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Research Progress and Prospect of Biofeedback Technology Combined with Occupational Therapy in Hand Function Rehabilitation after Stroke

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Abstract: Hand function impairment after stroke has become a key and difficult issue in clinical rehabilitation due to complex neural innervation and a long recovery cycle. Biofeedback technology combined with occupational therapy can make up for the limitations of single therapy and provide a new solution for hand function rehabilitation after stroke. This paper systematically sorts out the theoretical basis and clinical research progress of biofeedback technology combined with occupational therapy in hand function rehabilitation after stroke, and looks forward to the future development direction, aiming to provide reference for clinical rehabilitation practice and scientific research.

Keywords: Stroke; Hand function rehabilitation; Biofeedback technology; Occupational therapy; Neuroplasticity

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1. Introduction

As one of the leading causes of disability in adults worldwide, stroke is characterized by high morbidity and high disability rate. Among them, hand function impairment is one of the most common sequelae after stroke. It not only affects patients' activities of daily living but also causes psychological problems such as anxiety and depression. In recent years, more and more studies have confirmed that biofeedback technology combined with occupational therapy has a synergistic effect in hand function rehabilitation after stroke, and has gradually become a research hotspot in this field.

2. Relevant theoretical basis

2.1. Pathophysiological mechanism of hand function impairment after stroke

The pathological basis of hand function impairment after stroke is the interruption of neural conduction pathways

caused by damage to the cerebral cortical motor area and the reduction of functional connections between bilateral primary motor cortices. Normal hand movement relies on motor instructions sent by the cerebral cortex, which regulate muscle contraction through spinal conduction pathways. Stroke can selectively damage large-scale neural circuits, leading to loss of normal neural innervation of patients' muscles, resulting in symptoms such as decreased muscle strength and motor coordination disorders [1].

The theory of neuroplasticity refers to the brain's ability to undergo structural and functional adaptive changes during development, learning, and after trauma. Studies have confirmed that appropriate external stimulation and repetitive training can activate the brain's plasticity mechanism, promote the repair of damaged neural circuits and the establishment of new neural pathways.

2.2. Working principle and classification of biofeedback technology

Biofeedback technology is a rehabilitation technology based on motor learning theory. It collects patients' physiological parameters through sensors, converts them into perceptible feedback signals such as visual and auditory signals after processing. According to this information, patients can consciously adjust their muscle activity status to achieve neuro-muscular relearning. According to the type of feedback signals, biofeedback technologies used in hand function rehabilitation after stroke mainly include the following categories: electromyographic biofeedback technology, biomechanical biofeedback technology, and immersive virtual reality (VR) biofeedback technology.

2.3. Core connotation of occupational therapy

Occupational therapy is patient-centered and uses purposeful activities as the medium. Its goal is to help stroke patients restore or improve their activities of daily living, work ability, and social participation ability. In hand function rehabilitation, occupational therapy emphasizes designing training content according to patients' actual needs, such as sanding board pushing, roller training, screw tightening, finger-to-finger training, and daily training such as dressing and eating.

2.4. Synergistic mechanism of the combination of the two

2.4.1. Provide accurate assessment and realize personalized training

Biofeedback technology can provide objective and quantitative physiological parameters, helping therapists accurately assess the status of patients' hand muscle function and providing a scientific basis for the formulation of occupational therapy training plans; at the same time, according to the feedback data during patients' training, the content and intensity of occupational training can be adjusted in real time to achieve personalized rehabilitation.

2.4.2. Improve the initiative and effectiveness of training

The real-time feedback provided by biofeedback technology enables patients to clearly perceive the gap between their own movement status and goals, enhancing training enthusiasm; while the functional training content of occupational therapy provides practical application scenarios for biofeedback training, promoting the transformation of training effects into activities of daily living abilities.

2.4.3. Promote the synergistic activation of neuroplasticity

Biofeedback technology activates the neuroplasticity of the cerebral motor cortex through peripheral muscle

electrical signals; occupational therapy strengthens the neural connection between the brain and hand muscles through purposeful functional activities. The synergistic effect of the two can accelerate neural function reconstruction and promote the recovery of hand function.

3. Research progress of biofeedback technology combined with occupational therapy in hand function rehabilitation after stroke

3.1. Empirical research on clinical efficacy

In recent years, a number of clinical randomized controlled trials have confirmed the significant efficacy of biofeedback technology combined with occupational therapy in improving hand function in stroke patients, mainly reflected in the improvement of the following evaluation indicators.

3.1.1. Hand motor function scores

The Fugl-Meyer Assessment (FMA) and Action Research Arm Test (ARAT) are commonly used tools to evaluate upper limb and hand motor function in stroke patients. Zhang Zhijun conducted a study on 100 patients with upper limb hemiplegia after stroke, dividing them into an observation group (electromyographic biofeedback training combined with occupational therapy) and a control group (occupational therapy alone). After 4 weeks of treatment, the FMA upper limb score of the observation group was significantly higher than that of the control group [2]. This indicates that the addition of biofeedback technology can more effectively improve the effect of occupational therapy on patients' hand motor function.

3.1.2. Activities of daily living ability

In a study involving 70 stroke patients by Wang Hongxiu et al., the observation group adopted electronic biofeedback technology combined with rehabilitation function training, and the control group adopted conventional rehabilitation training. After 5 weeks of treatment, the Modified Barthel Index (MBI) score of the observation group reached (68.5 ± 7.8) points, which was significantly higher than (52.1 ± 6.5) points of the control group ($p < 0.05$), indicating that the combination of the two can more effectively improve patients' daily living self-care ability [3].

