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Original Article

Effect of somatosensory simulation training combined with EMG biofeedback on upper limb dysfunction in stroke patients

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Abstract: Objective: To explore the effect of somatosensory simulation training combined with EMG biofeedback in the rehabilitation of upper limb function in stroke patients with hemiplegia. Methods: Retrospective analysis of clinical data of 96 stroke patients with upper limb hemiplegia who underwent rehabilitation treatment in Xi'an International Medical Center Hospital from August 2019 to August 2021. These patients were divided into the patients into combined therapy group and control group according to the treatment modality. Patients in control group were given routine rehabilitation, and on this basis, somatosensory simulation training (SST) combined with EMG biofeedback were carried out in combined therapy group. Upper limb motor function [Fugl-Meyer assessment (FMA score), simple Test for Evaluating Hand Function (STEF score)], hand grab and relax test (HGRT), wrist active range of motion (AROM), nerve function [National Institutes of Health Stroke Scale (NIHSS score)], peripheral nerve conduction velocity, integrated EMG (iEMG) value of upper limb muscle group, and activities of daily living [modified Barthel Index (MBI score)] were compared between the two groups. Results: After treatment, the FMA score and STEF score of upper limb function in combined therapy group were higher, and HGTR and dorsiflexion AROM of the affected hand were also higher. Besides, NIHSS score and peripheral nerve conduction velocity of patients in combined therapy group were better improved, and iEMG values of upper limb muscle groups were higher, which effectively improved patients' activities of daily living and BMI score. Conclusion: SST combined with EMG biofeedback can better help stroke patients control the movement and muscle contraction of hemiplegic upper limbs, and improve the conduction velocity of peripheral nerve, so as to better improve patients' activities of daily living.

Keywords: Somatosensory simulation training, EMG biofeedback, cerebral apoplexy, hemiplegia, upper limb function

Introduction

Stroke is a common cardiovascular and cerebrovascular disease in clinic, which has become the primary cause affecting the life span of Chinese residents [1]. In recent years, with the aggravation of social aging in China, the incidence of stroke has increased at the rate of about 8.7% year by year [2]. In addition, due to bad eating habits and the increase of work pressure, prevalence of stroke in the young is increasing [3]. With the progress of thrombolysis and interventional therapy, the therapeutic effect of stroke has been continuously improved, but about 70% of patients will still have sequelae, most of which are hemiplegia, which has a negative impact their daily life. In the later rehabilitation treatment of hemiplegia, the function of upper limb is more difficult to recover than that of lower limb. According to statistics, the lower limb function of about 80% of hemiplegic patients will recover after 3-6 months, while upper limb function is often poorly improved due to it needs to undertake complex and fine movements of the body [4]. In daily life, most of the work needs to be undertaken by upper limb, which is an important guarantee for patients to realize self-care [5]. The loss of upper limb function will have a serious impact on the life quality and mental health of stroke patients. Therefore, promoting the rehabilitation of upper limb function in stroke patients with hemiplegia is the focus of clinical treatment.

At present, for stroke patients with impaired upper limb function, a variety of rehabilitation training methods are adopted to reconstruct the normal movement mode from their brain to relevant muscle groups. During the long process of rehabilitation training, because most rehabilitation training methods are relatively boring, it is easy to cause patients to lose interest, produce slack mood, and reduce treatment compliance, which will eventually have an adverse impact on the training effect [6]. In recent years, with the continuous exploration and research on the mechanism of nerve injury and rehabilitation in stroke patients, a variety of new training equipments have been developed and applied in clinical practice, which has achieved good clinical efficacy. For example, somatosensory simulation training (SST) is a new virtual rehabilitation training method [7]. Its principle is to effectively promote patients to mobilize muscles for coordinated movement through game mode, so as to stimulate relevant functional areas of cerebral cortex, which finally promoting the repair of injured brain motor neurons [8]. SST changes the shortcomings of traditional rehabilitation training, such as boring and monotonous, and can allow patients to choose their own game mode for training, which greatly improves the interest and interaction of training [9]. In order to achieve better scores in the game, patients will change their limb movements independently and complete the exercise of specific muscles, which greatly improves patients' subjective initiative in rehabilitation training process [10]. In addition, as an aerobic exercise, SST can effectively promote pituitary gland to secrete endorphins, which has a positive effect on the improvement of the response ability of central nervous system [11]. Meanwhile, doctors can effectively observe patients' training effect through the training system, which is of positive significance for training effect evaluation and training program adjustment [12].

