

Impact of Myo Feedback and Neuromuscular Electrical Stimulation on Muscle Activity and Neurotrophic Factors in Hemiplegic Children Post-Benign Brain Tumor Resection

Amr Mohamed Sabry^{1*}, Amira Mohamed Eltohamy¹, Mohamed Ali Elshafey^{1,2}, Mohamed Farouk Elshazly³

¹ Department of Physical Therapy for Pediatrics, Faculty of Physical Therapy, Cairo University, Giza, Egypt

² College of Physical Therapy, Arab Academy for Science, Technology and Maritime Transport, Egypt

⁴ Faculty of Medicine, Alexandria University, Alexandria, Egypt

Received: 17th July, 2026; Revised: 07th August, 2026; Accepted: 17th August, 2026; Available Online: 07th September, 2026

ABSTRACT

Background: Children with hemiplegia after brain tumor surgery often face challenges in upper limb motor function and neurological recovery. **Objective:** The study was conducted to compare the effect of neuromuscular electrical stimulation and myofeedback on upper limb muscle activity and brain derived neurotrophic factors in blood for children with hemiplegia after benign brain tumor resection. **Participants and Methods:** This randomized comparative trial involved forty-two children with hemiplegia and were randomly assigned into three groups (14 children in each group). Assessments of the three groups were carried out by SEMG and BDNF changes before and after 12 weeks of intervention. **Treatment:** The control group received the designed physical therapy program while the study group (A) received myofeedback training in addition to the designed physical therapy program and study group (B) received electric muscle stimulation in addition to the designed physical therapy program. **Results:** Significant improvements in SEMG and BDNF were observed in the myofeedback and NMES groups compared to the control group ($P < 0.05$). The myofeedback group showed the most significant improvements (SEMG: 95.92%, BDNF: 60.02%), followed by the NMES group (SEMG: 67.45%, BDNF: 34.71%). **Conclusion:** Myofeedback showed superior improvement than NMES program in upper limb muscular activities and motor function in children with hemiplegia after brain tumor surgery.

Keywords: Benign brain tumor; Hemiplegia; Myofeedback; Neuromuscular electrical stimulation; Brain-derived neurotrophic factor; Surface electromyography.

How to cite this article: Sabry A.M, Eltohamy A.M, Elshafey M.A, Elshazly M.F, Impact of Myo Feedback and Neuromuscular Electrical Stimulation on Muscle Activity and Neurotrophic Factors in Hemiplegic Children Post-Benign Brain Tumor Resection. 2026;16(82s): 1608-1618; DOI: 10.25258/ijddt.16.82s.187

Source of support: None

Conflict of interest: None

INTRODUCTION

Incidence of brain tumors in Egypt is 9.0 in 100.000 males and 8.0 in 100.000 females. Primary CNS tumors among males higher than females. Regarding patient age, frequency among adults was (89.4%) compared to pediatric age group (10.6%). Gliomas were the most common primary CNS tumors in adults (35%) followed by meningiomas (33.3%) then pituitary adenomas (15.6%); while in pediatrics embryonal tumors (17%)¹.

Considering the age at diagnosis, pediatric brain tumors can be classified as congenital when diagnosis is reached either antenatally or postnatally by 2 months of age; infant pediatric tumors are diagnosed between 2-12 months of age, and older pediatric tumors from (1-18 years). Age at diagnosis is one of the determinant factors of prognosis of pediatric brain tumors. Congenital brain tumors are quite different from other pediatric tumors regarding histological types and prognosis².

North American statistics indicate that there is one child with cancer in every 330 children under the age of 18, Pediatric cancer incidence in the United States is 15,780 every year aged between 0 to 19 years and its treatment (e.g.

chemotherapy, radiation therapy and surgery) may result in a wide range of negative sequelae, including psychosocial dysfunction, peripheral neuropathy, cognitive limitations, decreases in strength, coordination, and balance. One potential neurological impairment in children treated for brain tumors is hemiparesis, prevalent in up to 21% of survivors³. Brain tumors are the second most common cancer for children. Although children with brain tumors have a better prognosis than adults, treatment presents special problems, including possible damage to the developing brain⁴.

Surgery is an integral component and typically the first line of therapy for children with central nervous system tumors. The outcome regarding surgical morbidity and disease control can be greatly influenced by the initial care that these children receive. Conventional aims of neurosurgery including tumor removal, management of hydrocephalus, and diagnostic sampling have been radically modified with innovative technologies such as navigational guidance, functional mapping, endoscopic surgery, second-look surgery, and physiologic imaging. The overall role of the pediatric neurosurgeon in caring for children with nervous

*Author for Correspondence: Amr Mohamed Sabry

system tumors is also expanding to include unconventional responsibilities including disease staging, tissue procurement, and drug delivery. It is thus anticipated that the pediatric neurosurgeon will be increasingly relied upon for oncologic therapeutic strategies and should thus remain abreast of forthcoming information and technologies 5.

The clinical manifestations of brain tumors in children are dependent largely on the type and location of tumor and the age of onset. Brain tumors may produce symptoms by local invasion of the brain, by mass effect and compression on adjacent structures, or secondarily, through increased intracranial pressure⁶.

