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Progress of EEG Biofeedback Therapy for Attention Deficit Hyperactivity Disorder in Children

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Abstract: This paper summarizes the related research on EEG characteristics of children with attention deficit hyperactivity disorder and the research progress of EEG biofeedback therapy, analyzes the advantages and disadvantages of EEG biofeedback technology based on quantitative EEG QEEG and cortical slow potential SCP in the current research, and discusses the future development trend of EEG biofeedback therapy for attention deficit hyperactivity disorder.

Keywords: Attention Deficit Hyperactivity Disorder, EEG Biofeedback, Quantitative EEG, Cortical Slow Potential

1. Introduction

Attention Deficit Hyperactivity Disorder (Attention Deficit/Hyperactivity Disorder, ADHD) is usually considered as a kind of behavioral disorder, abbreviated as ADHD, and is common among school-age children[1]. ADHD and patients with hyperactivity, three typical characteristics of impulsiveness and poor concentration. The fifth edition of Diagnostic and Statistical Manual for Mental Disorders (DSM－5) developed by the American Psychiatric Association divides ADHD into three subtypes according to different performance characteristics: the first is ADHD-I (In Attention type, which is characterized by attention deficit. The second is the ADHD-H (Hyperactivity-impulsive) type characterized by hyperactivity impulse, and the third is the ADHD-C (combined) type[2] mixed with the above two symptoms.

The causes of ADHD and ADHD are not yet clear, so the diagnosis is generally based on the external manifestations of individual patients. Diagnostic criteria include DSM developed by American Psychiatric Association , and Chinese Mental Disorders Classification and Diagnostic Criteria etc. In clinical diagnosis, doctors will cooperate to use some diagnostic scales to assist diagnosis, including teachers' scales (such as Conners Teacher Rating Scale), parents' scales (such as Conners Parent Rating Scale) and children's rating scales (such as China Children's Attention Level Rating Scale) [3] , but the scale evaluation is subjective.

In recent years, many scholars have tried to explore more accurate methods for diagnosing ADHD and ADHD .They have found that the brain waves of ADHD are somewhat different from those of ordinary people. There are many kinds of EEG measurement techniques, such as quantitative EEG (quantitative EEG, QEEG and event-related potentials, ERPs. QEEG and technology are spectrograms [4] of the changes of EEG power with frequency obtained by Fourier transform of the original brain waves with the help of a computer, which can directly observe the power information of brain waves in different frequency segments. The brain wave frequency variation range is between 1- 30 times per second, which can be divided into four bands, namely δ (1-3hz) 、 θ (4-7hz)、 α (8-13hz) 、 β (14-30hz). Among them, the β waves with frequencies in the range of 12- 15Hz are called sensory-motor rhythm waves (sensory-motor rhythm, SMR), which are closely related to the maintenance of attention[5－6]. Different from spontaneous brain electrical activity, ERPs is a special brain evoked potential, which generates bioelectrical response in corresponding parts of the brain by giving specific stimulation to the nervous system or making the brain process the stimulation information, and is related to cognitive function, including P300, accompanied by negative potential (contengennegotive variation, CNV) and other components. The noninvasive measurement method based on

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EEG biological indicators, is cheap and more suitable for disease screening and monitoring. At present, it is very common to use brain waves and related technologies (e.g., EEG biofeedback technology) to diagnose and treat diseases in medical institutions. Compared with traditional methods, combining accurate biological indicators with modern technologies can better show advantages in the rehabilitation of ADHD.

This paper searches and analyzes the literature published in the database in the past ten years on ADHD, EEG characteristics and EEG biofeedback technology. English search keywords are ADHD/ADD and EEG, Beta, Theta, Beta/Theta, Theta/ Beta, smr, theta betaaratio, tbr, btr, EEG bie feedback/neurofeedback etc. Chinese search keywords are Attention Deficit Hyperactivity Disorder / Attention Deficit and EEG Features, Beta and Wave, θ and Wave, Beta/Theta, Theta/ Beta, TBR, BTR, Sensory Motor Rhythm, SMR, EEG Biofeedback / Neurofeedback Combination of Words. A total of relevant documents 89 articles (foreign language documents 70 articles, Chinese documents 19 articles) were retrieved. After screening and exclusion, the documents 75 articles closely related to this study were obtained. The selected domestic documents are all from CNKI and databases, and the selected foreign documents are all from Science Direct, Web Of Science, IEEE Xplore, Springer Link Journals and other databases. The purpose of this study is to explore a better way of rehabilitation for ADHD children in the future by analyzing the research progress of EEG characteristics of ADHD children and the application status of EEG biofeedback technology.

