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Research Status and Prospects of Using Brain-Computer Interface Neurofeedback Technology to Treat ADHD

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Abstract:

ADHD is a common neurodevelopmental disorder that affects about 3%-6% of the global population. Traditional treatments such as medication may be effective, but long-term use may bring side effects. In recent years, eletroencephalography(EEG)-based neurofeedback therapy has become a research hotspot, but it still has its limitations. Therefore, it is of great significance to explore new brain-computer interface(BCI) neurofeedback technology for the treatment of ADHD. The purpose of this study was to explore the application status and prospect of BCI neurofeedback technology in the treatment of ADHD through a literature review and case analysis. The research progress of BCI neurofeedback technology in the treatment of ADHD was systematically reviewed, and its efficacy and safety were evaluated. In this study, relevant literature was collected at home and abroad to sort out the principle, technical implementation, and application of BCI neurofeedback technology in the treatment of ADHD. Subsequently, combined with specific cases, the actual effect of this technology in the treatment of ADHD was analyzed. BCI interface neurofeedback technology has shown good application prospects in the treatment of ADHD, and its non-drug and non-invasive characteristics help to reduce the side effects of traditional treatments. However, the technology is still in the development stage, and further research and optimization are needed to improve efficacy and popularity.

Keywords: Brain-computer interface; Neurofeedback; ADHD

1. Introduction

ADHD is a severe disease that borders about 3% to 6% of the world's population. Behavioral disorders mainly contain inattention, irritability, impulsivity, willfulness, emotional instability, and other symptoms [1]. about 80%-85% of ADHD children still suffer from ADHD in their adolescence, and about 60% continue to have ADHD in adulthood [2-5]. Deficiency in dolpamine/norepinephrine is the neurochemical basis of ADHD. Still, the etiology is more complicated, genetic factors, environment factors, neurobiological factors, etc., may all contribute to the occurrence of ADHD [6]. Conventionally, pharmacotherapy is an effective and common way to treat ADHD. Medication used to treat ADHD contains methylphenidate, amphetamine, atomoxetine, and so on [7]. In addition to pharmacotherapy, cognitive behavioral therapy, diet therapy, motor therapy, and mindfulness meditation have been proven to be effective in enhancing the level of concentration. In recent years, EEG-based neurofeedback systems have become a popular research interest, and data shows the effectiveness of EEG-based neurofeedback systems [8]. However, every regulation has its limit. Traditional drug therapy for ADHD usually uses psychotropic drugs, which can achieve certain effects in a short time. Still, if drugs are taken for a long time, they will cause damage to the mind and memory and have certain side effects [9]. Other emerging treatment methods have a long treatment cycle, high treatment costs, and a large demand for professional doctors, so it is difficult to apply on a large scale [10].

As a non-pharmacological, non-invasive therapy for emerging self-regulated diseases, EEG-based neurofeedback therapy aroused the interest of researchers. It is a complex biofeedback based on the electrical activity of the cerebral cortex, in which individuals change the amplitude, frequency, or consistency of the electrical activity of the cerebral cortex through self-learning, thereby achieving plasticity regulation of specific brain regions. It is precise because of the low cost, no side effects and stable efficacy of neurofeedback that research on neurofeedback training to improve physical and cognitive performance has increased dramatically, and neurofeedback therapy has made great progress in the treatment of ADHD [10]. As a result, scientists managed to develop a BCI-based attention training game system called Cogoland. Studies have shown that the phenomenon of inattention was im-

proved after the subjects were subjected to the experiment [11,12]. So, we can predict that such a game system will potentially be used in future clinical treatments for ADHD. In the current grim context, it is urgent and important to use more effective, less side effects, and less costly ways to treat ADHD. In recent years, the phenomenon of adult ADHD has become more and more serious [13]. If the research progress is not accelerated, it will not only directly affect the psychological state and living standards of many people but also induce social contradictions and directly affect social development. This article will analyze whether the use of neurofeedback therapy for ADHD will become mainstream in the future from the development process, the current status of ADHD research, the current status of BCI research, and the current status of using BCI to treat ADHD. Finally, this article will discuss the prospects of BCI for the future use of ADHD treatment.