Surgical resection remains the mainstay of therapy for most primary brain tumors, both for reduction of tumor burden and to provide histologic diagnosis. There is a careful balance between the maximal surgical resection and the preservation of vital structures in eloquent regions. For many tumors, surgical resection is the most important mode of therapy; failure to achieve a radio-graphic gross total resection is associated with poorer out-come and often necessitates the need for additional therapy.⁷

Direct neurological consequences of surgical excision may include perioperative stroke, the onset of focal weakness, sensory impairment, or new cranial nerve dysfunction. The effects of hydrocephalus—particularly regarding the extent of ventricular dilation and the duration prior to intervention remain insufficiently characterized. Recent research indicates that patients undergoing surgery alone remain susceptible to long-term complications such as ataxia, hemiparesis, as well as persistent neurosensory and neurocognitive impairments.⁸

Tumors can cross anatomical areas, leading to complex neurological symptoms. Spastic hemiparesis or hemiplegia results from upper motor neuron involvement and typically affect muscle groups rather than single muscles. The site of damage above the pons or on the homunculus determines whether weakness is confined to certain limbs or is more widespread. Disruption between agonist and antagonist muscles causes involuntary or mirror movements in the affected limb.⁹

Tumors may induce systemic response leading to significant loss of muscle strength, this systemic response is thought to be mediated by tumor necrosis factor alpha and other cytokines released from tumor cells. Additional factors may contribute to generalized muscle weakness, including impaired nutrition, adverse effects of medications, and general deconditioning.¹⁰

Spastic hemiplegic children had impairment in the hand as result of damage to the motor cortex and corticospinal pathways responsible for the fine motor control of the fingers and hand. During tasks that require fine manipulation, such children often use several fingers and often show abnormal hand posturing as well as reduction in distal strength and dexterity ¹¹

The main symptom of spastic hemiplegia is paralysis on one side of the body. Some other symptoms are: Tight muscles on one side, exaggerated body movements joints that don't extend fully Walking on tiptoes poor reflexes crossed knees Impairment of the lower limb in children with hemiplegia following brain tumor resection is a complex issue, often

stemming from direct surgical damage, vascular complications, or secondary effects of the tumor, such as inflammation and swelling.¹²

Brain-Derived Neurotrophic Factor (BDNF) is a protein supporting neuron growth, survival, and connection (synaptic plasticity) for learning and memory, acting like fertilizer for the brain, and its levels in the blood can reflect brain health-¹³

Physical therapy plays a crucial role in improving upper limb function in children with hemiplegia through therapeutic exercises and motor training. Combining conventional physiotherapy with adjunctive interventions such as Kinesio Taping, Mirror Therapy, and Modified Constraint-Induced Movement Therapy can further enhance upper limb function and functional independence.¹⁴

Neuromuscular electrical stimulation (NMES) is widely used in neurological rehabilitation to improve muscle strength, enhance blood flow, reduce muscle atrophy, promote tissue healing, and alleviate pain. It can induce contractions in innervated, paralyzed, and spastic muscles, thereby facilitating motor recovery.¹⁵

Neuromuscular electrical stimulation effectively improved hand function, muscle strength, and spasticity in patients with cerebral palsy.¹⁶

Surface electromyography (SEMG) myofeedback helps patients relearn specific muscle movements by providing visual or auditory feedback when muscle activity reaches a predetermined threshold. It may be more effective than cyclic stimulation because it combines voluntary muscle activation with proprioceptive feedback, enhancing motor relearning and functional recovery.¹⁷

Electromyography biofeedback combined with rehabilitation training may be the best physical therapy for improving upper limb motor function and relieving pain in patients with post-stroke SHS according to our Bayesian network meta-analysis results. However, the above conclusions need further analysis and validation by more high-quality.¹⁸

MATERIALS AND METHODS

Study design:

A pretest-posttest randomized controlled trial was conducted from Jun 2024 to Sep 2025. Written informed consent was obtained from the parents of each participant, in accordance with the declaration of Helsinki. The study was approved by our institutional Physical Therapy Faculty ethics committee (NO: P.T.REC/012/006382) and registered at Clinical Trials. gov (NCT07606222)

Subjects:

Forty-two children (20 girls and 22 boys) with hemiplegia after brain tumor surgery were recruited from multiple oncology and physical therapy centers in Alexandria, Egypt. Participants were randomly allocated into three groups, control group, study A, and B—using simple randomization methods. The included children were 6-14 years of age, had hand use experience questionnaire between 25 :50 unite scale, had Grade 2 muscle power of wrist, elbow and fingers extensors the selected children were at least 6 weeks after surgical brain tumor resection in

one of the two hemispheres. Exclusion criteria: blindness, deaf child and skin diseases. Study was completed in 42 children.

Sample size calculation was conducted using G*power program (G power program version 3.1.9, Heinrich-Heine-University, Düsseldorf, Germany) for two tailed tests. Sample size calculation based on F tests – ANOVA (Fixed effects, omnibus, one-way), with an assumed medium effect

size ($d = 0.50$), type I error ($\alpha = 0.05$), power ($1 - \beta = 0.80$), and the effect size $f = 0.547869$ with a total sample size for 45 participants for 3 independent groups comparison. To account for an anticipated 10% dropout, the final adjusted sample size is 42 participants as minimum. Thus, the study will enroll 14 cases in each group to ensure adequate statistical power for detecting a large clinically meaningful difference.

