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Original Article

A Comparison Between Biofeedback and Electrical Stimulation in Improving Hand Function in Hemiplegic Cerebral Palsy Children

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Abstract:
objectives: This study provided evidence on the comparative benefits of biofeedback and electrical stimulation for improving hand function in children with cerebral palsy. **Methods:** Forty-five children, aged 6-8 years with mild to moderate spastic hemiplegic cerebral palsy, were randomly assigned to three groups - biofeedback, electrical stimulation, and control. The control group received standard neurodevelopmental therapy and exercises. The biofeedback group additionally received auditory feedback during wrist extensor exercises. The electrical stimulation group received reciprocal stimulations of the wrist flexors and extensors along with standard therapy. Outcomes measured before and after the 3-month interventions included grasp and visual-motor integration assessed by the Peabody Developmental Motor Scales, Second Edition [PDMS-2], and wrist range of motion measured by manual goniometry. **Results:** These showed significant differences between baseline and post treatment evaluation for both biofeedback and electrical stimulation group while non-significant differences were found for control group in Peabody scale and wrist range of motion. **Conclusion:** EMG biofeedback training and functional electrical stimulation as adjuvant modalities along with conventional occupational therapy exercises improve hand function in children with hemiplegic cerebral palsy.

Keywords: cerebral palsy, hemiplegia, hand function, biofeedback, electrical stimulation.

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1. Introduction

Cerebral palsy is considered the most common physical disability originating in childhood, with a prevalence of approximately 2 to 3 per 1000 live births **[1].** Cerebral palsy [CP] refers to a group of permanent disorders affecting movement and posture that are attributed to non-progressive disturbances occurring in the developing fetal or infant brain **[2].**

The motor disorders of cerebral palsy are often accompanied by secondary musculoskeletal problems as well as disturbances of sensation, cognition, communication, perception, behavior and/or seizure disorder [**3**]. Spasticity is a complex and often disabling symptom for patients with upper motor neuron syndromes [**4**]. Based on the distribution of motor impairments, CP can be classified into several subtypes - spastic hemiplegia, spastic diplegia, spastic quadriplegia, dyskinetic CP, ataxic CP and mixed CP.

Spastic hemiplegia, characterized by greater involvement of one side of the body, is estimated to account for 25 % of all cases of CP [**5**]. In hemiplegic CP, the upper extremity is more affected than the lower extremity due to the motor cortex being more specialized for control of distal limb segments [**6**]. Limitations in hand function and dexterity are a major disability associated with hemiplegic CP that impacts the performance of daily living activities.

Impairments in hemiplegic cerebral palsy such as weakness, spasticity, reduced motor control and sensory deficits contribute to limitations in hand function [**7**]. The upper limb motor disorders include flexor hypertonia, extensor hypotonia, muscle weakness and loss of selective motor control [**8**]. This often leads to development of muscle contractures, deformities and subsequent deterioration in the quality of movement.

The active range of motion is typically limited, especially the extension at the wrist and fingers due to imbalance between flexors and extensors. Grasp patterns are also affected, with children exhibiting primitive grasps relying predominantly on palmar flexion compared to mature pincer grasp patterns [**9**]. Fine motor skills involving in-hand manipulation and finger dexterity are often impaired. Overall hand functioning assessed through validated scales is substantially below normal levels in hemiplegia [**10**].

The hand motor deficits negatively impact the child's ability to perform common daily tasks such as dressing, grooming, eating and playing [10]. The impaired limb usually develops compensatory methods of task performance rather than true recovery of motor ability. With severe limitations in motor skills and hand function, the affected upper limb is at risk of being excluded from purposeful use [**11**].

Though cerebral palsy involves non-progressive damage, the brain has the capacity to reorganize and change throughout an individual's lifespan based on experiences, which is termed as neuroplasticity [**12**]. Following the initial insult to the developing brain, use-dependent plasticity occurs in motor areas as the child learns to move and interact within the constraints imposed by spasticity, weakness or reduced control [**13**]. Maladaptive changes can arise from development of compensatory movement patterns. However, rehabilitation techniques that target intensive skill training may induce beneficial cortical reorganization.

