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Brain-computer Interface Treatment for Attention Deficit Hyperactivity Disorder

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Abstract:

Attention Deficit Hyperactive Disorder (ADHD) is a neurodevelopmental disorder characterized by inability to concentrate for a long time, hyperactivity and emotional impulsivity. It usually develops in childhood. The pathogenesis is unclear. Brain Computer Interface (BCI) refers to a direct communication pathway between the brain and an external device, enabling information exchange between the two. This paper will explore the possibility of treating ADHD through brain-computer interface methods through the examples of existing inter-brain interfaces for the treatment of neurological diseases in ADHD, such as neurofeedback, transcranial magnetic stimulation, and digital therapy. All three of these modalities are treatments or diagnostic methods based on brain-computer interface technology. Then this paper analyzes the possible problems of these treatments through some data and ethical issues. The paper also proposes relevant solutions. Through the research in this paper, it can provide a new research direction for the treatment of ADHD in the future. Create a broader prospect for the treatment of ADHD.

Keywords: ADHD; BCI; Treatment methods; Neurodevelopmental disorders.

1. Introduction

The concept of brain computer interface (BCI) has gained attention in recent years. It refers to the direct connection between the brain and external devices, enabling information exchange. Currently, there are three types of BCI technology: invasive, semi-invasive, and non-invasive. BCI has made progress in various fields, particularly in medicine. Research in this area has led to advancements such as diagnosing diseases through brain electrical signal reading, and treating neurological disorders using methods like transcranial direct current stimulation and digital therapy.

This article will focus on Attention Deficit Hyperactive Disorder (ADHD), ADHD is a neurodevelopmental disorder characterized by inattention, emotional instability, and impulsivity, mostly in childhood. ADHD is known primarily as a polygenic genetic disorder with significant hereditary properties, and the expression of dopaminergic, serotonergic, and norepinephrine genes is significantly associated with ADHD [1]. At the same time, studies have shown that the reduction of gray matter and white matter in the brain [2]. The reduction of prefrontal cortex (PFC), caudate nucleus, cerebellar activity [3]. And cerebellar development delay may lead to ADHD [4]. In addition, the environment also plays a part in the occurrence of ADHD, and studies have shown that the absorption of harmful substances such as maternal stress, intrapartum hypoxia, alcohol, nicotine, and methamphetamine during pregnancy will easily cause ADHD in offspring, and heavy metal elements may also increase the risk of ADHD [5]. The diagnosis of ADHD primarily relies on empirical judgments based on quantified behaviors. Doctors typically use ADHD diagnostic scales, such as the Conners Child Behavior Questionnaire, which includes parent, teacher, and concise symptom questionnaires. While this method has a certain degree of accuracy, it cannot completely eliminate the risk of misdiagnosis due to subjective factors from the patient or observers.

Current treatments for ADHD typically involve a combination of approaches to manage symptoms and improve patient quality of life. The main treatment strategies include drug therapy, psychological intervention, and behavioral therapy. Common drugs such as methylphenidate and atomoxetine are used to regulate the patient's central excitability to relieve the effect. Psychological therapy and intervention are used to create a warm environment and create harmonious and friendly social relationships to help patients maintain a happy mood and reduce the anxiety and emotional impulsivity caused by ADHD. Currently, most ADHD diagnoses and treatments are rooted in psychology rather than biology. This approach has limitations as it relies heavily on behavioral observations and self-reporting, which cannot be accurately measured by medical devices. Consequently, there's a risk of misdiagnosis. Moreover, psychological interventions, while helpful in managing symptoms, have limitations and typically alleviate the condition rather than provide a cure. This underscores the need for more objective, biologically-based diagnostic tools and treatment methods.