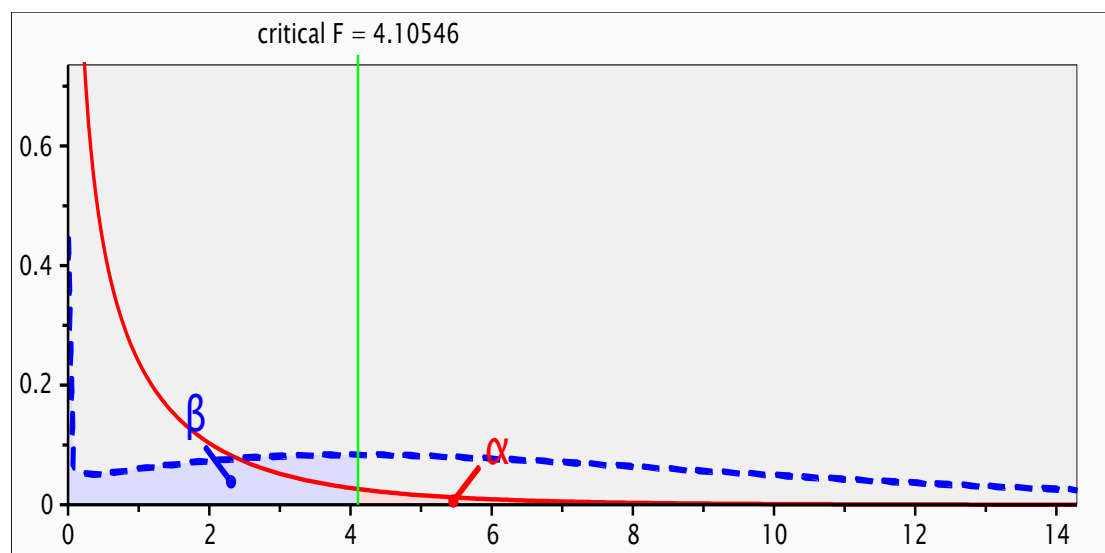


Fig. (1) sample size estimation

Randomization:

The children were assigned into three groups (control group, study group A and B) through simple randomization.

An independent person determined the group assignment by selecting a paper from a sealed envelope.

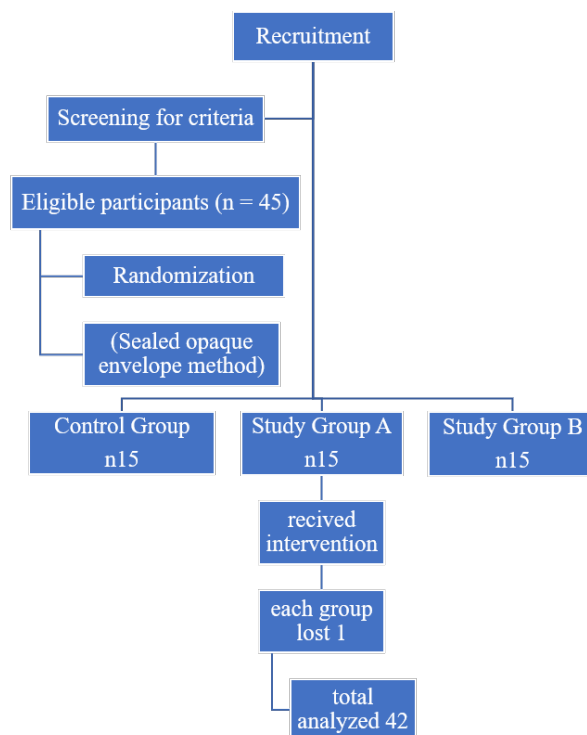


Fig. (2) Randomization

MATERIALS

Materials for child selection

Muscle tone was assessed with the Tardieu Scale, which measures spasticity by testing muscle responses at different stretch speeds and identifying the spasticity angle. The Modified Tardieu Scale evaluated dynamic spasticity in wrist flexors, pronators and elbow flexors, recording R2eR1 difference (dynamic component), R2 (passive range of motion), and R1 (catch point during rapid movement through the full range of motion).¹⁹

Muscle strength was measured by manual muscle test. A clinical assessment evaluates muscle power by applying resistance or observing movement against gravity, often using a standardized grading scale (0-5) to document findings for neurological conditions, injuries, or general fitness, helping diagnose weakness and guide treatment. Shoulder flexors, Elbow extensors, Common finger extensors, Supinator's and pronators muscles strength were measured.²⁰

The Children's Hand-Use Experience Questionnaire (CHEQ) is a tool designed for children with unilateral upper limb impairments to assess their experience using the affected hand during daily bimanual activities. It includes 27 activities where the child reports independence, hand use, time compared to peers, and level of discomfort. The questionnaire can be completed at home or during therapy sessions and typically takes 20–30 minutes.²¹

Materials for assessment

1-Surface electromyography

MyoTrac Infiniti biofeedback system: Manufacture thought Technology Ltd. 8205 Montreal/Toronto Blvd. Suite 223, Montreal West, QC, Canada device number SA9800. Surface EMG Biofeedback is a tool that measures muscle activity to help muscles work better and more efficiently.²²

2-Bruininks-Oseretsky Test (BOT-2)

Bruininks-Oseretsky Test (BOT-2) measures fine and gross motor proficiency, with subtests that focus on stability, mobility, strength, coordination, and object manipulation. The test is tailored to school-aged children and young adults among the ages of 4-21 years, who have varying motor control abilities ranging from normal to mild or moderate.²³

3-Blood analysis for neurotrophic factors

Brain-Derived Neurotrophic Factor (BDNF) has attracted increasing interest as potential biomarker to support the diagnosis or monitor the efficacy of therapies in brain disorders. Circulating BDNF can be measured in serum, plasma, or whole blood.²⁴

4-The Modified Tardieu Scale (MTS)

The Modified Tardieu Scale (MTS) is a clinical tool for assessing spasticity that includes quantitative measurement. Passive movements of MTS are tested at two speeds: as slow as possible (R2), and as fast as possible (R1).²⁵

Materials for treatment

Instruments

MyoTrac Infiniti biofeedback system: Manufacture thought Technology Ltd. 8205 Montreal/Toronto Blvd. Suite 223, Montreal West, QC, Canada device number SA9800



Fig. (3) Biofeedback device

2- Multistimulator: made in Italy with serial number 1680163144



Fig. (4) Electric stimulation device.

