International Journal of Multidisciplinary
Research and Growth Evaluation.

Application of Motor Imagery Brain-Computer Interface in the Rehabilitation of Upper Limb Dysfunction After Stroke

Yubin Xia [1], **Daekeun Jeong** [2*]
[1-2] Department of Physical Therapy, Graduate School of Sehan University, Jeollanam-do 58447, South Korea
[1] Admissions and Employment Office, Weifang Nursing Vocational College, Weifang, Shandong, China

* Corresponding Author: **Daekeun Jeong**

Article Info

ISSN (Online): 2582-7138
Impact Factor (RSIF): 8.04
Volume: 07
Issue: 03
May-June 2026
Received: 23-02-2026
Accepted: 25-03-2026
Published: 27-04-2026
Page No: 08-10

Abstract

Upper limb dysfunction following stroke is a significant factor affecting patients' daily living abilities, social participation, and quality of life. While traditional rehabilitation therapies can promote motor function recovery to some extent, their efficacy remains limited for patients with moderate to severe upper limb dysfunction. A motor imagery brain-computer interface (MI-BCI) that acquires and decodes EEG signals generated during motor imagery transforms the brain's motor intentions into external feedback, thereby reconstructing the closed-loop pathway of "cortical activation—peripheral feedback—sensory input." It is considered a cutting-edge rehabilitation technology for promoting neuroplasticity and reconstructing motor function. In recent years, multiple randomized controlled trials and systematic reviews have shown that MI-BCI has a positive effect on upper-limb motor function recovery, improvements in daily living abilities, and brain function reorganization after stroke, especially when combined with feedback methods such as robotics and functional electrical stimulation. However, this technology still faces challenges in terms of sample size, standardization of intervention protocols, long-term follow-up, and clinical implementation pathways. This article reviews and analyzes the mechanism of action and current clinical applications of MI-BCI, aiming to provide a theoretical basis and practical reference for the precise rehabilitation of upper-limb dysfunction after stroke.

DOI: https://doi.org/10.54660/.IJMRGE.2026.7.3.08-10

Keywords: stroke, upper limb dysfunction, motor imagery, brain-computer interface, rehabilitation therapy, neuroplasticity

1. Introduction

Stroke is characterized by high incidence, high disability rate, and high recurrence rate, and is one of the leading causes of long-term disability in adults worldwide. Upper limb motor dysfunction is one of the most common functional deficits after stroke, often manifesting as limited coordination of the shoulder, elbow, wrist, and hand, severely affecting daily living activities such as eating, dressing, transferring, and fine motor skills. Because upper limb motor function relies heavily on fine cortical control, recovery is usually slower than in the lower limbs, and long-term functional impairment is more likely.

Traditional upper limb rehabilitation typically includes task-oriented training, occupational therapy, neuromuscular facilitation techniques, robot-assisted training, and functional electrical stimulation, but these interventions often rely on the patient's remaining motor function. For patients with moderate to severe paralysis, especially those with very little or no active movement, traditional methods alone are often insufficient to activate the damaged cortical network fully. The emergence of MI-BCI provides such patients with a new pathway to bypass limited peripheral motor output and directly utilize central motor intention in rehabilitation training. The EEG-based MI-BCI system can identify sensorimotor rhythm changes during motor imagery and provide immediate feedback through robots, exoskeletons, virtual reality, or functional electrical stimulation, thereby enhancing central-peripheral coupling and promoting functional recovery. Multiple clinical studies and meta-analyses have shown that BCI training promotes recovery of upper limb motor function after stroke, with the strongest evidence for upper limb rehabilitation. [2, 5, 6, 7, 9]

2. Basic Principles and Rehabilitation Mechanisms of MI-BCI

2.1. The Neural Basis of Motor Imagery

Motor imagery is the mental activity in which an individual simulates the execution of an action in the brain without producing actual motor output. Studies have shown that motor imagery can activate neural networks similar to those activated by real movement, including the primary motor cortex, supplementary motor area, premotor cortex, and parietal lobe-related areas. Even if stroke patients cannot perform actual movements, they may still retain a degree of motor intention and motor imagery, providing a theoretical basis for MI-BCI intervention. The EEG signals generated during MI usually show event-related desynchronization or synchronization changes in the sensorimotor rhythm (SMR), especially in the μ and β frequency bands, which can serve as important features for BCI recognition. [3]

2.2. Closed-loop rehabilitation mechanism of MI-BCI

The MI-BCI system typically includes four core components: signal acquisition, feature extraction, pattern recognition, and feedback output. When a patient imagines movement in the affected upper limb, the system acquires EEG signals and identifies the patient's intention to move. Once the identification is successful, the system drives a robot, robotic hand, exoskeleton, or functional electrical stimulation device to perform the corresponding action. It provides the patient with visual, auditory, or proprioceptive feedback. This process constructs a closed-loop training model of "motor intention - brain signal decoding - external execution - sensory feedback".

