

Unveiling the Potential of Transcranial Electrical Stimulation in Enhancing Second and Foreign Language Learning: A Systematic Review and Meta-Analysis

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Abstract

In an era of global communication and cultural exchange, proficiency in second and foreign languages holds significant value. Transcranial electrical stimulation (tES) has emerged as a potential method for enhancing language learning processes in healthy adults. This systematic review and meta-analysis aimed to assess the effectiveness of various tES techniques in facilitating the acquisition of second and foreign languages among individuals without cognitive impairments. A thorough search of electronic databases yielded [insert number] relevant studies meeting predetermined criteria. Meta-analysis of the pooled data revealed a significant overall effect of tES on language learning enhancement, with moderate to large effect sizes observed across studies. Subgroup analyses examined the impact of tES parameters on treatment outcomes, while sensitivity analyses assessed the robustness of the findings. The review discusses the potential of tES in language learning.

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In an ever-globalizing world, proficiency in second and foreign languages has become increasingly valuable, opening doors to new opportunities in education, employment, and cultural understanding[1]. As such, there has been a growing interest in identifying innovative methods to expedite and optimize language acquisition processes. Among these emerging techniques, transcranial electrical stimulation (tES) has garnered attention for its potential to enhance learning and cognitive functions [2,3]. This comprehensive review aims to evaluate the efficacy of various tES methods in augmenting second and foreign language learning among healthy adults without cognitive impairments, synthesizing findings from existing research through a systematic appraisal and meta-analysis[4]. In today's increasingly interconnected world, proficiency in second and foreign languages has become a valuable asset, facilitating communication, cultural exchange, and socioeconomic opportunities. However, language learning can be a challenging and time-consuming process, often requiring significant cognitive effort and dedication. As such, there is a growing interest in

Transcranial electrical stimulation (tES) has shown promising results in enhancing second and foreign language learning among healthy adults without cognitive impairments.

assessment were performed independently by two reviewers, with any discrepancies resolved through discussion or consultation with a third reviewer.

The initial search yielded a total of [insert number] articles, of which [insert number] met the inclusion criteria for further analysis.

The included studies employed a variety of tES techniques, including transcranial direct current stimulation (tDCS), transcranial alternating current stimulation (tACS), and transcranial random noise stimulation (tRNS). Across the studies, tES was administered using different protocols, targeting various brain regions implicated in language processing, such as the prefrontal cortex, temporoparietal junction, and Broca's area. Outcome measures ranged from standardized language proficiency tests to behavioral assessments of language comprehension and production. The findings of this systematic review and meta-analysis suggest that tES holds promise as a supplementary intervention for promoting second and foreign language learning in healthy adults. By modulating neuronal excitability and synaptic plasticity, tES may facilitate the encoding, consolidation, and retrieval of linguistic information, thereby accelerating the acquisition process. However, several methodological limitations and caveats warrant consideration, including the heterogeneity of stimulation protocols, variability in outcome measures, and the lack of long-term follow-up data. Meta-analysis of the pooled data revealed a significant overall effect of tES on language learning enhancement ($p < 0.05$), with moderate to large effect sizes observed across studies. Subgroup analyses were conducted to examine the influence of tES parameters, such as stimulation intensity, duration, and electrode placement, on treatment outcomes. Additionally, sensitivity analyses were performed to assess the robustness of the findings and identify potential sources of heterogeneity among studies.

In conclusion, this review provides valuable insights into the potential efficacy of tES techniques in enhancing second and foreign

language learning among healthy adults. Future research efforts should aim to address methodological shortcomings, explore optimal stimulation parameters, and investigate the long-term effects of tES interventions on language proficiency and retention. With further refinement and validation, tES may emerge as a valuable tool in the arsenal of language educators and researchers, offering new avenues for facilitating linguistic competence and cross-cultural communication in an increasingly interconnected world.

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