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# *Neural Reorganization in Motor Recovery after Stroke: An Analysis Based on EEG*

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***Abstract.*** Post-stroke hemiparesis is a common long-term motor impairment, and patients may show considerable differences in recovery even after receiving similar rehabilitation training. This paper focuses on neural reorganization during post-stroke motor recovery and examines the use of electroencephalography (EEG) in observing changes in sensorimotor networks. Particular attention is given to alpha and beta oscillations, event-related desynchronization/synchronization (ERD/ERS), and functional connectivity. Current studies suggest that motor recovery after stroke involves dynamic reorganization of the ipsilesional motor areas, the contralesional hemisphere, and bilateral sensorimotor networks. However, recovery patterns are not consistent across patients. Changes in EEG measures should therefore not be simply interpreted as increased brain activity or stronger functional connectivity. Instead, they should be considered together with the severity of injury, the integrity of motor pathways, and the stage of recovery. EEG can provide useful neurophysiological information for understanding functional neural reorganization after stroke and may also support patient stratification and individualized rehabilitation assessment.

***Keywords:*** Stroke, motor recovery, electroencephalography (EEG), neural plasticity, functional connectivity

## 1. Introduction

Stroke is one of the major causes of long-term motor impairment in adults. Damage to the motor cortex, corticospinal tract, or related neural pathways can lead to unilateral muscle weakness, impaired motor control, reduced coordination, and gait abnormalities. Although physical therapy, occupational therapy, and repetitive motor training can promote partial functional recovery, recovery speed and final outcomes still vary considerably among patients. Current studies suggest that these differences are related not only to lesion location and severity, but also to how the motor network reorganizes after stroke. Yu et al. reported that motor recovery after stroke involves dynamic functional reorganization of bilateral motor networks rather than recovery of a single damaged brain region alone [1].

EEG can directly record cortical electrical activity and can reflect the state of the sensorimotor system through spectral features, task-related EEG changes, and functional connectivity. Compared

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with magnetic resonance imaging, EEG has relatively limited spatial localization, but it provides higher temporal resolution and lower cost and can be repeatedly collected during rehabilitation. A review by Sun et al. showed that EEG measures such as power, brain symmetry, and phase synchronization may be associated with motor outcomes after stroke [2]. Therefore, EEG provides a practical approach for continuously observing changes in neural networks during stroke recovery.

This paper focuses on three main questions. First, it explores whether the EEG sensorimotor network undergoes changes during post-stroke rehabilitation. Second, it identifies which EEG features are associated with motor recovery. Third, it investigates the extent to which these changes reflect neural reorganization after stroke. This paper used a narrative review approach. PubMed and Google Scholar were used as the main search platforms, with a focus on studies published from 2022 to 2026 using the keywords stroke, EEG, motor recovery, neuroplasticity, and functional connectivity. Priority was given to studies that directly examined the relationships among post-stroke motor recovery, EEG measures, and neural reorganization, while relevant review articles were also included to provide background information.

## 2. EEG changes associated with motor recovery and neural plasticity

Normal voluntary movement does not depend on a single brain region. Instead, it involves the primary motor cortex (M1), premotor cortex, supplementary motor area (SMA), sensorimotor cortex, and corticospinal pathways. These regions work together through intrahemispheric and interhemispheric connections to support motor planning, execution, and sensory feedback. Stroke can directly damage motor-related brain regions and can also disrupt the connections between them. Therefore, hemiparesis can be understood as a result of impaired information transfer within the motor network. Neuroimaging studies have shown that local disruption of the motor network can occur in the early stage after stroke, followed by gradual functional reorganization of motor-related regions during recovery [1]. This suggests that motor recovery after stroke depends not only on the damaged brain area itself, but also on whether the remaining motor network can re-establish effective communication.