Through SST, the surviving neurons can establish new nerve conduction pathways through axons, so that the relevant target functional areas of the brain can control the activities of muscle groups. On the other hand, helping patients establish new conditioned reflex through training to replace the original functional activities is another method to improve the limb function of stroke patients [13], and EMG biofeedback uses this principle. EMG biofeedback instrument can read the EMG signals of paralyzed muscles, and then the signals can be amplified and converted into images and guidelines that can be accepted by patients, so that patients can self-control the functional exercise of paralyzed muscles [14]. This therapy fully mobilizes patients' self-awareness and makes them actively participate in rehabilitation training, which is conducive to better master the skills and ability of regulating limb movement [15]. Besides, it can help to form the corresponding conditioned reflex through long-term repeated self-training [16]. Moreover, patients' conscious participation can repeatedly stimulate the relevant cerebral cortex and form corresponding excitation foci, which is the key factor for the remodeling of central nervous function and the re-establishment of neural circuit [17].

As a new rehabilitation technology, SST had not been frequently studied in the rehabilitation treatment of stroke patients with hemiplegia, especially in the treatment of hemiplegic upper limb function combined with EMG biofeedback. Therefore, this study aimed to explore the impact of SST combined with EMG biofeedback on upper limb function and daily activity ability of stroke patients with hemiplegia.

Materials and methods

The *choice of research obj*ect

A retrospective study was conducted to analyze the clinical data of stroke patients with hemiplegia undergoing rehabilitation treatment in Xi'an International Medical Center Hospital from August 2019 to August 2021. Due to the retrospective nature of the study, informed consent was waived. The study was approved by the ethics committee of Xi'an International Medical Center Hospital. Inclusion criteria: 1. Cerebral apoplexy is in line with the diagnostic criteria of *National clinical guideline for stroke* [18]; 2. The patient has clear consciousness and can cooperate with rehabilitation training; 3. Unilateral upper limb has motor dysfunction; 4. First stroke; 5. No traumatic disease exists in hemiplegic upper limbs. Exclusion criteria: 1. Complicated with mental illness; 2. Surgical

Table 1. Comparison of clinical date between groups [n (%), $\bar{x}$ ± s]

Items	Combined therapy group n=48	Control group n=48	t/χ²	P
Gender			0.376	0.539
Male	27 (56.25)	24 (50.00)		
Female	21 (43.75)	24 (50.00)		
Age (years)	56.32±13.45	57.21±14.11	-0.316	0.752
BMI (kg/m²)	24.61±2.64	25.17±2.86	-0.997	0.321
Disease course (d)	54.23±11.53	56.13±12.45	-0.776	0.440
Stroke type			0.924	0.336
Cerebral hemorrhage	7 (14.58)	4 (8.33)		
Cerebral infarction	41 (85.42)	44 (91.67)		
Hemiplegic limb			0.383	0.536
Left upper limb	22 (45.83)	19 (39.58)		
Right upper limb	26 (54.17)	29 (60.42)		
History of hypertension			0.178	0.673
Yes	31 (64.58)	29 (60.42)		
No	17 (35.42)	19 (39.58)		

operation history of the affected limb; 3. Combined with speech and hearing impairment; 4. Combined with shoulder per arthritis, humeral epicondylitis and other upper limb joint pain diseases. A total of 96 stroke patients were included and divided into combined therapy group and control group according to the treatment modality. No significant difference was found in age, gender, disease course, stroke type, hemiplegic limbs, and other general data between the two groups (**Table 1**).