Tools

Desk, mat, roll and fine motor toys (small ball, large cubes and jar)

Procedure

Control group. Children in this group were received the designed physical therapy exercise program for one hour three times weekly for twelve successive weeks' exercises were push up exercise on upper limbs from prone position supported on both hands. The child is instructed to slowly bend the elbows to lower the body toward the surface, Then, the child pushes through both hands to return to the starting position. active strength to wrist extensors using fine motor toys (such as pegboards, beads, stacking blocks, or small grasp-and-release objects) from sitting position are placed within reach. The child is instructed to actively extend the wrist while reaching for, grasping, and manipulating the toys, then return to the starting position, stretching for wrist, elbow flexors and pronators. The child is positioned comfortably in supine lying. The therapist stabilizes the proximal segment of the limb to prevent compensatory movements. For wrist flexor stretching, the elbow is extended and the wrist is gently moved into extension while maintaining finger extension. For elbow flexor stretching, the shoulder is stabilized and the elbow is slowly extended until a gentle stretch is felt. For pronator stretching, the forearm is gradually moved into supination while keeping the elbow in extension., weight bearing position on upper limb from side sitting position. The child is positioned in

side sitting with the affected upper limb placed on mat, with the elbow extended and the hand in contact, quadruped position on 3 points, with active elevation for the affected limb. The child is positioned in a quadruped position (hands and knees), with the affected upper limb bearing weight on the supporting surface. The child is encouraged to perform active elevation (lifting) of the affected upper limb slightly, from sitting, kneeling sitting position, scroll small ball forward with the affected limb, approximation shoulder, elbow, and wrist muscles. Controlled compressive forces are applied slowly, rhythmic along the longitudinal axis of the upper limb to the shoulder, elbow, and wrist joints.²⁶

Study Group (A): children received the same designed physical therapy exercise program in addition to myofeedback program. Child position sitting, upper limb rested on table. Placement of electrodes as in assessment, the change was in the device program, rehab strength program was selected, one channel was used and the program was started. The exercise was performed actively by asking the child to extend the wrist. When the child reached the preset threshold detected during the assessment, the device provided graphical and auditory feedback. The visual graph and sound motivated the child to continue the activity. The duration of the biofeedback training was 30 minutes.²⁷



Fig. (5) myofeedback training

Study Group (B): they received the selected physical therapy program in addition to NMES program 30 minutes three times weekly.

Protocol of neuromuscular electric stimulation

Position of child: sitting on position arm rested on table. Electrode placement was performed with one electrode placed on the common wrist extensors and the second on the distal third of the dorsum of the forearm. Instructions were explained to the child first, then the session was started. The menu was pressed, the faradic current was selected, and the intensity was raised slowly until muscle contraction occurred. Overall period of treatment was 3 months, a frequency of 50:100Hz with a pulse duration from 0.1-1MS.²⁸

Statistical analysis

Prior to analysis, the data were examined to verify the assumptions of normality and homogeneity of variance. Outliers were first identified and removed using box-and-whisker plots. A Shapiro-Wilk test was then conducted, the results of which confirmed that the data were normally distributed ($P > 0.05$). The assumption of equal variances was also satisfied, as indicated by a non-significant Levene's test ($P > 0.05$). Consequently, parametric statistical methods were deemed appropriate for the analysis.

The statistical analysis was conducted by using statistical SPSS Package program version 25 for Windows (SPSS, Inc., Chicago, IL). Quantitative data are reported as mean and standard deviation for children's demographic data, surface electromyography and brain-derived neurotrophic factor variables. Qualitative data are reported as frequency

(percentage) for gender and dominant hands variable and compared statistically among groups by Chi-square test. One -way analysis of variance (ANOVA) test used to compare among groups for children's demographic data, surface electromyography and brain-derived neurotrophic factor variables. Bonferroni correction test (Post hoc-tests) used to compare between pairwise within and between groups of the tested variables which P-value was significant from MANOVA test. Paired t-test used to compare between pre- and post-treatment within each group. All statistical

analyses were significant at 0.05 level of probability ($P \leq 0.05$).

RESULTS

A total of 42 children with hemiplegia after brain tumor surgery participated in this study and randomly assigned into 3 equal groups in the number. There are no significant differences ($P < 0.05$) in hemiplegia children's demographic data (Table 1) among control and study groups A and B for age ($P = 0.680$), weight ($P = 0.682$), height ($P = 0.643$), BMI ($P = 0.934$), gender ($P = 0.289$), and dominant hand ($P = 0.053$).

Table 1. Hemiplegia children's demographic data

Items		Groups			P-value
		Control group (n=14)	Study Group A (n=14)	Study Group B (n=14)	
Quantitative variables		Mean $\pm$ SD	Mean $\pm$ SD	Mean $\pm$ SD	
Age (year)		8.64 $\pm$ 3.56	9.50 $\pm$ 2.27	8.71 $\pm$ 2.55	0.680
Weight (kg)		29.29 $\pm$ 10.51	31.79 $\pm$ 9.34	28.93 $\pm$ 8.06	0.682
Height (cm)		130.64 $\pm$ 21.57	136.14 $\pm$ 13.29	131.14 $\pm$ 15.07	0.643
BMI (kg/m ²)		16.73 $\pm$ 1.26	16.74 $\pm$ 1.63	16.58 $\pm$ 0.89	0.934
Qualitative variable		Number (%)	Number (%)	Number (%)	
Gender	Boys	5 (35.70%)	9 (64.30%)	8 (57.10%)	0.289
	Girls	9 (64.30%)	5 (35.70%)	6 (42.90%)	
Dominant hand	Right	11 (78.60%)	14 (100%)	9 (64.30%)	0.053
	Left	3 (21.40%)	0 (0.00%)	5 (35.70%)	

control group; study Group A: received biofeedback program; Group B: received NMES program

Quantitative data (age, weight, height, and BMI) are reported as mean $\pm$ standard deviation and compared by ANOVA test.