2. EEG Characteristics of Children with Attention Deficit Hyperactivity Disorder

Comprehensive studies show that ADHD and brain waves of patients differ from those of ordinary people mainly in the following five aspects.

First, Compared with the general population, ADHD has more δ and θ waves, and has weaker α and β waves, the lower bands of β waves known as SMR waves. Mann and others found in 1992 that θ wave amplitude of ADHD children increased under rest conditions, especially in frontal lobe area. Under the condition of cognitive task, θ wave activity in frontal lobe and central region increased significantly, while β wave activity in posterior and temporal lobe region (12. 75 - 21Hz) Activity Decrease[7]. Li and others compared 26 age and sex matched normal and ADHD children found that ADHD of δ wave and θ wave are more; α wave and β wave (13 - 30Hz) activity is weaker[8]. Barry researchers found that ADHD of theta wave more, alpha wave and beta wave (12.5 - 25Hz) Weak activity [9]. Lubar researchers found that β and lower frequency band of wave (12 - 14Hz), namely SMR and weaker wave activity[10－12].

Second, the power ratios of ADHD, θ / β (θ and β are much higher than those of ordinary people. Barry pointed out in the study of 2003 that ADHD and patients tend to have higher θ wave power and lower β wave power[13]. Loo and ADHD patients tend to have higher θ wave power and lower β wave power[14], MONASTRA [15] in the 2005 research. Gonzálezcastro measured β/θ for three subtypes of ADHD respectively, which were lower than those of normal children of the same age [16].

Shi and others tested the brain waves of 44 age gender-matched normal children and found that ADHD Children, θ and wave relative power are obviously higher, β and wave relative power is lower, θ / β and higher than ordinary people[17].

Lansbergen and others found that the θ/β of ADHD boys was higher in resting state [18]. Zhang and other research found that ADHD has higher TBR (the power ratio of theta and beta) than ordinary people, and reconfirmed the prognostic value of TBR consistent with previous studies on ADHD [19].

Third, In ADHD, slow wave (sw) has increased activity, while fast wave (fw) has insufficient activity, SW/FW (power ratio of slow wave to fast wave) is much higher than that of ordinary people. Clarke and others pointed out as early as 2002 that ADHD and people's EEG slow wave activity increased and fast wave activity was insufficient [20]. Research by Putman and others shows that SW/FW in brain waves of ADHD is higher and is related to emotional regulation[21].

Fourth, the EEG features of ADHD and ADHD are different from those of sex, age, etc. In addition, since ADHD and have different subtypes, EEG is used to diagnose ADHD and dispute. Clarke's 1998 study showed that 15% of ADHD-C patients had increased β wave activity [22-23]. In 2011 Clarke discovered through more detailed research that ADHD has three different EEG features, the first is slow wave increasing and fast wave decreasing, the second is theta wave

increasing and beta wave decreasing, and the third is beta wave activity increasing[24]. Therefore, relevant research shows that it is inaccurate to diagnose ADHD and ADHD with brain waves. For example, Buyck and others have tested the brain waves of dozens of adults and children (including ordinary people and ADHD and patients) in the state of closing eyes. They found that ADHD-I type has higher θ / β and β than ordinary people and ADHD-C type, thus drawing the conclusion that ADHD cannot be diagnosed with brain wave[s[25−26]].

Fifth, the cortical slow potential of ADHD is different from ordinary people. SCP is a special ERPs component, which is a negative potential or positive potential lasting from 300ms to a few seconds in EEG, and is related to physiological stimulus, behavioral response, cognition and emotion, etc.[27]. Compared with ordinary people, ADHD has poor self-control ability on cortical potential [28], and is typically CNV amplitude reduction [29−30] in slow potential. In addition, ADHD, ERPs, Medium P300 has smaller amplitude and longer latency[31−33].