Routine rehabilitation

The patient was put in a good limb position to reduce limb spasm and contracture. Meanwhile, the patient was assisted with passive movements of the affected upper limb, such as weight-bearing exercises, shoulder and elbow extensions, and wrist extensions, as well as hand grip training, hand sensitivity training, and thumb synergy training with other procedures. Moreover, Chinese medicine techniques were used to further promote the rehabilitation of the affected upper limb, such as acupuncture and low frequency electrical stimulation of acupuncture points to induce limb movement and improve the muscle strength of the affected upper limb. The course of treatment lasted for 8 weeks.

SST therapy

SST was mainly carried out with the help of Wii game system. During training, muscle exercise was mainly carried out in tennis and bowling game modes, and the balance function of patients' limbs was exercised through yoga and balance game modes. During the process of training through the game system, patients need to concentrate and fully mobilize the contraction of limb muscles. Besides, game process needs to be promoted by sensing patients' limb movement, which is the key factor for the formation of patients' rapid action response. During the training, the patients successively performed three game modes: muscle exercise, yoga, and balance training. After the rehabilitation teacher fully evaluated the patients' physical condition, the project category of each game mode was determined, and patients could rest for 10 min during the switching of each game. In addition, for items that only need to be completed by one side of the limb in the training process, the patient should complete them with the affected side (**Figure 1**). The training time of each patient was 30 minutes, 5 times a week, and lasted for 12 weeks.

EMG biofeedback therapy

EMG biofeedback instrument (XCH-B2, Shanghai Nuocheng Electric Co., Ltd.) is used to assist stroke patients' hemiplegic limbs in comprehensive training. Before training, patients should be told how to perform muscle contraction exercise according to the displayed EMG signal through multimedia publicity, so as to improve their coordination. During training, patients can take a sitting or lying down position. Then, the electrode piece will be attached to the abdominal part of patients' deltoid muscle, triceps brachii muscle, and forearm muscle group, thus collecting the EMG signal generated by the relaxation of the patients' upper limb muscle. According to the collected EMG signal, the threshold of EMG biofeedback (about 1.25

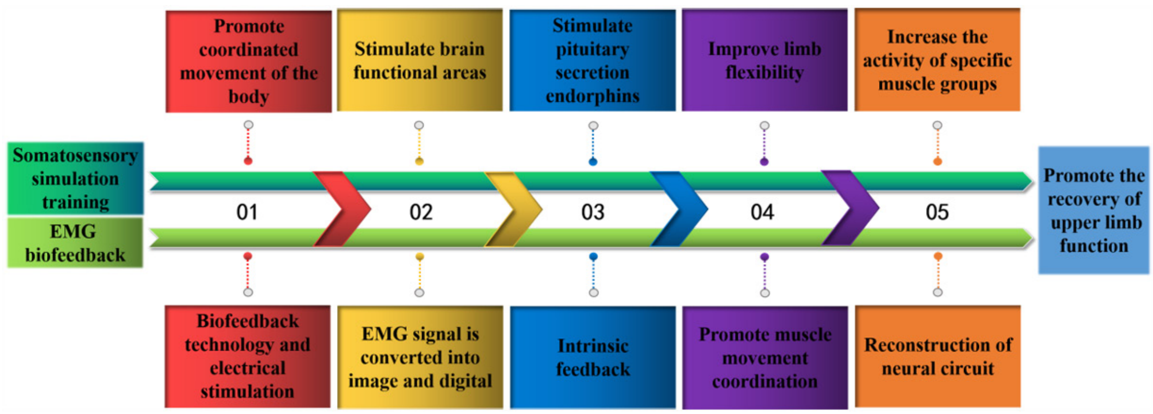

Figure 1. Mechanism of somatosensory simulation training and EMG biofeedback.

times) was set. During training process, patients actively carried out muscle contraction exercise. When the threshold was reached, the biofeedback instrument would carry out a positive feedback electrical stimulation to help patients complete a complete muscle contraction exercise. Besides, patients need to carefully observe the signal changes on the instrument screen during training, and gradually form a conditioned reflex according to the sound prompts, so as to control the contraction movement of paralyzed muscles (**Figure 1**). After each stimulation for 5 s, the interval is 15 s, and each training lasted for 20 min. Treatment was performed 5 times a week and lasted for 12 weeks.

