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Efficacy Analysis of Upper Limb Functional Electrical Stimulation Combined with rTMS on Speech Function in Aphasic Patients

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Abstract

Objective: To investigate the effectiveness of combining upper limb functional electrical stimulation with repetitive Transcranial Magnetic Stimulation (rTMS) on the speech function of patients with aphasia.

Methods: Research participants comprised 96 stroke patients undergoing training at the Rehabilitation Center of Nantong First People's Hospital, China, from May 2021 to July 2023. The 96 patients were randomly divided into three groups, with each group consisting of 32 patients. All three groups received conventional speech rehabilitation training, with the rTMS group receiving additional rTMS treatment, the functional electrical stimulation group receiving additional upper limb functional electrical stimulation treatment, and the combined group receiving both rTMS and upper limb functional electrical stimulation treatments. All treatments lasted for four weeks.

Results: After treatment, the combined group exhibited superior hand function grades compared to the functional electrical stimulation and rTMS groups, showing statistical significance ($P<0.05$). Additionally, scores for spontaneous speech, auditory comprehension, repetition, naming, Montreal Cognitive Assessment (MoCA), and Modified Barthel Index (MBI) were higher in the combined group than in the other two groups, demonstrating statistical differences ($P<0.05$).

Conclusion: Combining upper limb functional electrical stimulation with rTMS can effectively restore speech function in aphasic patients, enhances cognitive function and daily life abilities, and plays a crucial role in promoting patient prognosis recovery. This combined approach is worthy of widespread application.

Keywords: Aphasia; Upper Limb Functional Electrical Stimulation; Repetitive Transcranial Magnetic Stimulation; Daily Life Abilities; Cognitive Function

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Introduction

Stroke is a prevalent disease with high morbidity and mortality rates. In recent years, the incidence of stroke has been increasing annually, while the mortality rate has significantly decreased. Extensive data shows that approximately 25% of stroke patients suffer from language impairments [1-2]. Aphasia is a common clinical manifestation after a stroke, most commonly associated with damage to the left cerebral hemisphere, resulting in difficulties in understanding and expressing both oral and written language. After a stroke, aphasia significantly hinders both the quality of life and the rehabilitation progress for patients. In recent years, various disciplines have explored the cortical localization and functional connections between upper limbs, language function, and hand motor function from different perspectives, suggesting the crucial role of upper limb and hand motor function in aphasia rehabilitation. Left-hand action training has been proven effective for naming in aphasic patients with damage to the language area of the dominant hemisphere. It is believed that after damage to the language area of the dominant hemisphere, some language functions can transfer to the non-dominant hemisphere [3]. Repetitive Transcranial Magnetic Stimulation (rTMS) is a novel non-invasive Neuroregulation technique used in psychiatry, neurology, and rehabilitation medicine for disease treatment and brain function recovery. It has shown significant benefits for individuals dealing with post-stroke motor dysfunction, aphasia, and hemispatial neglect [4,5]. High-frequency rTMS has been proven effective in improving language function for those with severe post-stroke motor aphasia, fostering compensation in the right cerebral hemisphere, and promoting activation and reorganization of the left cerebral hemisphere

[6]. Several studies have explored the efficacy of rTMS, for example, Bai et al. studied how low-frequency rTMS affects non-fluent aphasia in stroke patients, utilizing functional magnetic resonance scans and blood analysis to identify activated brain regions, explore plasticity changes, and examine brain-derived neurotrophic factor levels. This study provided clinical and theoretical support for rTMS in treating aphasia [7]. In the study conducted by Haghighi et al., 12 post-stroke aphasia patients underwent regular speech and language training, with half receiving adjuvant repetitive Transcranial Magnetic Stimulation (rTMS) targeting the right hemisphere's inferior posterior frontal gyrus; the findings demonstrated notable enhancement in speech and language abilities, particularly in content, fluency, aphasia quotient, command comprehension, and repetition, in comparison to a sham condition [8]. Fahmy and Elshebawy assessed the impact of excitatory rTMS on post-stroke aphasic patients, it found that excitatory rTMS significantly improved language abilities in individuals with chronic post-stroke non-fluent aphasia, suggesting its benefit as a short- and long-term adjuvant therapy [9]. Functional electrical stimulation is a method employed to prevent or reduce long-term impairments in the upper arm of stroke patients. Several investigations have assessed the efficacy of functional electrical stimulation in preventing or reducing long-term impairments in the upper arm of stroke patients, e.g., [10-13], and Vafadar et al. provided a systematic review of the evidence for the effect of functional electrical simulation on shoulder subluxation [14]. An existing gap in the literature lies in the examination of the effectiveness of combining upper limb functional electrical stimulation with rTMS on the speech function of aphasic patients. Therefore, in this study, we aim to analyze the influence of this combined approach on the speech function of individuals with aphasia.

