Academic Journal of Medicine & Health Sciences
ISSN 2616-5791 Vol.5, Issue 3: 1-5, DOI: 10.25236/AJMHS.2024.050301

Progress in the Application of Brain-computer Interface Technology in Stroke Rehabilitation

Zhang Jiayu[1,a], Ren Xin[1,b], Guo Xiaolan[1,c,*], Zhang Meixia[2,d,*]

[1]School of Nursing, Shaanxi University of Chinese Medicine, Xianyang, China
[2]Department of Nursing, The First Affiliated Hospital of the Air Force Medical University, Xi'an, China
[a]zhangjiayu619@126.com, [b]1090851127@qq.com, [c]1104307158@qq.com, [d]2556008698@qq.com
[*]Corresponding author

Abstract: *Stroke patients are often left with different degrees of dysfunction in different aspects, which seriously affects patients' schedule and quality of life. At present, the rehabilitation of stroke patients mainly relies on passive and repetitive training of patients, and the rehabilitation effect is not ideal. brain computer interface is a cutting-edge rehabilitation technology that completely does not rely on peripheral nerves and muscles to interact with the external environment. This technology can interpret the movement intention of patients in real time, establish the connection pathway between the human brain and the machine, and conduct closed-loop feedback training. Trigger the neuroplasticity of the brain, ultimately achieve the purpose of functional rehabilitation of stroke patients, and provide patients with individualized rehabilitation training. This paper reviews the domestic and foreign research progress of brain-computer interface technology in the field of stroke rehabilitation in recent years, expounds the working process and principle of brain-computer interface technology, summarizes its application status in the aspects of stroke limb dysfunction, cognitive impairment, speech impairment and psychological rehabilitation, and finally analyzes its challenges and development trends, with a view to promoting the rapid development of brain-computer interface technology. It provides a new idea for the rehabilitation of stroke patients.*

Keywords: *brain-computer interface, Stroke, Rehabilitation nursing, summarize*

1. Introduction

Stroke is the leading cause of disability and death among adults in China, characterized by high incidence, high mortality and high disability rate[1]. After stroke, 75% of patients have limb dysfunction of varying degrees, and common complications also include speech disorders, cognitive disorders and psychological disorders, which seriously affect patients' daily life and social work[2] .

Brain Computer Interface (BCI) technology is a kind of rehabilitation therapy that has developed rapidly in recent years, which increases the possibility of successful rehabilitation of patients and is conducive to improving the quality of life of patients. Brain-computer interface technology can enable patients to use EEG electrical signals to communicate with the external environment and overcome the movement disorders of limbs[3]. In addition, brain-computer interface technology has great advantages over traditional rehabilitation technology. BCI technology is closed-loop, patient-oriented, and stimulates muscle movement without the paralyzed limb having to move [4]. BCI technology provides a new way for clinical diagnosis, treatment and rehabilitation in the aspects of diagnosis and evaluation, speech communication and so on. In view of the great potential of brain-computer interface technology in the rehabilitation of stroke patients, this paper reviews the application progress of BCI technology in the rehabilitation of stroke patients.

2. BCI Technology and Working Principle

The BCI system is a timely communication system that does not rely on the normal output pathways of the brain (peripheral nerves and muscles), but establishes direct communication and control channels between the human brain and computers or other electronic devices [5]. BCI mainly includes four parts: signal acquisition, feature extraction, decoding algorithm and output command. Signal acquisition and feature processing are to extract biological signals of human brain, and carry out

ISSN 2616-5791 Vol.5, Issue 3: 1-5, DOI: 10.25236/AJMHS.2024.050301

classification processing and other operations through the process of quantization, amplification and filtering. Decoding algorithm is the core of BCI system. The processed EEG signal is decoded and translated to form an output command, and the decoding algorithm can adjust the output signal according to changes in the brain and the surrounding environment, and then transmit the command through the output device to complete the execution action.