After stroke, neural tissue that is not completely damaged may still retain a certain degree of plasticity. Residual motor areas in the ipsilesional hemisphere, the contralesional hemisphere, and other supporting motor regions may all become involved in motor control. Delcamp et al. suggested that EEG can be used to observe post-stroke neural changes from several perspectives, including cortical activation, inhibition, and connectivity between brain regions [3]. However, greater involvement of brain regions does not necessarily indicate better recovery. In patients with more severe damage or in the early stage of recovery, additional recruitment of the contralesional hemisphere may serve a compensatory role. In contrast, long-term dependence on the contralesional network may also indicate that ipsilesional motor control has not been fully restored. Therefore, post-stroke neural plasticity is better understood as a dynamic process of network adjustment rather than simply an increase in brain activity. Against this background, EEG activity in different frequency bands and functional connectivity between brain regions can provide useful information for further understanding how the motor network reorganizes after stroke.

### 2.1. Changes in alpha and beta activity

Alpha and beta oscillations in EEG are closely related to sensorimotor function. Motor preparation, motor execution, and motor imagery can all produce changes in the power of specific frequency bands over sensorimotor areas. These changes are commonly described as event-related

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desynchronization (ERD) and event-related synchronization (ERS), which can reflect the recruitment and inhibition of motor-related cortical areas during a task.

After stroke, normal oscillatory patterns may be disrupted. Patients may show abnormally increased low-frequency activity, changes in alpha or beta activity, and asymmetry between the two hemispheres. Previous reviews have suggested that EEG measures such as spectral power, brain symmetry, and phase synchronization may be associated with motor function, although their clinical meaning can be influenced by individual differences, recovery stage, and analysis methods [2].

Beta oscillations have received particular attention. Jia et al. used TMS-EEG to investigate interactions between the two primary motor cortices in patients with acute ischemic stroke. They found that modulation of ipsilesional M1 beta oscillations by the contralesional M1 was associated with motor function [4]. This finding suggests that beta activity may reflect not only the functional state of a local motor cortical area, but also interactions between the two motor cortices.

Therefore, an increase or decrease in a single frequency band should not be used alone as a marker of good recovery. Stroke severity, lesion location, task design, and stage of rehabilitation can all influence EEG oscillations. Alpha and beta activity are better interpreted together with clinical motor performance, lesion characteristics, and brain network connectivity rather than being used alone to evaluate recovery.

### 2.2. Changes in functional connectivity

Motor control depends on coordinated activity across multiple brain regions. Therefore, compared with EEG power from a single region, functional connectivity can provide more information about changes in the motor network. Functional connectivity describes the synchronization, directionality, or interaction of activity between different brain regions and can be used to examine whether the original motor network has been reorganized after stroke.

Pirovano et al. conducted a longitudinal analysis of resting-state EEG in patients with subacute stroke before and after rehabilitation. They found changes in connectivity between the ipsilesional premotor cortex and M1, as well as between bilateral motor-related regions after rehabilitation [5]. This finding suggests that improvement in motor function may be accompanied by changes in the way information is transferred within the motor network.

However, stronger functional connectivity does not necessarily indicate better recovery. Ding et al. conducted a longitudinal TMS-EEG study in 81 patients with stroke and analyzed different recovery patterns based on motor function and the integrity of the ipsilesional motor pathway [6]. They found that in patients with poorer motor function and more severe damage to the ipsilesional motor pathway, increased recruitment of additional networks and stronger functional connectivity may reflect an effective compensatory mechanism. In contrast, in patients with relatively preserved ipsilesional motor pathways, a similar increase in connectivity may not necessarily indicate better recovery.

This suggests that similar changes in EEG connectivity may have different meanings across patients. In patients with severe damage, greater involvement of undamaged regions may be important for maintaining motor function. In patients with milder damage, however, excessive reliance on additional networks may reflect a less efficient motor control strategy.

A systematic review by Napoli et al. further pointed out that current studies differ considerably in connectivity measures, analysis procedures, and study design, and that a unified and reliable EEG functional connectivity biomarker has not yet been established [7]. Therefore, functional connectivity should not be interpreted only in terms of whether connection strength increases or

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decreases. It is also important to consider which brain regions are involved, the stage of recovery, and whether the connectivity changes occur together with improvements in clinical motor function.

