Transcranial Electrical Stimulation

Subjects: Others
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Transcranial electrical stimulation (tES) can adjust the membrane potential by applying a weak current on the scalp to change the related nerve activity. In recent years, tES has proven its value in studying the neural processes involved in human behavior. The study of central auditory processes focuses on the analysis of behavioral phenomena, including sound localization, auditory pattern recognition, and auditory discrimination. To our knowledge, studies on the application of tES in the field of hearing and the electrophysiological effects are limited. Therefore, we reviewed the neuromodulatory effect of tES on auditory processing, behavior, and cognitive function and have summarized the physiological effects of tES on the auditory cortex.

Keywords: auditory perception ; physiological effects ; transcranial alternating current stimulation ; transcranial direct current stimulation ; transcranial random noise stimulation

1. Introduction

The development of neuroimaging technology made it possible to study how brain networks affect behavior and potential cognitive functions [1]. Behavioral experiences can shape the dynamic process of repair and remodeling of remaining neural circuits [2]. Therefore, evaluating how experimentally induced neural changes affect behavior and potential cognitive processes is of utmost importance. Assessment methods in healthy humans mostly involve non-invasive brain stimulation methods.

Transcranial electrical stimulation (tES) is a non-invasive brain stimulation method that uses a low-intensity electrical current to stimulate the target area of the cerebral cortex [3], regulates the excitability of cerebral cortex neurons and the brain wave rhythm [4], and promotes nerve remodeling and repair [5]. TES mainly includes transcranial direct current stimulation (tDCS), transcranial alternating current stimulation (tACS), and transcranial random noise stimulation (tRNS) [6]. In cognitive and clinical treatment, tDCS is probably the most commonly used non-invasive tES method that applies weak currents of different intensities to brain tissue through electrodes (anode, cathode) that are placed on the scalp [7,8]. During tDCS, a constant electric field is created in the brain, which affects the discharge rate of the resting potential of neuronal cells. The effect of tDCS is polarity-related, anode stimulation is related to cell membrane depolarization, and cathode stimulation is related to cell membrane hyperpolarization [9,10,11]. In addition to the constant current, an alternating current can be applied to the scalp through electrodes by applying a specific frequency of the alternating current on the scalp to regulate the oscillation activity of the corresponding frequency band in the brain [12,13,14]. TACS applies a single frequency sinusoidal current [15] to regulate brain oscillations related to physiology at a specific frequency [16]. However, tRNS uses a variety of sinusoidal oscillations of different frequencies, which can generate random amplitudes, and the frequency of the generated noise signal includes all frequencies within 1/2 sampling rate [17]. Stochastic resonance (SR) as a non-linear phenomenon that enhances the detection of weak stimuli or the information content of signals by adding random interference (commonly called noise) [18,19], may be the potential underlying mechanism of tRNS [20].

2. History and Development

In recent years, tES has been used to explore the relationship between the activity of specific brain regions and cognition. Moreover, using tES to non-invasively stimulate the brain to regulate neural processes has been extensively studied in the field of brain behavior and has been put into clinical applications [21]. So far, the physiological effects of tES have been the focus of studies in the field of sports [22] and vision [23]; however, little is known about the impact of tES in the auditory domain. Furthermore, there is no accurate conclusion about the electrophysiological mechanism of tES in the field of hearing and its influence on related brain behavior and cognitive function. Therefore, in this study, we review tES-related behavioral and cognitive functions in the auditory field. The PubMed online database was searched using the following keywords in combination to identify articles between 2010 and 2020: transcranial direct current stimulation (tDCS), transcranial alternating current stimulation (tACS), transcranial random noise stimulation (tRNS) combined with auditory electrophysiology, auditory time resolution, auditory attention, and speech. All studies had to be carried out on healthy humans. Figure 1 presents a flowchart with the study inclusion/exclusion criteria.

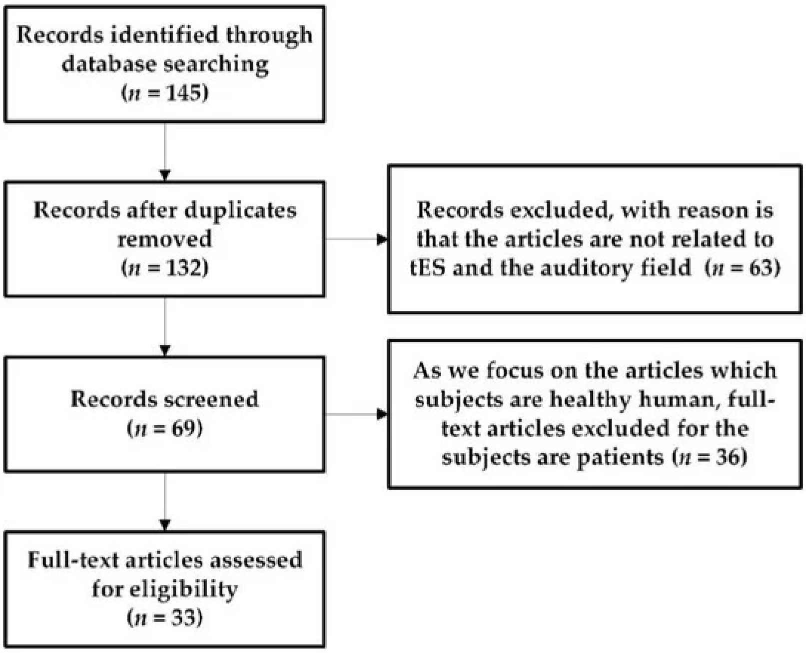

Figure 1. A flowchart presenting the study inclusion/exclusion criteria. We investigated a total of 145 articles in the database, excluding 13 duplicate articles. Further rough screening excluded 63 articles that the articles are not related to transcranial electrical stimulation (tES) and the auditory field. Finally, 33 articles were selected for review.

