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The Effect of Brain-Computer Interface Training Based on Motor Imagery Combined with Conventional Rehabilitation on Patients with Subacute Stroke Hemiplegia

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Abstract: *Objective:* Analyzing the value of combining motor imagery brain-computer cooperative training with conventional rehabilitation in patients with hemiplegia after subacute stroke, and understanding how this approach affects patients' upper limb movement, muscle spasticity, and daily living abilities. Methods: We selected 60 patients with subacute stroke-related hemiplegia for this study and used a random number table to divide them into groups, with 30 cases in the control group and 30 in the experimental group. The control group received conventional rehabilitation combined with upper limb motor function training, with an intervention period of 3 weeks, training 5 days per week. The experimental group, based on the same rehabilitation interventions as the control group, additionally received motor imagery BCI training, using the LSR-AII brain-computer interface for standardized training. Personalized training thresholds and movements were set according to each patient's limb dysfunction, with each session lasting 30 minutes, once a day. Results: Before intervention, there were no significant differences between the two groups in upper limb motor function, limb spasticity, daily living abilities, or fine motor function scores (p > 0.05). After intervention, both groups showed improvement in all functional scores. The experimental group showed greater improvements in Fugl-Meyer upper limb motor function scores, simplified upper limb function scores, and Barthel Index, while the observation group had higher rates of limb spasm improvement and motor function enhancement compared to the control group. The comparisons between groups showed statistically significant differences ($p < 0.05$). Conclusion: A comprehensive rehabilitation program combined with motor imagery brain-computer interface training can improve upper limb motor and fine functions in stroke patients and enhance their ability to take care of daily activities.

Keywords: Motor imagery; Brain-computer collaborative training; Conventional rehabilitation therapy; Subacute stroke; Hemiplegic patients

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1. Introduction

After a stroke, central motor control networks can easily be damaged, often showing up as movement problems on one side of the body, which limits patients' ability to carry out daily activities. The subacute stage, however, still has high neural plasticity and potential for functional recovery, offering a critical window for rehabilitation interventions. Traditional rehab mostly focuses on training peripheral muscles and correcting movement patterns, paying less attention to regulating central sensory functions. Combining motor imagery with brain-computer interface technology can capture patients' movement intentions and use functional feedback to build a central-peripheral control system, enhancing sensory-motor cortex activity, promoting synaptic plasticity and neural network reorganization, and providing a more precise approach for recovering function after stroke-induced hemiplegia [1].

2. Materials and methods

2.1. General information

The participants in this study were 60 patients with subacute hemiplegia after stroke admitted to our hospital. They were randomly assigned to two groups using a random number table, with a control group and an experimental group, each consisting of 30 patients. In the control group, patients were aged 45 to 78 years, with an average age of 62.35 ± 1.82 years, including 17 men and 13 women. Their educational levels were distributed as follows: 9 with primary school or below, 11 with junior high, 7 with high school or technical secondary school, and 3 with college or above. The experimental group was aged 44 to 79 years, with an average age of 61.98 ± 1.15 years, including 16 men and 14 women, and their educational levels were 8, 12, 6, and 4 patients, respectively. All enrolled patients had a disease course of 2 weeks to 3 months. There were no statistically significant differences in baseline demographic data between the two groups ($p > 0.05$), so comparison between groups was feasible.

2.2. Screening criteria

2.2.1. Inclusion criteria

(1) Meets the stroke diagnostic criteria of the "Chinese Guidelines for the Diagnosis and Treatment of Acute Ischemic Stroke," confirmed as a stroke by a head CT or MRI scan, with symptoms of one-sided limb paralysis [2].

(2) In the subacute phase of stroke, with a disease duration of 2 weeks to 3 months, stable vital signs, and no progressive worsening of the condition.

(3) The affected limbs have varying degrees of motor dysfunction, with muscle strength between levels 1 and 4, able to cooperate with basic rehabilitation exercises and motor imagery training [3].

2.2.2. Exclusion criteria

(1) Patients with other central nervous system diseases like brain hemorrhage or brain tumors, which can hinder limb movement and brain function recovery, are not included in this study.

(2) People whose affected limbs have fractures, severe joint contractures, tendon injuries, or other conditions that make it impossible to participate in rehab training [4].

(3) People with serious cognitive impairments, aphasia, or other functional issues who can't understand motor imagery training instructions or complete effectiveness assessments.

2.3. Method

The participants in the control group only received the conventional rehabilitation program and specialized training for upper limb motor function. All interventions followed the relevant regulations of the 'Chinese Guidelines for Stroke Rehabilitation'. The main focus of the intervention was exercise therapy and occupational therapy, supplemented with acupuncture and various physical therapies. Specific interventions included joint mobility exercises for the affected limb, muscle stretching, strength training, and training for motor control and coordination, along with medium-frequency pulse electrotherapy and acupuncture at acupoints. Each session lasted a total of 3 hours per day, with treatments conducted 5 times a week, and the continuous intervention period was no less than 3 weeks [5].