According to the summary, EEG of ADHD population is characterized by increased θ wave activity, insufficient β wave and SMR wave activity, increased slow wave activity, insufficient fast wave activity, higher TBR and SW/FW, but it is not excluded that a small proportion of ADHD population does not conform to this characteristic. The SCP of ADHD reflects their poor self-control of cortical potential. In ERPs, P300 amplitude is smaller, latency is longer, and CNV amplitude is lower.

3. Rehabilitation Technology Based on EEG Biofeedback

Drug therapy and behavioral therapy are the two most commonly used and accepted methods for the treatment of ADHD, but there are still some limitations in these two methods [34] . There is an urgent need for a new method to treat ADHD in the long run EEG biofeedback technology (also known as neurofeedback) is that people extract specific parameters from EEG signals as monitoring indicators, and use these parameters for brain function training to achieve the purpose of treating diseases, functional rehabilitation. When the technology is implemented, the rehabilitation technician attaches electrodes to the scalp and earlobe of the trainees, and the area to which the electrodes are attached depends on the training plan. Electrodes as “Sensors” Collects EEG signals from various regions of the brain, and then presents trainees' EEG signals in a way that can be interpreted by computers or other tools. In the training process (usually game training), the trainees' results will be given audio-visual feedback through the computer. Game training is controlled by brain wave activity. If the electrode attached to the scalp receives the trainee's brain wave pattern and meets the training pattern (e.g., SMR, β etc.), the game will proceed smoothly and the corresponding score will be obtained as “reward”. On the contrary, if the brain waves detected by the trainees do not conform to the training mode, the game will not be executed and scores will not be obtained.

With the advantage of non-traumatic and less side effects, EEG biofeedback technology has gradually become an effective treatment method for cognitive and behavioral dysfunction diseases[35], which can be used for ADHD, autism treatment. Research by Holtmann *et al*. [36] indicates that EEG biofeedback technology has obvious effect in improving ADHD symptoms in the short term. Rossiter and The effect difference of EEG biofeedback and drug therapy was studied by the method of inter-group control. The 46 subjects were divided into groups and intervened by two methods respectively. It was found that EEG biofeedback achieved the same effect as drug therapy[37]. Jiang and *et al* have improved the attention and short-term memory of 7-15 year old ,ADHD and children after repeated interventions with EEG biofeedback technology. [38] . Carmody and *et al* have treated 8-10 year old ,ADHD and 6 patients with EEG biofeedback intervention for more than months. It is found that the patients' attention is improved and their impulsive and hyperactive behaviors are also reduced. [39]

4. EEG Biofeedback Therapy Scheme and Evaluation for Attention Deficit Hyperactivity Disorder

Based on the summary of various researches at home and abroad, the treatment of ADHD by EEG biofeedback has gone through three stages[40]: sensorimotor rhythm scheme (SMR scheme), theta/beta EEG ratio scheme (TBR scheme) and cortical slow potential scheme (SCP scheme). Among them, SMR ,TBR and TBR belong to QEEG Scheme, SCP are ERP-based Scheme.

The first stage is SMR Scheme, Collect SMR as monitoring indicators, the subjects need to complete training (game program on computer) by controlling their own SMR When training, set the corresponding training target according to the patient's attention level. The subjects can ensure the game to continue continuously by continuously improving their SMR. Otherwise, the game is over. If the game can be played, there will be certain rewards. Lubar first used EEG biofeedback technology to treat Lub<r in 1976 through experimental research, it was found that the improvement of SMR can improve hyperactivity and distraction symptoms [41]. Lowering θ, Raising Fast Wave, SMR Or β is the core idea of Lubar's biofeedback training [42]. Research by Gruzelier and others shows that attention, cognitive ability, memory and academic performance of ADHD patients can be improved by improving SMR waves [43-44]; Kaiser chose to use SMR wave band to intervene more than 1,000 ADHD patients between 5 and 67 years old. Through the comparison before and after the intervention, it was found that attention, changes in reaction time and impulse control were significantly improved after the intervention. Thorpe's research results were consistent with Kaiser's [45].

