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Application Status and Prospect of Behavioral Training Combined with Electroencephalographic Biofeedback in the Treatment of Children with Attention Deficit Hyperactivity Disorder under the "Integration of Medical and Family Care" Model

Yudan Chen*, Chunxia Ke, Ping Liang, Yantao Li

Maternal and Child Health Hospital of Maoming, Maoming, 525000, Guangdong, China
**Corresponding author*

Abstract: *Attention Deficit Hyperactivity Disorder (ADHD) is a prevalent neurodevelopmental disorder in childhood, with a global incidence ranging from 5% to 10%. Its core symptoms (inattention, hyperactivity, impulsivity) severely impair children's cognitive development, academic performance, and social adaptation, increase the risk of accidental injuries, and impose a heavy care burden on families. Pharmacological treatments, while effective in the short term, are limited by adverse reactions and contraindications, whereas single non-pharmacological interventions lack sustainability and generalization of efficacy. This study aims to systematically synthesize the theoretical basis, application models, and clinical outcomes of behavioral training combined with electroencephalographic biofeedback for attention deficit hyperactivity disorder (ADHD) under the "Integration of Medical and Family Care" model, thereby providing evidence-based support for the development of scientific and effective comprehensive intervention strategies. A literature review was conducted based on the ecological systems theory and chronic disease management model. We analyzed the synergistic mechanisms of electroencephalographic biofeedback (improving neural function by regulating θ/β wave ratio and sensorimotor rhythm) and behavioral training (shaping adaptive behaviors through parental training and positive reinforcement), and systematically summarized their clinical application paths and implementation models. The "Integration of Medical and Family Care" model constructs a synergistic framework of "professional medical intervention + family environmental support" and forms a closed-loop management system of "assessment - intervention - family practice - re-assessment". This model demonstrates significant efficacy in improving ADHD core symptoms, enhancing executive functions, and optimizing family management.*

Keywords: *Attention Deficit Hyperactivity Disorder; Integration of Medical and Family Care; Behavioral training; Electroencephalographic biofeedback; Combined therapy; Literature review*

1. Introduction

Attention Deficit Hyperactivity Disorder (ADHD) is one of the most common chronic neurodevelopmental disorders in childhood, affecting 5% to 10% of children worldwide [1]. The persistent cognitive, academic, and social impairments caused by its core symptoms, coupled with substantial healthcare and family care costs, make it a critical public health concern [2]. Current clinical interventions face prominent challenges: pharmacological therapies (e.g., methylphenidate) can alleviate symptoms temporarily but are associated with adverse effects such as sleep disturbances and appetite loss, and long-term use is contraindicated in some populations [3]; non-pharmacological interventions, such as standalone electroencephalographic biofeedback or behavioral training, suffer from limited efficacy generalization beyond clinical settings and insufficient long-term maintenance [4,5]. The disconnect between "in-clinic neural regulation" and "real-life behavior consolidation" has become a major barrier to effective long-term ADHD management [6].

To address this dilemma, the "Integration of Medical and Family Care" model has emerged, integrating professional guidance from medical institutions with in-depth family participation [7]. This model is not a mere combination of technologies but a closed-loop intervention system grounded in chronic disease management principles [8]. Its core theoretical framework posits that

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electroencephalographic biofeedback can directly remodel neural pathways related to attention and impulse control by targeting θ/β wave ratio regulation and sensorimotor rhythm (SMR) enhancement [9], laying a physiological foundation for behavioral improvement. Simultaneously, systematic behavioral training implemented in the family environment (e.g., positive reinforcement, structured daily routines) facilitates the generalization and consolidation of newly acquired skills in real-life scenarios [10]. This spiral interaction between "neural function remodeling" and "behavioral habit formation" is hypothesized to produce a synergistic effect, enabling comprehensive management of ADHD's chronic nature [11]. However, existing evidence supporting this model remains fragmented, with a lack of systematic synthesis of its theoretical underpinnings, operational protocols, and synergistic mechanisms [12]. This review aims to fill this gap by comprehensively analyzing the theoretical basis, application paths, and clinical outcomes of the "Integration of Medical and Family Care" model, and identifying its challenges and future directions, thereby providing a solid evidence-based foundation for optimizing ADHD non-pharmacological interventions.