Evaluation of upper limb motor function

Assessment of the patient's upper limb motor function recovery after 8 weeks of intervention. Firstly, Fugl-Meyer assessment (FMA) scale is used to assess motor function of patients' upper limbs [19]. The scale includes 33 items, each of which is evaluated by three-level scoring method (0-2 points). The higher the score, the better the recovery of upper limb activity function; Secondly, simple Test for Evaluating Hand Function (STEF) is used to evaluate fine function recovery of patients' upper limbs. The scale includes 10 items, with a total score of 100. The higher the score, the better fine function recovery of upper limbs. Thirdly, hand grab and relax test (HGRT) is used to evaluate the function of affected hand. In the test, the times the patient effectively completed a complete grasp and extension within 10 s is counted. The more times, the better the recovery of hand function. Fourthly, the active range of motion (AROM) was used to evaluate the back extension activity of patients' wrist joint. During the detection, patients are asked to do the back extension activity of the affected wrist joint to the greatest extent, and the protractor is used for measurement.

Neurological function recovery

After 8 weeks of intervention, the National Institutes of Health Stroke Scale (NIHSS) was used to evaluate the recovery of neurological function after rehabilitation treatment [20], and the highest score is 45 points. The higher the score, the more serious the neurological deficit is. Besides, the nerve conduction velocity of the affected upper limb is measured by electromyography (NTS-2000, Shanghai Nuocheng Electric Co., Ltd.), mainly including median nerve, ulnar nerve, and radial nerve.

EMG detection of upper limb muscle group

After 8 weeks of intervention, the changes of integrated EMG (iEMG) of hemiplegic limb muscles were measured by EMG to further evaluate the recovery of muscle function. The electrode was attached on the abdominal part of the deltoid, triceps, and forearm muscles of the affected limb, and patients were asked to abduct the shoulder of the affected limb as much as possible, and stretch the elbow, interphalangeal, and wrist joints. EMG signal value were taken in the middle 10 s during the 15 s of stretching. The iEMG values of each muscle group during stretching activities are recorded for 4 times, and the average value is taken.