The second stage is TBR scheme, the method is similar to SMR scheme. The difference is that collection of θ wave sum β wave. The power ratio of the two is used as the monitoring index. The training process is controlled by θ wave sum β wave activity. Linden and others for the first time, significantly improved the attention and intelligence of ADHD children by suppressing θ waves and increasing β waves[46]. Winklemolen and others have adopted TBR and TBR programs for electroencephalogram biofeedback training of a 11 year old girl with ADHD and no longer meet the standards of ADHD after the scale evaluation. The teacher has described that they have been able to concentrate in school, and parents have expressed a reduction in impulsive behavior [47]. Gevensleben *et al*. found in the experiment that after TBR program training, ADHD of θ / β weakened and behavioral problems improved.[48]

The third stage is SCP and scheme, which are different from the training methods of QEEG and scheme. The SCP scheme is to train the subjects to learn to consciously control their cortical slow potentials. Specifically, the blank potentials are consciously converted into positive potentials or negative potentials through certain training tasks, such as thinking about and answering the questions set on the computer screen. CNV is usually selected for monitoring indicators in SCP and scheme. Heinrich and others reported the research results of using SCP, regimen therapy and ADHD for the first time. It was found that after training, ADHD and symptoms eased, CNV and amplitude increased[49]. Wangler and others used EEG biofeedback methods combined with TBR, and SCP to train the subjects, ADHD related symptoms improved, CNV amplitude improved. [50−51] Gevensleben *et al*. after EEG biofeedback training of SCP in the experiment, the α wave of the subject improved and the behavior problem was improved [52].

It is difficult to determine the best EEG biofeedback therapy for ADHD. Some scholars believe that the QEEG and biofeedback technologies based on SMR, TBR and TBR do not require the subjects to learn to control their brain waves autonomously, while the SCP and scheme require the subjects to actively control their brain waves, so the SCP and scheme are more difficult and have higher requirements on the subjects. [53] SCP and Scheme are more complicated than QEEG and Scheme, but studies have proved that they have achieved the same good results [54]. The EEG indexes collected in the SMR scheme are sensory and motor rhythm waves of 12 - 15Hz with a narrow frequency range. The placement of detection electrodes is strictly required and must be placed in the posterior part of the frontal lobe of the brain that controls primary sensation and movement. The goal of the TBR scheme is to enable the subjects to improve the θ wave power, while the SMR scheme is different from the SMR scheme requires not only to increase the power of the SMR and wave, but also requires the subject to keep generating the SMR and wave for as long as possible, which is related to the SMR and the unique mode of shuttle wave. [55] However, since the TBR scheme involves the power ratio of the two waves, the signal processing method is more strict, and the results obtained by different signal processing methods may be different. From this, we can see that different EEG biofeedback technologies have their advantages and disadvantages, and the results obtained in different studies are also different. In addition, EEG biofeedback technology has clear regulations on the acquisition site when acquiring EEG. However, the brain, as a whole network, tends to pull one hair and move the whole body. Changes in one site will affect other sites, which is also a factor that affects the research results. [56]. But we still have to be optimistic about the treatment of EEG biofeedback technology, ADHD and drug therapy will damage some circuits of the brain. In the long run, EEG biofeedback technology is a better choice. The method of combined use of multiple indicators can be considered. For example, Thompson *et al*. tried to use SMR, θ/β, α/θ and other

indicators to treat patients with attention deficit [57]. Fauzana and others applied EEG biofeedback training to a 15 year-old ADD patient by means of increasing SMR and inhibiting θ waves, and the patient's emotional and behavioral problems were improved and his attention was improved. [58]

Common Research and Design Methods for Evaluation of Effect of EEG Biofeedback Training

Comprehensive studies show that the following design methods are commonly used in the treatment of ADHD and ADHD by EEG biofeedback training methods.