Patients in the experimental group received routine rehabilitation treatment identical to that of the control group, and on top of that, brain-computer synergy (MI-BCI) training for motor imagination was added, with each session lasting 30 minutes, once daily, five days a week, for three consecutive weeks [6]. The training equipment used is the LSR AII brain-computer interface rehabilitation training system produced by a company in Shandong. The hardware includes a headset for EEG signal collection, a signal processing computer, and a functional electrical stimulation therapy device. The training takes place in a quiet, private rehab room, and all operations are carried out under the full supervision of a certified rehabilitation therapist. The specific training methods are as follows:

(1) Pre-training preparation

Before training, the therapist should assist the patient in sitting upright in front of the device screen, maintaining a relaxed state and steady breathing. Wear the head-mounted EEG collection electrode according to the international 10–20 lead standard, evenly apply conductive paste, then check the electrode fit to ensure the collected EEG signals are stable and accurate. At the same time, personalized training movements are developed based on the degree of upper limb dysfunction in the affected limb, and silicone stimulation electrode pads are attached to the corresponding functional muscles of the affected limb, slowly adjusting the intensity of the electrical stimulation current. The standard is that the patient can produce effective movements without tingling or discomfort.

(2) Personalized training threshold

Before training, the therapist uses the device's voice prompts and dynamic screen animations to guide the patient through repeated standardized motor imagery exercises. The device simultaneously collects and analyzes EEG signals from different task stages. Then, the therapist takes the average of 10 valid motor imagery signals to set the accuracy threshold for that training session, and recalibrates the threshold before each session to ensure the training matches the patient's real-time brain function [7].

(3) Brain-computer collaborative training

During training, patients must follow the device's voice commands to complete specified upper limb movement imagination. If the EEG signal accuracy of the movement imagination reaches a preset threshold, the device will automatically trigger the discharge function, driving the affected limb to perform corresponding movements and providing positive visual and somatosensory feedback. If the threshold is not reached, electrical stimulation cannot be triggered, and the limb does not move in coordination. At this point, the therapist should guide the patient to adjust the imaginary state and repeatedly reinforce the activation effect of the brain's motor cortex.

2.4. Observation indicators

(1) Upper limb motor function

The Fugl-Meyer Upper Extremity Motor Function Scale was used to assess the motor function of the hemiplegic upper limb in both groups of patients before and after admission. Higher scores indicate better limb motor function.

(2) Degree of limb spasticity

The Modified Ashworth Scale was used to evaluate muscle tone and spasticity of the hemiplegic upper limb. Lower grades indicate more significant improvement in upper limb flexor spasticity and reflect the effect of spasticity control in hemiplegia.

(3) Activities of daily living (ADL) ability

The Barthel Index was used to assess patients' ability for daily self-care activities, such as dressing and washing, thus reflecting the effect of hemiplegic limb function recovery on patients' daily life ability.

(4) Upper limb fine motor function

The Simple Upper Limb Function Evaluation Scale was used to assess patients' hand grasping and limb coordination abilities in the hemiplegic upper limb, reflecting the rehabilitation improvement of distal limb hemiplegia [8].

2.5. Statistical methods

The research data were analyzed using SPSS 27.0 software. Count data are described as the number of cases and percentages, and the χ^2 test was used for comparisons between groups. A p-value of less than 0.05 indicates a statistically significant difference.

3. Results

3.1. Comparison of upper limb motor function between the two groups of patients

Before the nursing intervention, there was no significant difference in Fugl-Meyer upper limb function scores between the two groups ($p > 0.05$); after the intervention, scores in both groups increased compared to baseline, but the experimental group's scores and improvement rate in upper limb motor function were significantly better than the control group's, and the difference between the groups was statistically significant ($p < 0.05$). The detailed results are shown in **Table 1**.

Table 1. Comparison of upper limb motor function between the two groups of patients [$\bar{x} \pm s$, n(%)]

Group	Number of cases	Pre-treatment FMA score	Post-treatment FMA score	Number of improvements
Control group	30	22.48 ± 4.61	37.62 ± 5.84	21 (70.00)
Experimental group	30	22.73 ± 4.56	46.85 ± 6.12	28 (93.33)
χ^2			5.450	
t			11.140	
p			0.020	

3.2. Comparison of the degree of limb spasticity between the two groups of patients

After the intervention, although the scores of both groups showed an upward trend, the improvement in the experimental group was more prominent, indicating that it was more effective in improving hand grip and coordination control. At the same time, the proportion of the experimental group reaching the functional improvement criteria was higher, suggesting that combined intervention performs better in promoting distal upper limb functional recovery, with the difference being statistically significant ($p < 0.05$). For specific data, see **Table 2**.