Qualitative data (gender and dominant hand) are reported as frequency (percentage) and compared by Chi-square test P-value: probability value

Statistical analysis for surface electromyography and brain-derived neurotrophic factors within each group is presented in Table (2). There were significantly ($P < 0.05$) increased in surface electromyography (Table 2 and Figure 1) at post-treatment compared to pre-treatment within Control group ($P = 0.0001$), study group A ($P = 0.0001$), and B ($P = 0.0001$). A significant increase in brain-derived neurotrophic factors was observed at post-treatment compared to pre-treatment within study group A ($P = 0.0001$) and B ($P = 0.0001$), as shown in Table 2 and Figure 2. In contrast, no significant difference was found within control group ($P = 0.091$). Moreover, the children with hemiplegia after brain tumor surgery received biofeedback program in group A improved more surface electromyography (95.92%) and brain-derived neurotrophic factor (60.02%) increasing at post-treatment followed by hemiplegia children received NMES program (67.45 and 34.71%, respectively) in group B, and

then those in control group (44.04 and 14.61%, respectively) who received physical therapy program. Statistical analyses of surface electromyography and brain-derived neurotrophic factors across groups are presented in Table 2. At pre-treatment, there were no significant differences observed among groups for surface electromyography ($P = 0.853$; see Table 2 and Figure 1) or brain-derived neurotrophic factors ($P = 0.778$; see Table 2 and Figure 2). By contrast, post-treatment results indicated significant differences among groups for both surface electromyography ($P = 0.001$) and brain-derived neurotrophic factor ($P = 0.001$). The marked increase in mean values of surface electromyography and brain-derived neurotrophic factor following treatment was most pronounced in group A, with group B showing the next highest improvement.

Table 2. Within and between groups comparison for surface electromyography and brain-derived neurotrophic factor

Variables	Items	Groups (Mean $\pm$ SD)			Effect size (η^2)	P-value ²
		Control group (n=14)	Study Group A (n=14)	Study Group B (n=14)		
Surface Electromyography	Pre-treatment	48.00 $\pm$ 10.66	49.00 $\pm$ 9.62	50.29 $\pm$ 11.78	0.002	0.853
	Post-treatment	69.14 $\pm$ 14.35	96.00 $\pm$ 13.66	84.21 $\pm$ 21.79	0.24	0.001*
	MD (Change)	21.14	47.00	33.92		
	95% CI	12.91 – 12.36	40.69 – 53.30	21.22 – 46.62		
	Improvement %	44.04%	95.92%	67.45%		
	Effect size (η^2)	0.17	0.50	0.34		
	P-value ¹	0.0001*	0.0001*	0.0001*		
Brain-derived neurotrophic factor	Pre-treatment	52.29 $\pm$ 20.30	50.93 $\pm$ 9.09	48.57 $\pm$ 9.64	0.01	0.778
	Post-treatment	59.93 $\pm$ 9.55	81.50 $\pm$ 13.24	65.43 $\pm$ 18.45	0.19	0.001*
	MD (Change)	7.64	30.57	16.86		
	95% CI	-1.39 – 16.68	23.53 – 36.60	10.75 – 22.95		
	Improvement %	14.61%	60.02%	34.71%		
	Effect size (η^2)	0.03	0.30	0.11		
	P-value ¹	0.091	0.0001*	0.0001*		

control group; study Group A: received biofeedback program; Study Group B: received NMES program

Data are expressed as mean $\pm$ standard deviation; MD: Mean difference; CI: confidence interval; η^2 : Eta square;

P-value: probability value; * Significant (P<0.05); P-value1: Probability value within each group; P-value2: Probability value within among groups

Post-hoc test between each pairwise groups comparisons at post-treatment for main variable outcomes are illustrated in Table (3). The post-hoc test and mean differences between groups showed that there were significant differences (P<0.05) in SEMG at post-treatment between pairwise of group A versus group B (MD=26.86; P=0.0001) and group A versus group B (MD=15.07; P=0.003). there is no significant difference (P>0.05) between pairwise of group B versus group B (MD=11.79; P=0.223). There were significant differences (P<0.05) in BDNF at post-treatment between pairwise of group A versus group B (MD=21.57;

P=0.0001) and group A versus group B (MD=16.07; P=0.014). But no significant difference (P>0.05) between pairwise of control group versus group B (MD=5.50; P=0.938). The post-hoc test between groups showed that the biofeedback program gave the best surface electromyography and brain-derived neurotrophic factor values followed by NMES program and then control program.

Table 3. Pairwise comparison (post-hoc test) between groups for surface electromyography and brain-derived neurotrophic factor at post-treatment

Variables	Items	Post-hoc test (post-treatment)		
		Control vs. Group A	Control vs. Group B	Group A vs. Group B
Surface electromyography	MD	26.86	15.07	11.79
	95% CI	10.78 – 42.94	1.92 – 28.20	-4.30 – 27.87
	P-value	0.0001*	0.003*	0.223
Brain-derived neurotrophic Factor	MD	21.57	5.50	16.07
	95% CI	8.12 – 35.02	-7.95 – 18.95	2.62 – 29.52
	P-value	0.001*	0.938	0.014*

control group; study Group A: received biofeedback program; Study Group B received NMES program

Data are expressed as mean difference and compared statistically by Bonferroni correction test.

P-value: probability value between pairwise groups (post-hoc test) MD: Mean difference CI: confidence interval * Significant (P<0.05)

