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Non-invasive brain stimulation in motor function recovery.

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Introduction

T Non-invasive brain stimulation (NIBS) has emerged as a promising therapeutic approach for enhancing motor function recovery in individuals affected by neurological conditions such as stroke, traumatic brain injury, and neurodegenerative diseases. By applying targeted stimulation to specific brain regions, NIBS aims to modulate neural activity and promote neuroplasticity, the brain's capacity to reorganize and form new connections. Techniques such as transcranial magnetic stimulation (TMS) and transcranial direct current stimulation (tDCS) are among the most widely used, offering the potential to enhance the effects of conventional rehabilitation. These methods are attractive because they are relatively safe, painless, and can be combined with task-specific training to maximize functional improvements. As research progresses, NIBS is increasingly being integrated into multidisciplinary rehabilitation programs, with the goal of accelerating recovery and improving quality of life for patients [1].

Transcranial magnetic stimulation works by delivering brief magnetic pulses to targeted cortical areas, inducing small electrical currents that can either excite or inhibit neuronal activity. Depending on the frequency and pattern of stimulation, TMS can increase cortical excitability to boost activity in underactive brain regions or reduce excessive excitability in overactive ones. This modulation can help restore balance between the hemispheres in cases such as stroke, where damage to one side of the brain often leads to imbalances in cortical activity. When applied repeatedly over several sessions, TMS can induce lasting changes in neural networks, supporting motor learning and recovery. Clinical trials have shown that combining TMS with physical therapy can lead to greater improvements in motor performance compared to therapy alone, particularly in upper limb function [2].

Transcranial direct current stimulation is another widely studied form of NIBS, in which a low-intensity electrical current is delivered through electrodes placed on the scalp. Unlike TMS, tDCS does not directly trigger neuronal firing; instead, it modulates the resting membrane potential of neurons, making them more or less likely to fire in response to subsequent stimuli. This subtle modulation can enhance the brain's responsiveness to rehabilitation exercises, making practice more effective. For example, applying anodal stimulation over the motor cortex can increase excitability and promote better motor control, while cathodal stimulation can reduce maladaptive hyperexcitability. The portability and low cost of tDCS make it especially appealing for potential home-based rehabilitation programs,

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allowing patients to receive stimulation alongside guided exercise sessions [3].

The effectiveness of NIBS in motor function recovery is believed to be closely tied to principles of neuroplasticity. By modulating cortical excitability, these techniques can prime the brain to respond more robustly to motor training, leading to more efficient strengthening of motor pathways. Repetitive practice of functional movements during or immediately after stimulation can further reinforce these pathways, helping to translate neural changes into tangible improvements in strength, coordination, and dexterity. Moreover, NIBS may help engage alternative neural networks to compensate for damaged regions, a process known as functional reorganization. This is particularly important in chronic stages of recovery, when spontaneous neural repair is less active and targeted interventions are needed to drive further improvement [4].

While the potential of NIBS in motor rehabilitation is compelling, there are still important challenges and unanswered questions. Individual variability in response to stimulation remains a significant issue, influenced by factors such as age, lesion location, baseline impairment, and genetic differences in neuroplasticity-related pathways. Optimal stimulation parameters, including intensity, duration, and electrode or coil placement, have yet to be standardized across different patient populations. Safety considerations are generally favorable, but mild side effects such as headache, scalp discomfort, or tingling sensations can occur. More research is also needed to determine how best to combine NIBS with other interventions, such as robotics, virtual reality, or pharmacological agents, to achieve the most effective and durable outcomes [5].

Conclusion

Non-invasive brain stimulation represents an exciting frontier in motor function recovery, offering a way to directly influence neural activity and enhance the brain’s ability to adapt after injury. Techniques such as TMS and tDCS have demonstrated promising results, particularly when paired with structured rehabilitation exercises. While challenges remain in optimizing protocols and predicting individual responses, ongoing research continues to refine our understanding of how these tools can be most effectively applied. As evidence grows and technology advances, NIBS is likely to play an increasingly important role in personalized neurorehabilitation strategies, helping more patients achieve meaningful and lasting improvements in motor function.

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