2. Development and classification of brain-computer interfaces

2.1 BCI Development

Since the beginning of the 20th century, BCI has undergone three distinct stages of development. In the early decades, BCI was largely confined to the realm of fantasy and science fiction. However, significant milestones began to emerge, paving the way for its transition from fiction to reality. In 1924, electroencephalogram (EEG) was measured and confirmed, which is widely regarded as the origin of BCI. In 1970, the United States established a related research team; in 1973, the concept of "BCI" was confirmed. Proof of BCI took place in the 80s and 90s of the 20th century. In 1988, the P300-based BCI paradigm was proposed, which utilizes the brain's response to rare stimuli. It is now one of the three major EEG-based BCI paradigms and is widely used. In 1992, the BCI system based on motor imagery (MI) was introduced, which interprets brain signals associated with imagined movements [6]. In 2000, a BCI system based on steady-state visual evoked potential (SSVEP) was developed, which analyzes brain responses to visual stimuli at specific frequencies.

2.2 Classification of BCI

2.2.1 Invasive brain-computer interfaces

Invasive BCIs involve surgical implantation of electrodes directly into brain tissue. While this approach offers the advantage of a high signal-to-noise ratio, it comes with significant risks. These risks stem from both the surgery itself and long-term exposure at the incision site, including potential vascular damage, infection, and biocompatibility issues.

2.2.2 Non-invasive brain-computer interfaces

Non-invasive brain-computer interfaces are relatively safer and more modern because they use wearable devices and do not perform surgery on the head. In the use of electrodes, it is divided into wet electrodes and dry electrodes. The wet electrodes use electrode gel, which is relatively high in terms of signal-to-noise, but it cannot be used for a long time, and the comfort is not particularly good for users, so it is mostly used in the medical field. Dry electrodes have a lower signal-to-noise ratio, but are more convenient and suitable for commercialization, and have a wider prospect in the future. In non-invasive BCI, EEG can be divided into three categories according to different potential types, namely MI, event-related potential (ERP), and slow cortical potential (SCP).

3. Available treatment

3.1 Neurofeedback

Due to the different sources of production, the EEG of non-invasive BCI can be divided into two types, the signals of mental activity and external stimuli. Mental activities are endogenous, mainly including MI, motor execution, as well as visual and verbal imagination; External stimuli, as the name suggests, are exogenous, mainly including ERP and SSVEP paradigms. Both paradigms can also be used together for research. In the current research, there have been many examples of non-invasive

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BCI using scalp EEG for diagnosis and treatment, such as the diagnosis and evaluation of chronic disorders of consciousness (DoC), and this paper can detect the patient's level of consciousness through the analysis of EEG, EEG can reflect whether the patient responds to stimuli and thus provide a basis for the diagnosis of the patient's level of disease, and P300, SSVEP, SMR, and brain rhythms have been used in existing studies [7][8].

In the diagnosis of ADHD, this paper can employ EEG detection methods similar to those used in DoC diagnosis. By analyzing the patient's EEG patterns, this paper can assess their attention to external stimuli and identify overactive EEG signals characteristic of ADHD. This approach could provide a more objective measure to assess the prevalence and severity of ADHD symptoms.

Neurofeedback refers to the use of the principle of conditioned reflex to enable patients to learn and master their own EEG according to brain activity feedback, so as to correct the abnormal EEG spectrum and improve clinical symptoms. In this way, this paper can collect the patient's brain waves, combine them with drugs such as methylphenidate hydrochloride, and purposefully enhance or decrease the patient's brain waves at different frequencies [9]. Another approach is computer-aided functional training. This method uses specifically designed training programs to target and exercise particular brain functions associated with ADHD. These exercises aim to improve the patient's cognitive skills and self-regulation abilities. After a course of such treatment, many patients show significant improvement in their ADHD symptoms. Patients can be improved by intensifying β wave activity and inhibiting theta wave activity, which may be due to the effect of theta waves on sleep [10].

3.2 Transcranial Magnetic Stimulation (TMS)

Transcranial Magnetic Stimulation (TMS) is a non-invasive physical therapy technique. It involves placing a magnetic coil on the patient's scalp. This coil generates a transient current, creating a magnetic field that can stimulate brain neurons through the skull without signal attenuation. Through different stimulation frequencies, the cortical nerve under the scalp is excited or inhibited, so as to promote or inhibit the local cerebral cortex function and regulate the brain function. In recent years, TMS has been widely used in the field of brain diseases, such as the treatment of auditory hallucinations, mild cognitive impairment, Alzheimer's disease, etc. The main modes of TMS include pair-pulse TMS (pTMS), single-pulse TMS (sTMS), and repetitive TMS, (TMS), rTMS can also be divided into high-frequency rTMS and low-frequency rTMS [11][12].