2. Related Works

2.1 Development Process

EEG neurofeedback therapy originated in the late 1960s, at the end of the 1970s, the US Air Force applied to the training of pilot attention and developed to the attention training of some specific items of competitive sports in the late 1980s. The process applied to people is that when the electroencephalogram meets the requirements, they will be fed back to the patient in the form of rewards. The electroenphalogram can be changed through a period of self-regulation, so as to regulate the functional state of the brain. In 1976, Shouse and Lubar were the first to apply EEG neurofeedback technology to the clinical treatment of ADHD. They demonstrated the effectiveness of this method, and the research showed that there was an improvement in the symptoms of distraction and hyperactivity [14]. Besides, they repeated the experiment and obtained similar results in 1979 [15]. Neurofeedback technology has undergone comprehensive functional advancements over the last four decades. Neurofeedbcak techniques have become more accurate and reliable, providing more precise physiological information. With the combination of neuroscience and artificial intelligence technologies, people are able to analyze and interpret neurofeedback data more deeply, leading to a better understanding of the relationship between brain function and behavior. In addition, neurofeedback technology can also be more multimodal and personalized, which can no longer be limited to a single EEG signal but combine a variety of physiological signals and behavioral indicators to provide more comprehensive feedback on brain activity and more personalized neurofeedback information. Although technology has improved to a great extent, whether neurofeedback therapy actually works well is still a controversial topic. Many studies suggest that neurofeedback can reduce the symptoms of ADHD, but there are also studies that state that neurofeedback does not really alleviate the core symptoms of ADHD [16]. In addition, in many countries, neurofeedback is not used as an official treatment or adjunct to ADHD [17]. There is a disconnect between the results of these studies and the application of neurofeedback at the social level. This study attempts to analyze the reasons behind the current status of ADHD, the status of BCI, and the status of the use of BCI in the treatment of ADHD and to propose possible solutions and proposals.

2.2 Research Status

2.2.1 The Status of ADHD Research

With the attention of society and the support of a large number of research data, the research on ADHD has made great progress. Unfortunately, the true cause of the disease has never been clearly known. Comorbidity is a major rule in patients with ADHD, who usually do not have only ADHD but also suffer from neurological diseases such as epilepsy, ASD, and social disorders at the same time [18]. Though behavioral therapy and neurofeedback therapy have confirmed their efficacy, pharmacotherapy is still the most widely used and effective treatment regimen in clinical practice [18]. The latest drugs to be used to treat ADHD, like Qekbree®and Azstrarys®, have the advantages of long-term effects and high stability and are taken only once a day[18].

2.2.2 The status of BCI

Brain-computer interfaces can be divided into two main categories: invasive BCI and non-invasive BCI. The non-invasive brain-computer interface does not require surgery; only the electrode that collects brain signals needs to be attached to the scalp, and its risk is small, but the accuracy of the detected brain signal is not high, so the functions realized are not, and can only be used to perform simple control or operation. Invasive brain-computer interfaces surgically implant electrodes directly into the cerebral cortex, which are closer to the neurons and allow for higher quality nerve signals, but are more risky and costly [19]. In the field of brain-computer interfaces, scientists still have many difficult problems to overcome. For example, how to deal with noisy electrical signals and get more and more accurate brain signals. How can we identify and interpret the different types and patterns of EEG signals collected by BCI to understand the brain's thoughts and intentions and convert brain signals into useful information based on this? And how to develop a more user-friendly human-computer interface. Solving these

technical challenges requires interdisciplinary collaboration between experts from different fields, including neuroscience and physiology, computer science and machine learning, biomedical engineering, and material science scientists, to better research the brain. Development of intelligent algorithms, research on brain electrodes with better performances, and more. The good news is that in recent years, the number of companies and university laboratories has increased dramatically, and brain-computer interfaces have gradually entered the public eye. These problems will hopefully be solved in the near future.

2.2.3 The Status of Using BCI to Treat ADHD

At present, the vast majority of neurofeedback is provided by non-invasive brain-computer interfaces based on EEG. EEG biofeedback therapy can process information about brain wave activity into visual and auditory signals by strengthening and inhibiting different bands of brain waves. That is to guide children to learn repeatedly, gradually achieve self-regulation, and improve ADHD symptoms [8]. Electrophysiologically, the enhancement of Theta waves(4-7Hz)is one of the most significant and stable symptoms in ADHD patients, and the ratio of Theta waves to beta waves (13-30Hz)(TBR) reflects the functioning state of the cerebral cortex [20]. Except for TBR neurofeedback, SCPs (slow cortex potential) and SMR (sensorimotor) are also effective neurofeedback techniques recognized by the academic community. Some systematic reviews have summarized and counted data on the output of relevant papers in recent years. Clinical treatment data from some Chinese hospitals have shown that the use of neurofeedback combined with drug therapy is superior to simple pharmacotherapy [21]. Other reviews have also shown that while standard treatment regiments for neurofeedback(TBR, SMR, SCP) have a clear positive effect on the treatment of ADHD, the available research is divided on whether neurofeedback therapy can be used as a separate treatment option for ADHD. It is easy to see that in the existing studies, specific data such as sample size, number of sessions, and patient initiation status showed a high degree of heterogeneity in different studies [20]. At the same time, some articles have proposed that with the gradual increase of data on neurofeedback learning, scientists should strengthen the standardization of neurofeedback learning and obtain a more realistic model through statistical modeling. A simple linear model obviously cannot accurately describe the process of learning through neurofeedback [17].

3. Discussion

Although there have been thousands of articles proving its effectiveness in the treatment of ADHD by neurofeedback, it still faces many challenges. First of all, as mentioned above, ADHD is comorbid, and a large number of patients have both ADHD and other diseases, such as epilepsy. And, Figure 1 shows the flowchart describing trend forecasting.

