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Consumer-Grade Electroencephalography Devices for the Diagnosis of Neurodevelopmental Disorders in Youth

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ABSTRACT

Background: Consumer-grade electroencephalography devices have become increasingly available over the last decade. These devices have been used in a clinical setting, notably for Neurodevelopmental Disorders.
Aims: The aim of this study was to chart peer-review articles that used currently available consumer-grade electroencephalography devices to support neurodevelopmental disorders diagnosis, identifying neural biomarkers. We provide an overview of the research conducted with Nautilus, Enobio, Mindwave and others. We also inform future research by exploring the current and potential scope of consumer-grade for neurodevelopmental disorders diagnosis in youth.
Methods: We followed a five-stage methodological framework for a scoping review that included a systematic search using the Preferred Reporting Items for Systematic Reviews and Meta-Analyses Extension for Scoping Review (PRISMA- ScR) guidelines. We searched the Pubmed and Web of Science electronic databases, charting study data according to neurodevelopmental disorders diagnosis for attention-deficit/ hyperactivity disorder, autism spectrum disorder, childhood-onset fluency disorder and level of clinical evidence.
Results: We identified 7 studies that used data recorded with consumer-grade electroencephalography evaluating neurodevelopmental disorders in youth. Attention-deficit/hyperactivity disorder diagnosis was the most studied with consumer-grade electroencephalography devices, followed by Childhood-Onset Fluency Disorder. Several methodologies used with consumer-grade electroencephalography devices and give insight into promising electroencephalographic biomarkers for the diagnosis of neurodevelopmental disorders.
Conclusion: Consumer-grade electroencephalography has proven to be a useful tool to support classification and diagnosis of neurodevelopmental disorders. This review provides a comprehensive review of their applications, as well as future directions for the use of these devices under naturalistic clinical settings.
Keywords: mEEG, consumer-grade, CG-EEG, ecological context, neurodevelopmental disorders, children

Introduction

Electroencephalography (EEG) has shown promise as a diagnostic tool for examining adult psychiatric or neurodevelopmental disorders (NDD), encompassing attention-deficit/hyperactivity disorder (ADHD), [1] autism spectrum disorder (ASD),[2] major depressive disorder,[3] dementia,[4] obsessive–compulsive disorder[5] or schizophrenia.[6] For instance, the U.S Food and Drug Administration approved an EEG biomarker, the Theta/Beta Ratio (TBR) for the clinical evaluation[7] of ADHD in July 2013. However, despite their relative ease-of-use, EEG caps, their electrolyte gel preparation or its application often induced discomfort, pain, and skin abrasion in hyperactive and autistic children.[8] Therefore, EEG devices face major challenges in clinical settings regarding invasiveness and comfort, in youth with NDD.

Neurodevelopmental disorders are considered as a clinical construct based on a genetic spectrum continuum and a high rate of comorbidities across these disorders, making their distinction difficult in real-life practice. Dyslexia and ADHD symptoms overlap about 25-40%, indicating a co-occurrence of these disorders.[9] The clinical heterogeneity and the complex etiology of NDD require the identification of biomarkers, including those acquired through EEG, to guide better for developmental outcomes, diagnosis and treatment responses.

Recently, studies on mobile EEG technologies have proliferated due to the compact, wireless nature of consumer-grade EEG (CG-EEG) devices. These systems offer portability, ease-of-use, integration into powerful developmental research designs and real-time monitoring capabilities. This approach is well-suited for pediatric populations in clinical and ecological settings, while offering the opportunity for more breaks between sessions with minimal impact on the data acquisition.[10] Recent developments in dry electrodes[11] further decrease preparation time, by eliminating the need for conductive gel or saline patches, as required in traditional EEG to minimize skin-electrode impedance. Unlike clinical-grade EEG systems which use dense arrays of electrodes (from 32 to 256 electrodes) to capture high-density brain activity, CG-EEG devices typically have fewer sensors (from 1 to 24 channels), strategically positioned over specific scalp regions to detect electrical signals. While their spatial is lower compared to clinical systems, these devices can still detect broad patterns of brain activity and basic neural signatures associated with cognitive and emotional processes.[12-13]

Lastly, CG-EEG devices are designed to be user-friendly and accessible to individuals without specialized training in neurophysiology. They often feature wireless connectivity and smartphone/tablet compatibility, allowing users to visualize their EEG data in real time through intuitive user interfaces and interactive applications. Some devices also offer built-in signal processing algorithms and data analytics tools for interpreting brain activity and track changes over time.

