Research Progress on the Enhancing Effect of Transcranial Direct Current Stimulation on Human Motor Performance

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Abstract: Transcranial direct current stimulation can alter human movement capability, has now moved from the research and experimental stage to practical sports training. This review systematically sorts out the previous research results on tDCS promoting human motor ability, discusses the limitations of existing research, and puts forward some suggestions for the future development direction of research, providing a reference basis for further research in this field.

1. Introduction

With the boost of technological innovation, competitive sports are no longer just a contest of physical training, but a competition of high-tech sports. Sports are closely related to the way the brain works, and the brain is instrumental in improving muscle strength, endurance and athletic learning. As a result, enhancing brain training is increasingly becoming the focus of attention in the sports world.

Transcranial direct current stimulation (tDCS) can change cortical excitability by placing negative and positive electrodes in moving-related areas and applying low-intensity direct current, thereby enhancing the brain's ability to work. Among them, anodic stimulation increases the excitability of the cortex, while cathodic stimulation reduces it. To date, tDCS have been widely used to treat array neuropsychiatric disorders, to study brain function and to enhance cognitive function in healthy individual. In recent years, researchers have begun to apply tDCS to the field of sports science to explore the enhancement effect and feasibility of tDCS on sports ability of healthy people and athletes[1] . At present, several tDCS devices are available to the public. For example, many professional athletes used the portable tDCS stimulator Halo Sport to assist in improving their athletic performance during exercise training. Among them, T. J. Carrie, an American professional football player, increased his in-place bounce height by 18 cm after training with the device[2] .

So far, however, the number of studies has been limited and the mechanism by which tDCS enhances athletic performance is largely unknown, and many researchers remain skeptical about the ideal extent of the effect of tDCS in enhancing athletic ability. This review reviews and analyzes the previous related research results, points out the problems existing in the existing research, and offers some suggestions for the future development direction of the research, with the aim of providing new auxiliary training methods and new ideas for how to improve athletic performance in human movement.

2. Enhance muscle endurance

Fatigue is the main factor that leads to a decline in athletic performance during training and competition. Therefore, it is markedly essential to seek efficacious ways to suppress the further development of fatigue. In recent years, research on using tDCS to improve endurance performance has attracted increasing attention. Angius et al. [3] contrasted the influence of distinct electrode placements of tDCS on knee extensor TTE in a study. In both cases, the anode tDCS were placed in the left M1 area, while the cathode tDCS were placed one in the right dorsolateral prefrontal cortex

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and the matching-side shoulder. Nine healthy male subjects underwent a right knee extensor TTE test after receiving 2 mA, 10 min of tDCS stimulation. The results showed that TTE lengthened more significantly when the electrodes were placed on the shoulder. Similarly, Abdelmola et al. [4] found that 1.5 mA, 10 min anode stimulation increased the time to end TTE of the subjects in 35%MVC compared with pseudo-stimulation. The difference in electrode placement may be the reason for the varying degrees of change in motor performance caused by tDCS, suggesting that extracranial electrical stimulation may be more beneficial for the improvement of motor ability.

However, Barwood et al. [5] observed that after 1.5 mA for 20 minutes, subjects' 20-kilometer cycling time trial performance was not affected. Furthermore, the scholars also established that 2 mA, 20 min of tDCS had no effect on athletic performance at high temperatures. These inconsistent results propose that the effect of tDCS may be contingent upon multiple variables, encompassing the laboratory milieu, current dose parameters, and the placement of electrodes in the head. Minor differences in these determinants can exert a pronounced influence on the final outcome. Therefore, how to rationally design exercise training programs and stimulation patterns to maximize the effect of enhancing athletic ability remains a direction that needs to be further studied in the future.

3. Increase muscle strength

Muscle strength is one of the core determinants influencing competitive execution across heterogeneous sporting disciplines, directly related to an athlete's athletic skills, prevention of sports injuries and rehabilitation. Lattari et al. [6] found that after anodic electrical stimulation, the subjects' Countermovement Jump (CMJ) height and peak power increased by 11.2% and 6.8%, respectively.

