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

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Abstract: *EEG biofeedback is the most commonly used non pharmacological therapy and is recommended as an effective treatment for attention deficit hyperactivity disorder (ADHD). Its characteristics are simple, effective, and minimal side effects. It can be used alone or in combination with various drugs or non pharmacological therapies. In order to explore the situation of EEG biofeedback therapy for children with ADHD in China in the past 15 years, this article searched for 40 literature that can evaluate the effect of EEG biofeedback therapy on children with ADHD from databases such as China National Knowledge Infrastructure(CNKI) and Wanfangdatabase, explained its therapeutic characteristics, analyzed its existing problems, and summarized the direction of future treatment development, providing reference opinions for the scientific use of EEG biofeedback technology for children with ADHD.*

Keywords: *EEG biofeedback; Attention deficit hyperactivity disorder (ADHD);Non pharmacological therapy; Progress*

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I. Introduction

Attention Deficit Hyperactivity Disorder (ADHD)is a common type of behavioral disorder in childhood [1-2]. The intelligence of ADHD childrenare normal or basically normal, mainly manifested as lack of concentration and short attention time, excessive activity, and impulsivity that are not commensurate with age and developmental level, often accompanied by learning difficulties, emotional or behavioral disorders, and drug abuse [3]. In clinical practice, ADHD is divided into three types: attention deficit type, hyperactive impulse type, and mixed type [1]. About 2/3 of the symptoms persist until adolescence, and 1/3 may last for a lifetime, significantly affecting patients' academic, physical and mental health, as well as their family life and social skills in adulthood [4]. The incidence rate in foreign countries is 3% to 6% [2], while in China, the incidence rate in school-age children is 4.31% to 5.83% [5]. The incidence is related to genetics, neurodevelopment, brain injury, lead poisoning, food additives, family and learning environment, etc. [6-9].

The treatment methods for children with ADHD can be roughly divided into drug therapy and rehabilitation training [10], with drug therapy as the main treatment. However, drug therapy has problems such as long-term medication, unclear optimal dosage of drugs, serious side effects, and unclear exact mechanism of treatment [11]. The main drugs used to treat children with ADHD are Ritalin, Tomoxetine, etc. Common side effects include decreased appetite, decreased sleep quality, headaches, and in more severe cases, anxiety, impatience, and other symptoms may occur, which may induce or worsen tic symptoms in patients with Tourette's syndrome. Long term use also carries the risk of drug abuse [12]. The current non pharmacological intervention methods have become an important direction for academic and clinical exploration.

EEG Biofeedback (EEG B), also known as Neurofeedback (NF), is based on the principle of operant conditioning. It collects a patient's EEG signal, amplifies and analyzes it, and provides timely feedback to the patient in the form of visual and auditory signals. The task difficulty is adjusted according to the actual situation of the patient, and the patient learns to selectively suppress 4-8Hz θ Wave, enhancing the sensory motor rhythm of 12-15Hz with SMR or/and β Wave (15~18Hz), thereby reducing the brain activity of the affected child in θ/SMR and θ/β Ratio, increase the low arousal level of the brain, enhance attention, and improve clinical symptoms. EEG-B has been recommended as an effective treatment for ADHD [13].

II. Clinical trials for NF treatment

NF therapy for ADHD involves complex and diverse non-specific factors that cannot be fully controlled. In order to evaluate the unique effects of NF treatment on ADHD, there are many randomized controlled trials abroad used to separate and control various non-specific factors in NF treatment, such as controlling electromyography [14], motivation and expected levels [15], and attention training [16]. The randomized

controlled trial of NF treatment for children with ADHD was divided into NF alone, combined NF (2 treatments), and comprehensive NF (3 or more treatments) experiments according to the number of treatments. The combination of NF therapy can be divided into two groups: the "treatment group andtreatment+NF group" trial that observes the superimposed NF treatment effect on the basis of non NF therapy, and the "NF group and NF+treatment group" trial that observes the superimposed non NF treatment effect on the basis of NF therapy. Specifically, there are the following types of NF treatment comparison groups: (1) no treatment group compared to NF group (Class A comparison); (2)comparison between treatment group and NF group (Class B); (3) comparison between treatment group and treatment+NF group (Class C); (4) treatment+NF group compared to NF group (Class D comparison). Obviously, Class A and Class B can compare and evaluate the effects of individual NF treatments, while Class C and Class D can compare and evaluate the effects of combined (superimposed) NF treatments.