Although less precise than clinical-grade EEG systems, CG-EEG can provide objective neurophysiological data that complement traditional diagnostic methods and offer insights into brain functioning and behavior, facilitating more accurate, holistic and timely diagnoses,[10] particularly in children with NDD.

The present mini-review explores the opportunities and challenges inherent in leveraging CG-EEG as a classification tool or diagnosis for NDD in the pediatric healthcare. Despite growing interest, no prior studies comprehensively address their integration into clinical practice alongside neuropsychological assessments. This review seeks to bridge this gap by demonstrating how CG-EEG can identify reliable biomarkers for NDD diagnosis.

Methods

SEARCH STRATEGY

The review methodology followed the Preferred Reporting Items for Systematic Reviews and Meta-analyses Extension for Scoping Reviews (PRISMA-ScR) guidelines[14] with five stages: i) identify the research question; ii) identify relevant studies; iii) select the studies; iv) chart the data; and v) collate, summarize, and report the results.

A comprehensive search was conducted across the electronic databases PubMed and Web of Science, to identify relevant peer-reviewed journal articles published in the last twenty years (2004– May 2024), focusing on the use of CG-EEG in NDD diagnosis in youth.

The keywords included "neurodevelopmental disorders", "ADHD", "attention-deficit/hyperactivity disorder", "communication disorders", "language disorders", "speech sound disorder", "childhood-onset fluency disorder (stuttering)", "social communication disorder", "specific learning disorders", "developmental coordination disorder", "stereotypic movement disorder", "Tourette syndrome", and "autism spectrum disorder (ASD)". Additionally, search terms encompassed various types of EEG technologies, such as "mobile EEG", "wearable EEG", "ambulatory EEG", "wireless EEG", "flexible EEG", "portable EEG" and “BCI”. The final part of the query focused on "diagnosis”, “detection”, and “classification" of these disorders in “children” or “infants”. The full query is available below.

1. **Search Strategy for Web of Science Database: Population, Intervention, Comparison, and Outcomes (PICO) Framework :**

"neurodevelopment* disorder*" OR "ADHD" OR "attention deficit" OR "attention-deficit" OR "attention-deficit/hyperactivity" OR "hyperkinetic disorder*" OR "communication disorder*" OR "language disorder*" OR "speech sound disorder*" OR "childhood-onset fluency disorder" OR "stuttering" OR "social communication disorder*" OR "pragmatic communication disorder*" OR "specific learning disorder*" OR "development* coordination disorder*" OR "stereotypic movement disorder*" OR "Tourette*" OR "autis*" OR "ASD" AND ("mobile EEG" OR "mEEG" OR "m-electroencephalogra*" OR "wearable EEG" OR "wearable electroencephalogra*" OR "ambulatory EEG" OR "ambulatory electroencephalogra* " OR "wireless EEG" OR "wireless electroencephalogra*" OR "flexible EEG" OR "flexible electroencephalogra*" OR "miniaturized EEG" OR "miniaturized electroencephalogra*" OR "portable EEG" OR "portable electroencephalogra*" OR "BCI")AND ("diagnos*" OR "diagnos* aid" [tiab:~0] OR "diagnos* assistance" [tiab:~0] OR "diagnos* tool" [tiab:~0] OR "diagnos* help" [tiab:~0] OR "detection" [tiab:~0] OR "classification") AND ("child*" OR "infant*")

2. **Search Strategy for PubMed Database: Population, Intervention, Comparison, and Outcomes (PICO) Framework :**

(TS=("neurodevelopment* disorder*" OR "ADHD" OR "attention deficit" OR "attention-deficit" OR "attention-deficit/hyperactivity" OR "hyperkinetic disorder*" OR "communication disorder*" OR "language disorder*" OR "speech sound disorder*" OR "childhood-onset fluency disorder" OR "stuttering" OR "social communication disorder*" OR "pragmatic communication disorder*" OR "specific learning disorder*" OR "development* coordination disorder*" OR "stereotypic movement disorder*" OR "Tourette*" OR "autis*" OR "ASD")) AND (TS=("mobile EEG" OR "mEEG" OR "m-electroencephalogra*" OR "wearable EEG" OR "wearable electroencephalogra*" OR "ambulatory EEG" OR "ambulatory electroencephalogra* " OR "wireless EEG" OR "wireless electroencephalogra*" OR "flexible EEG" OR "flexible electroencephalogra*" OR "miniaturized EEG" OR "miniaturized electroencephalogra*" OR "portable EEG" OR "portable electroencephalogra*" OR "BCI")) AND (TS=("diagnos*" OR "diagnos* aid" [tiab:~0] OR "diagnos* assistance" [tiab:~0] OR "diagnos* tool" [tiab:~0] OR "diagnos* help" [tiab:~0] OR "detection" [tiab:~0] OR "classification")) AND (TS=("child*" OR "infant*"))