Materials and Methods

General information

Based on different treatment methods, the patients were divided into three groups: combined group (32 cases), functional electrical stimulation group (32 cases), and rTMS treatment group (32 cases). As shown in Table 1, comparisons of general data among the groups indicated no statistically significant differences (P>0.05).

Inclusion criteria: ① Meeting the diagnostic criteria of the "Chinese Classification of Cerebrovascular Diseases 2015" [15]; ② Confirmed by CT or MRI as the first onset; ③ Disease duration of 15 to 90 days; ④ Age between 20 to 70 years; ⑤ Stable vital signs with no comprehension disorders; ⑥ Meeting the diagnostic criteria of the "Chinese Aphasia Rehabilitation Treatment Expert Consensus" [16]; ⑦ No articulation disorders due to damage to the pronunciation organs; ⑧ Informed consent forms were signed by patients and their families.

Exclusion criteria: ① Unstable vital signs; ② Severe cognitive impairment, unable to follow instructions; ③ Associated with significant damage to vital organs such as heart and lungs; ④ Neurodegenerative diseases; ⑤ Presence of metal implants in the body; ⑥ Aphasia caused by other diseases such as traumatic brain injury; ⑦ Accompanied by severe auditory or visual impairment; ⑧ History of epilepsy or family history of epilepsy; ⑨ Non-cooperation or other reasons for trial withdrawal.

Dropout and exclusion criteria: ① Occurrence of severe adverse reactions; ② Emergence of new lesions; ③ Patient request to withdraw from the trial.

Methods

All three groups received conventional speech rehabilitation training, including auditory stimulation training, articulation training, and psychological rehabilitation training, with a treatment time of 30 min per session, once a day, five days a week, for four weeks. The rTMS group received additional rTMS treatment, the functional electrical stimulation group received additional upper limb functional electrical stimulation treatment, while the combined group received both rTMS and upper limb functional electrical stimulation treatments. Specific methods are as follows:

Functional electrical stimulation group: In this group, the YSA series upper limb functional electrical stimulation was used. The programmatic electrical stimulation induced upper limb muscle contractions, producing hand grasping, extension, pinch, opposition, and wrist flexion movements. The stimulation of muscle contraction during functional movement stimulates muscle spindles and tendon proprioceptors, integrating central coordination of coordinated movement output and sensory input, achieving the goal of inducing central nervous system functional reorganization, and promoting neural function recovery. After wearing, the patient performed alternating training of finger extension and grasping in the treatment mode, followed by 5 min of passive limb movement, and then functional movement training.

rTMS treatment group: The rTMS treatment was performed using the CCY-1 type magnetic field therapy device produced by Wuhan Yiruide, and operated by professional therapists. Prior to treatment, patients are instructed to wear a suitable positioning cap. Therapists used the positioning cap to locate the right inferior frontal gyrus. Ten pulse stimulations are administered, identifying the minimum stimulation intensity that induces at least five wave amplitudes greater than 50 uV, referred to as the Resting Motor Threshold (RMT). During treatment, patients lie in a supine position, and the plane of the coil midpoint is perpendicular to the plane of the right inferior frontal gyrus. Parameters include 90% RMT, 1 Hz, each sequence lasting 12 sec with a 2-second interval. Treatment is conducted for 20 min per session, once a day, five days a week, for a total of four weeks.

Combined group: The combined group received both the upper limb functional electrical stimulation and rTMS treatments mentioned above. The treatment lasted for four weeks.

Observation indicators

In assessing hand function, the three groups were compared by utilizing the Twitchell-Brunnstrom scale before and after four weeks of treatment. The scale categorizes hand paralysis into six levels: Level I indicates no movement, Level II involves minimal flexion, Level III allows for hook grasp, Level IV enables thumb release and limited finger extension, Level V involves spherical and cylindrical grasps with concentrated finger extension but no individual extension, and Level VI indicates the ability to complete grasping but with lower speed and accuracy compared to the unaffected side. Additionally, the study evaluated language function recovery across the groups using the Western Aphasia Battery (WAB) before and after four weeks of treatment. Aphasia was diagnosed when the Aphasia Quotient (AQ = [spontaneous speech + auditory comprehension + repetition + naming] × 2) was less than 93.8. The WAB subtests included spontaneous speech (10 points each for information content and fluency), auditory comprehension (200 points, with

60 points for yes/no questions, 60 points for word recognition, and 80 points for continuous commands), repetition (100 points), and naming (100 points, with 60 points for word retrieval, 20 points for item generation, 10 points for sentence completion, and 10 points for responsive naming). Furthermore, the Montreal Cognitive Assessment (MoCA) was used to assess cognitive function before and after four weeks of treatment, covering various aspects such as orientation, attention, and abstract ability, the assessment yielded a total score of 30 points, with higher scores indicating superior cognitive function. Lastly, daily living abilities were compared among the three groups using the Modified Barthel Index (MBI) before and after four weeks of treatment. The MBI has a total score of 100 points, it comprises 10 items and reflects higher daily living abilities with increasing scores. The comprehensive evaluation aimed to analyze the impact of different therapeutic approaches on stroke patients' rehabilitation outcomes.