The significance of this closed-loop mechanism for rehabilitation is mainly reflected in three aspects. First, it can still strengthen the coupling relationship between motor intention and action result when the patient's active motor ability is insufficient. Second, it promotes cortical reorganization and synaptic plasticity through repetitive, goal-oriented feedback stimulation. Third, it helps to enhance the patient's sense of active participation and training motivation and improve rehabilitation training compliance. Existing research suggests that the key reason MI-BCI is superior to simple passive activity training is that it retains the neurorehabilitation characteristic of "intention-driven" training. [2, 4, 8]

3. Current Status of Clinical Application of MI-BCI in Upper Limb Dysfunction After Stroke

3.1. Application of Joint Robot Feedback

Robotic feedback is one of the earliest and most common output methods of MI-BCI. The robot can guide the patient to complete shoulder, elbow, wrist, or hand movements based on brain signal recognition, providing clear feedback on the movement. The randomized controlled study conducted by Ang *et al*. showed that EEG-based MI-BCI combined with MIT-Manus robotic arm training can improve upper-limb motor function in patients with chronic stroke, and its efficacy is superior to simple control training. Earlier clinical studies also suggested that MI-BCI combined with robotic feedback is effective and safe in the rehabilitation of upper limb function in patients with chronic stroke. [1, 2, 4]

The advantages of robotic feedback are that the movement output is stable and highly repeatable, and that standardized training is easy to implement; however, there are also problems, such as high equipment costs and complex clinical deployment. Recent systematic reviews suggest that the BCI-robot system has a significant promoting effect on motor recovery of hemiplegic upper limbs and may have sustained effects, but its gains compared with simple robot treatment still need to be further clarified by more high-quality studies. [12]

3.2. Application of combined functional electrical stimulation

Functional electrical stimulation (FES) is currently a highly promising feedback method in MI-BCI. FES can stimulate contraction of corresponding muscle groups upon recognizing the patient's motor intention, thereby inducing target movements such as wrist dorsiflexion and finger extension. It can not only provide clear peripheral feedback but also enhance sensory input and facilitate motor relearning. A meta-analysis shows that studies using FES as a BCI feedback device typically achieve larger effect sizes, suggesting that this method may be more beneficial for upper limb function recovery. [8]

A systematic review in 2024 further noted that BCI-FES training has a positive effect on upper limb function recovery in stroke patients, particularly by promoting motor function and improving certain clinical outcomes. However, heterogeneity persists across stroke stages, threshold settings, and combined treatment regimens. [13]

3.3. Application of combined visual feedback and virtual training

In addition to robots and FES, visual feedback is widely used in MI-BCI. The system can present a virtual arm or task scenario on the screen, allowing patients to observe the completion of the target action when the motor imagery is successful, thereby strengthening motor representation. Visual feedback devices are relatively simple and low-cost, making them more suitable for clinical promotion. Some studies have found that visual feedback-based MI-BCI can improve upper limb function in stroke patients and can be used in multi-center training programs. [7, 11]

However, the activation of proprioception by single visual feedback is relatively limited. Therefore, more and more studies are using multimodal feedback, that is, combining visual feedback with robots, FES, or task-oriented training to achieve more complete neural activation and functional transformation.

4. Future Development Direction

First, large-sample, multi-center, stratified randomized controlled trials should be conducted to clarify the optimal indications for MI-BCI across different stroke stages, injury severity, and feedback methods. Second, standardizing training parameters, evaluation indicators, and treatment course settings should be promoted to improve the comparability and quality of evidence across studies. Third, deep integration of MI-BCI with FES, robotics, virtual reality, non-invasive brain stimulation, and task-oriented training can be explored to develop individualized, precise rehabilitation programs. Fourth, with the development of artificial intelligence algorithms and wearable devices, MI-BCI is expected to achieve further breakthroughs in signal recognition accuracy, real-time performance, and portability, thereby increasing its clinical adoption. The above directions are generally consistent with recent research trends: on the one hand, systematic reviews are increasingly focusing on differences across feedback devices and task paradigms; on the other hand, recent clinical studies are seeking to improve efficacy through more refined feedback matching and neural mechanism assessment. [8, 10, 13, 14]