Earlier studies, however, revealed that 2 mA, 15 min of tDCS acting on the M1 zone improved fine motor control of the hands in the general population, but decreased in the group of excellent pianists Similar to this research result, Mesquita et al. [7] found that after applying 1.5 mA, 15-minute anodal tDCS stimulation to the C3 and C4 cortical regions of 19 black belt taekwondo athletes, the athletes' session-rating of perceived exertion and kicking frequency and speed test performance deteriorated. Previous studies have demonstrated that when muscle function reaches its maximum, tDCS intervention cannot further augment muscle function. These results suggest that in future tDCS protocols, it is fatal to take into account the subjects' professional level in motor-task expertise. Therefore, future studies will also need to explore whether there is a similar upper limit effect on the athletic performance of high-level athletes to further validate the effectiveness of tDCS for well-trained individuals.

4. Accelerate motor skills learning

In order to acquire complex motor skills and achieve the best performance, athletes often need to practice repeatedly and do a lot of exercise training. Therefore, accelerating the acquisition of motor skills to maximize athletic performance has become a current research hotspot. The US ski jumping Olympic team has applied tDCS technology to the actual training of seven top skiers to improve their athletic skills. The results showed that their jumping ability and coordination improved by 70% and 80% respectively after tDCS stimulation. Although the sample size of the experiment was small, this result indicates that the tDCS technique has moved from the research experiment stage to practical training.

Antecedent literature has proposed that since the stimulation effect of tDCS may be related to the stimulation intensity, enhancing the stimulation intensity may be an effective way to achieve the expected effect. Cuypers et al. [8] subjected 13 healthy subjects to anodic electrical stimulation of 1 mA, 1.5 mA, or pseudo-stimulation for 20 minutes while performing a one-handed motor sequence learning task. The results showed that at 1.5 mA stimulation intensity, the slope of the learning curve of the subjects increased more significantly, and their motor performance improved significantly, and this effect was observable both during exercise training and after the intervention (30 minutes after stimulation). Boggio et al. [9] also found significant improvement in working memory performance after applying 2 mA anode tDCS to the left dorsolateral prefrontal cortex in 18 patients with

Parkinson's disease, while no obvious effect was produced under 1 mA anode tDCS or pseudo-stimulation conditions. Based on this, it can be speculated that greater current intensities may lead to enhanced learning-related synaptic connections, thereby improving learning performance.

However, recent studies have revealed that a higher intensity of stimulation does not necessarily elevate cortical excitability. This means that while a higher intensity of 2 mA stimulation (the maximum current intensity used by tDCS in exercise science research) can reach deeper into the target cortex, it is not necessarily the optimal stimulation intensity. Therefore, further research is needed in the future to explore the effects of different stimulation intensities (e.g., 1 mA, 1.5 mA, 2 mA) and durations (10 min, 15 min, 20 min) on changes in motor cortex excitability in order to determine the optimal stimulation protocol for tDCS technology.

5. Conclusion

Based on the research evidence mentioned above, if applied properly, the changes in cerebral cortex function induced by tDCS play a crucial role in improving human motor performance. At present, the number of experimental studies on the effects of tDCS on motor performance is increasing rapidly. However, there are still some problems that need to be solved in practical research and application.

(1) The evidence from high-level athletes is still scarce, and most studies have very small sample sizes, which may lead to an increased probability of false positive results. Therefore, more athlete research data will be needed in the future to confirm the effectiveness of the technique.

(2) Minor differences in tDCS stimulation parameters, including current intensity, duration of stimulation, and placement of electrode patches, can also have a decisive impact on the experimental results. Due to the high interindividual variability of the subject's electric field, applying individualized current intensity to the subject may be the most effective way to induce cortical changes.

(3) By comparing outstanding athletes with non-outstanding ones, future studies will also need to determine whether the cap effect will prevent any additional improvements related to athletic performance.

Despite certain limitations, based on existing research, the changes in cerebral cortex function caused by non-invasive tDCS technology clearly have the potential to elevate human sporting performance and have broad application prospects and advantages in the realm of athletics.

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