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Mini Review

Optimizing Neuromodulation Montage Setup to Enhance the Efficacy of Upper Limb Motor Recovery

Hao Meng*

Department of Physical Medicine and Rehabilitation, University of Texas Health Science Center at Houston, USA

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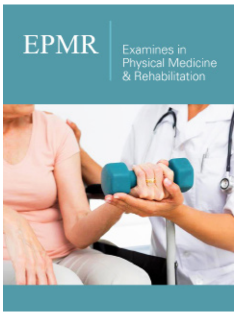

***Corresponding author:** Hao Meng, University of Texas Health Science Center at Houston, Houston, TX, 77030, USA

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Abstract

Motor function deficits, such as muscle weakness and poor coordination, are common symptoms resulting from stroke. Neuromodulation interventions, including transcranial electrical stimulation (tES), have been explored for treating these deficits and show promise in addressing upper limb impairments post-stroke. tES uses low-intensity electrical currents to modulate brain activity. Despite its potential, the efficacy of tES is highly influenced by electrode montage placement. Recent studies suggest that the conventionally used 10-20 EEG system for electrode positioning may not be optimal for targeting the M1 hand muscles. Advances in imaging and neuronavigation tools, as well as innovations in electrode technology such as High-Definition (HD) montages, have the potential to improve the precision and effectiveness of tES. These developments highlight the importance of optimizing the montage setup to enhance the efficacy of motor recovery interventions in stroke patients.

Keywords: Neuromodulation; tES; tDCS; tACS; M1; Motor recovery

Introduction

Motor function deficits, such as muscle weakness and poor coordination, are typical symptoms caused by stroke [1,2]. Neuromodulation interventions have been investigated for treating motor deficits caused by stroke and have been shown to have the potential for addressing upper limb impairments post-stroke [3-5]. Transcranial electrical stimulation (tES) is a non-invasive brain stimulation technique that uses low-intensity electrical currents to modulate brain activity [6]. tES has gained significant attention over the past decades. In particular, tES can be further categorized into transcranial direct current stimulation (tDCS) and transcranial alternating current stimulation (tACS) according to distinctive mechanisms [7]. In fact, tDCS depolarizes and hyperpolarizes the potentials of cortical motor neurons, while tACS could target specific brain rhythms and entrain neural networks [8,9]. However, significant heterogeneity in modulation effects across tES studies has been reported [8,10]. Therefore, the purpose of this article is to discuss potential ways to improve the efficacy of tES in motor recovery based on recent findings.

Discussion

One of the key advantages of tES devices is their ability to target specific anatomical regions, allowing for the customization of therapy to meet the individual needs of patients [11]. However, the efficacy of the tES technique can be significantly influenced by electrode montage placement [12,13]. For example, localizing the cortical area that best represents the primary Motor Cortex (M1) hotspot for the upper limb can have a significant impact on the efficacy of tES [14]. In fact, as of 2022, approximately 67% of tES-related papers utilized the 10-20 EEG system for electrode placement when targeting the M1 upper limbs [15]. However, this conventionally used method may not represent the optimal location for M1 hand muscles. Given the extensive research in neuromodulation for motor function improvement, accurately localizing the optimal M1 hotspot site for tES neuromodulation holds significant practical value. In fact, an early study has pointed out that through the 10–20 EEG system (C3/C4) for positioning tDCS electrodes, future work could benefit from the use of subject-specific computational models based on anatomical MRI [16]. Kim et al. [17] compared the anatomical hand knob area (determined by navigated-TMS) and hand motor hotspot (single-pulse TMS) and found that the stimulation applied at the hotspot more effectively modulates the cortical excitability. Recently, another study examined the Motor Evoked Potentials (MEPs) after tDCS was applied at the M1 hotspot and the C3/C4 site. The results showed that the M1 hotspot produced higher MEP amplitudes than the C3/C4 site after modulation [15]. Similar findings were also reported in a tACS study. Silva et al. [18] reported that the C3h/C4h and C1/C2 sites were more accurate than the C3 and C4 sites in locating the M1 hand muscles. Their study provided evidence that applying tACS at the hotspot and C3 sites modulates the corticospinal tract differently. Therefore, the findings from these newly emerged studies suggest that the conventionally used site for M1 modulation can be further improved with more sophisticated imaging or neuro navigation tools.

Additionally, results from previous studies suggested that the effects of tES stimulation could be more precisely localized by confining the current to the region beneath the active electrodes [19,20]. New developments in electrode technology, such as smaller sizes and innovative configurations like High-Definition (HD) montages, have been implemented to enhance the precision of Electric Fields (EFs). Mikkonen et al. [21] investigated whether different montage affects the interindividual variability in EFs in the M1 hand area. The findings indicated that HD-tDCS had the highest EF focality but also the greatest variability. A recent comparable study investigated the effects of applying both HD-tDCS and conventional tDCS for 20 minutes at M1 in combination with motor tasks [22]. The results showed that HD-tDCS led to a decrease in alpha power in subjects who had lower baseline alpha levels, whereas conventional tDCS resulted in a decrease in beta power in participants with higher baseline beta levels. This suggests that HD-tDCS and conventional tDCS distinctively modulate cortical activity. Interestingly, Zeng et al. [23] recently examined the efficacy of HD-tDCS and conventional tDCS combined with physical therapy in stroke motor recovery and found that both methods can improve upper limb motor function and daily activities. However, they also reported that the Modified Barthel Index (MBI) score of the HD-tDCS group was maintained for up to 8 weeks of follow-up. According to the findings from these recent studies, it seems that the modified tES montage has the potential to improve efficacy by confining EFs under certain circumstances. However, further studies are needed to understand the mechanisms of modified EFs in affecting modulation effects.

Conclusion

Despite emerging challenges in the application of neuromodulation devices, efforts are still being made to improve the efficacy of the available devices. Enhancing the montage setup, particularly for targeting M1 and increasing focality, could be an effective way to optimize efficacy in motor recovery interventions.

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