First, self-control conditions are used to judge the therapeutic effect of training by comparing the EEG indexes of subjects before and after training, often combined with subjective evaluation results. For example, Doren *et al*. also completed EEG biofeedback training with TBR scheme, and found that θ/β decreased and θ activity decreased after training [59]. Flisia - kantonijczuk and others conducted 20 course of EEG biofeedback training for a group of ADHD patients, effectively changing θ / β and θ /SMR. [60]

Second, taking drug therapy as an active control condition, the curative effect is evaluated by comparing drug therapy and electroencephalogram biofeedback technology. For example, Meisel and others conducted EEG biofeedback training for a group of 7-12 year-old children and TBR programs, and found that θ / β decreased, behavioral problems decreased, academic ability improved[6], while in the control group, altruism intervention failed to have obvious effect. [62] Duric and others conducted a randomized controlled study in 2014 year, comparing TBR scheme methylphenidate drugs with the mixed treatment of the three groups. It was found that TBR group had the same effect as the other two groups. [63]

Third, under double-blind placebo-controlled conditions, after the subjects were randomly treated with placebo and EEG biofeedback training, whether the attention deficit symptoms of the subjects were improved or not was analyzed. In the double-blind placebo-controlled study, there is no obvious evidence that EEG biofeedback training is better than placebo. [64−67]

Fourth, tracking research design, also known as longitudinal tracking research or longitudinal research, is a systematic and regular research on the same object over a relatively long period of time, or a research scheme that examines the object from the development of time. Heinrich and others tracked the SCP and Plan for 3 months and found that the therapeutic effect has been further improved.[68] Gani and others conducted follow-up after SCP and Scheme Treatment End 2 years, and found that the therapeutic effect in behavior and attention can still be maintained. [69]

In the process of research, different design schemes have certain limitations. If there is no effective control group in the self-control test, it is not convincing to judge the curative effect only by the changes of EEG indexes before and after treatment, and it is impossible to predict the delayed effect, and there is a certain controversy in using EEG indexes as the indexes for judging ADHD. Many scholars have failed to prove the effect of EEG biofeedback training by using double-blind placebo-controlled tests. Since operational conditioned reflex is the theoretical basis of EEG biofeedback therapy, the double-blind method makes it impossible for the therapist to set training targets according to the participants' real EEG conditions, and the participants did not take place “ real ”.

Learning, therefore, the specific form required by EEG biofeedback training method and the defects of the double-blind placebo experimental design method itself may weaken the effect of EEG biofeedback training. [70−71]

6. Future Development Trend of EEG Biofeedback Therapy for Attention Deficit Hyperactivity Disorder

A lot of evidence shows that EEG biofeedback technology can regulate the EEG activity of human brain. For patients with ADHD and ADHD, symptoms can be alleviated through this technology. QEEG and SCP programs with SMR and TBR as the main components are the research hot spots in current ADHD treatment programs. According to the EEG characteristics of different individuals, we can select appropriate treatment programs for ADHD .This personalized customization program with longer-term follow-up research is the future development trend.

The reason is: first, QEEG is based on ADHD of TBR higher than the average person .However, there are still researches that question whether TBR can be used as the judgment index of ADHD[72−74]; Second, ADHD has many subtypes. As mentioned earlier, the EEG characteristics corresponding to each type are different, and the adopted QEEG scheme should also be changed. Arns means to select QEEG scheme treatment and ADHD according to the EEG

characteristics of different individuals. This personalized training scheme can effectively improve clinical effects, and may require a larger sample size and control group [75] in actual application. Third, the effect of the SCP program is also uncertain and needs to be treated individually. For example, Wangler and others find that before treatment starts, CNV, high, ADHD children are better than CNV, and low children are better than SCP self-control after training, cognitive performance and so on. Fourth, the course of treatment using EEG biofeedback training is very long, generally more than 30, while the current tracking research time is short, which cannot be very convincing for the long-term effect of EEG biofeedback training. To sum up, whether it is QEEG Scheme or SCP Scheme, the future treatment methods for ADHD should be customized according to individual differences, and the sample size in the research design should be larger. In order to observe the long-term efficacy, it should be matched with a longer-term follow-up study. For the evaluation index of curative effect, future research may not be limited to QEEG, CNV, and other components in ERPs such as P300 and Electromyography EMG and other indexes may be considered.

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