Review Article

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The Impact of Neurofeedback Training on Midbrain Activity and Symptoms of Attention Deficit/Hyperactivity Disorder (ADHD) in Early Childhood: A Review Study

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Abstract
Attention-Deficit/Hyperactivity Disorder (ADHD) is a neurodevelopmental disorder characterized by hyperactivity, inattention, and impulsivity symptoms that can significantly impair a child's functioning and quality of life. Neurofeedback, a form of biofeedback, has emerged as a promising therapeutic approach for ADHD, utilizing real-time feedback of brain activity to help individuals self-regulate their brain function. This review paper examines the existing literature on the impact of neurofeedback training on midbrain activity and symptoms of ADHD in young children. The review begins with an overview of ADHD and its current treatment approaches, including medication and behavioural interventions. Then it delves into neurofeedback and how it works, focusing on targeting midbrain activity as a potential modality for ADHD treatment. The review discusses findings from empirical studies that have investigated the impact of neurofeedback training on midbrain activity and symptoms of ADHD in young children, including randomized controlled trials (RCTs), quasi-experimental studies, and case studies. Further, critically evaluated the methodological rigor and limitations of the studies, including sample size, study design, and outcome measures used. It also highlights the findings and trends in the literature, including the potential benefits of neurofeedback training in improving midbrain activity and reducing ADHD symptoms in young children. Then, underlying mechanisms of neurofeedback and its potential as a non-pharmacological intervention for ADHD, including long-term effects and the need for further research are discussed. Finally, the researcher summarizes the findings and implications for clinical practice, highlighting the potential of neurofeedback training as an adjunct or alternative treatment for ADHD in young children. The limitations and future directions for research in this area are discussed to establish the efficacy and safety of neurofeedback training for young children with ADHD.

Keywords: ADHD, neurofeedback, midbrain activity, early childhood, treatment

1. Introduction

Attention-Deficit/Hyperactivity Disorder (ADHD) is a neurodevelopmental disorder that affects a significant proportion of children and adolescents worldwide, with a prevalence of approximately 5-10% [1]. The condition is characterized by persistent inattention, hyperactivity, and impulsivity symptoms that can start in early childhood and continue into adulthood, leading to significant impairments in academic, social, and emotional functioning [2].

Interestingly, even in the general population, inattention symptoms are prevalent, with some studies reporting rates as high as 3 to 15% in community samples and 50% or more in clinical referrals [3]. Additionally, several risk factors have been identified as early predictors of attention problems, such as low birth weight, premature birth, prenatal tobacco contact, non-intact family members, young maternal age, paternal history of antisocial behaviour, and maternal depression, as reported by a recent longitudinal study involving over 2000 Canadian children aged five months to 8 years [4].

While medication and behavioral interventions are standard treatments for ADHD, concerns regarding their efficacy, safety, and long-term effects lead to the exploration of alternative and complementary approaches. One such approach is neurofeedback, a non-invasive therapeutic technique that provides real-time feedback on brain activity to help individuals self-regulate their neural function [5]. Individuals can learn to modulate their brain activity and improve their symptoms by presenting the feedback as visual or auditory cues.

Neurofeedback has shown promising results in treating various neurological and psychiatric conditions, including ADHD [6]. In particular, research has suggested that targeting midbrain activity may be helpful in treating ADHD. The midbrain, which includes the reticular activating system (RAS) and the locus coeruleus (LC), plays a critical role in regulating attention, arousal, and alertness [7]. Dysfunction in midbrain activity has been linked to the core symptoms of ADHD, including inattention, hyperactivity, and impulsivity [8]. Therefore, neurofeedback training that targets midbrain activity could be a potential therapeutic option for young children with ADHD.

Neurofeedback is gaining attention as a potential intervention for ADHD. However, the current literature on the impact of neurofeedback training on midbrain activity and ADHD symptoms in young children is limited and inconclusive. To address this

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gap, this review paper aims to systematically examine and analyse existing research on the effects of neurofeedback training on midbrain activity and ADHD symptoms in young children. This paper also attempts to explore the relationship between neurofeedback training and changes in midbrain activity in children with ADHD.

The findings of this review will help us better understand the potential benefits, limitations, and future directions of neurofeedback training as a treatment modality for ADHD in young children.

Overview of ADHD and Current Treatment Approaches

ADHD is a neurodevelopmental disorder affecting children and adolescents, with inattention, hyperactivity, and impulsivity symptoms. These symptoms can cause significant impairments in academic, social, and emotional functioning. Current treatment approaches for ADHD typically include medication, stimulants, and behavioral interventions, such as behavioral therapy and parent training. However, there is growing interest in alternative and complementary approaches, including neurofeedback.