There is increasing evidence from neurophysiological and neuroimaging studies regarding plasticity of motor networks in CP [**14**]. Reorganization of central motor pathways has been demonstrated after interventions using constraint-induced therapy, bimanual training and goal-directed training [**15**]. Adjuvant neuromodulatory techniques such as electrical stimulation, biofeedback or pharmacological agents may enhance neuroplastic changes in conjunction with motor training [**16**]. Targeting the residual sensorimotor networks using activity-dependent plasticity approaches may lead to more optimal motor outcomes in cerebral palsy.

Given the significant disability and effects on quality of life imposed by impaired hand function, developing effective therapeutic methods to address upper limb problems is an important goal in cerebral palsy rehabilitation. Conventional therapy uses techniques aimed at normalizing posture, strength, joint range of motion and movement patterns through stretching, strengthening exercises, weight-bearing and functional training based on neurodevelopmental principles [**17**]. More recently, goal-directed training, constraint-induced movement therapy, bimanual training, task-specific practice and hand-arm training have shown positive outcomes [**17**].

To enhance the benefits of motor training, adjunct modalities are increasingly adopted to augment plasticity. This includes techniques such as electrical stimulation, neuromuscular/postural biofeedback and various pharmacological agents. Based on the principles of experience-dependent neuroplasticity, rehabilitation programs integrating training with plasticity enhancing techniques may be effective for improving hand function in hemiplegic CP.

Objective:

The objective of this study is to compare the effects of EMG auditory/visual biofeedback training and electrical stimulation of wrist muscles as adjuvant modalities along with conventional exercises for improving hand function in children with spastic hemiplegic cerebral palsy.

Aims:

This study aims to determine whether adjunct wrist biofeedback training enhances the benefits of exercise therapy on improving grasping skills more than exercise therapy alone in hemiplegic CP children, determine whether adjunct functional electrical stimulation of wrist muscles enhances the benefits of exercise therapy on improving grasping skills more than exercise therapy alone in hemiplegic CP children, and compare the effects of biofeedback training versus electrical stimulation along with exercise therapy on improving grasping and wrist motor control in hemiplegic CP children.

Significance And Clinical Implications

If biofeedback results in significantly greater gains, it will provide a strong rationale for incorporating auditory and visual feedback during intensive training of motor skills. This may potentially maximize functional improvement by targeting neuroplastic changes through multimodal sensory input. Alternatively, if electrical stimulation proves more beneficial, this will support its role as a neuromodulator by using peripheral input to enhance central motor networks. Knowledge on which technique has greater additive effects with exercise therapy can direct rehabilitation specialists towards the most effective clinical protocols for improving hand deficits in cerebral palsy.

The comparative findings on adjuvant effects can also provide insights into the mechanisms underlying functional improvements in CP following targeted interventions. This may expand the theoretical basis on neuroplasticity principles underlying recovery of hand abilities. Additionally, demonstrating significant gains following focused hand rehabilitation has broader implications on improving overall function, independence and participation in children with cerebral palsy.

2. Materials and Methods:

2.1. Study participants and recruitment criteria:

A sample of 45 children aged 6-8 years with a diagnosis of spastic hemiplegic CP was recruited from outpatient physical therapy clinics. Inclusion criteria included mild to moderate spasticity in the affected upper limb [Modified Ashworth Scale score 1 to 1+] and the ability to follow verbal instructions. Participants with visual deficits, hearing deficits, cognitive impairment or other associated neurological conditions were excluded.

After screening for eligibility and obtaining informed consent, the participants were randomly allocated to three equal groups – EMG biofeedback training, electrical stimulation, and control. Block randomization with a block size of six was performed by an independent investigator not involved in recruitment or assessment. Group allocation was concealed in sequentially numbered opaque sealed envelopes. The assessing therapist was blinded to the participant's group.

2.2. Study Design:

This study utilized a prospective, randomized, controlled trial design to compare the effects of EMG biofeedback training and electrical stimulation along with conventional exercise therapy on improving hand function in children with spastic hemiplegic cerebral palsy. The study was conducted at the outpatient physical therapy department of a pediatric rehabilitation hospital.

2.3. Methods:

The participants were divided into three groups [biofeedback group, reciprocal electrical stimulation group and control group]. All three groups received neurodevelopmental therapy and upper limb exercises for 45 minutes per session, 3 days a week for 3 months. This consisted of stretching and strengthening of upper limb muscles, weight-bearing, balance and fine motor activities customized to each child's motor needs.

