinch_ring_D & pinch_ring_A	16	0.928	0.000
	Pair 6	pinch_little_D & pinch_little_A	16	0.842	0.000
	Pair 7	lateral_grip_D & lateral_grip_A	16	0.912	0.000
	Pair 8	three_point_grip_D & three_point_grip_A	16	0.917	0.000

The results showed improved hand movement parameters for each therapy (Table 3).

Table 3. Mean value of hand movement parameters for both groups

Paired Samples Test										
Therapy			Paired Differences					t	df	Sig. (2-tailed)
			Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
						Lower	Upper			
RAT	Pair 1	cylinder_grip_D - cylinder_grip_A	1.45238	1.71097	0.26401	0.91920	1.98556	5.501	41	0.000
	Pair 2	fingers_extension_D - fingers_extension_A	0.13095	0.13879	0.02142	0.08770	0.17420	6.115	41	0.000
	Pair 3	pinch_index_D - pinch_index_A	0.41667	0.35948	0.05547	0.30464	0.52869	7.512	41	0.000
	Pair 4	pinch_middle_D - pinch_middle_A	0.39524	0.37803	0.05833	0.27744	0.51304	6.776	41	0.000
	Pair 5	pinch_ring_D - pinch_ring_A	0.32619	0.25091	0.03872	0.24800	0.40438	8.425	41	0.000
	Pair 6	pinch_little_D - pinch_little_A	0.23333	0.17484	0.02698	0.17885	0.28782	8.649	41	0.000
	Pair 7	lateral_grip_D - lateral_grip_A	0.53095	0.68734	0.10606	0.31676	0.74514	5.006	41	0.000
	Pair 8	three_point_grip_D - three_point_grip_A	0.47381	0.54552	0.08418	0.30381	0.64380	5.629	41	0.000
FES	Pair 1	cylinder_grip_D - cylinder_grip_A	2.63750	2.69960	0.67490	1.19899	4.07601	3.908	15	0.001
	Pair 2	fingers_extension_D - fingers_extension_A	0.41250	0.25265	0.06316	0.27787	0.54713	6.531	15	0.000
	Pair 3	pinch_index_D - pinch_index_A	0.33125	0.43775	0.10944	0.09799	0.56451	3.027	15	0.008

	Pair 4	pinch_middle_D - pinch_middle_A	0.41250	0.52773	0.13193	0.13129	0.69371	3.127	15	0.007
	Pair 5	pinch_ring_D - pinch_ring_A	0.43750	0.30083	0.07521	0.27720	0.59780	5.817	15	0.000
	Pair 6	pinch_little_D - pinch_little_A	0.28125	0.28570	0.07143	0.12901	0.43349	3.938	15	0.001
	Pair 7	lateral_grip_D - lateral_grip_A	0.81250	0.75000	0.18750	0.41285	1.21215	4.333	15	0.001
	Pair 8	three_point_grip_D - three_point_grip_A	0.56250	0.54391	0.13598	0.27267	0.85233	4.137	15	0.001

The analysis of the possible correlations between movement parameters, therapy, and the type of CP showed the following statistically significant correlation:

