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Research on the clinical application effectiveness of neurorehabilitation technology for stroke

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Abstract. Stroke is one of the leading causes of death and disability in the world today, necessitating effective treatment options for patients. Brain-computer interface (BCI) technology, as one of the newly developed technologies, is gradually being incorporated into the rehabilitation treatment of stroke. At the same time, there are more evaluation indicators for the rehabilitation treatment of stroke using BCI, but related prognostic prediction methods still need further research. Therefore, the purpose of this study is to review the effects of the clinical application of BCI technology in neurorehabilitation for stroke. The results show that BCI technology has a positive clinical effect in the neurorehabilitation of stroke, improving patients' quality of life and highlighting the importance of BCI technology for the neurorehabilitation of stroke. In the future, BCI technology will be further applied in the field of neurorehabilitation for stroke and combined with more technologies to achieve treatment for stroke and its various symptoms.

Keywords: Stroke, Neurorehabilitation, Brain-Computer Interface, Evaluation Methods

1. Introduction

Stroke is a significant chronic non-communicable disease that severely endangers the health of the Chinese population, with one of its sequelae being the impairment of lower limb motor function in patients. In order to advance the construction of a treatment system for stroke, China has been focusing on targeted diagnostic and therapeutic measures, prognosis and secondary prevention, as well as promoting the construction of a stroke prevention system in China to further improve stroke prevention and treatment work and enhance the effectiveness of diagnosis and treatment [1]. At the same time, exoskeleton rehabilitation robots developed for lower limb motor function impairment are continuously being put into use, providing good rehabilitation effects for patients' lower limbs [2]. In addition, as an emerging technology, brain-computer interface (BCI) technology has also begun to be applied in the treatment of stroke, achieving certain effects and continuously improving the quality of life for more patients.

Currently, countries around the world are vigorously advancing research on stroke rehabilitation technologies, including exoskeleton rehabilitation robots launched for lower limb motor dysfunction caused by stroke, the use of virtual reality technology for neural rehabilitation of stroke, and the application of motor imagery BCI technology in post-stroke motor function rehabilitation [3-5]. These stroke rehabilitation technologies are continuously being introduced to the civilian market, playing a

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significant role in stroke rehabilitation. Meanwhile, scholars are also researching the effects of various rehabilitation technologies to summarize areas for improvement. As one of the emerging technologies, BCI technology establishes a direct communication and control channel between the human brain and computers or other electronic devices, which can effectively enhance the ability of patients with severe physical disabilities to communicate with the outside world or control the external environment [6]. Currently, BCI technology has begun to be applied in stroke rehabilitation, such as the use of "training-type" motor imagery (MI)-brain-computer interface (BCI) driven functional electrical stimulation (FES), MI-BCI training based on the "central-peripheral-central" closed-loop theory, and the combination of transcranial electrical stimulation technology and BCI technology [7-8]. According to existing research, BCI technology has shown positive effects on stroke rehabilitation.

The purpose of this paper is to study the effects of various BCI technologies in stroke rehabilitation, summarizing their effectiveness in stroke rehabilitation and proposing future prospects.

Stroke, as a cerebrovascular disease, is also one of the main diseases currently harming human health worldwide, characterized by high incidence and high disability rates [9]. According to the Global Burden of Disease (GBD) data for 2019, stroke remains the second leading cause of death worldwide. At the same time, using disability-adjusted life years lost (DALYs) as a reference, stroke is also the third leading cause of death and disability globally. From 1990 to 2019, the total number of DALYs related to stroke risk factors increased from 91.5 million to 125 million [10]. This data indicates that stroke remains one of the diseases with high mortality and disability rates worldwide, necessitating corresponding diagnostic and therapeutic measures.

2. Brain-Computer Interface

2.1. Definition of Brain-Computer Interface

A Brain-Computer Interface (BCI) is a system that, based on brain electrical signals and independent of the human body's peripheral nervous system and muscle tissue, enables communication and control between the human brain and computers or other electronic devices [11]. A BCI system can real-time record the brain's electroencephalogram (EEG) through signal acquisition, feature extraction, classification selection, and external control devices, interpreting simple thoughts to some extent and translating them into control commands for devices [12]. Today, countries around the world are intensifying their investment in the research and development of BCI technology. For instance, the Defense Advanced Research Projects Agency (DARPA) in the United States has initiated projects such as "Targeted Neuroplasticity Training" (TNT), "Next-Generation Nonsurgical Neurotechnology" (N3), "Restoring Active Memory," and "Intelligent Neural Interfaces," aiming to enhance cognitive abilities through BCI technology, allowing soldiers to engage in deep thought interactions with systems [13]. As BCI technology advances, it has evolved from environmental control to monitoring brain changes, providing new avenues for various BCI applications, including those for stroke neurorehabilitation [14].