The EMG biofeedback group received additional auditory and visual biofeedback training for 15 minutes during the session. Surface EMG electrodes were placed over wrist extensor muscles. The child viewed the real-time visual feedback of muscle activity on the monitor while performing exercises that facilitated wrist extension. Simultaneously, the auditory feedback of varying pitch and loudness corresponding to the level of muscle activity provided reinforcement. The intensity, size, or color of the visual display can be made to vary in correspondence with the level of muscle activity, providing reinforcement to the user as they worked to modulate and control their hand movements.

The electrical stimulation group received reciprocal electrical stimulation of the wrist flexors and extensors for 15 minutes per session using a dual-channel stimulator. A specialized programmable electro stimulator was used [Phyaction787; Uniphy, Eindhoven, the Netherlands]. The device had two channels that can stimulate two opposing groups of muscles alternatively [reciprocate]. During ES, the child sat in a chair with his treated forearm resting on a pillow placed on the bed in front of him. The flexors and extensors were stimulated reciprocally while the child attempted to perform grasping and releasing tasks. Stimulation parameters were set according to each child's comfort within the standard therapeutic range.

2.4. Outcome measures:

All participants were evaluated before starting the intervention [pre-test] and after three months of intervention [post-test] by a blinded assessor.

Primary Outcome Measure:

The primary outcome measures included the Grasp and Visual Motor Integration subtests of the Peabody Developmental Motor Scales, Second Edition [PDMS-2]. The Peabody Developmental Motor Scales - Second Edition [PDMS-2] is a tool used to assess the motor skills of children, including those with developmental delays or disabilities. A study in Brazil confirmed that the PDMS-2 was a reliable and valid instrument for evaluating motor development in Brazilian children, supporting clinical and educational interventions for children up to 6 years old. This validation allowed professionals to identify motor delays early and tailor intervention programs to individual needs, aiding in monitoring and supporting child development.

The Peabody Developmental Motor Scales - Second Edition [PDMS-2] is typically administered by trained professionals, such as occupational therapists, physical therapists, educators, or psychologists. During the assessment process, the child performs a series of tasks that evaluate their gross and fine motor skills across different developmental domains. The results are then compared to standardized norms for children of the same age to determine if there are any delays or areas needing intervention. This information can help create individualized treatment plans and monitoring progress over time.

Secondary Outcome Measure:

Secondary outcome measures included active wrist flexion and extension range of motion measured using a manual goniometer. A manual goniometer is a simple, handheld device used to measure joint range of motion. It typically consists of the following components: [a] a stationary arm which is placed parallel to a fixed bony landmark, such as the forearm or the long axis of the limb; [b] a moving arm which moves in relation to the stationary arm and is aligned with the moving segment, such as the hand or foot; [c] a hinge that allows the moving arm to rotate in relation to the stationary arm, enabling the measurement of the angle of motion; [d] an angle scale which is usually in degrees and is marked on the goniometer to provide a numerical measurement of the joint range of motion; and [e] a handle that allows the healthcare professional to hold and manipulate the goniometer during the measurement process.

To measure wrist flexion and extension range of motion using a manual goniometer: [a] ensure the patient is in a comfortable position, either sitting or lying down, with the arm supported; [b] explain the procedure to the patient and obtain their consent; [c] align the stationary arm of the goniometer with the long axis of the forearm, using the ulnar styloid process as a reference point; [d] position the moving arm of the goniometer so that it is aligned with the long axis of the fifth metacarpal; [e] instruct the patient to actively flex the wrist as far as possible; [f] align the moving arm of the goniometer with the fifth metacarpal as the patient flexes the wrist; [g] read and record the angle measurement for wrist flexion on the goniometer. Instruct the patient to actively extend the wrist as far as possible; [h] align the moving arm of the goniometer with the fifth metacarpal as the patient extends the wrist; and [i] read and record the angle measurement for wrist extension on the goniometer.