The main treatment plan for NF is θ/SMR, θ/β, θ/β+ SMR. The evaluation tools mainly include the Integrated Audiovisual Continuous Performance Test (IVA-CPT), Conners and SNAP-IV assessment scales, Wechsler Children's Intelligence Scale C-WISC test, Combined Raven Test (CRT), d2 Attention Test, etc. The main treatments outside of NF include methylphenidate (Ritalin), tomoxetine, psychological and behavioral guidance, traditional Chinese medicine, and sensory integration training [17].

2.1 Two-group randomized controlled trials

2.1.1 Class A comparative experiment: Comparison of therapeutic effects between EEG feedback and blank control group

Jiao Min et al. [5] used suppression of 4-8Hz θ Wave, enhancing the frequency range of 16 to 20 Hz β Wave, i.e. θ/β. Compared with the pre-treatment and untreated groups, the NF group showed significant improvement in IVA-CPT testing after 20 treatments for children with ADHD. After 40 treatments, there were significant improvements in comprehensive response control quotient (FRCQ), comprehensive attention quotient (FAQ), hyperactivity quotient, as well as hyperactivity, impulsivity, and aggressive behavior in the ConnersQuestionnaire, indicating that the therapeutic effect of NF is related to the number of treatments.

2.1.2 Class B comparative experiment: Comparison of therapeutic effects between drugs and NF

(1) Methylphenidate (Ritalin) group and NF group. Chen Yu et al. [18] reported a 6-month methylphenidate group and 60-sessionθ/SMR group showed significant improvement in FRCQ and FAQ during and after treatment, while the scores ofCornners Questionnaire significantly decreased after treatment. But the efficacy of 60-session θ/SMR group was better than that of the methylphenidate group at 3 to 6 months of follow-up. Fan Qiuxia [19] reported that compared to pre-treatment, theConners scores of 3-month Ritalin group and 36-session θ/SMR group showed a significant decrease. The improvement in the treatment of the Ritalin group was significant, but after a 3-month follow-up, the Ritalin group experienced recurrent symptoms, andthere was no recurrence in the θ/SMR group. Tang Min et al. [20] reported that compared to before treatment, the 3-month Ritalin group and 48-session θ/SMR group showed significant improvementin the Cormers and Wechsler Intelligence Scale (C-WISC) scores, but after treatment, the scoresof 5 factors likebehavioral, learning, physical, hyperactivity, and anxiety in CormersScale in the Ritalin group were significantly lower than those in the θ/SMR group, while the scores of digit breadth, encoding, arithmetic, and C-factor of C-WISC in the Ritalin group were significantly higher than those in theθ/SMR group. The above studies indicate that methylphenidate has a rapid effect in treating ADHD children, while NF has a significant long-term effect. However, Li Guangkai [21] reported that the improvement in FRCQ and FAQ in the group treated with 20 times of NF was significantly better than that in the conventional Ritalin group. NF treatment can also improve learning and behavioral factors of ConnersQuestionnaire [22]. Song Qinghai et al. [23] reported (86 cases) that the EEG-B training for all these children was carried out according to the plan of 45 minutes per session, 5 sessions per week, for a total of 40 sessions (8 weeks). The attention evaluation criteria after treatment was that ADHD children with attention in class for more than 3 hours were considered cured, those for more than 1 class hour were considered effective, and those for less than 1 class hour were considered ineffective. The results showed that after 40 sessions, the total effective rate of the MPH combined with EEG-B group (86.05%) was significantly higher than that of the EEG-B control group (65.12%). The scores of hyperactivity, inattention, and opposition violation (SNAP-IV) in both groups were significantly reduced compared to before treatment, while the combined group had a larger decrease in scores; As the number of treatments increases, both groups' θ/β values gradually decreased, but the effect of the combination group (2 weeks) was faster than that of the EEG-B group (4 weeks); At weeks 2, 4, 6, and 8 of treatment,the θ/βvalues of the combined group were significantly lower than those of the EEG-B group. (2) Ritalin group and NF subtype group. Du Wenran et al. [24] and Yang Xiangguo [25] adopted an ADHD classification treatment plan, using attention deficit disorder (ADHD-I), hyperactivity impulsivity (ADHD-HI), and mixed type (ADHD-C) respectively, and θ/β, θ/SMR, and θ/β+SMR underwent 40 sessions. The SNAP-IV scores of the Ritalin group and ADHD-I and ADHD-C patients in NF group were significantly reduced compared to before

