Proceedings of the 3rd International Conference on Biological Engineering and Medical Science
DOI: 10.54254/2753-8818/21/20230821

Effect of brain-computer interface training on functional recovery after stroke

Jiaheng Tang

Northwestern University Feinberg School of Medicine, 420 E Superior St, Chicago, IL 60611, United States

jiaheng.tang1999@gmail.com

Abstract. As the aging population continues to grow, the incidence of stroke is increasing yearly. Patients with stroke often have residual motor dysfunction symptoms, which seriously affects their life and work. The traditional treatment methods have limited applicability and efficacy, making it difficult for patients to control their muscles voluntarily and achieve cortical-muscle coupling. Brain-computer interface (BCI) technology can enable patients with severely impaired motor function to control external devices through brain-controlled movements, thus promoting the efficiency of motor rehabilitation training and becoming a hot research topic. This article systematically summarizes the basic technology of BCI, its application in stroke rehabilitation, and future development trends.

Keywords: brain-computer interface, stroke rehabilitation, EEG decoding.

1. Introduction

Stroke has become the leading cause of death and disability in adults [1]. Motor dysfunction caused by stroke is the most common in clinical practice. 40%-60% of stroke patients will have varying degrees of residual symptoms, which can lead to a severe decline in their ability to live and work. In addition, nearly one-third of stroke patients also experience emotional disorders and mood swings [2, 3].

Currently, the clinical treatment of stroke mainly focuses on peripheral therapy for patients, with a lack of direct intervention in the patient’s brain tissue, which has a significant impact on the patient’s brain tissue and is often accompanied by long treatment times and poor efficacy [2, 4, 5]. Therefore, there is an urgent need to adopt more effective and safe intervention measures for stroke patients to improve their survival status and enhance their quality of life.

Researchers have found that brain-computer interface (BCI) technology can effectively treat patients with motor deficits in clinical practice [6]. There are two types of BCI modes used for the diagnosis and treatment of limb movement disorders. One is an assistive BCI, which uses BCI devices to decode the patient's intention to move, thereby controlling external devices such as robots. Unlike traditional prostheses that only have slots for the residual limb, this BCI-based prosthesis can be directly connected to the residual limb's nerves and muscles, allowing users to control it using their brains and achieving a sense of reality during use. The other is a rehabilitation BCI, which can directly intervene in the patient's brain. Because the human nervous system is plastic, repetitive feedback to the

DOI: 10.54254/2753-8818/21/20230821

brain through BCI devices can strengthen the connections between neurons and achieve the goal of treatment [6, 7].

1.1. Signal acquisition

According to the signal acquisition method, BCI technology can be divided into invasive and non-invasive types. Invasive BCIs mainly use ECoG and Spikes for signal acquisition. In contrast, EEG is the primary method for non-invasive BCIs. The difference between these two signal acquisition methods is that ECoG and Spikes require the implantation of electrodes into the patient's brain cortex, while non-invasive BCI records brain signals non-invasively from the patient's scalp. Because invasive BCI signal acquisition methods have a higher spatial resolution, better signal-to-noise ratio, and wider frequency bands, but ECoG and Spikes require the implantation of electrodes into the user's brain cortex, which can lead to rejection reactions, deterioration of signal quality, and degradation of electrode performance over time. However, EEG has higher safety, more convenient acquisition, and lower cost because it does not require the implantation of foreign bodies through surgery.

1.2. Signal processing and decoding

The brain signals can be transformed from patterns of neural activity to neural activity data. However, the brain signals contain noise signals that affect signal quality, such as neural signals unrelated to patient psychological activity, power frequency interference, electro-ocular, and muscle artifacts. These noise signals may be caused by motion, such as blinking, eye movement, and head movement. Different preprocessing methods are applied to filter out noise unrelated to the user's psychological activity. However, in the process of filtering noise, maintaining the signal’s integrity is also a difficult problem.

After preprocessing, the brain signals will extract features based on the neural signal rules of different BCI modes, and then train the classification model using pattern recognition technology or machine learning algorithms. However, there are still many unsolved but essential problems in the decoding aspect of current BCI technology:

1. The information output rate of current BCI technology is limited, seriously affecting external devices' functionality.
2. Data fidelity is also vital for functional application BCI.
3. Due to individual user differences, most current classification models must be customized for specific users.

The customization process requires much time to train the model using the user's brain signals. An efficient and suitable model can only be found through a large number of model training.