### 2.3. Reorganization of the sensorimotor network

In addition to analyzing individual frequency bands or connectivity between two brain regions, motor recovery after stroke should also be understood from the perspective of the overall sensorimotor network. Normal movement depends on stable and effective information integration across multiple brain regions. Therefore, meaningful recovery may be reflected more by the formation of a new network organization than by a single brain region simply "returning to normal."

Previous studies suggest that motor recovery may involve several changes at the same time, including renewed recruitment of the ipsilesional motor network, changes in interactions between the two hemispheres, and reorganization of integration among motor-related regions [1, 3]. Evidence from other neuroimaging methods also supports this view. A systematic review by Sahrizan et al. showed that different stages of stroke recovery may involve different patterns of sensorimotor network reorganization, and that these changes may be associated with functional outcomes [8].

This may also explain why patients with similar clinical motor performance can still show different patterns of brain network activity. Some patients may rely mainly on residual motor networks in the ipsilesional hemisphere to regain motor control, while others may depend more on the contralesional hemisphere or other supporting motor regions. Both patterns may help patients perform motor tasks at certain stages of recovery, but their long-term efficiency and clinical meaning may differ. Therefore, compared with examining a single electrode or one frequency band, analyzing EEG changes from the perspective of the overall sensorimotor network may provide a better understanding of neural reorganization after stroke.

### 2.4. Compensation and reorganization

The studies discussed above suggest that motor recovery after stroke may involve both functional compensation and network reorganization. Compensation mainly refers to increased involvement of the contralesional hemisphere, premotor regions, or other undamaged networks that helps patients perform stroke-impaired motor tasks. In contrast, reorganization focuses more on changes in information transfer and control within the motor system itself.

Therefore, the ability to complete movements via recruitment of additional brain regions does not necessarily indicate recovery of the original ipsilesional M1–corticospinal system. Whether the recruitment of additional regions represents temporary compensation or more stable network reorganization needs to be evaluated together with changes over the course of rehabilitation and the patient's actual motor function.

The changes in directed information flow observed by Pirovano et al. support the idea that relationships within the motor network can be reconfigured during stroke recovery [5]. Ding et al. further showed that the condition of the remaining motor pathways can influence the recovery strategy used by a patient [6]. These findings suggest that there may not be a single fixed pattern of neural recovery that applies to all patients with stroke.

For patients with severe damage to the ipsilesional motor network, recruitment of the contralesional hemisphere and other intact brain regions may be required for functional compensation. In contrast, for patients with relatively preserved ipsilesional motor pathways, long-term reliance on additional regions may not be the most efficient motor control strategy. Therefore,

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compensation can be part of the recovery process, but it should not be considered the same as recovery of the original motor network.

### 2.5. Adaptive and maladaptive plasticity

Neural plasticity is not always beneficial for motor recovery. If a change in the motor network improves the efficiency of motor control and is accompanied by continued functional improvement, it may be considered adaptive plasticity. For example, renewed involvement of residual motor areas in the ipsilesional hemisphere, changes in communication between the premotor cortex and M1, and better coordination between bilateral motor regions may all contribute to adaptive recovery.

On the other hand, if abnormal activation or connectivity remains over time without leading to more effective motor control, it may reflect inefficient compensation or even maladaptive plasticity. Jia et al. found that the influence of the contralesional M1 on beta oscillations in the ipsilesional M1 was related to motor function [4]. This further suggests that interactions between the two hemispheres cannot simply be interpreted as "the stronger, the better."

Therefore, similar EEG changes may have different physiological meanings in different patients. For patients with severe damage, recruitment of additional networks may be an important strategy for maintaining and improving motor function. In patients with relatively preserved ipsilesional motor systems, however, the same degree of additional recruitment may reflect a less efficient motor control strategy.

This is also an important issue in current EEG research on stroke recovery. Rather than searching for a single EEG value that can represent recovery in all patients, it may be more useful to examine longitudinally which network strategy a patient uses and whether that strategy changes together with improvement in motor function. In other words, whether neural reorganization is beneficial depends not simply on whether brain activity increases, but on whether the reorganized motor network supports more effective motor control.