Signal acquisition is the key step to implement BCI technology. According to the method of signal acquisition, neural interfaces can be classified into three categories: invasive, non-invasive, and semi-invasive.Non-invasive techniques include electroencephalogram (EEG), Functional near-infrared spectroscopy (functional near-infrared spectroscopy), electroencephalogram (EEG), and functional near-infrared spectroscopy (functional near-infrared spectroscopy). fNIRS and Magnetoencephalography MEG are non-invasive techniques for signal acquisition, which are safe, non-invasive and convenient. However, EEG is susceptible to noise, and the number and position of electrodes are greatly affected, which leads to the risk of receiving wrong signals. fNIRS and MEG are time-consuming, limited by the site and high cost. The invasive technique mainly consists of microelectrode (IM) in cortex, which can directly record EEG signal with high temporal and spatial resolution and good signal quality, but it needs to be implanted into intracranial brain by surgical method, which is difficult and has the risk of secondary infection and secondary craniocerebral injury. Semi-invasive techniques include Electrocorticography ECOG, which is in direct contact with cortical neurons, has excellent temporal and spatial resolution, the ECoG signal has a relatively low amplitude, may contain some level of noise, and requires electrodes to be implanted directly on the surface of the brain. There is a risk of injury and infection. Therefore, the selection of neural interface should comprehensively consider the research objectives, equipment costs, patient comfort and other aspects, so as to provide patients with an appropriate neural interface.

3. The Application of BCI Technology in Stroke Rehabilitation

3.1 Application of BCI Technology in Limb Rehabilitation of Stroke

Stroke usually results in nerve tissue damage that affects motor, sensory, cognitive and other functions of the body. The adaptive changes that can occur in the structure and function of the brain's nervous system are called Neuroplasticity, which is the basis for the rehabilitation of stroke patients. Effective rehabilitation therapy must restore the normal function of the body by promoting the connection of the remaining neurons in the brain. The effect of traditional rehabilitation therapy is not obvious, and studies have shown that patients using BCI technology have better rehabilitation effect [6].

3.1.1 Application of BCI technology in upper limb rehabilitation of stroke

In terms of therapeutic effect, the training of brain-computer interface rehabilitation robot is not only conducive to the recovery of limb function, but also to the remodeling of brain neural network [7]. A clinical study on stroke patients showed that BCI system could enable patients to carry out rehabilitation training at different control levels through movement observation and motor imagery, improve patients' participation and accelerate their rehabilitation progress[8]. Multiple studies [9, 10]have shown that repetitive electrical stimulation of a certain intensity could regulate brain functional areas, thus playing a therapeutic role in improving movement disorders after stroke. Ruben[11]explored the rehabilitation methods for upper limb function of 10 stroke patients with hemiplegia, and found that the rehabilitation treatment effect based on BCI technology was significantly better than that of traditional rehabilitation technology, which was related to the fact that traditional rehabilitation methods required patients to have a certain motor basis, while BCI technology had little demand on patients' residual motor function. And can integrate sensory-motor pathways to promote patient recovery. BCI technology can also be combined with virtual reality, video games and other technologies. Athanasios [12] applied multi-modal virtual reality technology with motion initiation to the upper limb rehabilitation of patients, and the research results showed that this technology could regulate the ability of brain activity pattern and enhance the relationship between body electrophysiology and supervisory experience. A meta-analysis[13]showed that rehabilitation training based on BCI technology could increase FMA scores of the upper limbs by 5.4-8.1 points, which was statistically significant.