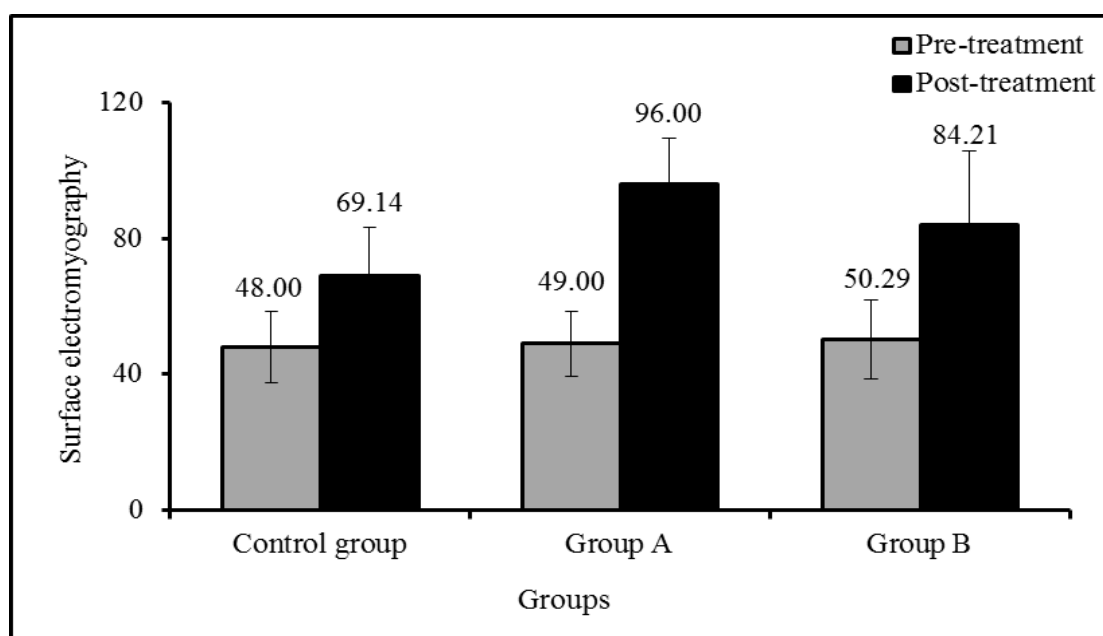


Figure 1. Mean values of pre- and post-treatment surface electromyography

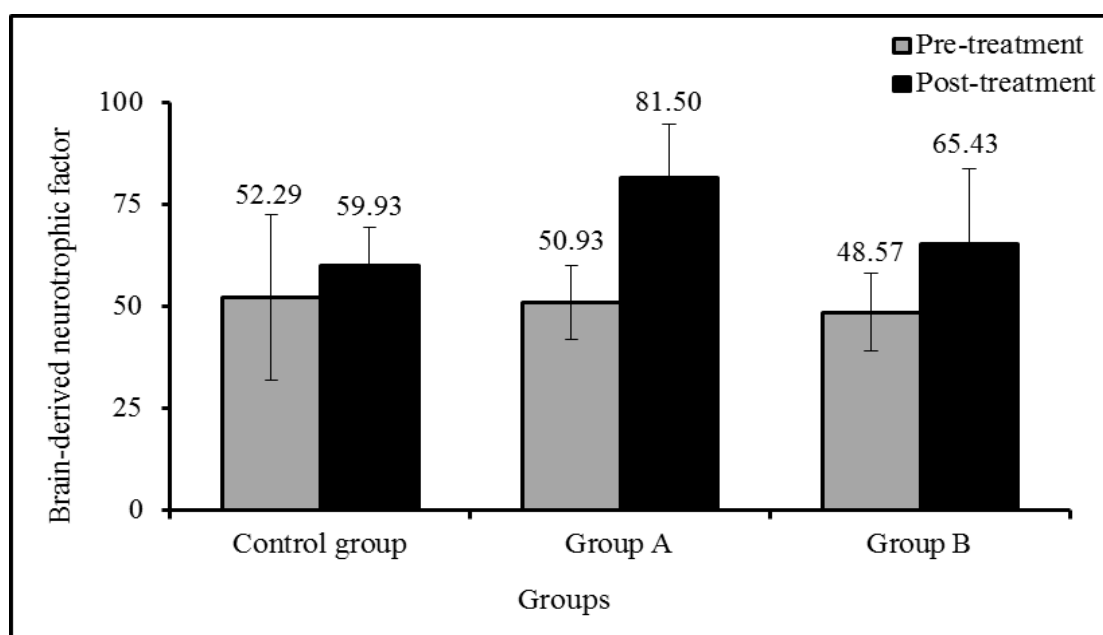


Figure 2. Mean values of pre- and post-treatment brain-derived neurotrophic factor

DISCUSSION

The present study investigated the effects of myofeedback and NMES programs on surface electromyography (SEMG) change and brain-derived neurotrophic factor (BDNF) in children with hemiplegia after brain tumor surgery. The results demonstrated significant improvements in both SEMG and BDNF levels in the myofeedback and NMES groups compared to the control group, with the myofeedback group showing the most pronounced enhancements. These findings suggest that both interventions are effective in promoting motor recovery and neurological outcomes in this pediatric population, with myofeedback exhibiting superior efficacy.

Likewise, a study on 48 participants were randomly assigned to an experimental group ($n = 22$), which performed app-based biofeedback breathing exercises, or a control group ($n = 26$). They demonstrated that baseline characteristics—including sex distribution, age, height, weight, and body mass index (BMI)—did not significantly differ between groups²⁹.

Also, a study conducted on 20 patients. Patients were randomly assigned to one of two groups: biofeedback ($n = 10$) or control ($n = 10$). They stated that the demographic data indicated no statistically significant differences between the two groups (all $p > 0.05$)³⁰.

This further aligned with a researcher who carried out a study on 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. They illustrated that 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 and degree of spasticity³¹.

This is in agreement with our observations, that the biofeedback and electrical stimulation are improving hand function in children with cerebral palsy³².

Likewise, another study noted that the electromyography biofeedback training may have a positive effect on neuromuscular control of pronator teres and brachioradialis³³.

Further supporting our study, that children with hemiplegic spastic CP showed a better response to reciprocal electrical stimulation (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 regular exercise of the wrist extension³⁴.

Similarly, a study in 2015 showed that there was a positive effect of biofeedback on the range of motion in elbow, wrist and finger in patients with stroke. Furthermore, increase in the ROM is coupled with improvement and facility in activities of daily living performances³⁵.

Similarly, another study in 2013 showed that children who received biofeedback showed significant improvements in muscle tone and ankle range³⁶. Besides, study reported that the biofeedback group displayed statistically significant improvements regarding tonus of plantar flexor muscles and active ROM of ankle joints³⁷. In addition, study conducted and observed that the improvements in active range of motion and surface EMG potentials were significantly greater in the EMG biofeedback group at the end of the treatment³⁸.