Neurofeedback, also known as EEG biofeedback, is a non-invasive therapeutic technique that provides real-time feedback on brain activity to help individuals self-regulate their brain function. This is typically done through visual or auditory cues, allowing individuals to learn to modulate their brain activity. Neurofeedback can be applied in at least three different ways: (i) as a therapeutic tool for normalizing abnormal brain activity in patients in order to influence symptoms such as motor learning in post-stroke recovery and others [9] or in epilepsy or attention deficit hyperactivity disorder [10-13] (ii) as peak-performance training to improve cognitive performance in healthy participants [14]; and (iii) as brain-state dependent stimulation, an experimental method for studying the causal role of particular neural processes (such as brain oscillations) for behavioural and cognitive functioning [15-17] Neurofeedback treatment protocols primarily concentrate on alpha, beta, delta, theta, and gamma treatment or a combination of these, such as alpha/theta proportion, beta/theta ratio, and so on [18,19]. Delta (less than 4 Hz), theta (4-8 Hz), alpha (8-13 Hz), beta (13-30 Hz), and gamma (30-100 Hz) are the different frequency components that each represent a specific physiological function [20]. According to the findings, the alpha frequency range should be divided into lower alpha (7-9.5 Hz) and upper alpha (9.5-12 Hz). The lower alpha band is linked to attentional processes, whereas the upper alpha band is linked to semantic memory operations [21-23]. If we are comparing children with ADHD and Non-ADHD, in a group of children with ADHD, a high percentage will have an abnormal EEG (increased theta or a high theta/beta ratio); in a group of children without ADHD, a high percentage will have a normal EEG (lower levels of theta or a lower theta-beta ratio) [24]. A study conducted in Iran on children aged 5 to 12 years affected by ADHD found some exciting findings, (i) Neurofeedback is an effective treatment that helps improve selective attention among children (ii) There was no improvement in passive attention associated with computer work [25]. As per the diffident findings, neurofeedback has been used to treat various neurological and psychiatric conditions, including ADHD, with promising results [26].

Midbrain Activity and ADHD:

One area of interest in neurofeedback research for ADHD is targeting midbrain activity. The midbrain, which includes the reticular activating system (RAS) and the superior colliculus (SC), is crucial in regulating attention, arousal, and alertness [27]. At the same time, the research findings show that the RAS, which is made up of groups of neurons, is ultimately responsible for attention, arousal, muscle tone modulation, and the ability to focus [28]. On the other hand, a study by Sreenivasan and Sridharan demonstrated that the human SC has anatomical connectivity patterns with cortical and subcortical structures consistent with its role in specifically modulating choice bias throughout the attention [29]. The midbrain network communicates directly and indirectly with the well-known fronto-parietal network in the forebrain via the thalamus to control the locus of attention [30, 31]. Midbrain activity may aid in explaining perceptual decisions made during an attention task [32]. Several factors are responsible for ADHD; some research findings shows that ADHD may also be caused by low levels of the neurotransmitters such as Dopamine, Serotonin and Norepinephrine [33]. Ernst et al. (1999) revealed that a group of children presenting with ADHD problems had a strong association with an abnormality of dopa decarboxylase in the right midbrain region, research found that the accumulation of [18F] DOPA in the right midbrain was 48% higher in 10 ADHD children than in 10 average children [34]. Dysfunction in midbrain activity has been implicated in the etiology of ADHD, with research suggesting that increased midbrain activity may contribute to the symptoms of ADHD. Therefore, targeting midbrain activity through neurofeedback training may be a promising approach for ADHD treatment.

Targeting Midbrain Activity in Neuro-feedback training for ADHD:

Several empirical studies have investigated the impact of neurofeedback training on midbrain activity and symptoms of ADHD in young children. These studies have utilized various study designs,

including randomized controlled trials (RCTs), quasi-experimental studies, and case studies, to examine the effects of neurofeedback on midbrain activity and ADHD symptoms.