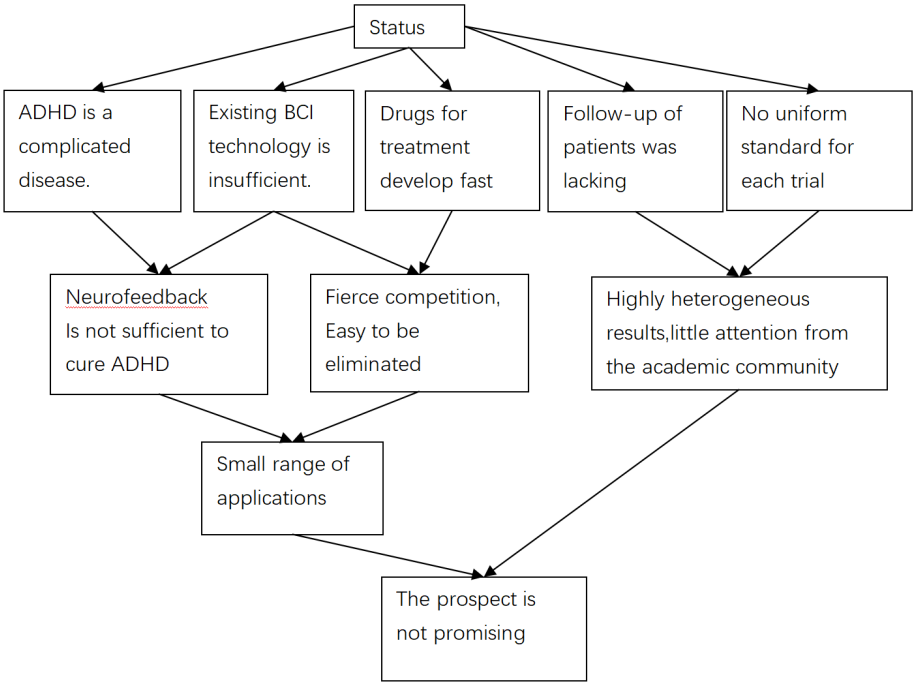

Fig 1. Flowchart describing trend forecasting (Photo credit: original)

However, the existing neurofeedback mainly relies on the non-invasive brain-computer interface of EEG, which has low accuracy in capturing and feedback brainwaves, and the noise signal from the brain will also interface with the capture of useful signals. Therefore, the clinical application of neurofeedback is very limited, and it can only treat or adjuvant the treatment of patients with a single condition or mild disease [12]. In addition, the cost of treatment is also a factor that needs to be considered. A user-friendly EEG can cost tens of thousands of dollars; whether this is too expensive for a treatment that aims to be a home therapy is worth thinking about carefully. Another strong competitor, pharmacotherapy, is also developing rapidly and not to be underestimated. In recent years, the side effects of drugs for the treatment of ADHD have decreased, the intake has decreased, the time to effect has been shortened, and the maintenance time has increased. Suppose neurofeedback therapy is always catching up with the effects of drug treatments rather than rapidly developing to replace them. In that case, it is a technology that has no future in the treatment of ADHD. Another major disadvantage of neurofeedback therapy is that it is time-consuming and generally long, with almost all studies lasting more than three months and giving patients more than 20 treatments in total, and patients who discontinue treatment usually do not experience good improvement [12,17,20]. This leads to a contradiction that is prone to arise in practical applications. Patients need to go to the hospital several times a week for about half an hour of treatment, plus the time spent commuting, each week has to set aside a few half days for treatment of ADHD. This goes on for months. Many adult patients and parents of children patients find it difficult to ensure the therapy is not interrupted, and once it is interrupted, the effect of the treatment is easily decreased; self-discipline can also affect the outcome of treatment[17, 20]. Overall, neurofeedback has been used in the treatment of ADHD for decades. The data show that it does have a certain effect and has been recognized by many countries as effective. Still, it has not been used on a large scale, nor has it become an independent treatment tool, and it is of little help against the complex symptoms of multiple diseases. So there are two trends in the future. The first is the breakthrough development of BCI and biomedical technology, and ADHD neurofeedback therapy has become the mainstream treatment of ADHD due to its tiny side effects and significant effects. The second is to maintain the status quo, where neurofeedback can only exist as an adjunctive therapy.

4. Conclusion

There are some loopholes in the existing research, such as the fact that the literature on neurofeedback does not mention the situation at the time of follow-up, so we have no way of knowing whether the patient is cured or not and if there is a follow-up to prove that the patient is physiologically cured of ADHD with neurofeedback therapy. It will increase the credibility of neurofeedback therapy. Due to the limitations of technology, the BCIs currently used in the treatment of ADHD are non-invasive, and if more accurate invasive BCIs can be used, the treatment effect may be better. There is no unified and standardized process for neurofeedback for ADHD, which has led to a high degree of heterogeneity in the results of different studies. The use of BCIs neurofeedback in the treatment of ADHD has been proven to be effective by many studies. Still, the future of this technology is not very clear due to the lack of understanding of the specific causes of complex ADHD, coupled with technical limitations and the rapid development of pharmacotherapy. However, the rapid development of BCI and AI has turned this gloomy outlook around. If the academic community invests enough attention and money in this technology, perhaps this technology will really mature //and be used in the treatment of ADHD one day.

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