1.3. Device control

Many external devices can be communicated with and controlled through BCI. In the case of communication or control applications, the control interface can translate the decoded logical control signals represented by the user into semantic control signals and then convert these into physical control signals [4, 6, 8]. BCI technology can be used in stroke rehabilitation to convert brain information into conscious movements of disabled limbs. In addition, existing BCI technology can allow users to trigger upper limb exoskeletons through motor imagery-based BCI devices, assisting patients with grasping, releasing, and arm-body movements. BCI can also be used for lower limb movement function rehabilitation, assisting the body in completing supporting walking and other movement functions [7].

2. Application of brain-computer interface in stroke rehabilitation

The main goal of stroke rehabilitation is the restoration of motor function. However, due to the limited effectiveness of traditional treatment methods, there is an urgent need for more effective treatment options. The emergence of BCI has become the most promising tool for motor function recovery in the future.

DOI: 10.54254/2753-8818/21/20230821

2.1. Application of BCI in stroke treatment

Motor function recovery is the most researched application of BCI stroke. BCIs mainly help patients with impaired motor function after a stroke to improve their quality of life through two methods. The first is an assistive BCI, which completely bypasses the damaged neural pathway and controls external devices such as prosthetics or exoskeletons through the BCI device, receiving the patient's motor intention. For example, an intelligent prosthetic limb system consisting of a neural-muscle-bone prosthetic limb, a mechanical arm and hand controlled by the motor cortex signals of the brain, and a hemiplegic stepper and interactive gait correction device.

The second method is a rehabilitative BCI, which effectively promotes neuroplasticity to restore damaged neural connections and thus restore impaired functions. For example, the BCI upper limb motor recovery system controlled by motor imagery and the BCI synchronous closed-loop rehabilitation system combined with virtual reality technology [9-11].

2.2. Advantages of BCI rehabilitation technology

Compared to traditional rehabilitation methods, BCI can be applied to a broader range of patients with post-stroke motor impairments. Before the widespread understanding of BCIs, traditional post-stroke motor impairment treatments mainly included occupational and constrained-induced movement therapy. However, patients with severely impaired motor function do not have the minimum required motor ability for conventional rehabilitation programs [6, 12]. In contrast to the conventional approach, BCI relies on the user's brain signals to drive the interface. Therefore, even stroke patients who have completely lost their motor control ability can imagine movement and activate the cortex associated with motor actions. Studies have shown that even imagining a motor action can produce brain activation consistent with actual movement. In addition, BCI can help patients establish a connection between their brain's intention and external assistive devices, inducing patients to achieve self-regulation and coupling coordination between the cortex and peripheral neuromuscular systems under the plasticity rehabilitation mechanism.

2.3. Adverse reactions and limitations of BCI

Based on the above content, BCI has received extensive attention and development due to its wide range of applications and significant therapeutic effects. However, as an emerging, complex, and interdisciplinary communication technology, many problems still need to be solved. First, the information acquisition technology of BCI still needs to be improved. Non-invasive BCI detects weak signals, but if electrodes are implanted in the brain, the implanted electrodes are wrapped by inflammatory cells over time, which can lead to signal loss. In addition, BCIs also need to address security risks such as hacking attacks, mind control, and data theft, which can lead to privacy leaks [11].

3. Future outlook

With the significant improvement of medical technology, BCI technology has been widely recognized and developed rapidly, showing good research and application prospects in post-stroke motor recovery. However, BCIs are still in the early development and theoretical exploration stage in this field. If we want to apply this technology widely to clinical practice, we still need to face many challenges.

The first challenge is to solve the problem of bidirectional interaction in BCI technology. Although BCI technology has made significant progress in motor recovery, the recovery of a limb requires both motor function and sensory ability (such as touch and proprioception) to be restored. By combining kinetic and sensory functions, bidirectional BCI and closed-loop systems can be merged to adjust the user's movement pattern based on sensory feedback. Studies on neural prostheses based on bidirectional brain-machine interfaces have been conducted, and this problem is believed to be resolved soon [13-15].

The second challenge is the application of synchronous and asynchronous BCI. The BCI systems for post-stroke recovery mentioned above, such as mechanical arms, mechanical hands, and paraplegic

DOI: 10.54254/2753-8818/21/20230821

gait trainers, all use synchronous BCIs. The working principle of synchronous BCI systems is to obtain the user's real-time brain signals, which also means that patients need to continuously "work" to produce brain signals to control the BCI system. However, users are idle most of the time when using BCI external devices. Only BCI that can correctly identify the user's idle state and generate idle-state actions through asynchronous BCI can avoid system errors and improve the availability of online systems and user autonomy [13, 16].