2. Research status of the "integration of medical and family care" model

2.1 Theoretical basis

ADHD's etiology and pathogenesis involve complex interactions among genetic, neurobiological, and environmental factors [13,14]. The "Integration of Medical and Family Care" model for ADHD stems from a profound understanding of ADHD as a chronic neurodevelopmental disorder, emphasizing that effective intervention cannot be confined to a single setting but must rely on long-term family engagement and multi-environmental coverage. Guided by the ecological systems theory, individual development is shaped by interactions across multiple environmental layers (microsystem: family, school; mesosystem: home-school collaboration; exosystem: community healthcare) [8]. ADHD behavioral problems often manifest in environmental interactions, necessitating interventions that transcend individual-level approaches to build supportive ecosystems through collaboration among medical institutions, families, and schools [15]. The "Integration of Medical and Family Care" model extends clinical interventions to daily life by linking professional medical guidance with family implementation, achieving systemic support for children.

Drawing on the chronic disease management model, the importance of collaborative participation has been well-established. Given ADHD's chronicity and recurrence risk, intervention focuses not only on symptom control but also on long-term social function improvement [16]. Families, as the primary daily environment for children, play a pivotal role in daily management, behavioral supervision, and emotional support. Studies have confirmed that behavioral interventions with active parental involvement significantly improve treatment adherence and sustain long-term efficacy [17], highlighting the critical role of family engagement in ADHD management. This theoretical framework clarifies the collaborative roles of medical institutions and families, aligning with the "professional guidance + family practice" core philosophy of the Maternal and Child Health Hospital of Maoming and providing robust logical support for model implementation [18].

2.2 Core intervention technologies

2.2.1 Electroencephalographic biofeedback therapy

Electroencephalographic biofeedback therapy is based on operant conditioning principles. Using multi-parameter biofeedback equipment, it converts children's brain electrical activity into intuitive visual or auditory signals, guiding them to autonomously regulate brainwave patterns. Clinically validated protocols include the sensorimotor rhythm (SMR) protocol, θ/β wave ratio protocol, and cortical slow potential (SCP) protocol [4]. The core mechanism involves strengthening beneficial brainwave patterns (16-20 Hz SMR waves) and inhibiting adverse ones (e.g., excessive θ waves), directly improving neural pathway function related to attention and impulse control, and optimizing brain function in children with ADHD [19]. Recent randomized controlled trials have demonstrated that electroencephalographic biofeedback can significantly reduce inattention and impulsivity symptoms by normalizing abnormal brainwave patterns [9].

2.2.2 Behavioral training

Behavioral training targets adaptive behavior development in children with ADHD and equips parents with effective management skills [10]. Parent training components include ADHD disease

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education, behavioral management technique instruction (e.g., positive reinforcement, contingency management), and parent-child communication guidance [20]. It instructs parents to promptly acknowledge and reward positive behaviors (e.g., sustained attention during homework) and establish structured daily routines to enhance self-regulation [10]. For children, structured training (visual tracking exercises, auditory discrimination games, sensory integration training) is designed to improve attention span, impulse control, and executive functions [5]. Implemented in the familiar family environment, this training model translates professional medical interventions into actionable daily practices, enabling continuous behavioral guidance and shaping. Meta-analyses have confirmed that parent-mediated behavioral training significantly reduces ADHD symptom severity and improves family functioning [10,20].

2.3 Implementation process of the "integration of medical and family care" model

The model follows a standardized, individualized closed-loop implementation process, integrating medical professional intervention with family practice.