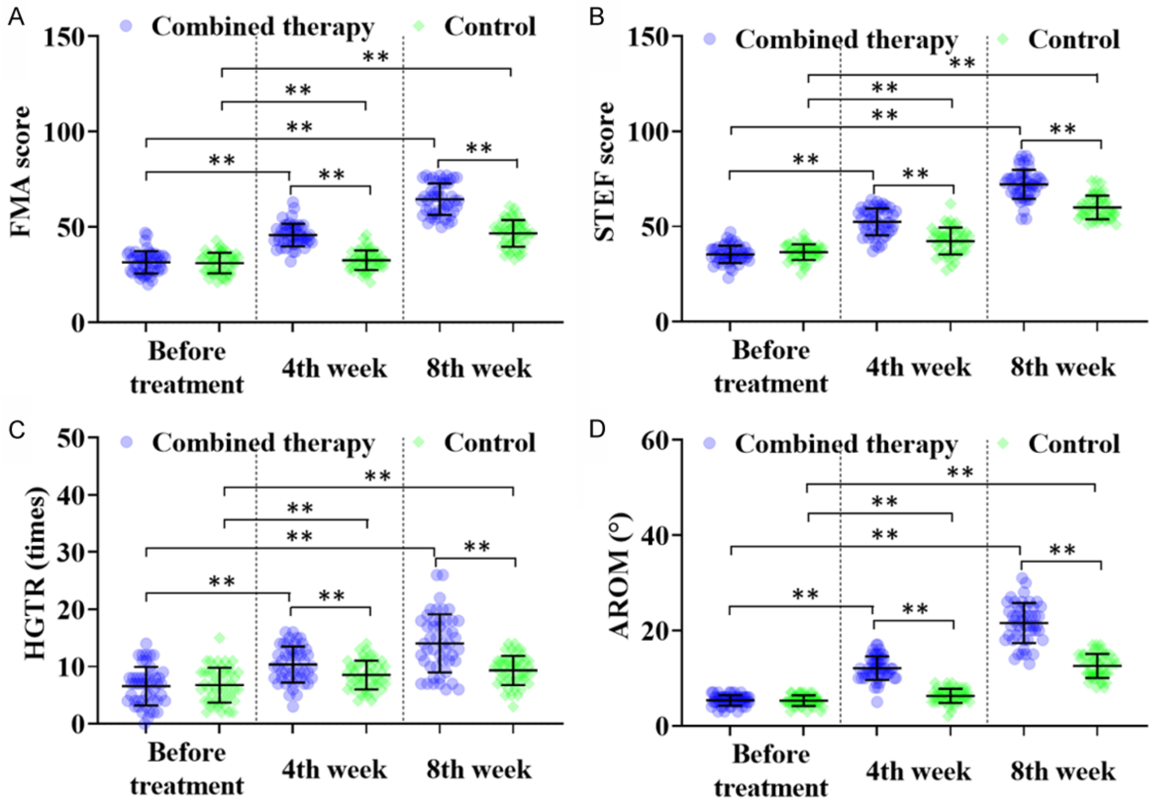

Figure 2. Improvement of motor function of affected upper limb. A: Comparison of FMA scores between groups. B: Comparison of STEF scores between groups. C: Comparison of HGTR between groups. D: Comparison of AROM between groups. $^{**}P < 0.01$. Note: FMA: Fugl-Meyer assessment; STEF: simple Test for Evaluating Hand Function; HGTR: hand grab and relax test; AROM: active range of motion.

Assessment of activities of daily living

After 8 weeks of intervention, the modified Barthel Index (MBI) is used to evaluate patients' activities of daily living. There were 10 items in total, with a full score of 100. The scores of < 40, 40-60, and > 60 represent severe, moderate, and mild dysfunction, respectively.

Statistical analysis

SPSS 22.0 was adopted for statistical analysis. The counting data were described by n (%), and chi-square test was used to compare differences between groups. The measuring data were described by x ± s, and t-test was employed for comparison between groups. Differences in functional exercise outcomes and activities of daily living of patients at different time points were analysed by repeated measures ANOVA, and the pair-wise comparisons were made using the Bonferroni method. The significance level was 0.05 and *P* value was taken as a two-sided value.

Results

SST combined with EMG biofeedback could better improve patients' upper limb function

We evaluated the recovery of upper limb function from the upper limb mobility and wrist mobility. As shown in **Figure 2A**, **2B**, after 4 and 8 weeks of training, the FMA and STEH scores of the affected limbs in both groups were significantly higher than those before training, and the above index levels in combined therapy group increased more significantly. Hence, the motor function and fine function of the affected limbs recovered better after combined training. In addition, the levels of HGRT and AROM in both groups after treatment were significantly higher than those before treatment, especially in combined therapy group (**Figure 2C**, **2D**), suggesting that the control function of patients' hand has been effectively restored, and the back extension activity of the wrist can be better controlled.