- Moderate positive correlation between therapy and cylinder grip ($p < 0.0001$, $r = 0.618$), therapy and pinch index ($p < 0.0001$, $r = 0.643$), therapy and pinch middle ($p < 0.0001$, $r = 0.616$), therapy and pinch ring ($p < 0.0001$, $r = 0.585$), and therapy and three-point grip ($p < 0.0001$, $r = 0.664$)
- Strong positive correlations between therapy and fingers extension ($p < 0.0001$, $r = 0.798$), and therapy and lateral grip ($p < 0.0001$, $r = 0.814$)
- Moderate positive correlation between cylinder grip and pinch little ($p < 0.0001$, $r = 0.699$)
- Strong positive correlations between cylinder grip and finger extension ($p < 0.0001$, $r = 0.798$), cylinder grip and pinch index ($p < 0.0001$, $r = 0.811$), cylinder grip and pinch middle ($p < 0.0001$, $r = 0.832$), cylinder grip and pinch ring ($p < 0.0001$, $r = 0.839$), cylinder grip and lateral grip ($p < 0.0001$, $r = 0.768$), and cylinder grip and three-point grip ($p < 0.0001$, $r = 0.844$)
- Moderate positive correlation between fingers extension and pinch little ($p < 0.0001$, $r = 0.528$)
- Strong positive correlation between fingers extension and pinch index ($p < 0.0001$, $r = 0.876$), fingers extension and pinch middle ($p < 0.0001$, $r = 0.828$), fingers extension and pinch ring ($p < 0.0001$, $r = 0.825$), fingers extension and lateral grip ($p < 0.0001$, $r = 0.894$), and fingers extension and three-point grip ($p < 0.0001$, $r = 0.830$)
- Moderate positive correlation between pinch index and pinch little ($p < 0.0001$, $r = 0.683$)
- Strong positive correlation between pinch index and lateral grip ($p < 0.0001$, $r = 0.868$)
- Very strong positive correlation between pinch index and pinch middle ($p < 0.0001$, $r = 0.953$), pinch index and pinch ring ($p < 0.0001$, $r = 0.910$), and pinch index and three-point grip ($p < 0.0001$, $r = 0.926$)
- Strong positive correlation between pinch middle and pinch little ($p < 0.0001$, $r = 0.724$), and pinch middle and lateral grip ($p < 0.0001$, $r = 0.871$)
- Very strong positive correlation between pinch middle and pinch ring ($p < 0.0001$, $r = 0.913$), and pinch middle and three-point grip ($p < 0.0001$, $r = 0.942$)
- Strong positive correlation between pinch ring and pinch little ($p < 0.0001$, $r = 0.844$), and pinch ring and lateral grip ($p < 0.0001$, $r = 0.825$)
- Very strong positive correlation between pinch grip and three-point grip ($p < 0.0001$, $r = 0.908$)
- Moderate positive correlation between pinch little and lateral grip ($p < 0.0001$, $r = 0.555$)
- Strong positive correlation between pinch little and three-point grip ($p < 0.0001$, $r = 0.702$)
- Very strong positive correlation between lateral grip and three-point grip ($p < 0.0001$, $r = 0.908$)
- All values of hand movement parameters at discharge were correlated with those at admission: strong correlation for cylinder grip ($p < 0.0001$, $r = 0.887$), pinch little ($p < 0.0001$, $r = 0.839$), and very strong correlation for fingers extension ($p < 0.0001$, $r = 0.979$), pinch index ($p < 0.0001$, $r = 0.915$), pinch middle ($p < 0.0001$, $r = 0.900$), pinch ring ($p < 0.0001$, $r = 0.918$), lateral grip ($p < 0.0001$, $r = 0.926$), and three-point grip ($p < 0.0001$, $r = 0.911$).

The evolution of hand movement parameters following RAT respectively FES therapy, is graphically represented in Figure 3.