3.1.2 Application of BCI Technology in Rehabilitation of Lower Limbs After Stroke

Lower limb dysfunction is the most common sequela of stroke. Although the damaged nerves can be recovered to varying degrees after a period of rehabilitation treatment, 50% to 60% of patients still have neuromuscular system dysfunction of varying degrees. For example, hemiplegia measures weakened muscle strength, proprioceptive disorders, poor balance control, abnormal gait and even inability to walk [14]. Brain-computer interface technology has been widely used as a rehabilitation treatment method for stroke patients. When using BCI technology to conduct rehabilitation training for patients, neuroplasticity can be induced by real-time detection of Motor Image (MI), so as to restore nerve function [15]. Zhang Ruiping [16] randomly divided 80 stroke patients into control group and observation group, with 40 cases in each group. Both groups received routine rehabilitation training. The observation group received lower limb training of brain-computer interface rehabilitation robot on the basis of routine rehabilitation training. It was higher than 77.50% in control group (P<0.05). The BDNF(6.01±1.13) ng/ml and NGF (145.73±12.64) pg/ml in the observation group were higher than those in the control group (4.85±1.02) ng/ml and (130.54±16.39) pg/ml, and the difference was statistically significant (P<0.05). The results showed that BCI could promote the recovery of lower limb function, improve the rehabilitation effect and improve the quality of life. Marc Sebastian Romagosa [17] conducted 25 treatment and evaluation visits using MI-BCI in 25 stroke patients with gait disorders. The results showed that walking speed was clinically significantly increased by 0.19m/s, 95%CI (0.13 -- 0.25), p < 0.001. Patients also experienced reduced spasticity and improved their range of motion and muscle contractions. This suggests that brain-computer interface therapy can effectively promote long-term functional improvement in gait speed in chronic stroke survivors. In addition, BCI technology can also be combined with Functional electrical stimulation (FES) and Virtual Reality (VR) to reduce the difficulty of performing motion imagination tasks and improve classification accuracy[18]. Eunjung Chung[19] conducted a study on 23 stroke patients with hemiplegia, 13 of whom received BCI-FES training and 12 of whom only received Functional electrical stimulation (FES) training. The results showed that, Gait speed (29.0-42.0cm/s, P=0.002) and stride frequency (65.2-78.9 steps/min, P=0.02) in BCI-FES group were significantly improved compared with those in FES group (23.6-27.7cm/s) and stride frequency (59.4-65.5 steps/min). BCI-FES can increase the walking ability of stroke patients with hemiplegia. Athanasios Vourvopoulos[20] found that rehabilitation training based on BCI-VR is more effective for patients with the most severe motor disorders, which may be related to the less input and output of damaged motor cortex in such patients, and the more flexible neural regulation of brain regions.

3.2 Application of BCI Technology in Speech Rehabilitation of Stroke

According to studies, more than 30% of stroke patients have speech disorders. The brain-computer interface technology based on pronunciation imagination can directly restore imaginary speech by extracting brain activity signals [21]. For patients with pronunciation difficulties, they no longer need to input words one by one inefficiently, but can communicate with the outside world more effectively through speech synthesis through this BCI technology. Studies have found that the left inferior frontal gyrus of the brain is the physiological basis for the phenomenon of articulatory imagination[22]. Aleman [23] found activation of the left inferior frontal gyrus during speech processing of imagined speech through fMRI, which also confirmed this view. Nolfe [24] found that BCI technology based on P300 components could predict the degree of recovery of speech disorder, and the study results showed that the amplitude of P300 was reduced in patients with speech disorder. On this basis, Kleih [25]used the P300-BCI spelling system to assess the language function of patients with speech disorder after stroke. The results showed that 4 stroke patients with speech disorder could successfully communicate with the matching speller after P300-BCI rehabilitation training, and the accuracy rate was 100%. The above research indicates that P300-BCI technology can not only be used for language training of patients with speech disorders, but also can evaluate the degree of recovery of patients' speech function. Different from English words, the structure and grammar of Chinese characters are more complex. Han [26] developed a new Chinese character writing robot controlled by BCI, which uses the mixed features of P300 and SSVEP to effectively encode large instruction sets, decodes the combined features through correlation component analysis, and generates efficient Chinese characters and English letter writing. The results showed that the average accuracy was 87.23% and the maximum accuracy was 100%. In addition, the brain-computer interface can also recognize the EEG electrical signals sent through the brain-computer interface, and then transmit them as new incoming information to the corresponding receiving brain region, so as to realize the real communication between two patients with speech disorders.

