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*Review*

# Electroencephalogram (EEG) in ADHD: A Comprehensive Systematic Review of Diagnostic and Therapeutic Applications

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**Abstract:** Attention Deficit Hyperactivity Disorder (ADHD) is one of the most common neuropsychiatric disorders in childhood and can persist into adulthood. Despite its prevalence, diagnosis remains primarily clinical, and it is based on behavioural observation and standardised questionnaires but with few objective tools to validate diagnoses. The use of electroencephalogram (EEG) has emerged as a potential tool to identify neurophysiological biomarkers of ADHD, and research on EEG-based neurofeedback has shown promising results as a therapeutic intervention. This article reviews recent studies looking at the role of EEG in the assessment and treatment of ADHD, with a focus on key findings, current limitations, and future directions.

**Keywords:** ADHD; EEG; neurofeedback; biomarkers; clinical diagnosis; impulsivity; hyperactivity; neurophysiology

## 1. Introduction

Attention Deficit Hyperactivity Disorder (ADHD) is a chronic neurodevelopmental disorder that affects approximately 5% of children and 2.5% of adults worldwide (Polanczyk et al., 2007; Thomas et al., 2015). The main symptoms of inattention, hyperactivity, and impulsivity have a significant impact on the quality of life, academic performance, interpersonal relationships, and social integration of those who suffer from it (American Psychiatric Association, 2013). Since diagnosis of ADHD remains predominantly clinical, growing research in neurophysiology has led to the development of methods using objective measures, such as electroencephalogram (EEG), to complement behavioural assessments.

The EEG measures the brain's electrical activity through electrodes placed on the scalp. It detects the behaviour of brain waves that reflect different mental and cognitive states. Theta (4-7 Hz), alpha (8-13 Hz), and beta (13-30 Hz) brain waves have been extensively studied in ADHD, with evidence of atypical patterns found in those with the disorder. In particular, an increase in the theta/beta ratio has been observed in children with ADHD, suggesting dysfunction in neural networks related to attention control and cognitive inhibition (Clarke et al., 2013).

This article critically reviews the most recent literature on the use of EEG in diagnosing ADHD and its application in therapeutic interventions such as neurofeedback.

## 2. Material and Methods

We searched scientific databases such as PubMed, PsycINFO, Scopus, and Web of Science for this systematic review. The keywords included combinations of "ADHD," "EEG," "biomarkers," "neurofeedback," "brain waves," and "treatment," including studies published between 2000 and 2024 that presented peer-reviewed empirical data on EEG use in individuals with a clinical diagnosis of ADHD. We applied inclusion criteria that required studies to include clinical samples, analysis of brain wave patterns, or evaluation of the efficacy of EEG-based neurofeedback.

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The initial search process identified 153 studies, of which 58 met the inclusion criteria. The selected studies focused on using EEG as a diagnostic tool and neurofeedback as a therapeutic intervention. The studies were grouped into two broad categories: studies on EEG-based diagnosis (32) and studies on neurofeedback (26).

## 3. EEG as a Diagnostic Tool for ADHD

EEG has been widely used in ADHD research due to its ability to identify specific patterns of brain activity associated with the disorder. One of the most consistent abnormalities in children with ADHD is the increased theta/beta ratio, which reflects a dysregulation of the neural networks responsible for sustained attention and inhibition of responses (Barry et al., 2003). This increase in theta activity, associated with states of drowsiness or hypovigilance, and the reduction in beta activity, linked to active attention, has been corroborated in numerous studies (Clarke et al., 2013; Snyder et al., 2015).

Monastra et al. (2001) conducted one of the first studies to demonstrate that the theta/beta index can be a useful clinical biomarker, with a sensitivity of 86% and a specificity of 98% for differentiating children with ADHD from controls. Although this finding has been replicated in multiple studies, its specificity has been questioned, as similar patterns of EEG activity have also been observed in other disorders, such as anxiety or sleep disorders (Lenartowicz & Loo, 2014; Liechti et al., 2013). Despite these limitations, EEG remains a promising tool, especially when combined with other clinical assessment methods. Another subtype of patient with ADHD shows a reduction in Alpha Peak Frequency (APF). The alpha rhythm is predominant in the posterior regions of the brain and increases in amplitude with eye closure; this is the dominant frequency in the EEG spectrogram when the eyes are closed. The APF changes with brain maturation: at one year of age, the AFP should be 6 Hz, at eight years 8 Hz, and 9 Hz between 10-12 years, reaching 10 Hz around the age of 13, remaining stable into old age.

Patients with a reduction in APF exhibit a lower alpha frequency than expected for their age; these patients, who are neurophysiologically distinct from those with an excess of theta waves, show a frontal excess of theta waves, which are actually alpha waves (Arns, 2012).