treatment [24-25], indicating the therapeutic effect of strengthening of ADHD-I patients' βwaves is superior to the training effect of strengthening SMR waves in children with ADHD-HI. The Ritalin group has a faster onset of effect, while the NF group has a better long-term efficacy than the Ritalin group after a 6-month follow-up [24]. Su Jingjing et al. [26] reported (sample 120 cases) that the EEG-B trainingwas carried out according to the plan of 45 minutes per session, 3 sessions per week, for a total of 24 sessions (8 weeks). The MPH combined with EEG-B group and the EEG-B group showed no significant changes in serum adrenocorticotropic hormone (ACTH) levels before and after treatment, whilethe combined group had a more significant increase in serum corticosterone (CORT) levels compared to the EEG-B group, indicating that combined treatment improved the HPA axis neuroendocrine hormone better than EEG-B treatment. The improvement of attention deficit, hyperactivity impulsivity, and behavioral performance (SNAP-IV) in the combination group were more significant than those in the EEG-B group. The total clinical effective rate (control rate+significantrate+effective rate) in the combination group was significantly higher than that in the EEG-B group, indicating that the combination therapy has better clinical total effective rate and core symptom efficacy than in the EEG-B. (3) Traditional Chinese medicine group and NF group. Tang Qimin et al. [27] reported (50 cases) that the EEG-B training for all patients was carried out according to the plan of 45 minutes per session, 5 sessions per week, for a total of 20 sessions (8 weeks); The EEG-B group (control group) did not take any other medication during the study period, while the combination group (treatment group) took Bu Pi Yi Shen Chong twice a day, 10g per dose, for a total of 4 weeks on the basis of the above EEG-B training. The total effective rate of the treatment group was 80.0%, significantly higher than the control group's 60.0% ($P<0.05$); θ/β value, the scores of the Attention Deficit Hyperactivity Disorder Scale and Behavioral Scale, as well as the SI score of the Clinical Efficacy Scale for Psychiatric Disorders of the two groups were significantly reduced compared to before treatment, but those of treatment group were lower than those of control group. Yan Guojuan et al. [28] reported that the SNAP-IV scores of both the 3-month traditional Chinese medicine (Jingling oral liquid) group and the 30-session NF group decreased significantly compared to before treatment. The improvement of SNAP-IV score, clinical effectiveness, and remission rate in the traditional Chinese medicine group were better than those in the NF group, while the inefficiency rate (55.3%) in the NF group was higher than that in the traditional Chinese medicine group (20.1%). It can be seen that the therapeutic effect of traditional Chinese medicine+NF is better than NF, but the therapeutic effect of traditional Chinese medicine is better than NF alone.

2.1.3 Class C comparative test: comparison between drugs and drugs+NF

(1) Methylphenidate group and methylphenidate+NF group.