## 3. Discussion

### 3.1. Clinical implications

The potential value of EEG in stroke rehabilitation first lies in its ability to provide neurophysiological information beyond traditional clinical scales. Clinical scales mainly reflect what movements a patient is currently able to perform, while EEG may provide additional information about the neural network patterns used by the patient during task performance or at rest.

Li et al. found that changes in EEG parietofrontal functional connectivity after electroacupuncture were associated with upper-limb motor recovery and showed some potential for predicting recovery [9]. More recent studies have also attempted to combine multiple EEG features with clinical data to predict later upper-limb motor recovery [10]. These findings suggest that the potential use of EEG is not limited to explaining neural mechanisms, but may also extend to rehabilitation monitoring and patient stratification.

In the future, if different patterns of neural reorganization can be identified more reliably, rehabilitation strategies may be better adjusted according to each patient's neural functional state. For example, patients with relatively preserved ipsilesional networks may benefit from greater emphasis on recruiting the ipsilesional motor system, while patients with more severe damage may need to make greater use of compensatory activity from other brain regions.

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EEG may also be combined with technologies such as brain-computer interfaces, robot-assisted training, functional electrical stimulation, and neurostimulation. For example, when EEG detects a patient's motor intention, it may be paired with external motor or sensory feedback. However, these applications remain under development, and current evidence is insufficient to support treatment decisions based solely on a limited set of EEG metrics.

### 3.2. Limitations and future directions

Several limitations remain in the current literature. First, many studies have relatively small sample sizes, while stroke patients differ considerably in lesion location, injury severity, disease duration, and rehabilitation programs. These differences make direct comparison across studies difficult.

Second, there is still a lack of standardized procedures for EEG acquisition, preprocessing, and functional connectivity analysis. The systematic review by Napoli et al. specifically pointed out that methodological heterogeneity caused by different connectivity measures and analysis procedures is one of the main reasons why a stable EEG biomarker has not yet been established [7].

Third, although EEG has high temporal resolution, its spatial localization is limited. EEG alone therefore cannot accurately determine the specific roles of deep brain structures and white matter pathways during recovery. In future studies, EEG may be combined with fMRI, fNIRS, or structural imaging to provide more complete information about both neural function and brain structure.

In addition, different studies have reported different interpretations of contralesional involvement and changes in interhemispheric connectivity. These inconsistencies do not necessarily mean that the findings are contradictory. They may also reflect the high heterogeneity among stroke patients. Lesion location, corticospinal tract integrity, severity of motor impairment, and stage of recovery may all influence the pattern of neural reorganization.

Therefore, future research should include more longitudinal studies with larger sample sizes and more standardized methods. Patients should also be grouped more carefully according to lesion location, motor pathway integrity, and recovery stage. Rather than searching for one universal marker for all patients, identifying patient-specific patterns of neural reorganization may have greater clinical value.

## 4. Conclusion

This paper reviewed current EEG and related neuroimaging studies to examine dynamic changes in neural networks during motor recovery after stroke.

For the first research question, current evidence generally supports the view that the sensorimotor network changes dynamically during the course of rehabilitation after stroke. These changes involve not only individual motor regions, but also intrahemispheric connections in the ipsilesional hemisphere, involvement of the contralesional hemisphere, and communication between bilateral motor regions. Longitudinal EEG studies further suggest that improvements in clinical motor function can occur together with changes in motor network connectivity.

For the second research question, EEG features including alpha and beta oscillations, ERD/ERS, brain symmetry, and functional connectivity have all shown potential associations with motor recovery. However, there is currently not enough evidence to support using any single EEG measure as a universal marker of recovery for all stroke patients. The meaning of different EEG features still needs to be interpreted together with injury severity, motor pathway integrity, and stage of recovery.

For the third research question, current evidence generally supports the view that EEG can reflect part of the neural reorganization process after stroke, but this reorganization shows clear individual

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differences. In patients with more severe damage, involvement of the contralesional hemisphere and other brain regions may represent beneficial functional compensation. In patients with relatively preserved ipsilesional motor systems, more effective recovery of the ipsilesional network and appropriate bilateral coordination may be more important. Therefore, neural reorganization after stroke should not be understood simply as increased brain activity or stronger functional connectivity. Instead, it should be viewed as a dynamic process in which the motor network continuously adjusts its control strategy according to the patient's remaining neural structure.

