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Application Progress of Transcranial Direct Current Stimulation in the Regulation of Cognitive Function

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Abstract: *Transcranial Direct Current Stimulation (TDCS) is a non-invasive technique to regulate the activity of cortical neurons. The DC intensity used is low and constant (0.5 ~ 2 MA), and commonly the duration is 5 ~ 30 minutes. In recent years, TDCS has been widely studied and applied in the fields of neuroscience and neuropathology thanks to its low cost, convenient portability and remarkable regulation effect. This paper introduces the physiological effects and implementation methods of TDCS, and discusses the application progress of TDCS in the regulation of cognitive function from the perspective of learning and memory, attention, perception, emotion and decision-making.*

Keywords: *Transcranial Direct Current Stimulation (TDCS), cognitive function, regulation*

1. Introduction

Transcranial Direct Current Stimulation (TDCS) is a non-invasive technique to regulate the activity of cortical neurons. The DC intensity used by TDCS is low and constant (0.5 ~ 2 MA), and the duration is generally 5 ~ 30 minutes. Around the year 2000, Priori, Nitsche and Paulus successively published research articles on stimulating cerebral motor cortex with TDCS. So far, after more than ten years of development, TDCS, as a research hotspot, has been recognized as a potential neural regulation technology. Compared with other neural regulation technologies (such as Transcranial Magnetic Stimulation, etc.), TDCS enjoys the features of low cost, convenient portability, easy operation and fair tolerance. It has been widely studied and applied in the fields of neuroscience and neuropathology. It is briefly introduced in the following paper, regarding the physiological effects and implementation methods of TDCS, and the research progress and development trend of TDCS regulating brain cognitive functions such as learning and memory, attention, perception, emotion and decision-making.[1]

2. Physiological effects and implementation methods of TDCS

Previous animal experimental studies showed that TDCS may change the resting membrane potential of neurons and affect brain excitability. Especially, anodic TDCS depolarizes neurons, reduces the threshold of motor potential and enhances the excitability of the brain. On the contrary, cathode TDCS hyperpolarizes neurons, increases the threshold of motor potential and reduces brain excitability. In 2000, Nitsche et al. applied TDCS to the primary motor cortex of human brain and detected the excitability of cerebral cortex through motor evoked potential (MEP) caused by Transcranial Magnetic Stimulation. It was found that anodic stimulation enhanced brain excitability, and cathodic stimulation was just the opposite. Since then, many studies have proved that the same effect exists. Now this effect is directly used by many researchers as a priori knowledge. However, in recent years, some studies have shown that this effect does not accommodate all cases. TDCS can not only change the excitability of cerebral cortex during stimulation, but also produce a long-term aftereffect. Some studies have shown that this aftereffect is closely related to the regulation of the efficacy of neurotransmitter receptors such as NMDA and GABA, thereby affecting LTP/LTD. In addition, TDCS can also change the excitability of the brain at the level of brain network. TDCS is often combined with EEG technology, with online and offline implementation methods. The former studies the psychological or physiological effects of subjects during TDCS stimulation, and the latter studies the short-term or long-term effects of subjects after TDCS stimulation. The stimulation parameters of TDCS generally include electrode position, electrode size, current intensity and stimulation time. If these parameters are slightly different, the stimulation effect will be very different. The electrode placement position of TDCS is generally determined according to the EEG international 10 ~ 20 system. As shown in Figure

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1, the commonly used anode electrode positions include the primary motor cortex (lead C3 marked by A in (a)), the left dorsolateral prefrontal lobe (lead F3 marked by A in (c)), the occipital lobe (lead Oz marked by A in (d)), and the commonly used cathode electrode positions include the right supraorbital (mark C in (a) and (c)), central area (mark C in (d)), arm (mark C in (b)), etc. In addition, the electrode size used in most studies is 25 ~ 35 cm^2, the current intensity range is 0.5 ~ 2 mA, and the stimulation time is generally 5 ~ 30 minutes.[2]