In the treatment of ADHD, the target is the dorsolateral prefrontal region as the stimulation point because the cerebral prefrontal cortex is involved in some learning, willpower, and memory functions [13][14]. The dorsolateral prefrontal cortex has a high degree of excitability in EEG analysis of ADHD patients [15-17]. After experiments, it was found that the symptoms of patients were relieved after treatment. Compared with before treatment, SNAP-IV inattention, hyperactivity/impulsivity, and oppositional defiance scores were all significantly reduced, all of which had statistically significant levels [18].

3.3 Digital Therapeutics (DTx)

Digital therapeutics (DTx) is a software-based approach that provides patients with evidence-based therapeutic interventions to prevent, manage, or treat diseases [19]. While the first use of this technology dates back to 2000, the term "digital therapeutics" was not coined until 2015, marking a formal recognition of this emerging field. And the first use of the technology was in 2000 According to the industry white paper, digital therapeutics can be divided into three categories: prevention, management, and treatment [19]. Prevention is provided for those who are at risk of disease to prevent the occurrence of disease, management is to control the deterioration of the disease and reduce other complications or adverse reactions of the patient through a series of means. The treatment is to try to cure the patient's disease. Digital therapeutics provides patients with a more comprehensive and accurate diagnosis, as well as more effective treatment, than traditional clinical observation methods.

Traditional ADHD treatments often demand significant time and financial investments from patients and their caregivers. Moreover, commonly prescribed medications like methylphenidate can induce adverse effects such as sleep disturbances and anorexia [20]. Digital therapeutics offers a promising alternative that can address these limitations, providing more accessible and potentially safer treatment options.

Digital therapy for ADHD initially explored the potential of video games. Early research demonstrated that certain online video games could increase dopamine release in the brain, potentially offering therapeutic benefits for ADHD symptoms [21]. In 2020, the first digital therapeutics device, EndeavorRx, was developed to treat some children with ADHD. AKL-T01 was developed as a digital therapy software for children with ADHD, whose page is a yellow humanoid figure floating in a crooked, frozen river. The task is simple: tap on the blue fish overhead, but avoid the red and green fish, as well as the blue birds. It is also possible to drive a raft to avoid the frozen peaks along the riverbank. With video games as the main carrier, patients only needed 25 minutes of play per day to have a significant increase in attention after four weeks [22]. Then they studied the patient's condition with the help of medication. Symptoms improved in both drug-using and non-drug-using patients with no other negative effects, demonstrating the broad promise of digital therapeutics for the treatment of ADHD [23].

Recent studies have showcased innovative digital solutions for ADHD management. For instance, SELASKOWSKI developed an app specifically for adult ADHD patients, focusing on psychological education. Users of this app reported significant improvement in their symptoms [24]. Another example is Todaki, a chatbot program designed to provide psychological support through conversational interactions. This AI-powered tool has shown promise in helping patients effectively alleviate their ADHD symptoms [25]. These advancements illustrate the diverse approaches within digital therapeutics for ADHD treatment. Through the brain-computer interface, the electrical signals of the brain can be read more effectively. Detect the effect of digital therapy more accurately and effectively, and adjust the plan of digital therapy according to different situations to obtain better treatment results.

4. Analysis of the pros and cons of brain-computer interface therapy

4.1 Therapeutic Effects

4.1.1 Neurofeedback

Previous research data [9] have demonstrated that neurofeedback shows significantly higher efficacy rates compared to basic treatment. It also outperforms primary treatment in terms of SNAP-IV scores for Inattention, Hyperactivity/Impulsivity, and Opposition/Defiance (Table 1). However, it's worth noting that the incidence of adverse reactions tends to increase to some extent with neurofeedback.