2.3.1 Baseline assessment and protocol formulation

Led by medical institutions, this stage involves comprehensive assessment to clarify individual characteristics and intervention targets [21]. ADHD diagnosis is confirmed using the *Chinese Classification and Diagnostic Criteria of Mental Disorders (3rd Edition, CCMD-3)* [22], and contraindications are excluded via the Wechsler Intelligence Scale [23]. Symptom severity is evaluated using the ADHD Diagnostic Scale and Conners Parent Questionnaire [21], while visual and auditory attention is assessed through the Integrated Visual and Auditory Continuous Performance Test (IVA-CPT) [23]. Brainwave characteristics and family environmental factors (e.g., parenting styles, family support) are also documented. Based on assessment results, individualized combined intervention plans are developed: electroencephalographic biofeedback parameters (protocol type, treatment frequency, session duration, course length) are determined, and behavioral training is tailored to specific symptom profiles (e.g., visual attention training for inattention-predominant ADHD, impulse control training for hyperactive-impulsive ADHD) . A supporting parent training plan is also formulated to ensure effective family implementation.

2.3.2 Professional intervention and family training

Following informed consent from parents, medical institutions deliver standardized electroencephalographic biofeedback therapy. Professional technicians operate multi-parameter biofeedback equipment, attaching electrodes to the child’s ears, forehead, and parietal region, and guiding brainwave regulation through real-time visual/auditory feedback (e.g., game-based interfaces where progress is linked to desired brainwave patterns). Brainwave data is continuously monitored during sessions, with dynamic parameter adjustments to ensure precise neural regulation [19].

Concurrent systematic parent training adopts a "theoretical teaching + practical demonstration" approach Content includes ADHD pathophysiology, electroencephalographic biofeedback mechanisms, behavioral management techniques (positive reinforcement, behavior modification), structured training operation methods, and parent-child communication strategies. Case analyses, role-playing, and hands-on practice are used to enhance parent competence in implementing family-based interventions independently.

2.3.3 Family practice and continuous supervision

Family behavioral training is integrated into daily life: parents conduct 15-20 minutes of structured training daily (e.g., visual tracking exercises before homework, auditory discrimination games during family time), apply positive reinforcement to encourage adaptive behaviors, and establish consistent routines (e.g., fixed bedtime, homework schedules) . A family intervention log is maintained to record training adherence, symptom changes, and implementation challenges.

Medical institutions provide ongoing supervision and support: offline follow-up visits (every 2 weeks) and online community consultations address parent questions [24]; intervention parameters (biofeedback protocols, training intensity) are adjusted based on family feedback and symptom changes; simplified training procedures are provided for families facing implementation difficulties, while advanced training modules are introduced for children with significant symptom improvement [25]. A parent communication platform facilitates experience sharing and mutual support, enhancing intervention adherence.

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2.3.4 Efficacy evaluation and protocol optimization

Phased efficacy evaluations are conducted by medical institutions and families jointly after each treatment course. Core symptom improvement is assessed using the ADHD Diagnostic Scale and Child Behavior Checklist, visual/auditory attention is re-evaluated via IVA-CPT, and school performance is obtained through the Conners Teacher Questionnaire [26]. Brainwave pattern changes (pre- vs. post-treatment) are compared, and training adherence and family compliance are evaluated using intervention logs.

Based on evaluation results, the intervention plan is optimized: for children with significant symptom improvement, electroencephalographic biofeedback frequency is reduced, with a focus on strengthening family behavioral training [24]; for those with minimal improvement, biofeedback protocols are adjusted (e.g., switching from θ/β ratio to SMR protocol) or behavioral training intensity is increased. After the full intervention cycle, a maintenance plan is developed, including simplified family training modules [25]. Medical institutions conduct monthly follow-up visits for 6 months to monitor efficacy sustainability and adjust strategies as needed.

This closed-loop process achieves "neural-behavioral" synergy: electroencephalographic biofeedback lays the physiological foundation for behavioral change, while family behavioral training consolidates and reinforces these changes, enabling dynamic, individualized intervention optimization [11]. A recent clinical study confirmed that this combined model produces superior outcomes compared to single interventions, with 78% of children showing significant symptom improvement versus 42% in the single biofeedback group and 39% in the single behavioral training group [12].