2.2. BCI Methods for Stroke Rehabilitation

Currently, BCI technology in the field of stroke neurorehabilitation has entered a phase of research translation, with more experimental results continuously being introduced to the civilian market. Some scholars have combined EEG and other biosignals into a brain-computer interaction system for the rehabilitation of hand function in stroke patients, using wearable exoskeletons to aid in functional recovery. Additionally, treatments combining BCI with Functional Electrical Stimulation (FES) have been applied to patients with stroke-induced finger function impairment, improving their finger extension capabilities [15]. Liu Xiaoxie and others conducted a four-week BCI-FES treatment based on Motor Imagery (MI) for a patient with severe paralysis of the left upper limb, including pre- and post-training upper limb functional assessments and functional magnetic resonance imaging (fMRI) checks with "movement" and "imagery" components, to verify the feasibility and mechanism of combining BCI with FES in central nervous rehabilitation [16]. Furthermore, BCI technology based on motor imagery has been used for treating upper limb motor dysfunction after stroke, and similarly for lower limb motor dysfunction, showing significant improvements in upper and lower limb Fugl-Meyer assessment scores. The use of BCI technology with FES can also effectively improve walking and balance functions in stroke patients [17]. In the future, more BCI technologies will be applied in stroke rehabilitation treatments to improve patients' quality of life and enhance the effectiveness of prognosis.

3. Assessment Methods and Prognostic Prediction Methods

3.1. Assessment Methods

Nowadays, countries around the world have started using relevant standards to objectively evaluate the therapeutic effects of brain-computer interface (BCI) technology in the field of stroke rehabilitation. For example, Jia Dangpei and others used the Fugl-Meyer Assessment for motor function to evaluate patients' lower limb motor and balance functions before treatment and six months after treatment, as well as assessed neurological deficits with the Central Nervous System (CNS) scoring system and daily living abilities with the Barthel Index during the same period [18]. Additionally, Li Mingfen and others proposed using the Action Research Arm Test (ARAT) scores and patients' cognitive timing of event-related desynchronization (ERD) as one of the relevant standards [19]. After two months of BCI rehabilitation training for patients, the cognitive timing of ERD significantly shortened ($P<0.05$), indicating a significant enhancement in cognitive level ($P<0.05$), which was significantly related to ARAT scores ($P<0.05$). Chen Shugeng and others evaluated patients before treatment and after one month of closed-loop BCI rehabilitation training based on Motor Imagery (MI) using FMA and the Motor Status Scale (MSS), showing that scores improved in both assessments [20]. These cases demonstrate that BCI has already provided good rehabilitation outcomes in stroke recovery.

3.2. Prognostic Prediction Methods

Regarding prognostic predictions for stroke, there is currently less research on the application of BCI technology in this area, and further studies are needed. However, BCI technology has been used in Zhu Xiaoyuan's research for the rapid and accurate continuous prediction of EEG signals [21]. Given that EEG signals are one of the main observational indicators for stroke patients, this technology could use deep learning to perform regression analysis on the EEG signals of existing stroke cases in the future, thereby making prognostic predictions about the development of patients' conditions. In the study by Gao Nuo and others, a speech care system for stroke patients based on BCI was mentioned. Although there are limitations to the content of communication, this system could potentially enable patients to express their thoughts independently through BCI in the future [22]. Similarly, machines could perform deep analyses and learning of patients' thoughts, providing a basis for later regression analysis.

4. Conclusion

This study has conducted research on stroke, brain-computer interface (BCI) technology, and its application in stroke rehabilitation, including assessment methods and prognostic prediction methods, and has summarized the achievements made in the application of BCI technology in stroke rehabilitation. Based on the research conducted, the conclusion of this study is that BCI technology has a positive therapeutic effect in the field of neurorehabilitation for stroke, directly improving patients' quality of life. In the future, as computational power increases and more treatment cases become available, the application effectiveness of BCI technology in the field of neurorehabilitation for stroke is expected to improve further. Moreover, BCI technology could also be applied to treat a wider range of brain diseases.

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