ISSN 2616-5791 Vol.5, Issue 3: 1-5, DOI: 10.25236/AJMHS.2024.050301

3.3 Application of BCI Technology in Cognitive Rehabilitation of Stroke

Post-stroke cognitive impairment is one of the most common sequelae of stroke. According to a study, 30%-35% of patients have cognitive impairment in different fields within a short time after stroke, which not only seriously affects the quality of life of patients, but also brings heavy economic burden to the society. As a new rehabilitation technique, BCI can not only be used to evaluate the efficacy of cognitive impairment after stroke, but also be applied to the rehabilitation of cognitive ability[27]. Nie and Yang [28] found that brain-computer interface technology based on motor imagination can promote neuronal remodeling, increase the expression of scaffold protein and regulatory protein, and enhance prominence plasticity, thus promoting cognitive functions related to learning and memory. According to the study of Curtis T Cripe[29], rehabilitation training based on BCI technology can enhance patients' self-initiative and improve their cognitive function. At the same time, BCI can also monitor the global attention level related to the task process, and monitoring the change of attention during BCI training can ensure that the patient is better focused on the current training task. Lee [30]used EEG-BCI techniques in 31 patients and measured cognitive improvement using cognitive ability tests, card matching games, and other memory and attention tasks. The results showed that immediate memory ($P=0.038$), delayed memory ($P<0.01$) and attention ($P=0.039$) were significantly improved. Shukin [31] used cognitive P300 evoked potential and diagnostic scale to evaluate the therapeutic effect of stroke patients with cognitive impairment. The above studies indicate that BCI technology can be used as a means of assessment to assess the degree of consciousness disorder and treatment effect of patients, and can also be used as a means of rehabilitation to promote the rehabilitation of cognitive function of patients.

3.4 Application of BCI Technology in Psychological Rehabilitation of Stroke

After stroke, patients are prone to depression, irritability, extreme depression, boredom and avoidance of rehabilitation training. At present, most of the rehabilitation training based on BCI technology, especially BCI-VR training, has added virtual scenes related to psychological state, soothing patients' emotions, improving patients' psychological state, improving patients' compliance with rehabilitation training, and thus improving rehabilitation effects.

4. Discussion

At present, the application of brain-computer interface technology in the field of stroke rehabilitation is developing rapidly, and the research direction shows a diversified development trend. However, due to some software and hardware problems of the BCI system, such as the cumbersome operation of BCI and external equipment, it is not easy to carry, and the maintenance cost is high. There is no unified standard for the extraction and decoding of brain information, and the signal transmission speed is slow, as well as the biosafety and ethical problems of technology application. Although BCI technology is in the development stage, with the country's strong investment in natural science and other fields, it is believed that BCI technology will become increasingly mature and perfect, and its clinical application will be more and more extensive.

References

[1] Barthels, D.H. Das, Current advances in ischemic stroke research and therapies[J]. Biochim Biophys Acta Mol Basis Dis. 1866(4): 2020p.165260.

[2] Chamola, V., et al., Brain-Computer Interface-Based Humanoid Control: A Review[J]. Sensors (Basel). 20(13): 2020p.

[3] Luo, S., Q. RabbaniN.E. Crone, Brain-Computer Interface: Applications to Speech Decoding and Synthesis to Augment Communication[J]. Neurotherapeutics. 19(1): 2022p.263-273.

[4] Carelli, L., et al., Brain-Computer Interface for Clinical Purposes: Cognitive Assessment and Rehabilitation [J] Biomed Res Int. 2017: 2017p.1695290.

[5] Pillette, L., et al., Why we should systematically assess, control and report somatosensory impairments in BCI-based motor rehabilitation after stroke studies[J]. Neuroimage Clin. 28: 2020p. 102417.

[6] Lima, E.O., et al., Transcranial Direct Current Stimulation and Brain-Computer Interfaces for Improving Post-Stroke Recovery: A Systematic Review and Meta-Analysis[J]. Clin Rehabil. 38(1): 2024p.3-14.

ISSN 2616-5791 Vol.5, Issue 3: 1-5, DOI: 10.25236/AJMHS.2024.050301

[7] Yang, W., et al., The Effect of Brain-Computer Interface Training on Rehabilitation of Upper Limb Dysfunction After Stroke: A Meta-Analysis of Randomized Controlled Trials[J]. Front Neurosci. 15: 2021p.766879.

[8] Liu, L., et al., Brain-Computer Interface-Robot Training Enhances Upper Extremity Performance and Changes the Cortical Activation in Stroke Patients: A Functional Near-Infrared Spectroscopy Study [J]. Front Neurosci. 16: 2022p.809657.

[9] Jaqueline da Cunha, M., et al., Functional electrical stimulation of the peroneal nerve improves post-stroke gait speed when combined with physiotherapy. A systematic review and meta-analysis[J]. Ann Phys Rehabil Med. 64(1): 2021p.101388.

[10] Marquez-Chin, C.M.R. Popovic, Functional electrical stimulation therapy for restoration of motor function after spinal cord injury and stroke: a review[J]. Biomed Eng Online. 19(1): 2020p.34.

[11] Carino-Escobar, R.I., et al., Prognosis of stroke upper limb recovery with physiological variables using regression tree ensembles[J]. J Neural Eng. 18(4): 2021p.