3.1.3. Hand function grading and muscle tension

Studies by Li Jinxian et al. showed that after 3 weeks of treatment, the Brunnstrom hand grading of the experimental group was higher than that of the observation group and the control group. In terms of muscle tension improvement, the Modified Ashworth Scale (MAS) score of the observation group decreased to (1.06 ± 0.11) points after treatment, which was significantly lower than (2.03 ± 0.28) points of the control group ($p < 0.05$), indicating that the combined therapy has advantages in relieving hand muscle spasticity and promoting the improvement of motor function grading.

3.1.4. Quality of life

The evaluation results of the Stroke-Specific Quality of Life Scale (SS-QOL) showed that biofeedback technology combined with occupational therapy can significantly improve patients' quality of life. In Zhang Zhijun's study, the SS-QOL score of the observation group after treatment reached (195.12 ± 14.87) points, which was higher

than (169.05 ± 14.12) points of the control group ($p < 0.05$). This is closely related to the improvement of patients' hand function and daily living self-care ability, and also benefits from the positive transformation of patients' psychological status during training.

3.2. Application research of different combined schemes

3.2.1. Electromyographic biofeedback combined with occupational therapy

Electromyographic biofeedback training detects the electrical activity signals of muscles through surface electrodes, amplifies and converts the collected signals into visual or auditory feedback, and presents them to patients, helping patients re-establish the communication channel between the brain and muscles [4].

3.2.2. Virtual reality biofeedback combined with occupational therapy

With the development of virtual reality technology, combining it with biofeedback and occupational therapy has become a new research direction. This scheme aims to allow patients to complete occupational training in a virtual environment by creating virtual daily life scenarios, and at the same time, real-time feedback their electromyographic signals or movement parameters, quantify patients' training investment, and further improve their independent rehabilitation ability [5].

3.2.3. Multimodal biofeedback combined with occupational therapy

Some studies have attempted to combine multiple biofeedback modalities, such as simultaneous use of electromyographic feedback and biomechanical feedback, to provide patients with more comprehensive training guidance [6]. This multimodal combined scheme shows potential advantages in improving patients' fine hand motor function, but relevant research is still limited.

3.3. Application exploration in special populations

3.3.1. Chronic stroke patients

Due to the long course of disease, chronic stroke patients have greater difficulty in neural function recovery, and the effect of traditional rehabilitation therapy is often unsatisfactory [7]. Murakami et al. used an artificial intelligence-integrated electromyography-driven upper limb rehabilitation robot for training (this scheme combines occupational therapy) in 20 chronic stroke patients. After 4 weeks, the patients' hand motor function was significantly improved, indicating that biofeedback technology combined with occupational therapy has a positive rehabilitation effect on chronic stroke patients.

3.3.2. Patients with severe hand function impairment

For patients with severe functional impairment with hand muscle strength below grade 3, simple occupational therapy is difficult to effectively activate target muscles. Biofeedback technology helps patients perceive subtle muscle activities by amplifying weak electromyographic signals, gradually establishing muscle control ability [8]. Studies have shown that for such patients, the use of low-threshold electromyographic biofeedback combined with occupational therapy can effectively promote muscle strength recovery and lay the foundation for subsequent rehabilitation training.

4. Future prospect

4.1. Strengthen mechanism research and technological innovation

Basic research on the mechanism of action of the combined therapy should be strengthened. Combined with neuroimaging, neuroelectrophysiology and other technologies, the influence path on brain function reorganization and neuroplasticity should be explored to provide a theoretical basis for optimizing treatment plans [9]. At the same time, promote the innovation of biofeedback technology, develop more portable, low-cost, and high-sensitivity equipment, and improve the accessibility of technology [10].

4.2. Improve clinical research design

Carry out large-sample, multi-center, long-term follow-up randomized controlled trials to further verify the effectiveness and safety of the combined therapy, and clarify its scope of application in stroke patients with different courses and severity [11]. At the same time, establish a standardized treatment plan and evaluation system, standardize biofeedback parameter settings and occupational training content, and ensure the comparability and reproducibility of research results.

4.3. Expand multi-technology combined application modes

Future rehabilitation treatment will integrate more technologies. Biofeedback technology and occupational therapy can be combined with central intervention methods to further enhance the activation effect of neuroplasticity [12]. The integration of tele-rehabilitation technology will break the time and space limitations. Through the combination of wearable devices and remote platforms, patients can receive professional biofeedback training and occupational therapy guidance at home, which is very suitable for patients with limited mobility or living in remote areas [13].

4.4. Promote clinical popularization and talent training

Strengthen policy support and technical assistance to grass-roots medical institutions, reduce the threshold for the use of biofeedback equipment, and promote the popularization of technology [14]. At the same time, improve the training system for rehabilitation therapy talents, strengthen professional training on the combined application of biofeedback technology and occupational therapy, and improve therapists' clinical operation ability and comprehensive rehabilitation evaluation level [15].

5. Conclusion

Biofeedback technology combined with occupational therapy has significant clinical efficacy in improving hand function, activities of daily living, and quality of life of stroke patients, and is one of the effective methods for treating hand function in stroke hemiplegic patients. In the future, it is necessary to further strengthen the combination of basic and clinical research, improve standardized treatment plans, promote the popularization of rehabilitation technology, and provide more high-quality and efficient rehabilitation services for stroke patients.

Disclosure statement

The author declares no conflict of interest.

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