5. Conclusion

A motor imagery brain-computer interface provides a new technical approach for the rehabilitation of upper limb dysfunction after stroke. Its core advantage lies in its ability to directly drive external feedback using central motor intention when the patient's active movement is limited, thereby reconstructing the sensorimotor closed loop and promoting neuroplasticity. Current evidence generally supports the idea that MI-BCI can improve upper limb motor function in stroke patients and shows promise for daily living abilities and brain function reorganization, especially when combined with robots or functional electrical stimulation. Nevertheless, current research still suffers from problems such as high heterogeneity, insufficient sample size, and low standardization. In the future, high-quality clinical research and standardized technical pathways are needed to promote MI-BCI from a "promising cutting-edge technology" to a "routine rehabilitation method that can be promoted". [2, 6, 7, 8, 13]

References

1. Ang KK, Guan C, Chua KSG, *et al*. Clinical study of neurorehabilitation in stroke using EEG-based motor imagery brain-computer interface with robotic feedback. In: *2010 Annual International Conference of the IEEE Engineering in Medicine and Biology Society*; 2010; Buenos Aires, Argentina. p. 5549–52.
2. Ang KK, Chua KSG, Phua KS, *et al*. A randomized controlled trial of EEG-based motor imagery brain-computer interface robotic rehabilitation for stroke. Clin EEG Neurosci. 2015;46(4):310–20.
3. Cincotti F, *et al*. EEG-based brain-computer interface to support post-stroke motor rehabilitation of the upper limb. In: *2012 Annual International Conference of the IEEE Engineering in Medicine and Biology Society*; 2012; San Diego, CA, USA. p. 4112–5.
4. Ang KK, Guan C, Phua KS, Wang C, Zhou L, Tang KY, *et al*. Brain-computer interface-based robotic end effector system for wrist and hand rehabilitation: results of a three-armed randomized controlled trial for chronic stroke. Front Neuroeng. 2014;7:30.
5. Carvalho R, Dias N, Cerqueira JJ. Brain-machine interface of upper limb recovery in stroke patient's rehabilitation: a systematic review. Physiother Res Int. 2019;24:e1764.
6. 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. BMC Neurol. 2020;20:385.
7. Bai Z, Fong KNK, Zhang JJ, *et al*. Immediate and long-term effects of BCI-based rehabilitation of the upper extremity after stroke: a systematic review and meta-analysis. J Neuroeng Rehabil. 2020;17:57.
8. Mansour S, Ang KK, Nair KPS, Phua KS, Arvaneh M. Efficacy of brain-computer interface and the impact of its design characteristics on poststroke upper-limb rehabilitation: a systematic review and meta-analysis of randomized controlled trials. Clin EEG Neurosci. 2022;53(1):79–90.
9. Peng Y, Wang J, Liu Z, Zhong L, Wen X, Wang P, *et al*. The application of brain-computer interface in upper limb dysfunction after stroke: a systematic review and meta-analysis of randomized controlled trials. Front Hum Neurosci. 2022;16:798883.
10. Fu J, Chen S, Jia J. Sensorimotor rhythm-based brain–computer interfaces for motor tasks used in hand upper extremity rehabilitation after stroke: a systematic review. Brain Sci. 2023;13(1):56.
11. Jiang Y, Yin J, Zhao B, Zhang Y, Peng T, Zhuang W, *et al*. Author spotlight: using motor imagery brain-computer interface to improve motor and cognitive function in stroke patients. J Vis Exp. 2023;(199):e65405.
12. Qu H, Zeng F, Tang Y, Shi B, Wang Z, Chen X, *et al*. The clinical effects of brain–computer interface with robot on upper-limb function for post-stroke rehabilitation: a meta-analysis and systematic review. Disabil Rehabil Assist Technol. 2024;19(1):30–41.
13. Ren C, Li X, Gao Q, Pan M, Wang J, Yang F, Duan Z, *et al*. The effect of brain-computer interface controlled functional electrical stimulation training on rehabilitation of upper limb after stroke: a systematic review and meta-analysis. Front Hum Neurosci. 2024;18:1438095.
14. Kim MS, Park H, Kwon I, *et al*. Efficacy of brain-computer interface training with motor imagery-contingent feedback in improving upper limb function and neuroplasticity among persons with chronic stroke: a double-blinded, parallel-group, randomized controlled trial. J Neuroeng Rehabil. 2025;22:1.

How to Cite This Article

Xia Y, Jeong D. Application of motor imagery brain-computer interface in the rehabilitation of upper limb dysfunction after stroke. Int J Multidiscip Res Growth Eval. 2026 May-Jun;7(3):8–10. doi:10.54660/.IJMRGE.2026.7.3.08-10.

Creative Commons (CC) License