[12] Vourvopoulos, A.I.B.S. Bermúdez, Motor priming in virtual reality can augment motor-imagery training efficacy in restorative brain-computer interaction: a within-subject analysis[J]. J Neuroeng Rehabil. 13(1): 2016p.69.

[13] Kruse, A., et al., Effect of brain-computer interface training based on non-invasive electroencephalography using motor imagery on functional recovery after stroke - a systematic review and meta-analysis[J]. BMC Neurol. 20(1): 2020p.385.

[14] Bruni, M.F., et al., What does best evidence tell us about robotic gait rehabilitation in stroke patients: A systematic review and meta-analysis[J]. J Clin Neurosci. 48: 2018p.11-17.

[15] Mills, E.J., et al., Multiple treatment comparison meta-analyses: a step forward into complexity[J]. Clin Epidemiol. 3: 2011p.193-202.

[16] Zhang Ruiping, Jiang Xueling, Zhang Yang, et al.Application of Brain-Machine Interface Rehabilitation Robot in Lower Limb Motor Function Recovery of Patients in the Acute Phase of Stroke: A Study in China Practical Medicine[J].China Practical Medicine,2021,16(34):196-198.

[17] Sebastián-Romagosa, M., et al., Brain-computer interface treatment for gait rehabilitation in stroke patients[J]. Front Neurosci. 17: 2023p.1256077.

[18] Bouton, C.E., Merging brain-computer interface and functional electrical stimulation technologies for movement restoration[J]. Handb Clin Neurol. 168: 2020p.303-309.

[19] Chung, E., B.H. LeeS. Hwang, Therapeutic effects of brain-computer interface-controlled functional electrical stimulation training on balance and gait performance for stroke: A pilot randomized controlled trial [J]. Medicine (Baltimore). 99(51): 2020p. e22612.

[20] Vourvopoulos, A., et al., Effects of a Brain-Computer Interface With Virtual Reality (VR) Neurofeedback: A Pilot Study in Chronic Stroke Patients[J]. Front Hum Neurosci. 13: 2019 p.210.

[21] Anumanchipalli, G.K., J. ChartierE.F. Chang, Speech synthesis from neural decoding of spoken sentences [J]. Nature. 568(7753): 2019 p. 493-498.

[22] Cooney, C., R. FolliD. Coyle, Neurolinguistics Research Advancing Development of a Direct-Speech Brain-Computer Interface[J]. iScience. 8: 2018p.103-125.

[23] Aleman, A., et al., The functional neuroanatomy of metrical stress evaluation of perceived and imagined spoken words[J]. Cereb Cortex. 15(2): 2005 p.221-8.

[24] Grau, C., et al., Conscious brain-to-brain communication in humans using non-invasive technologies [J]. PLoS One. 9(8): 2014p.e105225.

[25] Shukin, I.A., et al., [Post-stroke rehabilitation training with a brain-computer interface: a clinical and neuropsychological study] [J]. Zh Nevrol Psikhiatr Im S S Korsakova. 118(7): 2018p.25-29.

[26] Tonin, L., et al., Behavioral and Cortical Effects during Attention Driven Brain-Computer Interface Operations in Spatial Neglect: A Feasibility Case Study[J]. Front Hum Neurosci. 11: 2017 p.336.

[27] Aam, S., et al., The Impact of Vascular Risk Factors on Post-stroke Cognitive Impairment: The Nor-COAST Study[J]. Front Neurol. 12: 2021p.678794.

[28] Nie, J.X. Yang, Modulation of Synaptic Plasticity by Exercise Training as a Basis for Ischemic Stroke Rehabilitation[J]. Cell Mol Neurobiol. 37(1): 2017 p.5-16.

[29] Cripe, C.T., et al., Improved Sobriety Rates After Brain-Computer Interface-Based Cognitive Remediation Training[J]. Cureus. 14(1): 2022p.e21429.

[30] Baykara, E., et al., Effects of training and motivation on auditory P300 brain-computer interface performance[J]. Clin Neurophysiol. 127(1): 2016 p. 379-387.

[31] Ruiz, S., et al., Real-time fMRI brain computer interfaces: self-regulation of single brain regions to networks[J]. Biol Psychol. 95: 2014 p.4-20.