Table 1. Comparison of SNAP-IV scores before and after neurofeedback

Group	SNAP-IV parent form (I)		SNAP-IV parent form (H)		SNAP-IV parent form (O)	
	before	after	before	after	before	after
Control Group	1.70±0.39	1.13±0.25	2.16±1.40	1.47±0.32	1.32±0.15	0.96±0.17
Treatment Groups	1.68±0.41	1.28±0.22	2.12±0.38	1.16±0.29	1.30±0.18	1.12±0.17
t	0.274	3.489	0.562	2.511	0.661	5.155
p	0.785	0.001	0.576	0.013	0.510	0.001

4.1.2 TMS

Existing experimental data reveal significant improvements in ADHD patients following TMS treatment [18]. Specifically, notable changes were observed in SNAP-IV scores for inattention, hyperactivity/impulsivity, and oppositional defiance (Table 2). These results suggest that TMS could be a promising treatment option for ADHD.

Table 2. Comparison of SNAP-IV scores before and after TMS

Group	SNAP-IV parent form (I)		SNAP-IV parent form (H)		SNAP-IV parent form (O)	
	before	after	before	after	before	after
Treatment Groups	1.717±0.486	1.350±0.567	0.994±0.704	0.883±0.676	0.769±0.661	0.719±0.627
p	0.001		0.002		0.080	

4.1.3 Digital Therapeutics

According to existing studies, digital therapeutics show few drawbacks. However, one notable limitation is their similarity to traditional treatments in terms of treatment duration. As shown in Table 3, digital therapeutics often requires a longer treatment cycle and may not demonstrate significant immediate effects. Thus, they are currently considered a conservative treatment option.

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Table 3. Comparison of SNAP-IV scores before and after Digital therapeutics

Group	SNAP-IV parent form (I) before after	SNAP-IV parent form (H) before after	SNAP-IV parent form (O) before after
Treatment Groups t p	1.99±0.39 1.43±0.44 2.371 0.01	1.64±0.30 1.33±0.53 2.248 0.051	1.62±0.31 1.56±0.27 1.853 0.01

4.2 Problems and Solutions

4.2.1 Problems with the three treatment modalities and how to solve them

Neurofeedback is more expensive than traditional treatments and has an increased rate of adverse effects. The sample source of transcranial magnetic stimulation is relatively simple, the sample size is not large, and there is a lack of follow-up investigation. Some of the software of digital Therapeutics has no significant improvement in impulsive behavior in ADHD.

Moving forward, this paper research will focus on several key areas. Firstly, this paper plans to conduct a more comprehensive, large-scale survey to validate this paper findings. This paper will also enhance this paper follow-up procedures to track long-term outcomes. Additionally, this paper aim to optimize digital therapeutic software by incorporating more motivational elements and intuitive interfaces. These improvements could potentially enhance patient engagement and treatment efficacy.

4.2.2 Ethical issues and solutions

This paper should ensure that the use of BCI is consistent with the goals of medicine, otherwise it may lead to some ethical problems and public questioning. This paper should ensure that the harms of BCI do not outweigh the benefits of using BCIs in patients; Recognize neurological differences between individuals and avoid risks; Ensuring patient privacy at the neurological level; Ensuring the patient's sense of identity in everyday life; The issue of the power of attorney of family members or other persons [26].

5. Conclusion

This article has reviewed several recent diagnostic and therapeutic approaches for ADHD based on brain-computer interface (BCI) technology. The advancements in BCI technology and its increasing applications in the medical field suggest promising potential for ADHD treatment. While a complete cure may still be a distant goal, BCI-based interventions could significantly improve ADHD management and patient outcomes in the near future. In the distant future, this paper can even use BCI technology to completely cure ADHD more efficiently and safely. In the future, this paper may be able to achieve more accurate reading of brain signals through the optimization of brain-computer interface devices and the algorithm. Through further research on brain structure and physiology, a more efficient way of reading signals can be obtained. It can even solve more diseases in other neurological areas.

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