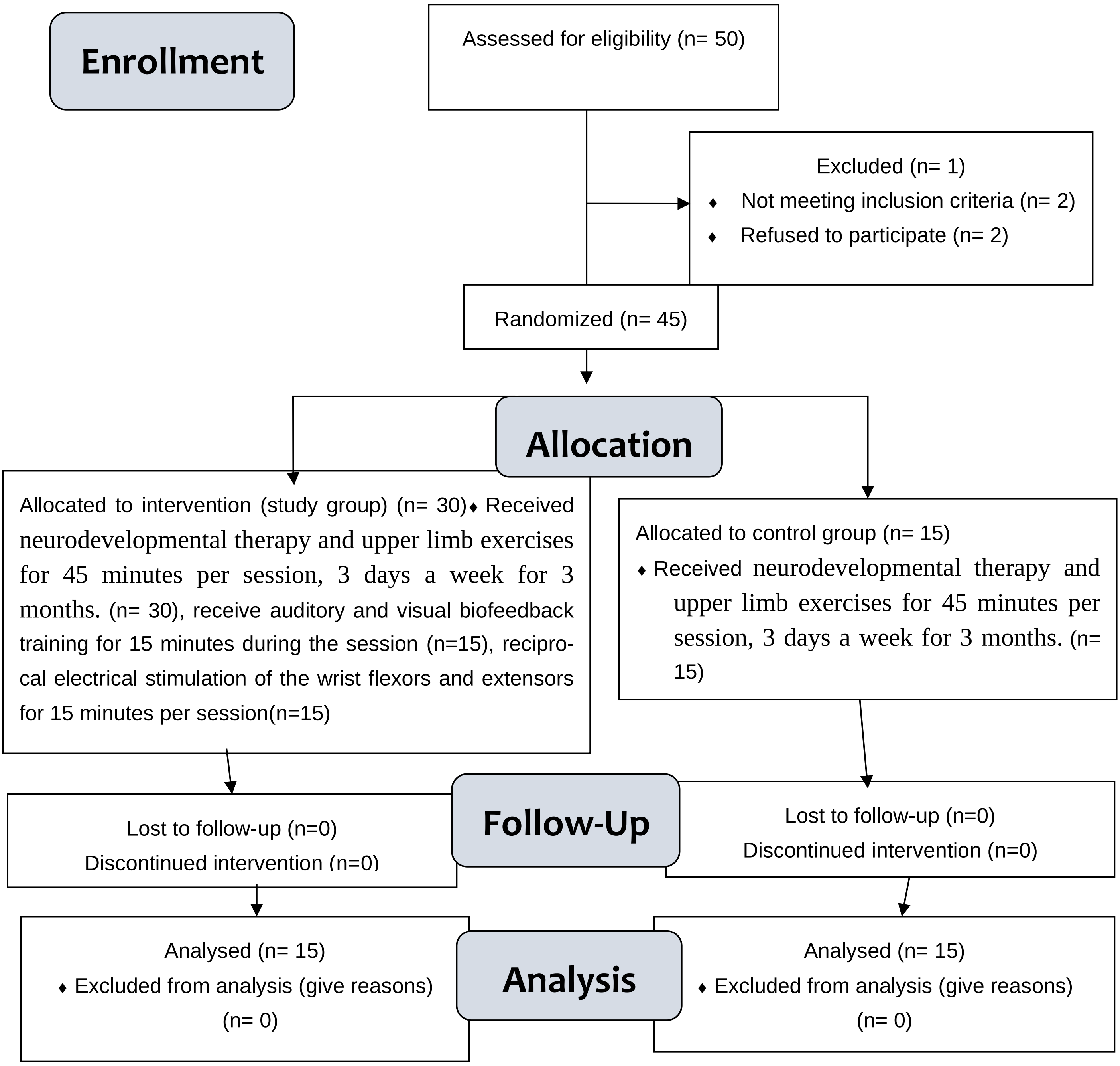

Figure [1]: Study flow chart.

Data Analysis:

Calculation of sample size:

Based on pilot results, the sample size was calculated to detect a minimally clinically important difference of 10 points in the grasp subtest of PDMS-2 between groups at 80% power and alpha error of 0.05. The estimated required sample size was 12 per group. Accounting for a dropout rate of 15%, the sample size was set at 15 participants per group.

Statistical Analysis:

Data were analyzed using IBM SPSS Statistics software. Demographic variables were compared between groups using ANOVA and Chi-square tests. Within- and between-group changes in outcome measures were analyzed using repeated measures ANOVA. Post-hoc tests were conducted for significant group x time interactions. Alpha was set at 0.05.

3. Results:

A total of 45 children with spastic hemiplegic CP were randomized into three equal groups EMG biofeedback training [n=15], electrical stimulation [n=15] and control [n=15]. **Table 1** shows the demographic and clinical characteristics of the participants in each group. There were no significant differences between the three groups at baseline in terms of age, gender distribution, type of involved hemiplegia, hand dominance [p>0.05]. This indicated that randomization was successfully achieved equivalent groups.