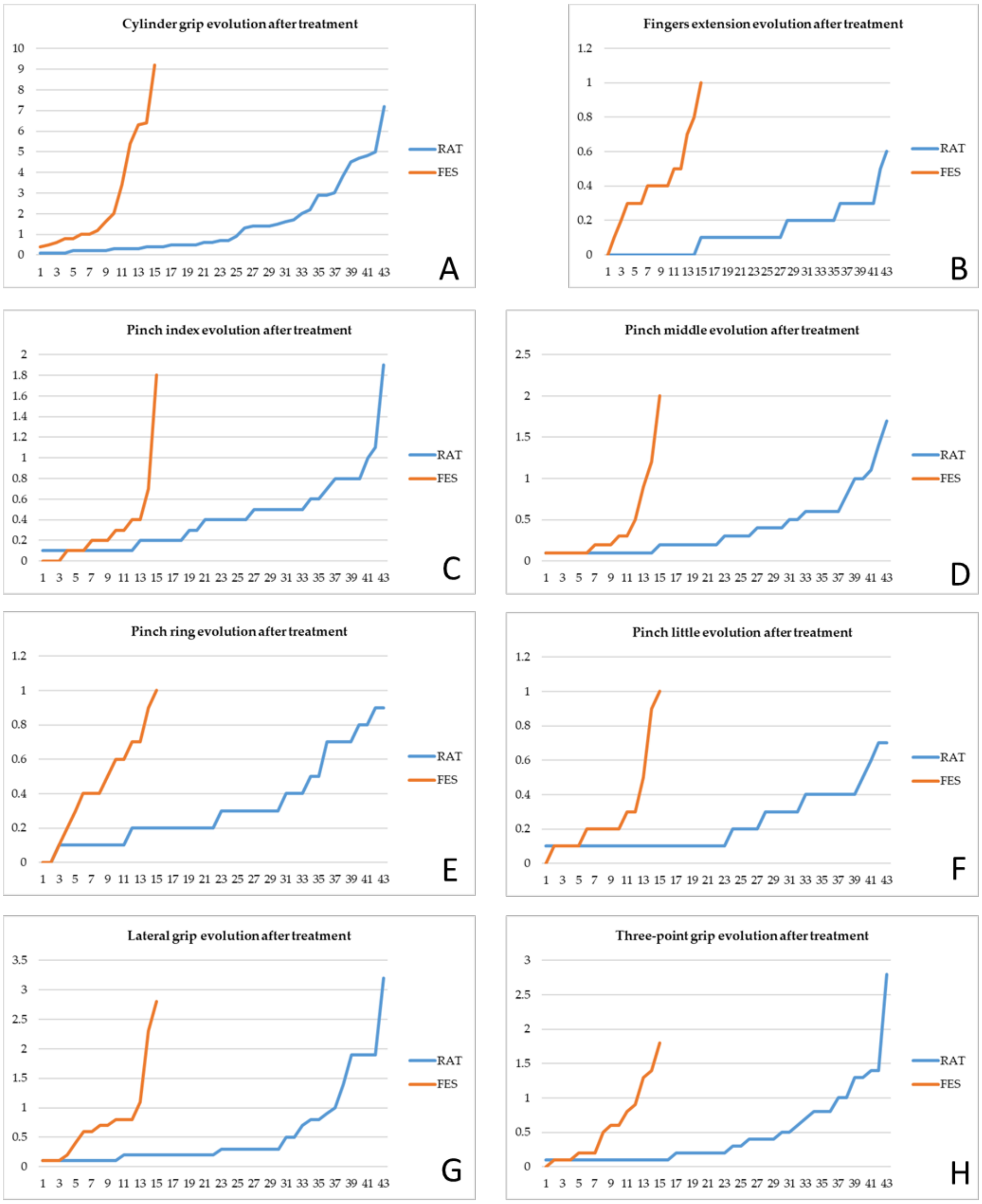

Figure 3. Evolution of hand movement parameters after treatment (A - Cylinder grip. B – Fingers extension. C – Pinch index. D – Pinch middle. E – Pinch ring. F – Pinch little. G – Lateral grip. H – Three-point grip)

3. Discussion

Both rehabilitation programs – robot-assisted therapy combined with physical therapy (RAT-PT) and functional electrical stimulation combined with physical therapy (FES-PT) – positively affect all analyzed parameters. Our results show a more significant improvement in hand movement parameters after FES compared to RAT in patients with CP. Furthermore, no correlations have been found between the type of CP and the evolution of hand movement parameters, nor between the affected side and these parameters.

Patients with higher initial values of grip strength, cylinder grip, finger extension, pinch, lateral grip, and three-point grip at the start of the rehabilitation program demonstrated a more favorable evolution, quantified by improved values in these parameters.

The findings from our research are corroborated by the results documented in specialized literature, where both Functional Electrical Stimulation (FES) [26–29] and Robotic-Assisted Therapy (RAT) [23,30,31] demonstrate a consistent enhancement in the functionality of the hands in patients with cerebral palsy (CP).