Tang Wenjie et al. [29] reported (64 cases) that methylphenidate was combined 16 times over an 8-week period of θ/SMR treatment for ADHD takes effect quickly, with higher task completion, total score, concentration, and fluctuation ratio in the d2 attention test compared to the methylphenidate group. The omission error, violation error, and error rate in the d2 test, as well as the attention deficit score and hyperactivity impulse score in the ADHD Symptom Assessment Questionnaire showed a more significant decrease compared to the methylphenidate group. Du Han [30] reported that within 3 months, the behavior factor, hyperactivity factor, and hyperactivity indexin Conners Scale, and θwave frequencies of methylphenidate +40-time θ/SMR group were significantly lower than those of the methylphenidate group, while thefrequencies ofβand SMR waves were significantly higher than those of the methylphenidate group. Chang Weili et al. [31] reported that the EEG-B training plan in a combined group of 76 cases was as follows: θ/β and θ/SMR, 30-40 minutes/time, 3 times/week, a total of 36 times, and the combination group showed significantly lower opposition defiance, hyperactivity index, and attention scorein the SNAP-IV test than the MPH group after treatment. The quotients of FRCQ, FAQ, VAQ, ARCQ, and VRCQ in the IVA-CPT evaluation were significantly higher than those in the MPH group, and there was no significant difference in the incidence of adverse reactions between the two groups. Li Jingying (sample of 48 cases) reported that the EEG B training plan in the combined group was 23 minutes per session, 2-3 sessions per week, and a total of 24-36 sessions over 12 weeks. After treatment, the Conners' hyperactivity index in the combination group decreased more significantly than in the MPH group, and the Wechsler Memory Scale showed significant improvements in memory quotient (MQ), operational intelligence (PIQ), total intelligence (IQ), attention factor quotient (CIQ), and verbal intelligence (VIQ), while there was no change in cognitive function above the MPH group, with significant differences between the two groups. The above studies indicate that the combination of methylphenidate and NF can alter the core symptoms and cognitive function of ADHD children, and its efficacy is superior to methylphenidate treatment alone.

(2) Tomoxetine group and Tomoxetine+NF group

GuJiaowei et al. [33] (46 cases in the combination group and 45 cases in the combination group) reported that after 4 months, the scores of FAQ, FRCQ, and ConnersScale in the tomoxetine group and the combination of tomoxetineand 48-time θ/SMR group were significantly improved compared to before treatment. The improvement in visual and auditory quotient, hyperactivity index, learning problems, impulsivity

hyperactivity,and conduct problems in the ConnersScale was similar in both groups after treatment. However, the improvement in psychosomatic disorders and anxiety in the combination group was better than that those oftocoxetine group. Zhang Lijun et al. [34] (sample of 140 cases) reported after 48-timeθ/SMR treatment combined with atomoxetine over a period of 4 months for ADHD, the children's attention quotient and audio-visual quotient were significantly higher than those in the atomoxetine group, whileConners' hyperactivity index, impulsivity, conduct problems, psychological disorders, and anxiety scores in the combination group were significantly lower than those in the atomoxetine group. Song Zhenxi [35] (sample of 48 cases) reported that the control group was treated with 12 weeks of atomoxetine, while the combination group was treated with atomoxetine in combination with θ/β+SMR EEG-B training (according to the plan of 23 minutes/session, 2-3 sessions/week, a total of 24-36 sessions in 12 weeks). After treatment, the Conners' hyperactivity index of both groups decreased compared to before treatment, and the scores of combined Raven test (CRT) improved. However, the decrease in Conners' hyperactivity index in the combined group, as well as the improvement in perceptual discrimination, analogical comparison, comparative reasoning, series relationships, abstract reasoning ability, and intelligence, were greater than those in the moxitento group. The above studies indicate that the combination of atomoxetine and NF is superior to the treatment of atomoxetine alone.

(3) Evoked potential group, psychological intervention group, traditional Chinese medicine group, and treatment+NF group.

Zhang Shaoyan [36] (80 cases) reported a 7-week brainstem auditory evoked potential group and a combination of evoked potentials and 21 times (20-30 minutes each time) of θ/SMR group. The Achenbach Children's Behavior Scale and IVA-CPT scores in theθ/SMR groupwere significantly improved compared to before treatment. The combined group had significantly higher effective rates (92.5%) than the evoked potential group (72.5%). XuShihong [37] reported 1-session psychological behavioral interventiongroup and 1-sessionpsychological behavioral interventionin combination with 20-time θ/SMR group. The Conners' score reduction and total effective rate of combination group were significantly higher at 95% compared to 37.5% in the group receiving only one psychological and behavioral treatment. Ding Yiyun et al. [38] (Sample 50) reported that the 12-week traditional Chinese medicine Jingning granules group (twice a day, 10g/time) and the combination of traditional Chinese medicine and 20-times θ/β+SMR (20-30min/session) group showed significant improvement in SNAP-IV score, digital elimination test, traditional Chinese medicine main syndrome (restlessness and lack of concentration), and secondary syndrome (insomnia and excessive dreaming, hand and foot heat, dry mouth and self-sweating, night sweating) compared to before treatment. Thefrequency of θ wave in combined group reduceed, βand SMR wave frequencies increased, and the combined group showed better overall symptom improvement than single traditional Chinese medicine treatment. However, the sample size of this study was relatively small, and there was a significant difference in dropout rates between the two groups. The combined group had a higher dropout rate (13 cases, 52%), while the traditional Chinese medicine group had a zero dropout rate, which affected the effect value of the study.