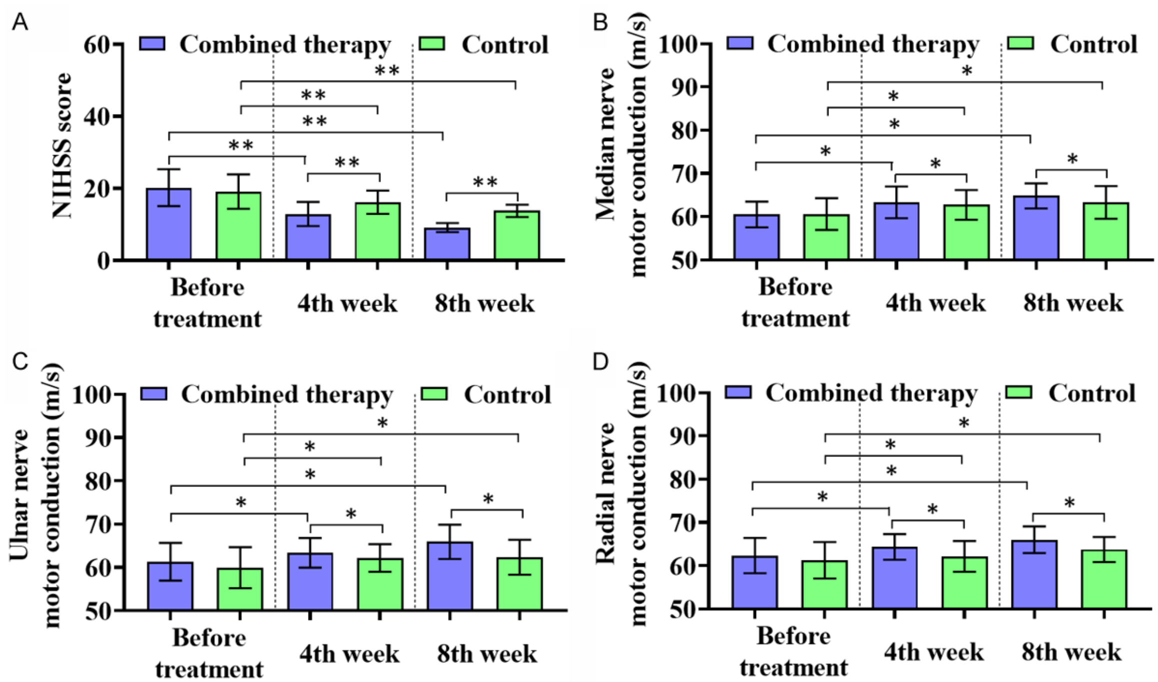

Figure 3. Improvement of upper limb nerve function. A: Comparison of NIHSS scores between groups. B-D: Comparison of conduction velocity of median nerve, ulnar nerve, and radial nerve. $^{**}P < 0.01$, $^{*}P < 0.05$. Note: NIHSS: National Institutes of Health Stroke Scale.

SST combined with EMG biofeedback could effectively improve patients' upper limb nerve function

Stroke will lead to neurons injury and the dystrophic injury of peripheral nerves of the affected limbs, which will have an adverse impact on patients' neurological function. After treatment, we found that the NIHSS scores of both groups were significantly lower than those before treatment, especially in combined therapy group (**Figure 3A**). Hence, combined therapy can better restore and improve patients' nerve function. In the evaluation of nerve conduction velocity, the study found that the combined therapy could better improve the conduction velocity of median nerve, ulnar nerve, and radial nerve (**Figure 3B-D**), suggesting that it can better promote neurons to establish new synaptic connections, which is conducive to the re-establishment of neural circuits.

SST combined with EMG biofeedback could effectively improve iEMG of Upper limb muscle group

IEMG value can objectively reflect the recovery of muscle strength of hemiplegic limbs in stroke patients during rehabilitation treatment. The study showed that iEMG values of deltoid, triceps brachii, and forearm muscles in both groups were significantly improved at 4th and 8th week after treatment, especially in combined therapy group (**Figure 4**), suggesting that the muscle contraction of hemiplegic limbs in stroke patients can be better recovered after SST combined with EMG biofeedback treatment.