The findings from these studies are promising, with many studies reporting positive effects of neurofeedback training on midbrain activity and ADHD symptoms in young children. For example, a randomized controlled trial by Meisel et al. found that neurofeedback training targeting midbrain activity significantly improved ADHD symptoms in children aged 7-12 [35]. Similarly, a quasi-experimental study by van Dongen-Boomsma et al. showed that neurofeedback training significantly reduced ADHD symptoms in young children [36]. Various studies reported that the dopaminergic midbrain, which includes the ventral tegmental area (VTA) and the substantia nigra (SN), is linked to reinforcement learning, motivation, and decision-making, all of which are frequently disrupted in neuropsychiatric disorders [37, 38]. The mentioned studies demonstrated that neurofeedback training is relevant in treating various psychological or neurological disorders because it operates on operant conditioning principles [39]. Transfer of neurofeedback training is essential for clinical applications, including those involving reward system disorders [40]. Another study revealed that control of midbrain activity might make individualizing neurofeedback training easier [41]. However, some studies have reported mixed results, with some showing limited or no effects of neurofeedback training on midbrain activity or ADHD symptoms. For example, a study by Rahmani et al. found that neurofeedback treatment is not a practical clinical method for ADHD and that more RTCs are needed to compare common treatments [42].

Several Indian studies focused on ADHD and midbrain activation to measure the severity of ADHD problems among children in India. A study states that millions of Indians have ADHD, especially young children [43]. The situation became even worse when the awareness about ADHD and its problems was found to be low among Indian mothers [44]. Some Indian studies focused on the factors that lead to the development of ADHD, including family patterns, socio-demographic conditions, and others [45]. Some studies focused on the neuro mechanism of ADHD. A study by researchers from the Indian Institute of Science denoted the significant role of Superior Colliculus in treating ADHD; the study described that the midbrain region might help treat Attention deficit problems [46]. A review study explored various interventions for the treatment of ADHD, with several studies agreeing that neurofeedback is a promising technique for the treatment of ADHD [47].

Methodological Rigor and Limitations of Studies:

Despite the promising findings, many studies examining the impact of neurofeedback training on midbrain activity and ADHD symptoms in young children have some methodological limitations. These limitations include small sample sizes, lack of control groups, variability in neurofeedback protocols, and short-term follow-up periods. Additionally, some studies lack standardized outcome measures for assessing ADHD symptoms, and there is a lack of consistency in the neurofeedback protocols used across studies.

Furthermore, there needs to be more research on the long-term effects of neurofeedback training. The sustainability of the effects beyond the training period still needs to be well-established. The mechanisms underlying the effects of neurofeedback on midbrain activity and ADHD symptoms are also not fully understood, and further research is needed to elucidate the underlying neural mechanisms.

Implications for Clinical Practice:

Despite the limitations, the findings from the existing literature suggest that neurofeedback training targeting midbrain activity may be a promising adjunct or alternative treatment for young children with ADHD [48].

Neurofeedback has the advantage of being a non-pharmacological intervention, which may be appealing to some families who are concerned about medication side effects or prefer non-pharmacological approaches. Additionally, neurofeedback has been found to have minimal side effects and can potentially be tailored to individual needs, making it a potentially personalized treatment option for children with ADHD.

The findings from the reviewed studies highlight the need for further research with rigorous methodologies, larger sample sizes, more extended follow-up periods, and standardized outcome measures to establish the effectiveness and long-term benefits of neurofeedback training for ADHD in young children. More research is needed to understand the underlying neural mechanisms by which neurofeedback influences midbrain activity and ADHD symptoms.

Neurofeedback can also be combined with other behavioral and psychological interventions for a multimodal approach to ADHD treatment. However, it is essential for clinicians to carefully consider the individual needs and preferences of each child and family and to thoroughly assess the appropriateness and feasibility of neurofeedback training as part of an integrated treatment plan.

In conclusion, The EEG is typically recorded in neurofeedback, and various brain-activity components are extracted and fed back to the subjects. Subjects become aware of developments occurring during training and can evaluate their progress to achieve peak performance. Electrode placement is done based on specific brain functions and symptoms. The entire treatment process is

simplified by remembering the information about these scalp areas. The alpha, beta, theta, and alpha/theta protocols are the most commonly used protocols in neurofeedback training. Neurofeedback training targeting midbrain activity shows promising results in improving symptoms of ADHD in young children. Although the current evidence is still limited, it suggests that neurofeedback may be a valuable adjunct or alternative treatment for ADHD in young children. However, further research with robust methodologies and long-term follow-up is needed to establish the effectiveness, mechanisms of action, and clinical utility of neurofeedback for ADHD. Clinicians should consider each child and family's needs and preferences when incorporating neurofeedback training into their ADHD treatment plans. With continued research and advancements in the field, neurofeedback may become a valuable therapeutic option for young children with ADHD, providing a non-pharmacological approach to addressing their symptoms and improving their overall well-being.

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