Furthermore, a systematic review and meta-analysis by analyzing the effect of NMES on skeletal muscle and then on biomechanics of movement, functional mobility, strength, spasticity, muscle architecture, and body composition of children and adolescents with chronic neurological disorders and chronic diseases. They noted that the use of NMES programs for children diagnosed with cerebral palsy, spinal muscular atrophy, and obstetric injury of the brachial plexus was effective in improving muscle strength, biomechanics of movement, and functional mobility³⁹.

In our study, after brain tumor surgery, hemiplegic children in group A who received the biofeedback program showed the greatest brain-derived neurotrophic factor (BDNF) improvement (60.02%), followed by group B with neuromuscular electrical stimulation (34.71%), and the control group (14.61%).

Supporting our study, that a notable increase in serum BDNF and NGF levels in patients following combined treatment of biofeedback electrical stimulation combined with early intensive rehabilitation training⁴⁰.

Furthermore, a study stated that the combined effect of hippotherapy and neurofeedback on the BDNF level of

W2G showed an increased tendency (pretraining, 1968.28 ± 429.08 pg/ml; post training, 1976.28 ± 425.35 pg/ml)⁴¹.

Also, another study carried out a study on 11 healthy male subjects completed three interventions (NMES, voluntary exercise, and resting interventions) for 20 min on different days. They highlighted that NMES was more effective for enhancing serum BDNF than voluntary exercise⁴².

The observed improvements in SEMG in the myofeedback group align with previous studies highlighting the benefits of myofeedback in enhancing motor control and muscle activation patterns in individuals with neurological impairments⁴³ myofeedback provides real-time feedback on muscle activity, allowing patients to adjust and refine their motor strategies, potentially leading to more effective motor learning and recovery. The significant increase in BDNF levels in the myofeedback group further supports the notion that this intervention promotes neuroplasticity and neuronal adaptation, crucial for functional recovery after brain injury ⁴⁴.

The NMES group also demonstrated significant improvements in SEMG and BDNF, consistent with research indicating that electrical stimulation can enhance muscle strength and promote neural plasticity ^{45,46}. However, the lesser magnitude of improvement compared to the biofeedback group may suggest that while NMES is beneficial, it may not be as effective in promoting active motor engagement and learning as myofeedback. The lack of significant changes in the control group underscores the importance of targeted interventions in promoting recovery in children with hemiplegia. Standard physical therapy, while beneficial, may not provide the same level of specificity and intensity as biofeedback or NMES in addressing motor impairments.⁴⁷

The findings of this study have implications for rehabilitation strategies in pediatric patients with hemiplegia after brain tumor surgery. Incorporating myofeedback and NMES into treatment plans may enhance motor outcomes and promote neurological recovery. Further research is needed to explore the long-term effects of these interventions and to identify patient-specific factors that may influence treatment response.

CONCLUSION

This study demonstrates that myofeedback and NMES programs are effective interventions for improving motor function and neurological outcomes in children with hemiplegia after brain tumor surgery. The myofeedback program showed superior improvements in surface electromyography (SEMG) and brain-derived neurotrophic factor (BDNF) levels compared to NMES and standard physical therapy.

Source of funding

The research did not receive any specific grant from funding agencies in the commercial, or not for profit sectors.

Conflict of interest

The authors have no conflict of interest to declare

Ethical approval

Approved by Physical Therapy Faculty Ethics Committee [P.T.REC/012/006382] and ClinicalTrials.gov: NCT07606222.