3. Outline and Future Perspectives

We outline the research of tES in the field of behavior and cognition around the three aspects of tES auditory electrophysiological effects, auditory processing, and speech processing. In the electrophysiology study, tES was combined with EEG or MEG to better understand the nature of neurophysiological mechanisms through analyzing ERP components. Importantly, tES data collection will produce significant artifacts; therefore, there are many experiments to study the effect of offline tES on auditory perception. Electrophysiological data needs to be measured offline after the stimulation is terminated [25,41]. Therefore, additional experiments were needed to confirm the impact of tES on potential neural mechanisms. In addition, the measurement of tES electrophysiology helps to understand the clinical research related to auditory processing in different diseases, including neurological diseases [107,108], bipolar disorder [109], and aphasia [110], among others.

Subsequently, we described the impact of tES on auditory processing in terms of auditory temporal resolution and selective spatial attention. In previous studies, a connection was shown between the frequency of auditory endogenous neuron oscillation activity and the temporal resolution of perception [63]. As a method of adjusting the frequency of neural oscillations, tACS affects endogenous brain oscillations by changing the frequency of brain oscillations, which may be effective in improving the auditory function in healthy elderly people who have a lower frequency of endogenous oscillations due to age [111,112]. In addition, auditory spatial attention studies aim to improve the auditory cognitive function of healthy people with a lower frequency of endogenous oscillations due to age. In general, the complex cognitive functions are mediated by multiple functionally connected brain regions, and the impact of tES on the corresponding brain activity is a goal of the study [113]. Therefore, additional experiments were needed to combine tES and neuroimaging technology to explore the connection between different areas of the auditory network [114].

Speech processing deficit was one of the most dominant cognitive symptoms of dyslexia [115,116]. Impaired auditory processing reduces the ability to accurately segment the speech stream into its important speech components (such as rhymes, syllables, and phonemes). Therefore, regarding studies on the influence of tES on speech processing, we summarized the influence of tES on cv-syllable classification and speech understanding. So far, tDCS has achieved positive results in some cognitive areas related to speech tasks [117,118]. The potential of tACS to induce neural oscillations at different frequencies in AC seems to be effective in restoring the altered oscillation patterns of patients with dyslexia [87,89,119]. However, few studies have been published on the improvement of auditory and language perception by tRNS [97]. Considering that, in some cognitive fields, tRNS may be more effective than tDCS [96], it is necessary to explore the role of tRNS in speech processing.

Regarding the effects of three different types of tES on auditory behavior, and considering the physiological and neuromodulation characteristics of tDCS, the behavioral effects produced by tDCS may be related to the adjustment ability of task-related neural processing rather than the temporal and spatial specificity of the electric fields generated by the stimulation itself [120]. Therefore, the connection between tDCS and auditory behavior will be manifested by the changes in ERP amplitude induced by different auditory tasks [31,46]. However, due to the lower temporal resolution of tDCS, tACS was used in more cases to explore changes in behavior within a higher temporal resolution. TACS promoted neuronal activity in specific frequency bands [121,122] to study the causal connection between brain rhythm and specific aspects of auditory behavior [57,100,101]. However, there is still some controversy about the related oscillation mechanism of tACS affecting behavior. To study how tACS carries or regulates oscillatory activity in the auditory cortex, it is also necessary to use a multimodal non-invasive brain stimulation recording technology and development reliable artifact rejection methods to identify neural oscillations during stimulation [123,124]. In addition, the tRNS method focuses on studying the relationship between behavior and specific frequency noise inherent in neural processing [17]. The combined application of tRNS and cognitive tasks can further elucidate the relationship between brain oscillations and auditory behavior [67,68]. In addition, tRNS may be more effective than tACS and tDCS in improving human behavior [96,125,126]; therefore, it is necessary to further explore the role of tRNS in speech processing.

In summary, the different ways of applying the tES method are suitable for studying the interaction between different types of physiology and behavior or cognition. Although some conclusions about the mechanism of tES on the auditory cortex and its impact on auditory cognition have direct electrophysiological evidence, clear conclusions are still needed to draw. Therefore, it is crucial to further study the potential role and effect of tES in the auditory field. Electrophysiological recording can further be combined with tES to clarify the relevant neurophysiological mechanisms involved. In addition, because the tES method is relatively new, the experimental scheme has not yet reached optimal standardization, therefore, it is necessary to consider different mechanisms of action to select the optimal design for the stimulation experiment. Furthermore, the effects of stimulation parameters, electrode position and shape also need to be further discussed. It has been proven that tES is clinically effective in treating hearing-related diseases, therefore, to further explore the long-term effects of tES is clearly warranted.