SST combined with EMG biofeedback could effectively improve patients' activities of daily living

The recovery of activities of daily living in stroke patients can effectively evaluate their life quality. After treatment, the BMI scores of both groups were significantly improved, especially in combined therapy group (**Table 2**). Therefore, SST combined with EMG biofeedback treatment can significantly improve the degree of limb dysfunction, thus effectively improving their life quality.

Discussion

In the treatment of stroke patients with hemiplegia, the motor function recovery of upper

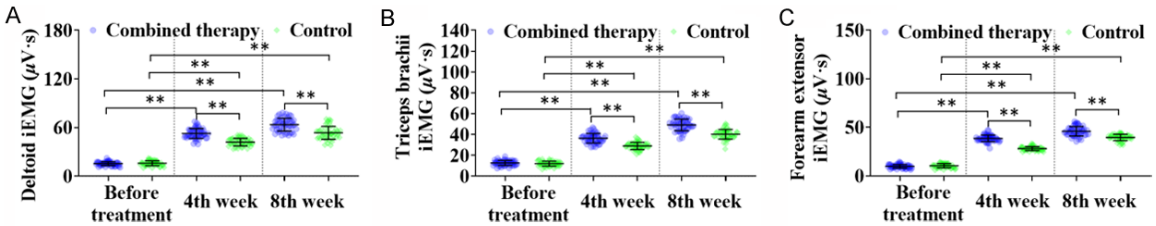

Figure 4. iEMG detection of upper limb muscle group. A: Comparison of deltoid iEMG value between groups. B: Comparison of triceps brachii iEMG value between groups. C: Comparison of forearm muscle iEMG value between groups. $^{**}P < 0.01$. Note: iEMG: integrated EMG.

Table 2. Comparison of BMI score between groups ($\bar{x} \pm s$)

Group	Cases	Before treatment	4 weeks after treatment	8 weeks after treatment	F	*P*
Combined therapy group	48	26.89±6.62	42.76±8.12*	55.77±9.52*	150.31	< 0.001
Control group	48	25.67±6.08	32.19±7.31*	45.16±8.65*	85.79	< 0.001
t		0.940	6.703	5.715		
P		0.349	< 0.001	< 0.001		

Note: MBI: Modified Barthel Index; Compared with before treatment, $^{*}P < 0.05$.

limb is usually more difficult than that of lower limb due to its function is more complex and delicate, which will have a serious impact on their ability of daily activities and life quality [21]. In the current therapy of upper limb dysfunction in stroke patients, it is mainly through repeated functional strengthening training to reconstruct the brain's control over movement of muscle groups [22]. However, the training process is often boring, which will have a negative impact on patients' treatment compliance. Therefore, it is a research hotspot in rehabilitation therapy to continuously carry out in-depth research on the rehabilitation mechanism of stroke patients and apply new training equipment to their rehabilitation training under the guidance of theory. In recent years, with the development of electronic information technology, SST has been applied to the rehabilitation training of stroke patients. This new and entertaining game training method can fully mobilize patients' enthusiasm for active training, which plays the effect of "training in fun" [23]. During training process, patients need fully mobilize the whole body muscles for coordinated movement to promote the game process, which can repeatedly stimulate the locally damaged neuromotor system and reactivate the excitability of nerve conduction [24]. Meanwhile, it can improve the blood supply in the damaged area of brain tissue, which can reduce the defect degree of nerve function, thus better restoring the motor function of hemiplegic limbs [25]. In addition, the application of EMG biofeedback instrument helps to convert the EMG signal generated by muscle contraction in the hemiplegic area into image and sound mode, and feed it back to the patients' sensory system [26]. Through repeated treatment, it can form an effective conditioned reflex, which can help patients gradually control the random movement of their body, and continuously improve the accuracy and intensity of control [27]. Therefore, the application of the above rehabilitation training technology is of great significance to reduce the spasm of upper limb flexors in stroke patients and accelerate the recovery of upper limb function.