Figure 1: Full search query used in the systematic review.
The query was applied to PubMed and Web of Science to identify studies on the use of consumer-grade EEG for NDD diagnosis in children and infants

INCLUSION/EXCLUSION CRITERIA

Studies were included if they 1) Focused on the use of CG-EEG devices, 2) Targeted population comprised individuals under 18 with NDD, including but not limited to autism spectrum disorder (ASD), attention-deficit/hyperactivity disorder (ADHD), and learning disabilities, 3) Addressed the application of CG-EEG devices for diagnostic purposes or related assessments. Studies were excluded if they were 1) Focused solely on clinical-grade EEG devices, 2) Addressed remediation/neurofeedback with EEG, 3) Targeted adult populations or unspecified age group, or 4) Were conference papers, editorials, or opinion pieces without primary data.

Results

A LITERATURE SEARCH

The initial search yielded 51 articles. 10 duplicates were excluded. Selected articles underwent full text screening by two authors independently, with conflicts resolved by a third senior author. After this step, 34 studies were excluded for meeting criteria : studies about “remediation/neurofeedback” (n = 13) ; studies not about mobile EEG (n=7) ; conference papers (n= 5) ; studies not about EEG (n=1) ; studies on adults population (n=2) ; studies about epilepsy (n=4) ; studies not about “Neurodevelopmental Disorders” (n=2) ; paper retracted (n=1).