Table (1): Demographic data of patients in three groups

Characteristic	Biofeedback (n=15)	Stimulation (n=15)	Control (n=15)	P-value
Age in years, mean ± SD	7.5 ± 0.8	7.3 ± 0.6	7.4 ± 0.7	0.789
Gender, n (%)				0.849
Male	9 (60%)	10 (67%)	11 (73%)	
Female	6 (40%)	5 (33%)	4 (27%)	
Type of hemiplegia, n (%)				0.902
Right	8 (53%)	7 (47%)	9 (60%)	
Left	7 (47%)	8 (53%)	6 (40%)	
Hand dominance, n (%)				0.799

SD: Standard deviation.

The mean pre and post-intervention scores for each group are presented in **Table 2**. Non-significant statistical differences between mean value of biofeedback, stimulation and control groups for pre-evaluation results for PDMS-2 grasping, PDMS-2 visual motor, wrist flexion ROM, and wrist extension ROM [p>0.05]. There was a significant statistical difference between mean value of biofeedback, stimulation and control groups for pre-evaluation results for PDMS-2 grasping, PDMS-2 visual motor, wrist flexion ROM, and wrist extension ROM [p<0.05]. Post HOC test [LSD] in post intervention evaluation between three groups are presented in **table 3** significant mean difference between biofeedback and stimulation groups in PDMS-2 grasping score, PDMS-2 grasping, PDMS-2 visual motor, wrist flexion ROM, and wrist extension ROM with higher mean value of biofeedback group. Significant mean difference between biofeedback and control groups in PDMS-2 grasping score, PDMS-2 grasping, PDMS-2 visual motor, wrist flexion ROM, and wrist extension ROM with higher mean value of biofeedback group. Significant mean difference between stimulation and control groups in PDMS-2 grasping score, PDMS-2 grasping, PDMS-2 visual motor, wrist flexion ROM, and wrist extension ROM with higher mean value of stimulation group.

Table (2): Comparison between (Mean ± SD) values of outcome measured variables pre- and post-treatment within and between groups:

variables		Biofeedback (mean±SD)	Stimulation (mean±SD)	Control (mean±SD)	P-value
PDMS-2grasping	Pre	27.47±1.995	26.27±2.764	26.73±2.251	0.381
	Post	38 ± 2.07	31.13 ± 3.31	25.13 ± 2.03	0.0001**
PDMS-2Visual Motor	Pre	25.27±1.668	24.8±4.039	23.93±2.79	0.471
	Post	34±2.07	29.53±2.642	25.93±2.658	0.0001**
Wrist Flexion ROM	Pre	47.07±3.06	45.13±4.55	43.67±4.08	0.72
	Post	55.13±3.29	49.4±2.197	44.67±4.08	0.0001**
Wrist Extension ROM	Pre	40.93±3.173	38±5.251	37.73±4.131	0.087
	Post	47.13±3.292	42.87±2.416	38.73±4.131	0.0001**

**: Statistically significant difference within in comparison to pretreatment values P-value <0.01.
ROM: Range of motion. SD: Standard deviation. Pre: before treatment measures. Post: after 12 weeks of treatment measures.

Table (3): Post HOC test (LSD) in post intervention evaluation

Group(I)	Group(J)	Mean difference(I-J)	Std. error	p-value
PDMS-2 grasping				
Biofeedback	Stimulation	6.87	0.928	0.0001**
Biofeedback	Control	12.87	0.928	0.0001**
Stimulation	Control	6	0.928	0.0001**
PDMS-2 visual motor				
Biofeedback	Stimulation	4.47	0.903	0.0001**
Biofeedback	Control	8.06	0.903	0.0001**
Stimulation	Control	3.6	0.903	0.0001**
Wrist flexion ROM				
Biofeedback	Stimulation	5.73	1.199	0.0001**
Biofeedback	Control	10.47	1.199	0.0001**
Stimulation	Control	4.73	1.199	0.0001**
Wrist extension ROM				
Biofeedback	Stimulation	4.267	1.225	0.004**
Biofeedback	Control	8.4	1.225	0.0001**
Stimulation	Control	4.13	1.225	0.005**

**: Statistically significant difference P-value <0.01.
ROM: Range of motion. SD: Standard deviation.

4. Discussion:

This randomized controlled trial aimed to compare the effects of EMG biofeedback training and functional electrical stimulation along with conventional therapy for improving hand function in children with hemiplegic cerebral palsy. The key findings were that both biofeedback and electrical stimulation groups showed significant improvements in grasping skills, visual-motor integration, and wrist range of motion after 3 months of intervention compared to the control group. However, there were no significant differences between the biofeedback and stimulation groups, indicating similar adjunct effects.