Statistical analysis

Data analysis was conducted using SPSS 22.0 statistical software. Measurement data are presented as mean ± standard deviation ($\bar{x} \pm s$). Group comparisons were carried out through one-way Analysis of Variance (ANOVA), and pairwise comparisons between groups were conducted using the Least Significant Difference (LSD) method. We conducted within-group comparisons before and after treatment using the paired t-test. We presented categorical data as percentages (%) and utilized the chi-square test for between-group comparisons, considering $P<0.05$ as statistically significant.

Results

Comparison of hand function grade

There was no significant difference observed in the hand function grade among the three groups ($P>0.05$) before treatment. After treatment, the hand function grade in the combined group was significantly lower than that in the functional electrical stimulation group and the rTMS group, with a statistically significant difference ($P<0.05$). There was no significant difference in the hand function grade between the functional electrical stimulation group and the rTMS group after treatment ($P>0.05$). Table 2 and Table 3 show detailed statistics.

Comparison of speech function scores

Spontaneous speech, auditory comprehension, repetition, and naming scores among the three groups did not show significant differences before the treatment ($P>0.05$). As shown in Table 4, one can see after treatment, the spontaneous speech, auditory comprehension, repetition, and naming scores in the combined group were significantly higher than those in the functional electrical stimulation group and the rTMS group, and the differences were statistically significant ($P<0.05$).

Comparison of cognitive function and daily life abilities

MoCA and MBI scores did not exhibit significant differences among the three groups before treatment ($P>0.05$). However, post-treatment, the combined group demonstrated significantly higher MoCA and MBI scores compared to the functional electrical stimulation and rTMS groups, with statistically significant differences ($P<0.05$), as illustrated in Table 5.

Discussion

Aphasia is a common complication of stroke, and its treatment is a complex and challenging process. The specific mechanisms of language function recovery after stroke remain unclear, and different rehabilitation methods have varying effects on language recovery. In China, over one-third of patients with acute cerebrovascular diseases experience varying degrees of aphasia, requiring clinical treatment or intervention for language function recovery [17]. Language intervention involves identifying the specific language-impaired areas in patients and providing targeted rehabilitation training to maximize language function recovery [18]. Therefore, early and proactive treatment, as well as promoting the recovery of speech function, are particularly crucial for patients with post-stroke aphasia.

Research [19] indicates that post-stroke aphasia is most commonly associated with damage to the left cerebral hemisphere. As left-hand movement training has a lateralized effect on naming in both cerebral hemispheres, it is believed that the functions of the damaged language area in the dominant hemisphere can transfer to the non-dominant hemisphere. Therefore, functional electrical stimulation of the upper limbs is particularly important for promoting language function recovery in individuals with aphasia. During functional electrical stimulation of the upper limbs, programmed electrical stimuli are used to induce contraction of the patient's upper limb muscles, facilitating the recovery of hand movements such as extension and grasping. Subsequent functional movements are employed to promote muscle contraction, thereby better inducing central nervous system reorganization and recovery [20]. Transcranial Magnetic Stimulation (TMS) is a non-invasive, painless brain stimulation method that generates a pulsed magnetic field through electromagnetic induction technology, producing a weak electric current in the underlying cortical neurons, leading to their depolarization. The impact of TMS on neurons is determined by the stimulus intensity, frequency, and duration [21]. Additionally, repetitive TMS (rTMS) can effectively increase cerebral blood flow, regulate the growth of nerve cells, and restore the function of ischemic penumbra areas. It can also enhance the integrity of white matter tracts, activate local neurons, and enhance brain excitability. Moreover, rTMS can directly stimulate tissue in the affected frontal lobe, promote the reorganization of neural function in the unaffected hemisphere, strengthen the executive control network function of the brain, and play a crucial role in facilitating the recovery of language

Table 1: Comparison of general data among the three groups.

Group	Number	Gender		Age (years)	Disease duration (days)	Etiology	
		M	F			Ischemic	Hemorrhagic
Combined group	32	20	12	60.41 ± 11.92	28.63 ± 9.13	22	10
FES Group	32	22	10	62.72 ± 12.29	26.22 ± 8.12	22	10
rTMS treatment group	32	18	14	61.19 ± 12.71	31.84 ± 8.24	19	13
F/χ^2		1.067		0.509	0.051	0.831	
P		0.587		0.603	0.951	0.66	

Table 2: Comparison of hand function classification among three groups n (%) before treatment.