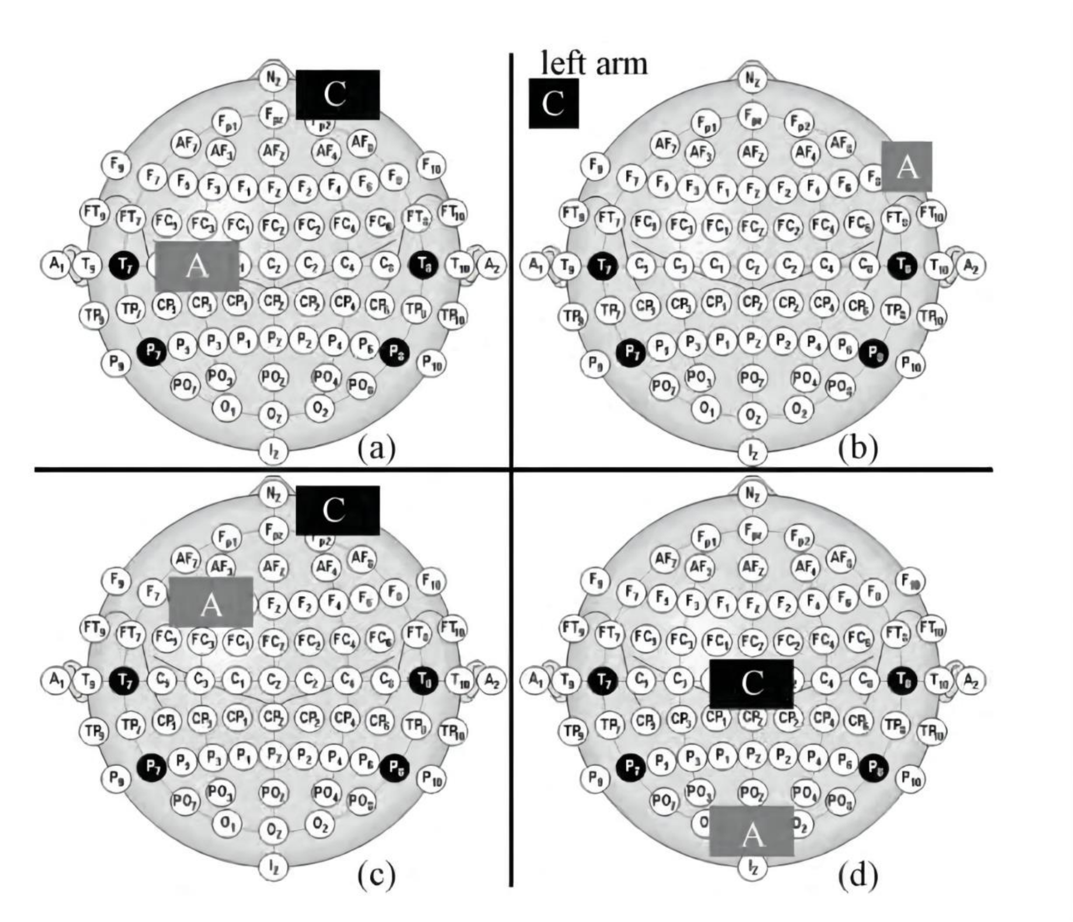

Fig. 1 Electrode positions of TDCS

3. Effects of TDCS on learning and memory

Both learning and memory are significant cognitive functions, which play an irreplaceable role in understanding, adapting and transforming the subjective and objective environment. In short, learning is the process of acquiring new information, and memory is the result. They are often discussed together. In terms of learning and memory, TDCS is often used in the research of working memory and motor learning, which are discussed below.

3.1 Working memory

Working memory includes short-term storage, real-time processing and control of information. Dorsolateral prefrontal cortex (DLPFC) is closely related to working memory. Therefore, when TDCS is applied to working memory research, DLPFC is generally used as a stimulation spot. Some studies have shown that while anode TDCS improves the performance of working memory, the energy of theta and alpha band of EEG is enhanced. On the contrary, cathode TDCS shows that the change of working memory performance by TDCS is related to the modulation of brain neural rhythm. Subsequently, TDCS has been applied to improve the working memory ability of patients with Parkinson's disease, stroke and Alzheimer's disease, and some achievements have been made. However, the principle of TDCS on working memory is still undecided, and there is no corresponding optimal stimulation mode for both healthy people and sick patients.[3]

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3.2 Motor learning

The application of anodic stimulation to the primary motor cortex can significantly improve the performance of motor learning, which is considered to be a milestone in the impact of TDCS on cognitive function. Since then, TDCS has been widely used in cognitive enhancement of healthy people and motor rehabilitation of patients with neurological diseases. TDCS can effectively regulate skill learning, motor adaptation and use dependent learning in healthy people. In the aspect of skill learning, when subjects perform the motor sequence task, anodic TDCS stimulation is applied to the primary motor cortex (M1 for short), which can significantly reduce the reaction time and improve the task performance. In terms of motor adaptation, TDCS applied to M1 can significantly improve the internal coordination of joint points and muscles in force field adaptation. In addition, the cerebellum plays an important role in motor learning. Studies have shown that TDCS stimulation of the cerebellum can also affect the performance of field of view and motor adaptation tasks. Although many studies have proved that TDCS can improve motor learning ability, it should be noted that due to the different stimulation modes and individual differences, the existing studies also show many differences and even contradictions. Therefore, in the future research, it is particularly necessary to explore the best individualized stimulation model. In addition, using appropriate brain imaging technology to observe the changes of brain activity while TDCS stimulation is beneficial to reveal the principle and mechanism of TDCS regulating motor learning.