Finally, the research direction of hybrid BCI technology, which uses electroencephalography and other physiological signals such as electromyography and heart rate, is also a challenge. These combinations can work together to control algorithms more accurately and improve the reliability of detecting user intent results [17].

4. Conclusion

In recent years, there has been significant research progress in hardware and algorithms in the field of brain-computer interface technology. As an interdisciplinary field, BCI has extensive research and application prospects in the medical field, and this technology has already achieved exciting results in stroke rehabilitation. We look forward to the future development of this critical research field and hope that this technology can benefit everyone.

References

[1] Li, L., Yu, Y., Jia, Y., & Huang, H. Meta-analysis of the effect of brain-computer interface on upper limb motor function after stroke. Chinese Journal of Rehabilitation Theory and Practice, 27(07), 765-773 (2021).

[2] Wang, L., Peng, B., Zhang, H., Wang, Y., Liu, M., Shan, C., Cao, L., Wang, L., Xie, W., Wang, P., & Ma, L. Summary of the 2020 China Stroke Prevention and Treatment Report. Chinese Journal of Cerebrovascular Diseases, 19(02), 136-144(2022).

[3] Ostwald, S. K., Godwin, K. M., Ye, F., & Cron, S. G. Serious adverse events experienced by survivors of stroke in the first year following discharge from inpatient rehabilitation. PM&R, 5(2), 107-113 (2013).

[4] He, F., He, B., Wang, Z., Chen, L., & Ming, D. Neurofeedback methods and rehabilitation application of brain-machine interaction movement training. Chinese Journal of Biomedical Engineering, 40(6), 719-730 (2021).

[5] Kruse, A., Suica, Z., Taeymans, J., 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. Journal of Neuro Engineering and Rehabilitation, 17(1), 1-20 (2020).

[6] Mane, R., Chouhan, T., & Guan, C. BCI for stroke rehabilitation: motor and beyond. IOP Publishing (2020).

[7] Yang, S., Li, R., Li, H., Xu, K., Shi, Y., Wang, Q., Yang, T., & Sun, X. Exploring the Use of Brain-Computer Interfaces in Stroke Neurorehabilitation. BioMed Research International (2021).

[8] Chaudhary, U., Birbaumer, N., & Ramos-Murguialday, A. Brain-computer interfaces for communication and rehabilitation. Springer Nature (2016).

[9] Ren, H., & Xie, Z. Efficacy observation of brain-computer interface technology in the rehabilitation treatment of upper limb motor function in patients with stroke. Chinese Practical Medicine (2020).

[10] Chen, X., Wang, Y., & Zhang, D. Retrospect of 2018 hotspots in brain-computer interface development. Science and Technology Review, 37(01), 173-179 (2019).

[11] Saha, S., Mamun, K. A., Ahmed, K., Mostafa, R., Naik, G. R., Darvishi, S., Khandoker, A. H., & Baumert, M. Progress in Brain Computer Interface: Challenges and Opportunities. Frontiers (2021).

DOI: 10.54254/2753-8818/21/20230821

[12] Sebastián-Romagosa, M., Cho, W., Ortner, R., Murovec, N., Von Oertzen, T., & Kamada, K. Brain Computer Interface Treatment for Motor Rehabilitation of Upper Extremity of Stroke Patients—A Feasibility Study. Frontiers (2020).

[13] Remsik, A., Young, B., Vermilyea, R., Kiekhoefer, L., Abrams, J., & Evander Elmore, S. A review of the progression and future implications of brain-computer interface therapies for restoration of distal upper extremity motor function after stroke. Expert Review of Medical Devices (2016).

[14] Cervera, M. A., Soekadar, S. R., Ushiba, J., Millan, J. D. R., Liu, M., Birbaumer, N., & Garipelli, G. Brain-computer interfaces for post-stroke motor rehabilitation: a meta-analysis. American Neurological Association (2018).

[15] Huo, C. C., Zheng, Y., Lu, W. W., et al. Prospects for intelligent rehabilitation techniques to treat motor dysfunction. Neural Regeneration Research (2019).

[16] Xiang, X. W., Zhu, J. Y., Sun, Y. B., et al. Clinical study of brain-computer interface rehabilitation training system for upper limb dysfunction in the recovery period of ischemic stroke. Chinese Journal of Medical Innovation (2020).

[17] Zhang, M. H. The impact of brain-computer interface technology on upper limb and hand function of stroke patients with hemiplegia (Doctoral dissertation, Hebei Normal University) (2020).