Group	Before treatment					
	□	□	□	□	□	□
Joint group (n=32)	16 (50.00)	3 (9.38)	1 (3.13)	4 (12.50)	6 (18.75)	2 (6.25)
Functional electrical stimulation (n=32)	18 (56.25)	2 (6.25)	3 (9.38)	4 (12.50)	5 (15.63)	0 (0.00)
rTMS treatment group (n=32)	21 (65.63)	4 (12.50)	1 (3.13)	0 (0.00)	4 (12.50)	2 (6.25)
Z	0.753					
P	0.451					

Table 3: Comparison of hand function classification among three groups n (%) after treatment.

Group	After treatment					
	□	□	□	□	□	□
Joint group (n=32)	10 (31.25)	1 (3.13)	2 (6.25)	1 (3.13)	5 (15.63)	13 (40.63)
Functional electrical stimulation (n=32)	15 (46.88)	1 (3.13)	4 (12.50)	1 (3.13)	7 (21.88)	4 (12.50)
rTMS treatment group (n=32)	16 (50.00)	0 (0.00)	7 (21.88)	1 (3.13)	6 (18.75)	2 (6.25)
Z	2.071					
P	0.038					

Table 4: Comparison of language function recovery among three groups (Score, $(\bar{x} \pm s)$.

Group	Spontaneous speech		Auditory comprehension		Repetition		Naming	
	Before treatment	After treatment	Before treatment	After treatment	Before treatment	After treatment	Before treatment	After treatment
Joint group (n=32)	12.28 ± 1.94	17.68 ± 1.03	125.39 ± 12.38	175.66 ± 13.41	53.59 ± 3.15	82.06 ± 3.12	55.05 ± 3.51	84.53 ± 3.26
Functional electrical stimulation group (n=32)	13.03 ± 1.38	15.41 ± 1.02	125.06 ± 12.36	149.57 ± 12.72	53.80 ± 3.22	75.05 ± 3.14	55.04 ± 3.58	76.09 ± 2.84
rTMS Treatment group (n=32)	13.24 ± 1.92	15.45 ± 1.06*	125.87 ± 12.27	150.38 ± 12.69*	53.67 ± 3.32	74.80 ± 3.19*	55.00 ± 3.41	75.87 ± 3.79*
F	0.884	24.943	1.888	26.078	1.279	32.852	1.846	38.195
P	0.413	0.000	0.152	0.000	0.279	0.000	0.158	0.000

Note: *P>0.05 compared with the Functional Electrical Stimulation Group

Table 5: Comparison of cognitive function and daily living ability scores among three groups (Score, $(\bar{x} \pm s)$.

Group	MoCA score		MBI score	
	Before treatment	After treatment	Before treatment	After treatment
Joint group (n=32)	18.63 ± 2.22	25.38 ± 2.51	66.26 ± 9.03	81.93 ± 7.77
Functional electrical stimulation group (n=32)	18.68 ± 2.07	22.15 ± 1.80	66.00 ± 9.00	71.90 ± 5.81
rTMS treatment group (n=32)	18.68 ± 2.12	21.84 ± 2.03*	66.42 ± 9.14	72.05 ± 6.37*
F	1.024	15.497	0.947	13.533
P	0.137	0	0.108	0

Note: *P>0.05 compared with the Functional Electrical Stimulation Group

function in patients [22].

This study explored the efficacy of upper limb functional electrical stimulation combined with rTMS on the speech function of aphasic patients. The results showed that after four weeks of treatment, the hand function grade in the combined group was significantly lower than that in the functional electrical stimulation group and the rTMS group, indicating that upper limb functional electrical stimulation combined with rTMS effectively improved hand motor function in aphasic patients. This improvement in hand motor function may contribute to the enhancement of language recovery. The combined group also showed significantly higher scores in spontaneous speech, auditory comprehension, repetition, and naming compared to the other two groups, suggesting that the combination of upper limb functional electrical stimulation and rTMS has a superior effect on speech function improvement in aphasic patients. Cognitive function and daily life abilities are crucial aspects of overall rehabilitation for stroke patients. In this study, the combined group demonstrated significantly higher scores in MoCA and MBI compared to the functional electrical stimulation group and the rTMS group after treatment, indicating that the combined treatment had a positive impact on cognitive function and daily life abilities in aphasic patients.

In conclusion, upper limb functional electrical stimulation combined with rTMS effectively improves hand motor function and speech function, as well as cognitive function and daily life abilities, in aphasic patients. This combined approach shows promise as an effective rehabilitation strategy for aphasia after stroke. Future research should explore the optimal combination of various rehabilitation methods and investigate the long-term effects of these

interventions.

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