In clinical settings, EEG offers several advantages as a complementary diagnostic tool. It is a non-invasive and fairly affordable technique that provides objective neurophysiological data to help confirm a diagnosis of ADHD in complex cases. In addition, EEG can detect comorbidities, such as sleep disorders, which are common in ADHD patients (Cortese et al., 2015). However, the lack of standardisation in EEG protocols and the need for specialised personnel limit its widespread use in conventional clinics.

ADHD is a heterogeneous disorder with differentiated clinical subtypes: inattentive, hyperactive-impulsive and combined. Studies examining EEG in these subtypes have found significant neurophysiological differences. For example, children with the inattentive subtype tend to show greater increases in theta waves, while children with the hyperactive-impulsive subtype have an increase in beta waves (Loo & Barkley, 2005; Barry et al., 2003). Another subtype of ADHD, about 20-30%, shows an increase in beta spindling waves in the frontocentral regions, Spindling Excessive Beta (SEB). In their study, Krepel and colleagues, found a clear link between the presence of SEB and impaired impulse control, measured on both self-reported and neuropsychological scales, demonstrating that this is a transdiagnostic trait. Furthermore, it was found that the presence of the beta spindling pattern was not correlated with sleep maintenance issues, contrary to previous studies.

The analysis focused on frontocentral SEB, indicating site specificity for the association with impulse problems. This is consistent with other research suggesting a potential involvement of thalamo-cortical networks in regulating impulsive behaviour (Krepel et al, 2021).

These findings suggest that EEG could help diagnose ADHD in general as well as distinguish between subtypes, which could have important implications for personalised treatment.

## 4. Using EEG-Based Neurofeedback to Treat ADHD

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Neurofeedback is a treatment technique that uses real-time visual or auditory feedback to help patients self-regulate their brain activity.

Regarding ADHD, neurofeedback aims to train patients to reduce excessive theta activity and increase beta activity, thus promoting greater sustained attention and self-control (Arns et al., 2014). Neurofeedback has become a popular therapeutic option because it is non-invasive and does not have pharmacological side effects.

The efficacy of neurofeedback in ADHD has been evaluated in several clinical trials and controlled studies. In a meta-analysis by Arns et al. (2014), neurofeedback was found to significantly reduce symptoms of inattention and hyperactivity compared to placebo and wait-list treatments, with a moderate to high effect size ($d = 0.62$). The authors concluded that neurofeedback is a promising intervention for ADHD, especially in patients who do not respond well to pharmacological treatments.

Other studies have produced positive results. Steiner et al. (2014) conducted a randomised controlled trial that compared neurofeedback to standard pharmacological treatment (methylphenidate). They showed that both treatments were equally effective in reducing the primary symptoms of ADHD. However, some studies have produced more moderate or mixed results, and it has been proposed that variability in treatment methodology and duration may influence the observed outcomes (Thibault & Raz, 2016).

Despite the promising results, neurofeedback faces several challenges in terms of clinical implementation. A significant limitation is the lack of standardisation in treatment protocols. Several neurofeedback modalities focus on modulating the theta/beta index, while others use different brain rhythms, such as alpha or gamma (Escolano et al., 2014). In addition, the duration of treatment is usually long, with between 20 and 40 sessions, which can be costly and require a high level of commitment on the part of the patient.

Another challenge is the possibility that the observed effects are partly attributable to placebo factors. Patient expectancy of receiving an innovative and technologically advanced treatment can influence the results (Thibault & Raz, 2016). This shows the need for placebo-controlled studies to evaluate the effectiveness of neurofeedback compared to sham treatments more rigorously.

Some studies suggest integrating neurofeedback with other therapies, such as medication or cognitive behavioural therapy (CBT), to maximise its therapeutic benefits (Sonuga-Barke et al., 2013). In addition, technological innovations, such as combining EEG with fMRI or incorporating virtual reality environments, could provide more accurate and personalised feedback, optimising results (Rubia, 2018).

## 5. Discussion

The studies reviewed highlight the potential of EEG as a valuable tool for the complementary diagnosis of ADHD. Although the theta/beta index has been shown to be a useful biomarker, more research is needed to improve its specificity and clinical applicability. Advances in wearable EEG technologies could facilitate their use in clinical and educational settings, providing a more accessible and cost-effective assessment for ADHD patients (Banaschewski et al., 2021).

Future studies must investigate combining EEG with other neuroscientific tools, such as fMRI, to get a more complete picture of brain dysfunctions in ADHD. In addition, longitudinal studies examining the durability of neurofeedback effects and their impact on long-term cognitive and emotional functions are required. It would also be useful to explore whether certain subtypes or neurophysiological profiles respond better to this intervention, which would allow for more precise personalisation of treatment.

## 6. Conclusions

EEG has proven to be a valuable tool for both the diagnosis and treatment of ADHD, providing objective data on brain activity that can complement traditional clinical assessments. However, the lack of standardisation in protocols and the interindividual variability in EEG patterns underscore the need for further investigations. Neurofeedback, as an EEG-based intervention, has shown

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promise but requires more placebo-controlled studies and more robust protocols to validate its long-term efficacy.

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