3.3 Impact of TDCS on attention

Attention is one of the complicated cognitive functions, including alert network, orientation network, executive network and so on. As an important cognitive function, attention is closely related to memory and learning, which has been a research hotspot in the area of cognitive neuroscience for a long time. TDCS is often used to brain regions regarding top-down regulation, such as DLPFC and parietal region, in the study of physiological mechanism of attention. As an effective tool, TDCS has been extensively used in the study of attention, and has achieved some outcomes in the interpretation of the mechanism of attention. Many researchers claim that their research outcomes may promote the rehabilitation of attention deficit and other functions, but there are also some problems: the stimulation methods used in many studies are varied, and the differences and relevance of different research results have not been well verified, which need to be further studied.[4]

3.4 Impact of TDCS on perception

Perception is the brain's organization, understanding and integration of sensory stimuli containing external environmental information. TDCS is often used to study different ways of perception. In some studies the contrast sensitivity reduced during and at the end of cathode TDCS stimulation, and returned to the baseline level after 10 minutes, suggesting that TDCS can temporarily change the visual contrast sensitivity. From the perspective of hearing, TDCS is often used to study the processing of auditory information. It is worth noting that TDCS has a certain inhibitory effect on tinnitus in clinic, so it is also considered as a potential treatment for hearing damage. In addition, TDCS is also extensively used in the study of somatosensory. The stimulating parts include somatosensory cortex, motor cortex and cerebellum. The sensory modes studied include touching, temperature and pressure. The results show that TDCS has different effects on tactile resolution, somatosensory stimulated potential, temperature and pressure threshold.[5]

3.5 Impact of TDCS on emotion

So far, TDCS is mainly used in facial emotion recognition and emotion regulation. In the recognition and processing of facial expression, studies showed that when anode stimulation is applied to the left temporal region, and cathode stimulation is applied to the right temporal region, females have better performance in facial emotion expression recognition than males. In addition, studies showed that TDCS applied to cerebellum, orbitofrontal cortex and other parts will also affect the recognition and processing of facial expression. So far, there is no evidence that TDCS can directly regulate emotion or generate an emotion. For one thing, TDCS cannot directly and effectively act on deep brain parts related to emotion (e.g. amygdala); for another, the generation of emotion is affected by many factors. Existing studies also show that the recognition of facial emotion and expression by TDCS is affected by gender, personalities and other factors.

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3.6 Impact of TDCS on decision-making

Most studies on the application of TDCS to decision-making shall stimulate DLPFC. Some studies found that TDCS is applied to left and right DLPFC to study its impact on game related risk selection missions. The experimental results show that in the experimental group of anode stimulated right DLPFC and cathode stimulated left DLPFC, most subjects would like to choose low risk, indicating that the function of left and right DLPFC in decision-making behavior is lateralized. As a relatively advanced cognitive function, decision-making is closely related to other cognitive functions. Therefore, there are also studies to investigate the relationship between decision-making and other cognitive functions through TDCS. In addition, some studies have found that the impact of TDCS on decision-making correlate with several elements. For example, Pripfl and other studies show that the impact of TDCS on risk decision-making is related to the degree of emotional arousal induced.[6]

4. Conclusion

The research boom of TDCS rose at the beginning of this century. After more than 10 years of development, TDCS has been widely used in neuroscience and neuropathology - not only in the study of cognitive functions such as learning and memory, attention, perception, emotion and decision-making of healthy people, but also in neurological diseases (such as Parkinson's disease, stroke, Alzheimer's disease, etc.). Rehabilitation research on patients' cognitive and motor ability, and some results have been achieved. However, so far, following problems occur in the research of TDCS: first, the mechanism of TDCS is not clear. Although researchers have used several brain activity imaging technologies to explore and explain the physiological effects of TDCS from multiple levels such as nerve cells and brain networks, the relationship between the physiological effects still needs to be further organized and clarified. Second, in the existing studies, whether applied to healthy people or sick patients, the stimulation modes of TDCS for particular cognitive or motor functions are rather different, and different stimulation modes may trigger the same effect. Further, affected by the initial state of the brain (such as fatigue) and case differences, the same stimulation mode may also generate different effects, and these influencing factors are still in short of systematic research, which also makes it difficult for further clinical application. In the future research, the development of individualized optimal stimulation model has become the consensus of many researchers. Third, although TDCS has been effectively applied in many fields, TDCS technology failed in spatial focus, resulting in serious impact in the positioning and analysis of effective stimulation spots. However, the High-Definition Transcranial Direct Current Stimulation (HD-TDCS) in recent years can effectively solve this problem. In short, TDCS has attracted more and more researchers' attention because of its prominent regulatory effect in the field of neuroscience and neuropathology, as well as its features of low cost, strong portability, simple operation and fair tolerance. TDCS, as an extremely effective neural regulation technology, is believed to make greater contributions in the fields of neuroscience and neuropathology in the near future.

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