REFERENCES

- Hewedi I, Ibrahim R, Elserriy T, et al. Frequency of primary central nervous system tumors in a tertiary hospital, Cairo, Egypt. *J Community Health Manag.* 2018;5(3):140-6.
- Hedr W, Sherin A, Elwany A. Surgical management of huge pediatric brain tumors in Egypt: A model from developing countries. *Pan Arab J Neurosurg.* 2022;17(1):31-9.
- Ward E, DeSantis C, Robbins A, Kohler B, Jemal A. Childhood and adolescent cancer statistics. *CA Cancer J Clin.* 2014;64(2):83-103.
- Dong J, Li S, Li L, et al. Prognostic factors in pediatric brain tumors. *Br J Radiol.* 2021;95(1129):20210689.
- Agus MS. Pediatric neuro-oncology advances. *Weill Cornell Med J.* 2024;15(1):45-52.
- Karsonovich T, Ahmad T. Neonatal Brain Tumors. *StatPearls.* 2025.
- Ngwenya LB, Chiocca EA. Extent of resection in glioblastoma surgery. *J Neurosurg.* 2011;115(5):994-1002.
- Mansour MA, Mohsen A, Medhat S, et al. Surgical outcomes in pediatric brain tumors. 2025.
- Chaichana KL, Zadnik P, Weingart JD, et al. Multiple resections for patients with glioblastoma: prolonging survival. *J Neurosurg.* 2013;118(4):812-20.
- Dietrich J, Rao K, Pastorino S, Kesari S. Corticosteroids in brain cancer patients: benefits and pitfalls. *Expert Rev Clin Pharmacol.* 2011;4(2):233-42.
- Kinugawa K, Mano T, Wada H, et al. Improvement in lower extremity hemiplegia post brain tumor surgery. *J Phys Ther Sci.* 2022;34(6):473-7.
- Bojanic DM, Petrovacki-Balj BD, Jorgovanovic ND. Quantification of dynamic EMG patterns during gait in children with cerebral palsy. *J Neurosci Methods.* 2011;198(2):325-31.
- Bathina S, Das UN. Brain-derived neurotrophic factor and its clinical implications. *Arch Med Sci.* 2015;11(6):1164-78.
- Kimura T, Kaneko F, Iwamoto E, Saitoh S, Yamada T. Neuromuscular electrical stimulation increases serum BDNF in humans. *Exp Brain Res.* 2019;237(1):47-56.
- Chih-Hung U, Shiue CC, Kuan YC, et al. NMES effects on lactate and BDNF. *Am J Phys Med Rehabil.* 2023;102(2):151-8.
- Galina NA, Bykova VV, Vakarchuk RN, Tatevosian RE. Neuromuscular adaptations in CP. *Seismic Instruments.* 2019;55(1):59-69.
- Feng S, Tang M, Huang G. Biofeedback applications in rehabilitation. *Yunnan J Tradit Chin Med.* 2018.
- Huang H. Biofeedback for motor recovery in stroke patients: a systematic review. *J Rehabil Res Dev.* 2018;55(3):323-34.
- Haugh AB, Pandyan AD, Johnson GR. A systematic review of the Tardieu Scale for spasticity. *Disabil Rehabil.* 2006;28(15):899-907.
- Mulder ML, Van den Steen E, De Neve J, Weir A. Core muscle strength measurement reliability. *J Back Musculoskelet Rehabil.* 2022;35(5):993-1001.
- Sandberg MK, Al-Doujaaily H, Sharps B, et al. Prion neuropathology mechanisms. *Nat Commun.* 2014; 5:4347.
- Amer A, Alomari M, Jarl G, et al. Arabic CHEQ reliability and validity. *Hong Kong J Occup Ther.* 2022;35(1):84-95.
- Ryll UC, Eliasson AC, Bastiaenen CH, Green D. CHEQ change scores validity in unilateral CP. *Phys Occup Ther Pediatr.* 2019;39(2):168-80.
- Gamez AB, Hernandez Morante JJ, Martinez Gil JL, et al. sEMG biofeedback in elderly adults. *Sci Rep.* 2019;9(1):13153.
- Deitz JC, Kartin D, Kopp K. Review of Bruininks-Oseretsky Test of Motor Proficiency-2. *Phys Occup Ther Pediatr.* 2007;27(4):87-102.
- Polacchini A, Metelli G, Francavilla R, et al. Reproducible measurements of serum BDNF. *Sci Rep.* 2015; 5:17989.
- Boyd RN, Graham HK. Botulinum toxin type A for children with cerebral palsy. *Eur J Neurol.* 2000;6 Suppl 4:23-35.
- Kaur M, Gianey HK, Singh D, Sabharwal M. Multi-objective differential evolution in e-health. *Mod Phys Lett B.* 2019;33(5):1950022.
- Kang TW, Park SY, Jo HJ. Mobile app biofeedback breathing exercises effects. *Front Rehabil Sci.* 2025; 6:1696503.
- Miri M, Tahami E, Veisi G. EMG-biofeedback in multiple sclerosis strengthening. *Mult Scler Relat Disord.* 2025; 93:106193.
- Hamed AES, Matty SM, El-Din Taha TS. Reciprocal electrical stimulation effect on grip strength in spastic hemiplegic CP. *J Med Sci Res.* 2021; 4:3.
- Taha TSE, Elsayed M, Maaty SM, et al. Biofeedback vs electrical stimulation in hemiplegic CP children. *Egypt J Phys Ther Rehabil.* 2025;22.
- Usta Ozdemir H, Kitis A, Demirkan AF. EMG biofeedback after tendon transfer surgery in CP. *Jt Dis Relat Surg.* 2024; 35:448-54.
- Hamed AES, Matty SM, El-Din Taha TS. Reciprocal

- electrical stimulation for handgrip strength. *J Med Sci Res.* 2021; 4:3.
35. Haji-Ahmad T, Haghgoo HA, Pishyareh E, Biglarian A. Biofeedback effect on hand function post-stroke. *Zahedan J Res Med Sci.* 2015; 17:2204.
 36. Giggins OM, Persson UM, Caulfield B. Biofeedback in rehabilitation. *J Neuroeng Rehabil.* 2013; 10:60.
 37. Dursun E, Dursun N, Alican D. Biofeedback treatment effects on gait in CP. *Disabil Rehabil.* 2004;26(2):116-20.
 38. Armagan O, Tascioglu F, Oner C. EMG biofeedback in hemiplegic hand: placebo-controlled study. *Am J Phys Med Rehabil.* 2003;82(11):856-61.
 39. Cobo-Vicente F, San Juan AF, Larumbe-Zabala E, et al. NMES improves muscle strength in children with chronic neurological disorders: meta-analysis. *Phys Ther.* 2021;101(8):170.
 40. Chen T, Yang J, Yan J, Ding X. Biofeedback electrical stimulation combined with rehabilitation post-stroke. *Am J Transl Res.* 2025; 17:652.
 41. Lee N, Park S, Kim J. Hippotherapy and neurofeedback effect on BDNF in ADHD. *J Exerc Nutrition Biochem.* 2017; 21:35-42.
 42. Kimura T, Fuminari K, Iwamoto E, Saitoh S, Yamada T. NMES increases serum BDNF. *Exp Brain Res.* 2019; 237:47-56.
 43. Bolek J. Multiple-site SEMG reward programming in pediatric rehabilitation. *Appl Psychophysiol Biofeedback.* 2006;31(3):263-72.
 44. Marshall PW, Lovell R, Jeppesen GK, Andersen K, Siegler JC. Hamstring fatigue and central motor output. *PLoS One.* 2014;9(7): e102753.
 45. Dutta A. Biofeedback-based interventions for motor rehabilitation after stroke. *J Neuroeng Rehabil.* 2019;16(1):1-13.
 46. Lu B, Lu Y, Christian K. BDNF: regulator of neuronal plasticity and function. *Neuron.* 2013;80(3):655-68.
 47. Knutson JS, Fu MJ, Sheffler LR, Chae J. NMES for motor restoration in hemiplegia. *Phys Med Rehabil Clin N Am.* 2015;26(4):729-42.