Table 2. Comparison of modified ashworth scale grades in two groups of patients after treatment [n(%)]

Group	Number of cases	Level 0	Level 1	Level 1+	Level 2	Level 3	Spasm improvement rate
Control group	30	4 (13.33)	8 (26.67)	7 (23.33)	8 (26.67)	3 (10.00)	19 (63.33)
Experimental group	30	10 (33.33)	11 (36.67)	6 (20.00)	3 (10.00)	0 (0.00)	27 (90.00)
χ^2					3.305		
p					0.046		

Note: The improved Ashworth Scale (MAS) grading criteria are as follows: Grade 0 means muscle tone is at a normal level; grade 1 is a mild increase in muscle tone; grade 1 also represents a slight rise in muscle tone; grade 2 indicates a noticeable increase in muscle tone, and grade 3 represents a severe increase in muscle tone.

3.3. Comparison of the daily living activities abilities of the two groups of patients

The Barthel Index scores of the two groups of patients were similar before the intervention. After treatment, the control group increased from (43.25 ± 6.18) points to (61.47 ± 7.26) points, while the experimental group increased from (43.71 ± 6.05) points to (74.38 ± 8.14) points. The improvement in the experimental group was more significant ($p < 0.05$). For specific data, see **Table 3**.

Table 3. Comparison of Barthel index scores and improvements between the two groups of patients [x̄ ± s, n(%)]

Group	Number of cases	Barthel index score before treatment	Barthel index score after treatment	Number of improvements
Control group	30	43.25 ± 6.18	61.47 ± 7.26	22 (73.33)
Experimental group	30	43.71 ± 6.05	74.38 ± 8.14	29 (96.67)
χ^2		6.491		
t		10.436		
p		0.021		

3.4. Comparison of fine motor function of the upper limbs between the two groups of patients

The stats show that before the intervention, there was no significant difference in upper limb fine motor function scores between the two groups ($p > 0.05$). After the respective interventions, the scores in the experimental group improved significantly more than those in the control group, and the difference between the groups was statistically significant ($p < 0.05$). Detailed stats are shown in **Table 4**.

Table 4. Comparison of upper limb fine motor function between the two groups of patients [x̄ ± s, n(%)]

Group	Number of cases	Pre-treatment Score	Post-treatment score	Number of cases with functional improvement
Control group	30	21.86 ± 4.25	34.72 ± 5.18	20(66.67)
Experimental group	30	22.14 ± 4.37	42.65 ± 5.96	28(93.33)
χ^2			2.837	
t			15.971	
p			0.038	

4. Discussion

The subacute phase is the golden window for neural remodeling and neural function recovery in stroke patients with hemiplegia. During this period, the patient's condition is stable, and the sensory-motor cortex of the brain still possesses strong neuroplasticity. Therapists assisting patients in promptly carrying out standardized rehabilitation interventions can improve upper limb motor dysfunction and reduce the risk of limb spasticity and residual disability. Routine clinical rehabilitation mainly focuses on passive physiotherapy and basic muscle strength training, which can, to some extent, improve the patient's basic limb activity ability. However, this training mode is relatively single in its methods and more focused on correcting the patient's peripheral motor performance, providing insufficient stimulation for the integration and reconstruction of central nervous system motor networks, making it difficult to activate neural pathway functions [9]. Therefore, some patients experience relatively slow progress in recovering fine upper limb functions and muscle tone regulation, and the improvement in spasticity is also not ideal, leaving room for overall functional recovery to be enhanced.

The results of this study show that after 3 weeks of intervention, the upper limb motor function, fine motor ability, spasticity status, and activities of daily living of patients in both groups improved compared with before treatment, confirming that conventional rehabilitation treatment has clear rehabilitation value for patients with subacute stroke hemiplegia. However, intergroup comparison showed that the experimental group receiving combined MI-BCI brain-computer synergy training had greater improvements in all evaluation indicators than the control group, with more significant improvement in spasticity rates and daily living ability, suggesting that motor imagery brain-computer synergy training can compensate for the limitations of conventional rehabilitation and enhance the overall rehabilitation efficacy of stroke hemiplegia. MI-BCI technology, based on non-invasive EEG signal collection and decoding mechanisms, can capture cortical electrical activity during patients' motor imagery, using real-time threshold feedback combined with functional electrical stimulation to build a closed-loop rehabilitation path of "brain intention, peripheral limb movement". This training model does not require patients to produce active limb movement; motor imagery training can activate the suppressed sensorimotor cortex after stroke to a certain degree, inducing plastic changes in the affected limb through continuous neural feedback stimulation, thereby enhancing the reactivation ability of dormant neural networks. During the subacute brain plasticity window, this mechanism helps reconstruct the impaired motor pathways of patients and improves the efficiency of neural function recovery. In addition, this technology can also mobilize patients' subjective training motivation through real-time positive feedback, addressing the boredom and poor compliance of conventional rehabilitation training, and strengthening the rehabilitation effect [10].

In summary, for patients with subacute stroke hemiplegia, adding MI-BCI motor imagery brain-computer interface training on top of the usual rehab program can help restore movement in the affected arm, ease muscle spasms, improve fine motor skills, and boost daily self-care abilities. This approach works better than just regular rehab alone and has strong clinical value, making it a great additional method to promote during subacute stroke recovery.

Disclosure statement

The author declares no conflict of interest.

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