Our study has certain limitations. Firstly, we could not withhold patients from receiving all prescribed therapies in the recovery program due to ethical considerations. Consequently, we could not establish a control group exclusively undergoing Physical Therapy (PT) without Robotic-Assisted Therapy (RAT) or Functional Electrical Stimulation (FES). This limitation hindered our ability to isolate the effects of these specific interventions precisely. Simultaneously, the patient's conditions could notably impact the intervention results. For instance, fatigue can diminish concentration ability, leading to decreased motor performance and, consequently, to potential biases.

We intend to continue the study to follow the long-term effects of the two specific interventions and increase the sample size. A future study with more participants will ensure that the results accurately portray the distinct influence of each intervention on hand function in individuals with cerebral palsy (CP).

4. Materials and Methods

The study was conducted between July and October 2023 and involved 58 patients aged 7 to 14 years diagnosed with spastic cerebral palsy, receiving treatment at the Department of Neuropsychomotor Rehabilitation of Children at the National University Center for Children Neurorehabilitation 'Dr. Nicolae Robanescu'.

Patient Selection Criteria:

Inclusion criteria: Diagnostic of spastic CP with hand function impairment, age ranging from 5 to 18 years, spasticity on modified Ashworth Scale (mAS) < 3, and an acceptable level of cooperation for the RAT group (IQ ≥ 80) [32].

Exclusion criteria: Additional interfering diseases, recent surgery, unstable or inadequately consolidated fractures, bone deformity, severe spasticity (mAS > 3), skin eruptions, infected, or inflamed areas of the forearm, wrist, or hand level, severe mental retardation, communication problems, hyperactivity, attention deficit disorder. The FES group has four additional exclusion criteria: seizure, metal implants, pacemaker, and oncological pathology.

The FES group consisted of patients with IQ < 80 who met the additional criteria for inclusion in this group.

Before commencing the study, we provided comprehensive information to the parents of the patients regarding each therapeutic intervention their child would undergo, including a thorough explanation of the potential risks involved. It was emphasized that the patient would receive complete medical services irrespective of their participation in the study. Patients had the autonomy to withdraw from the study at any moment without facing any consequences. Only those patients whose parents provided written consent were included in the study. The study received approval from the Ethics Committee of the National University Center for Children Neurorehabilitation 'Dr. Nicolae Robanescu.'

According to the functional hand rehabilitation program, there were two groups of patients. The RAT group received classical physical therapy (PT) and robot-assisted therapy, and the FES group received PT and functional electrical stimulation (FES).

During the two-week rehabilitation program, all patients received twice-daily 30-minute PT sessions, including passive muscle stretching, proprioceptive neuromuscular facilitation, and joint mobilization.

The RAT group also participated in a 15-minute session/day of passive hand movement with the Gloreha Sinfonia device. Gloreha is an upper limb neuromotor rehabilitation support device that can passively mobilize the metacarpophalangeal, proximal interphalangeal, and distal interphalangeal finger joints, associating a series of visual and acoustic stimuli with motor therapy. It enables the performance of passive mobilization exercises accompanied by simultaneous, three-dimensional representation on screen and functional tasks with real objects. The passive exercises with Gloreha consisted in:

- Single Finger Sequence (individual flexion and extension of the fingers, in order from thumb to little finger)
- Fist (Flexion of the index, middle, ring, and little fingers; Flexion of the thumb; Extension of the thumb; Extension of the index, middle, ring, and little fingers.
- Counting (functional movements for counting with fingers, from 1 to 5)
- Pinches Sequence (Thumb-index; Thumb-middle; Thumb-ring; Thumb-little)
- Handle (Flexion and extension of the thumb; Flexion and extension of the index, middle, ring, and little fingers)
- Wave (flexion from the little finger to the thumb and extension from the thumb to the little finger to create a harmonic "wave" effect)
- Single Finger Randomc (flexion and extension of each finger separately in a random sequence)
- Random Numbers (movements associated with the numbers from zero to five, in random order)
- Picking Objects (functional movements of grasping an object with two fingers - the thumb and the index finger)
- Grasping Objects (functional exercises of grasping an object with the whole hand).