2.4 Opportunities and challenges

2.4.1 Opportunities

China’s large population base and relatively low physician-patient ratio pose significant barriers to the widespread implementation of behavioral interventions. The "Integration of Medical and Family Care" model leverages family resources to expand intervention coverage, reducing healthcare costs while improving accessibility. Clinical studies have demonstrated that this model significantly enhances visual attention, auditory discrimination, behavioral self-regulation, and self-control in children with ADHD, with particularly pronounced effects in early intervention (preschool to early school age) [24,25]. Electroencephalographic biofeedback combined with behavioral training has also been shown to improve executive functions (working memory, inhibitory control) and reduce family stress [11], making it a promising non-pharmacological intervention strategy for ADHD.

2.4.2 Challenges

Despite its potential, the standardized promotion of the model faces several challenges:

Clinical Challenges: Variability in intervention implementation across medical institutions and inconsistent parent training quality affect efficacy uniformity. There is an urgent need for standardized operation protocols and training for compound talents with expertise in both medical technology and family guidance.

Research Challenges: Most existing studies are small-sample, single-center trials with short follow-up periods, lacking high-quality evidence from multi-center, large-sample randomized controlled trials [9]. Objective evaluation indicators (e.g., neuroimaging, electrophysiological markers) are underutilized, and the synergistic mechanisms between biofeedback and behavioral training remain incompletely understood.

Policy and Resource Challenges: Limited access to electroencephalographic biofeedback equipment in primary healthcare settings and insufficient policy support for family-centered interventions hinder model scalability, the establishment of a "medical institution-community-family" linked service system is needed to improve accessibility .

3. Discussion

The "Integration of Medical and Family Care" model offers a novel approach to long-term ADHD management by integrating professional neural regulation with family-based behavioral shaping [12]. Its core value lies in "neural-behavioral" synergistic intervention: electroencephalographic biofeedback directly targets neural pathway dysfunction, while family behavioral training promotes real-world

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application of therapeutic gains. This closed-loop system effectively overcomes the limitations of single interventions, addressing both the physiological and environmental determinants of ADHD, Clinical evidence confirms that the model not only improves core symptoms but also enhances academic performance, social adaptation, and family functioning, with sustained effects at 6-month and 1-year follow-ups .

However, several critical issues need to be addressed for widespread adoption:

Mechanism Elucidation: Future research should employ neuroimaging (fMRI, DTI) and electrophysiological techniques to explore the neural mechanisms underlying the synergistic effect, clarifying how biofeedback-induced neural changes interact with behavioral training to produce sustained improvement [6].

Individualized Precision Intervention: Development of predictive models based on individual characteristics (symptom subtype, age, neurobiological profile) to identify optimal intervention combinations and parameters, improving treatment personalization [18].

Service System Construction: Strengthening primary healthcare resource allocation, promoting the deployment of biofeedback equipment in community hospitals, and establishing standardized parent training programs to enhance model accessibility and sustainability.

The model's success also depends on addressing contextual factors such as cultural differences in parenting styles and socioeconomic disparities in healthcare access [10]. Future interventions should incorporate culturally tailored parent training and policy support to ensure equitable access [20].

4. Conclusion

The "Integration of Medical and Family Care" model, combining behavioral training with electroencephalographic biofeedback, provides an effective non-pharmacological intervention pathway for children with ADHD. By constructing a closed-loop system of professional medical intervention and continuous family support, the model addresses both the neural and environmental dimensions of ADHD, enabling sustained efficacy generalization to daily life. This review systematically summarizes the model's theoretical basis, core intervention technologies, implementation processes, clinical advantages, and challenges. Evidence confirms its significant efficacy in improving core symptoms, enhancing executive functions, and optimizing family management.

Future research should focus on mechanism exploration (using advanced neuroimaging and electrophysiological techniques), protocol optimization (developing individualized predictive models), and service system construction (establishing "medical institution-community-family" linkage) to promote the model's development toward precision and personalization. This model not only provides a new paradigm for ADHD intervention but also offers valuable methodological insights for the comprehensive management of other childhood neurodevelopmental disorders [8].

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