2.2 Multiple randomized controlled trials

2.2.1 Class A comparative test

ZhengSiqi et al. [39] randomly divided 15 children with mixed type ADHD into an untreated group, a 48-session NF group, and an NF+hypnosis group. NF treatment plan is 25 minutes per session, 2 sessions per week, for a total of 48 sessions/6 months. After treatment,the FRCQ and FAQ of the NF+hypnosis group were significantly higher than those of the NF group, and the FRCQ and FAQ of the NF group were significantly higher than those of the untreated group.

2.2.2 Type B comparative test

Zhou Guoling et al. [40] randomly divided 120 children with ADHD into a sensory integration training group (six months), θ/β Group A (the treatment plan is 30 minutes/time, 2-3 times/week, 80 times/2 courses), and methylphenidate group (six months). The FRCQ, FAQ, and CRT test scores of the three groups were significantly improved compared to before treatment. Compared to the methylphenidate group, θ/βgroup and the sensory integration group have a faster effect, and after one month of treatment, there is a significant improvement in FRCQ and FAQ. The CRT bonus rate is higher, and the teachers' scores for ADHD symptoms are lower. After 6 months of treatment, θ/βgroup reached the level of methylphenidate groupin FAQ, and the score reduction of θ/βgroup in ADHD symptoms was significantly higher than that in the control group. The FRCQ and FAQ of ADHD-C in the methylphenidate group were higher than those in the θ/β group and sensory integration group, the FAQ ofADHD-I in θ/βgroup was higher than that of sensory integration group, and the FRCQ ofADHD-HI in sensory integrationgroup was higher than that of θ/β Group. It can be seen that methylphenidate has greater advantages in improving cognitive ability and core symptoms in children with ADHD, θ/β secondly, while sensory integration training can effectively improve sensory integration disorder in children with ADHD.

2.2.3 B+C comparative test

Li Junhua et al. [41] randomly divided 90 children with ADHD into 3 groups: NF group, Ritalin group, NF+Ritalin group, with 30 cases in each group. NF is performed for 3 times a week, 20 minutes each time,a total of 5 weeks. After treatment, the mean score of IQ (C-WISC), FRCQ, and FAQ of the three groups all improved, with the highest in the combination group, followed by the NF group, and the lowest in the Ritalin group. The Ritalin group (3 weeks) took effect faster than the NF group (15 times/5 weeks), and the combined group had a significant therapeutic effect, with an effective rate of 87.5%. Du Wenran et al. [24] used the same grouping method as Li Junhua et al.[41] and used NF classification to treat children with ADHD. After treatment, the quotients of IVA-CPT scores in all three groups significantly increased, while SNAP-IV and Weiss scores significantly decreased. The effective rate of the combination group (85%) was higher than that of the Ritalin group (78%) and NF group (66%), and the combination group had better short-term (3 months) and long-term efficacy (6 months) than the Ritalin group and NF group. The efficacy of NF in treating different subtypes of ADHD varies, with ADHD-I being the most effective, followed by ADHD-C, and ADHD-HI being the worst.

2.2.4 A+B+C comparative test

Huang Xinxin et al. [42] randomly divided children with ADHD into an untreated group θ / SMR group, 4-month psychological behavior group, psychological behavior +θ/SMR combined group, with 60 cases in each group. NF treatment is performed 1-2 times per day, 35-50 times per month, lasting for 4 months. The attention span time, Conners' impulsivity hyperactivity score, and hyperactivity index of the three treatment groups all showed varying degrees of improvement compared to before treatment. The three therapies have different therapeutic effects on children with different subtypes of ADHD, The attention span time of theθ/SMR group (ADHD-I, ADHD-HI), various typesof children inpsychological behavior group, and combination group significantly increased; In terms of improving attention span, the combination group was better than θ/SMR group (ADHD-I, ADHD-C) and psychological behavior group (ADHD-HI, ADHD-C), and psychological behavior groupwas better than θ/ SMR group (ADHD-C). The impulsivity hyperactivity and hyperactivity index scores in the combination group were significantly lower than those in the untreated group and θ/SMR group (ADHD-C). It is indicated that combination therapy is superior in improving attention span, reducing impulsivity hyperactivity score, and hyperactivity index in children with ADHD than θ/SMR and psycho-behavioral therapy,the treatment effect of θ/SMR on children with ADHD-C is not significant, and the improvement of attention is not as good as that of psycho-behavioral therapy.