In contrast, the FES group received an additional 15-minute session/day of electrical stimulation using the H200 Wireless Hand Rehabilitation System (H200 System), which generates the electrical stimulation to open and close your hand and move your thumb. The H200 System has an integrated radio frequency stimulation unit and five stimulating electrodes and responds to wireless signals from a control unit to turn stimulation on and off and adjust the stimulation intensity level. At the beginning of each FES session, a test stimulation of the extensor muscles, which open the hand and extend the fingers, and of the flexor muscles, which close the hand, was performed. The FES parameters were:

- Pulse: Balanced Biphasic
- Waveform: Symmetric
- Intensity (Peak): 0–80 mA, 1-mA resolution (positive phase)
- Positive Pulse Duration: 100 μsec
- Negative Pulse Duration: 100 μsec
- Inter-Phase Interval: 50 μsec
- Max Power Load: 500 ohm (80 mA, 120 V)
- Pulse Repetition Rate: 20–45 Hz, 5-Hz resolution
- Ramp Up: 0–3.1 seconds
- Ramp Down: 0–3.1 seconds

Patients were assessed at admission and discharge. Data collection included sociodemographic information and movement performance assessed with computerized dynamometry, measuring the strength of cylinder grip, finger extension, pinch index, pinch middle, pinch ring, pinch little, lateral grip, and three-point grip.

Statistical Data Processing:

IBM SPSS Statistics 26 was used for data processing. In our investigation, we sought to uncover potential connections between therapeutic interventions, the intricacies of hand movements, and the interplay among different hand movements. To rigorously assess these relationships, we employed two key statistical metrics: statistical significance denoted by "p" values and the Pearson correlation coefficient represented by "r."

Firstly, the paired sample t-test emerged as a pivotal tool in determining the average discrepancy between observations recorded at the initiation and conclusion of the study across various parameters related to movement performance, which allowed us to discern statistically significant changes and quantify the effectiveness of the therapeutic approaches under scrutiny. To lend further credibility to our findings, we set a stringent criterion for statistical significance at $p < 0.05$, ensuring a high level of confidence in the observed outcomes.

Moreover, the Pearson correlation coefficient, ranging from -1 to 1, was employed to elucidate the strength and direction of the relationships between different datasets. A coefficient closer to 1 indicated a strong positive correlation, suggesting that as one variable increased, the other also tended to increase. Conversely, a coefficient near -1 signaled a robust negative correlation, implying that as one variable increased, the other tended to decrease. A coefficient around 0 indicated a lack of a linear relationship between the datasets. This comprehensive statistical analysis allowed us to establish the significance of observed changes and delve into the nuanced dynamics of correlations within our data sets.

5. Conclusions

Both functional electrical stimulation and robot-assisted therapy, when added as supplementary rehabilitation techniques to physical therapy, positively impact hand movement functional rehabilitation. Although electrical stimulation has more pronounced effects than robot-assisted therapy, we recommend incorporating both techniques into the rehabilitation program to achieve optimal results.

Author Contributions: Conceptualization, C.S. and M.V.M.; methodology, C.S., M.V.M., and A.M.; software, C.S.; validation, C.S., M.V.M., and A.M.; formal analysis, C.S., M.V.M., and A.M.; investigation, C.S.; resources, C.S., M.V.M., and A.M.; data curation, C.S. and M.V.M.; writing—original draft preparation, C.S., M.V.M., M.M., and A.M.; writing—review and editing, C.S., M.V.M., and A.M..; visualization, C.S., M.V.M., M.M., and A.M.; supervision, C.S.; project administration, C.S. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: The study complies with the Declaration of Helsinki and was approved by the Ethics Committee of the National University Center for Children Neurorehabilitation "Dr. Nicolae Robanescu" (protocol code 9305, approved on 19 July 2023).