Through the study on upper limb motor function recovery of stroke patients, it was found that after combined therapy, the fine motor function and activity ability of upper limb were more significantly improved. Rogers et al. [28] found that using virtual reality technology for rehabilitation training of stroke patients could increase the recovery rate of upper limb motor function by about 3 times. In addition, after combined treatment, the effective grasping times of the affected limb and the back extension range of the wrist joint were significantly improved, suggesting that patients' control ability on the flexor and extensor muscles of the upper limb joint was significantly improved. Chuang et al. [29] suggested that the combined EMG biofeedback treatment effectively increased the strength of the patient's core muscles and improved trunk control, which was more beneficial to the recovery of upper limb motor function. The reason may be that the coordinated contraction movement of the whole body muscles in SST reactivates the nerve conduction, and EMG biofeedback helps patients form the conditioned reflex of self-control muscle contraction [30, 31], which are both conducive to the re-establishment of the conduction pathway between the brain and muscles, so as to better control the accuracy of upper limb movement on the affected side.

The damage of stroke to central neurons will cause neurological deficit. Besides, the injury of central neurons will interrupt its nutritional effect on descending nerve fibers, resulting in secondary injury of peripheral nerves [32]. Therefore, NIHSS score and peripheral nerve conduction velocity can effectively reflect the effect of rehabilitation treatment. The study found that patients' NIHSS score in combined therapy group decreased more significantly, while the conduction velocity of median nerve, ulnar nerve, and radial nerve increased more, suggesting that their neural function has been significantly restored. Zhuang et al. [33] suggest that EMG biofeedback can effectively rebuild neural networks and activate active motor cortices with repetitive reinforcement, which can effectively accelerate the recovery of upper limb function in post-stroke patients. The reason may be that after combined treatment, the blood supply of patients' injured cerebral cortex can be effectively improved, which is conducive to the repair of injured neurons [34]. In addition, it can better promote the surviving neurons to establish new synaptic connections, which can not only improve patients' motor function, but also effectively restore the nutritional supply of peripheral nerve, so as to improve the conduction velocity of peripheral nerve, so as to improve the conduction velocity of peripheral nerves [35, 36]. iEMG value reflects the total amount of discharge during skeletal muscle contraction, and its intensity is positively correlated with muscle strength level. By detecting the iEMG value of each muscle group of the affected limb during the contraction exercise, we found that the combined therapy could better improve the iEMG value of each muscle group of upper limb. Therefore, SST combined with EMG biofeedback can better improve the muscle strength level of upper limb. Thanks to the joint rehabilitation training, patients can better restore the control of upper limb muscle groups and improve the level of muscle tension, which are both conducive to reduce limb dysfunction level and make the core muscle groups better participate in patients' daily life activities. Therefore, the BMI score in combined therapy group was higher.

There are limitations to this study, firstly, in terms of researcher selection, the high level of literacy for patients and the requirement for patients without cognitive impairment and unilateral involvement, which led to a small sample size for our study. In addition, the fact that patients were mainly rehabilitated at home in the later stages of their lives led to a short follow-up period, which had an impact on the adequacy of data collection for our study. Finally, we did not explore the optimal frequency and duration of treatment for EMG and TTS, and did not examine differences in the efficacy of EMG and TTS in patients with different stroke sites. Therefore, further studies are needed to expand the sample size in subsequent studies to further study patients with different conditions, periods, and levels of stroke in order to benefit more stroke patients.

Conclusion

In conclusion, SST combined with EMG biofeedback can better improve the activity and fine motor function of upper limbs in stroke patients with hemiplegia, and help patients better control their hands to complete grasping and back extension. In addition, after joint training, it can better reduce patients' NIHSS score and improve the conduction velocity of peripheral nerve, which is conducive to the re-establishment of conduction pathway between central nerve and muscle, thus helping patients better control the fine movement of upper limbs. Furthermore, the recovery of upper limb muscle tension in combined therapy group is better, which can make the core muscle group better participate in activities of daily life, so as to improve the life quality of stroke patients.

Disclosure of conflict of interest

None.

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