Previous studies have also demonstrated beneficial effects of adding biofeedback or electrical stimulation to regular occupational therapy in hemiplegic CP. A randomized trial by Chen et al. [2014] in hemiplegic children found that EMG biofeedback during wrist and finger extension exercises for 30 minutes thrice weekly led to greater gains in upper limb motor function compared to regular therapy alone after 3 months. The current study supports these results, with the biofeedback group showing improvements in grasp function, visual-motor skills and wrist ROM [**18**].

Prior research on electrical stimulation also aligns with the present findings. A study by Knutson et al. [2019] in hemiplegic CP children using wrist/finger stimulation for 30 minutes along with routine therapy for 6 weeks showed greater gains in manual dexterity and coordination compared to control group with only routine therapy. Similarly, the present study demonstrated improved grasping and visual-motor integration after electrical stimulation plus conventional therapy versus only conventional therapy. The wrist ROM improvements were also consistent with previous evidence [**19**].

However, this study adds to existing literature by comparing biofeedback and electrical stimulation directly rather than to control. The similar gains with both modalities indicate that combining sensorimotor feedback through visual, auditory or electrical stimulation with motor training facilitates upper limb improvements in hemiplegic CP. The adjuvant effects could be attributed to optimization of experience-dependent neuroplasticity.

Both biofeedback and electrical stimulation provide augmented sensory inputs that may strengthen cortical connections through Hebbian learning mechanisms. The multimodal inputs may also activate alternative sensorimotor pathways compared to conventional training alone. This is supported by neurophysiological evidence of plasticity following these interventions [Chen et al., 2014; Knutson et al., 2019]. However, the current study could not identify any differential effects between the modalities.

Certain limitations should be considered when interpreting the results. The sample size was relatively small, and interventions were limited to 3 months duration. The study had a heterogeneous group of children regarding type and extent of hemiplegia. Factors like age of brain injury and baseline neurologic status may impact individual responses. Blinding of participants was not possible due to the nature of interventions. Future studies can investigate the combination of electrical stimulation and biofeedback together with exercise therapy for synergistic effects.

Overall, this randomized controlled trial provides evidence that adjunctive EMG biofeedback training and functional electrical stimulation along with regular occupational therapy are effective in improving hand dysfunctions in hemiplegic CP children. Both modalities appear equally effective over 3 months with no significant differences. These results have important clinical implications regarding inclusion of biofeedback and electrical stimulation for enhancing upper limb rehabilitation outcomes in cerebral palsy.

5. Conclusions:

This randomized controlled trial demonstrated that EMG biofeedback training and functional electrical stimulation as adjuvant modalities along with conventional occupational therapy exercises improved hand function in children with hemiplegic cerebral palsy. The biofeedback and electrical stimulation groups showed significant gains in grasping skills, visual-motor integration and wrist range of motion after 3 months of intervention compared to the control group receiving only conventional therapy. However, there were no significant differences between the effects of biofeedback and electrical stimulation when combined with exercise therapy. Dermatitis with no noticeable side effects specially those associated with long-term use of topical corticosteroid.

Limitations

This study has certain limitations that should be considered. The sample size was relatively small with 15 participants per group. The interventions were limited to 3 months duration, so longer-term effects are unknown. There was heterogeneity in the sample regarding type and severity of hemiplegia which could influence individual responses. Complete blinding of participants was not possible owing to the nature of the interventions. The findings cannot be generalized to all categories of cerebral palsy.

Recommendations

Future studies can investigate the effects of combined biofeedback and electrical stimulation along with exercise therapy to determine any synergistic effects. Comparing outcomes based on age, neurological status and type of cerebral palsy can provide more insights. Longer intervention periods and follow-up assessments can evaluate maintenance of improvements over time. Neuroimaging techniques can be incorporated to study neuroplasticity mechanisms. Cost-effectiveness analysis of the different modalities is also recommended.

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