Informed Consent Statement: Informed consent was obtained from all subjects' parents involved in the study. Written informed consent to publish this paper has been obtained from the patients' parents.

Data Availability Statement: The data presented in this study are available on request from the corresponding author.

Acknowledgments: We would like to thank Anca Constantin and Bogdan Pirvu from the National University Center for Children Neurorehabilitation "Dr. Nicolae Robanescu", for their help in evaluating patients. We would also like to thank all the children and their families who participated in our research.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Graham HK, Rosenbaum P, Paneth N, Dan B, Lin JP, Damiano DL, et al. Cerebral palsy. Nat Rev Dis Prim. 2016;2:15082.
2. Oskoui M, Joseph L, Dagenais L, Shevell M. Prevalence of cerebral palsy in Quebec: Alternative approaches. Neuroepidemiology. 2013;40(4):264–8.
3. McIntyre S, Goldsmith S, Webb A, Ehlinger V, Hollung SJ, McConnell K, et al. Global prevalence of cerebral palsy: A systematic analysis. Dev Med Child Neurol. 2022;64(12):1494–506.
4. Makki D, Duodu J, Nixon M. Prevalence and pattern of upper limb involvement in cerebral palsy. J Child Orthop. 2014;8(3):215–9.
5. Arnould C, Bleyenheuft Y, Thonnard J-L. Hand functioning in children with cerebral palsy. Front Neurol. 2014;5:48.
6. Vaz DV, Cotta M, Fonseca ST, De Melo Pertence AE. Muscle stiffness and strength and their relation to hand function in children with hemiplegic cerebral palsy. Dev Med Child Neurol. 2006;48(9):728–33.
7. Sakzewski L, Ziviani J, Boyd RN. Efficacy of upper limb therapies for unilateral cerebral palsy: a meta-analysis. Pediatrics. 2014;133(1):e175–204.