2.2.5 Type D comparative experiment: Ritalin+NF group, Tomoxetine+NF group and NF group

Liu Wenlong et al. [43] reported (sample of 64 cases) that the EEG-B training was performed with θ/β And θ/SMR, 3-5 times per week, a total of 40 times,medication treatment was lasting for 3-6 months. The MPH combined with EEG-B group and ATX combined with EEG-B group showed significant improvement in FRCQ, FAQ, hyperactivity/impulsivity, and attention (SNAP-IV) in IVA-CPT tests after treatment compared to before, and the therapeutic effect was comparable. The combined effect was significantly better than that of EEG-B control group, especially in improving the attention deficit of children.

III. Summary and Outlook

3.1 Summary

NF can effectively improve the core symptoms and cognitive function of ADHD children, mainly manifested as: (1) NF treatment has a definite therapeutic effect compared to no treatment (seen in Class A), and NF treatment has a long-term therapeutic advantage of 6 months compared to methylphenidate (Ritalin) (seen in Class B). (2) The combination of drugs (methylphenidate, or toxetine) and NF has a better short-term (3 months) and long-term (6 months) efficacy (seen in Class C) than drugs alone, or NF treatment alone, and can also reduce the total number and frequency of NF treatment. (3) The efficacy of NF is closely related to its course of treatment or treatment frequency (20-40 times or more), weekly frequency (2-4 times or more), and single treatment time (20-40 minutes). The comparison between NF and drug efficacy is also influenced by factors such as drug dosage and time. (4) The therapeutic effects of NF on different subtypes of ADHD vary, and there are also individual differences in children with the same subtype. (5)Psycho-behavioral interventions have a significant promoting effect on NF treatment. To some extent, the promoting effect on certain subtypes even exceeds that of drugs. (6) The treatment mechanisms of EEG-B, medication, and psychotherapy are different, and there are differences in the effectiveness of improving core symptoms, cognitive function, social function, and other aspects of ADHD patients. Each of the three treatments has its own advantages and limitations. Drug therapy for children with ADHD takes effect quickly, but only has short-term efficacy, making them prone to drug dependence and also having side effects; Psychobehavioral therapy and EEG-B do not take effect as quickly as medication, but can maintain long-term efficacy. Psychobehavioral therapy requires specialized psychotherapists, and currently, there is a severe shortage of such talents in China. Therefore, psychological therapy for ADHD is mostly limited to

scientific research and has not been popularized in the community. The implementation of neurofeedback therapy for children with ADHD, also known as EEG biofeedback therapy, requires expensive precision instruments and specialized medical technicians. In other words, only tertiary or above hospitals have the conditions to implement it, and the cost is not low (much higher than drug treatment). Due to factors such as time, space, and economy, many families do not have the conditions for long-term effective neurofeedback therapy. Hong Yuming et al. [44] designed ain-home neurofeedback training system for ADHD children, which to some extent solved the above problems.

3.2 Outlook

In order to make NF treatment more targeted, it is necessary to further explore effective implementation plans (such as course and frequency), and strengthen classification treatment and classification evaluation. Further research is needed to compare the efficacy of NF with traditional Chinese medicine, psychological and behavioral therapies, as well as various combination therapies. Subsequent research also needs to use large sample, multicenter randomized controlled trials to test the reliability and effectiveness of NF. The evaluation of therapeutic effects should not be limited to short-term (within 6 months) evaluations of attention, intelligence, problematic behavior, and academic performance. It is necessary to strengthen the comprehensive evaluation of the physical development, mental state, psychological and behavioral development, as well as quality of life over 6 months.

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