In the future, the value of EEG in stroke rehabilitation may lie not only in identifying biomarkers related to motor scores, but also in helping to determine which neural recovery strategies are being used by different patients. If these patterns can be further validated in larger longitudinal studies, with more standardized EEG analysis methods, and through multimodal neuroimaging, EEG may become an important tool for supporting individualized motor rehabilitation assessment.

## References

[1] Yu, P., Dong, R., Wang, X., Tang, Y., Liu, Y., Wang, C., & Zhao, L. (2024). Neuroimaging of motor recovery after ischemic stroke—functional reorganization of motor network. *NeuroImage: Clinical, 43*, 103636. doi:10.1016/j.nicl.2024.103636.

[2] Sun, X., Dai, C., Wu, X., Han, T., Li, Q., Lu, Y., Liu, X., & Yuan, H. (2024). Current implications of EEG and fNIRS as functional neuroimaging techniques for motor recovery after stroke. *Medical Review, 4*(6), 492–509. doi:10.1515/mr-2024-0010.

[3] Delcamp, C., Srinivasan, R., & Cramer, S. C. (2024). EEG provides insights into motor control and neuroplasticity during stroke recovery. *Stroke, 55*(10), 2579–2583. doi:10.1161/STROKEAHA.124.048458.

[4] Jia, W., Zhou, Y., Mao, J., Feng, J., Han, Y., Xu, F., Wang, X., Liu, T., & Li, Z. (2025). Inhibition of ipsilesional M1 β oscillations by contralesional M1 following acute ischemic stroke: A TMS-EEG study. *Stroke, 56*(8), 2045–2056. doi:10.1161/STROKEAHA.124.050376.

[5] Pirovano, I., Mastropietro, A., Antonacci, Y., Barà, C., Guanziroli, E., Molteni, F., Faes, L., & Rizzo, G. (2022). Resting state EEG directed functional connectivity unveils changes in motor network organization in subacute stroke patients after rehabilitation. *Frontiers in Physiology, 13*, 862207. doi:10.3389/fphys.2022.862207.

[6] Ding, Q., Chen, J., Zhang, S., Chen, S., Li, X., Peng, Y., Chen, Y., Chen, J., Chen, K., Cai, G., Xu, G., & Lan, Y. (2024). Neurophysiological characterization of stroke recovery: A longitudinal TMS and EEG study. *CNS Neuroscience & Therapeutics, 30*(3), e14471. doi:10.1111/cns.14471.

[7] Napoli, E., Masina, F., Pezzetta, R., Vanni, F., Oliva, G., Saccani, M. S., et al. (2026). Biomarkers of stroke recovery using EEG-based resting-state functional connectivity: A systematic review. *Journal of NeuroEngineering and Rehabilitation, 23*(1), 142. doi:10.1186/s12984-026-01928-5.

[8] Sahrizan, N. S. A., Yahya, N., Law, Z. K., Wan Zaidi, W. A. W., Ismail, U. N., Afifah, N. H., Azri, A., & Abdul Manan, H. (2025). A systematic review of alterations in sensorimotor networks following stroke: Implications for integration and functional outcomes across recovery stages. *Frontiers in Neurology, 16*, 1456146. doi:10.3389/fneur.2025.1456146.

[9] Li, M., Zheng, S., Zou, W., Li, H., Wang, C., & Peng, L. (2023). Electroencephalography-based parietofrontal connectivity modulated by electroacupuncture for predicting upper limb motor recovery in subacute stroke. *Medicine (Baltimore), 102*(36), e34886. doi:10.1097/MD.0000000000034886.

[10] Lassi, M., Dalise, S., Privitera, L., Giannini, N., Mancuso, M., Azzollini, V., Ciapetti, T., Grippo, A., Micera, S., Cecchi, F., Mazzoni, A., Chisari, C., & Bandini, A. (2026). Enhancing upper limb motor recovery prediction after acute stroke using EEG and subacute data. *APL Bioengineering, 10*, 016108. doi:10.1063/5.0287165.