8. Sporea C, Ferechide D, Florescu MS, Cristescu I. Comparative assessment of dexterity tests results using two internationally recognized scales in patients with cerebral palsy, users of medical textiles. Ind Textila. 2020;71(4):388–92.
9. Pérez-Mármol JM, García-Ríos MC, Ortega-Valdivieso MA, Cano-Deltell EE, Peralta-Ramírez MI, Ickmans K, et al. Effectiveness of a fine motor skills rehabilitation program on upper limb disability, manual dexterity, pinch strength, range of fingers motion, performance in activities of daily living, functional independency, and general self-efficacy in hand osteoart. J Hand Ther. 2017;30(3):262–73.
10. Haaland KY, Mutha PK, Rinehart JK, Daniels M, Cushnyr B, Adair JC. Relationship between arm usage and instrumental activities of daily living after unilateral stroke. Arch Phys Med Rehabil. 2012;93(11):1957–62.
11. Dlamini MD, Chang Y-J, Nguyen TTB. Caregivers' experiences of having a child with cerebral palsy. A meta-synthesis. J Pediatr Nurs. 2023;73:157–68.
12. Sporea C, Orzan OA, Florescu MS, Cristescu I. Improving the perspectives on quality of life for adolescents with cerebral palsy by medical textile. Ind TEXTILA Editor BOARD. 2020;80.
13. Miller F. Cerebral Palsy. Springer-Verlag New York; 2005.
14. Miller F, Bachrach SJ. Cerebral palsy: A complete guide for caregiving. JHU Press; 2017.
15. Bjornson KF, Belza B, Kartin D, Logsdon R, McLaughlin J, Thompson EA. The relationship of physical activity to health status and quality of life in cerebral palsy. Pediatr Phys Ther Off Publ Sect Pediatr Am Phys Ther Assoc. 2008;20(3):247.
16. Yıldızgören MT, Yüzer GFN, Ekiz T, Özgirgin N. Effects of neuromuscular electrical stimulation on the wrist and finger flexor spasticity and hand functions in cerebral palsy. Pediatr Neurol. 2014;51(3):360–4.
17. Wright PA, Granat MH. Therapeutic effects of functional electrical stimulation of the upper limb of eight children with cerebral palsy. Dev Med Child Neurol. 2000;42(11):724–7.
18. Mouthon LCG. Using Functional Electrical Stimulation to Improve Upper Limb Function: Determining Feasibility and Effectiveness in Children with Hemiplegic Cerebral Palsy. University of Toronto (Canada); 2017.
19. Sporea C, Ferechide D. Benefits of upper limb functional electrical stimulation in children with spastic cerebral palsy. Mod Med. 2021;28(2).
20. Bang H-S, Kim D-H. The effects of functional electrical stimulation on hand function of children with spastic cerebral palsy. J Korean Acad Sens Integr. 2016;14(2):1–10.
21. Johnston TE, Finson RL, McCarthy JJ, Smith BT, Betz RR, Mulcahey MJ. Use of functional electrical stimulation to augment traditional orthopaedic surgery in children with cerebral palsy. J Pediatr Orthop. 2004;24(3):283–91.
22. Bressi F, Santacaterina F, Cricenti L, Campagnola B, Nasto F, Assenza C, et al. Robotic-Assisted Hand Therapy with Gloreha Sinfonia for the Improvement of Hand Function after Pediatric Stroke: A Case Report. Appl Sci. 2022;12(9).
23. Jouaiti M, Dautenhahn K. Robot-assisted therapy for upper limb impairments in cerebral palsy: A scoping review and suggestions for future research. Paladyn, J Behav Robot. 2023;14(1):20220104.
24. Vanoglio F, Bernocchi P, Mulè C, Garofali F, Mora C, Taveggia G, et al. Feasibility and efficacy of a robotic device for hand rehabilitation in hemiplegic stroke patients: a randomized pilot controlled study. Clin Rehabil. 2017;31(3):351–60.
25. Bressi F, Cricenti L, Bravi M, Pannunzio F, Cordella F, Lapresa M, et al. Treatment of the Paretic Hand with a Robotic Glove Combined with Physiotherapy in a Patient Suffering from Traumatic Tetraparesis: A Case Report. Sensors. 2023;23(7).
26. Yildizgören MT, Nakipoğlu Yüzer GF, Ekiz T, Özgirgin N. Effects of neuromuscular electrical stimulation on the wrist and finger flexor spasticity and hand functions in cerebral palsy. Pediatr Neurol [Internet]. 2014;51(3):360–4. Available from: http://dx.doi.org/10.1016/j.pediatrneurol.2014.05.009
27. Ou CH, Shiue CC, Kuan YC, Liou TH, Chen HC, Kuo TJ. Neuromuscular Electrical Stimulation of Upper Limbs in Patients With Cerebral Palsy. Am J Phys Med Rehabil. 2023;102(2):151–8.
28. Rodriguez-Reyes G, Alessi-Montero A, Díaz-Martínez L, Miranda-Duarte A, Pérez-Sanpablo AI. Botulinum toxin, physical and occupational therapy, and neuromuscular electrical stimulation to treat spastic upper limb of children with cerebral palsy: A pilot study. Artif Organs. 2010;34(3):230–4.
29. Wright PA, Durham S, Ewins DJ, Swain ID. Neuromuscular electrical stimulation for children with cerebral palsy: A review. Arch Dis Child. 2012;97(4):364–71.
30. Lins AA, de Oliveira JM, Rodrigues JJPC, de Albuquerque VHC. Robot-assisted therapy for rehabilitation of children with cerebral palsy - A complementary and alternative approach. Comput Human Behav [Internet]. 2019;100:152–67. Available from: https://doi.org/10.1016/j.chb.2018.05.012
31. Kim C. Comprehensive Physiotherapy Approaches for Children With Cerebral Palsy: Overview and Contemporary Trends. Phys Ther Korea. 2023;30(4):253–60.
32. Groth-Marnat G. Handbook of psychological assessment. John Wiley & Sons; 2003.