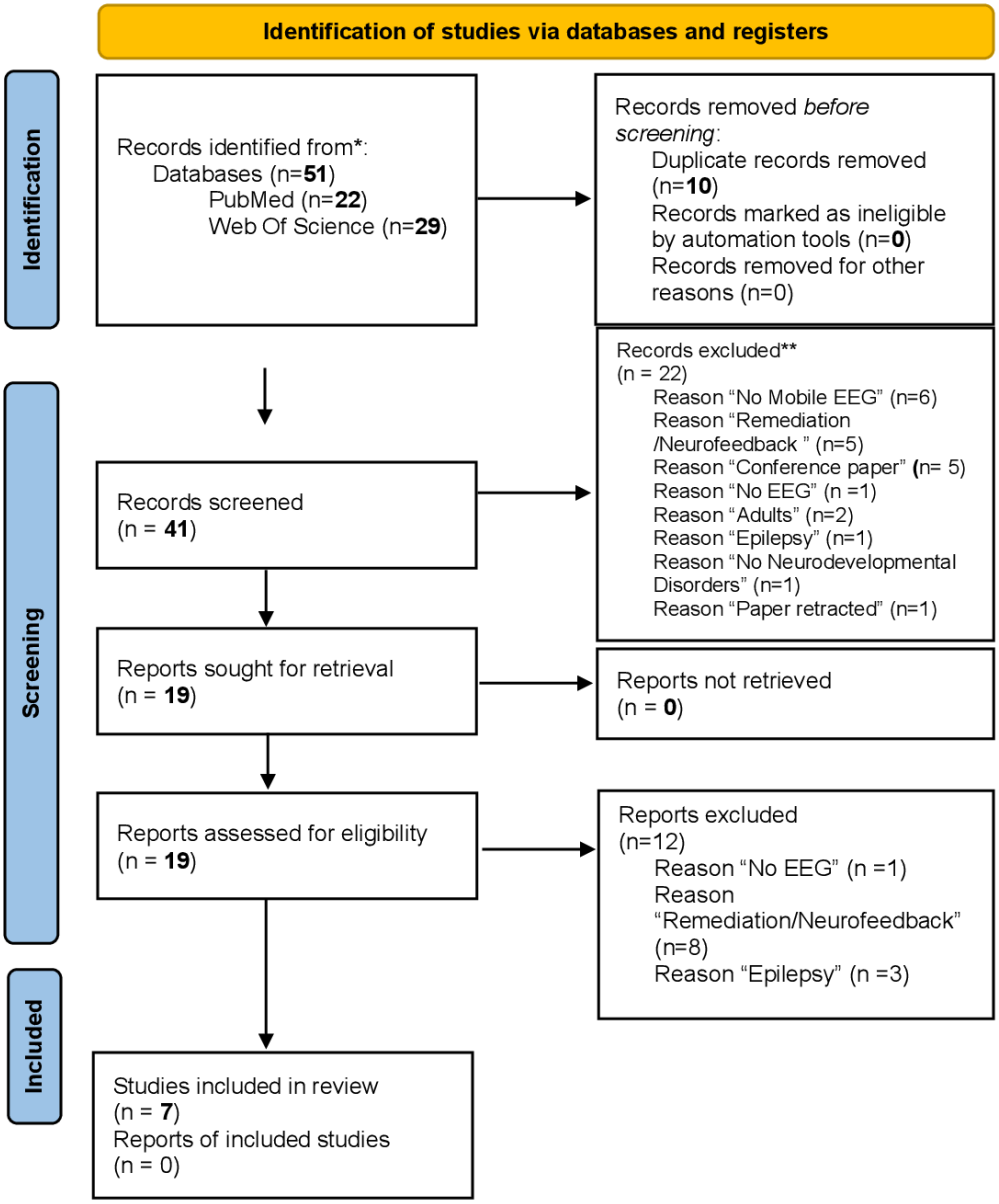

FIGURE 2: Flowchart of the mini-review described according to the PRISMA statement 2020

This PRISMA 2020 flow diagram outlines the study selection process, including identification, screening, eligibility assessment, and inclusion steps. The reasons for exclusion at each stage are specified

Seven studies were finally included in the present review (Table 1). For each study, the following variables were extracted: first author, publication year, consumer-grade device, number of subjects with/without disorders, method, application, EEG measures, and main results. The data were synthesized qualitatively and strongly support that CG-EEG can help to distinguish clinical profiles through specific neural biomarkers that can assist diagnosis for children with NDD.

Study	Devices reviewed	Participants	Method	EEG Measures	Main Results
Al-Nafjan et al., 2018	Enobio, Neuroelectrics	15 children diagnosed with stuttering* 6-13 years	Frontal EEG recording during presentation of visual stimuli SAM assessment; SLP evaluation	PSD: delta (1–4 Hz), theta (4–8 Hz), alpha (8–13 Hz), beta (13–30 Hz) & gamma (30–40 Hz)	EEG-based BCI system is sufficient to differentiate between affective states of individuals in treatment contexts
Chen et al., 2021	A novel eight-channel wearable EEG system	49 children 5-7 years 29 ADHD; 20 TD	EEG recording during K-CPT; DBDRS assessment	PSD: delta, theta, alpha, TBR in frontal, central, parietal, occipital	Significant task-related changes in delta and alpha power in ADHD are in correlations with task performance.
Chen, Lee, et al., 2022a	A novel eight-channel wearable EEG system	70 children 5-7 years 38 ADHD (30 boys; 8 girls) 32 TD (25 boys, 7 girls)	EEG recording during K-CPT; DBDRS assessment	PSD: Central parietal delta (1-4 Hz), alpha (8-13 Hz), and beta (13-30 Hz) powers	Combination of DBDRS, K-CPT, and slow-rate task-related central parietal EEG data could provide the best discriminative validity to diagnose preschool children with ADHD
Chen, Chen, et al., 2022b	A novel eight-channel wearable EEG system	73 children 57 boys; 16 girls 5-7 years 42 ADHD; 31 TD	EEG recording during resting state & K-CPT; DBDRS assessment	PSD: Central delta, parietal delta, parietal alpha, central beta, parietal beta	Task-related neural dynamics reveal specific biomarkers that can assist clinical planning for ADHD, increased delta power from rest to task conditions suggests difficulty in maintaining alertness and stable executive functions.
Lin et al., 2024	BCI, wearable wireless 32-channel EEG cap with semi-dry sponge electrodes, developer: Artise Biomedical Co., Ltd	72 children 8-16 years 53 ADHD (42 boys; 11 girls) 19 TD (14 boys; 5 girls)	EEG recording during CPT and CATA task	FC: alpha, theta, delta, and beta frequency bands analyzed	Significant differences in alpha and theta FC were found between ADHD and TD groups, especially during CATA. FC analysis indicated that CATA combined with CPT could enhance ADHD detection.
McCabe et al., 2023	NeuroSky MindWave	367 children 7-12 years 35 ADHD-C (31 boys; 4 girls) 77 ADHD-I (63 boys; 14 girls) 225 TD (108 boys; 117 girls)	Frontal EEG recording during eyes-closed resting, eyes-open resting, and focus tasks; EDS assessment	Frontal delta and theta power	Significant increase in delta and theta power in children with subtypes of ADHD compared to TD children, more specifically, in the ADHD-C compared to ADHD-I and TD groups
Serrano-Barroso et al., 2021	NeuroSky MindWave	75 children 7-12 years 23 ADHD (18 boys; 5 girls) 52 TD (32 boys; 20 girls)	EEG recording changes during a video game; CARAS-R assessment	PSD: theta/beta ratio SCP	The ADHD group showed lower and more variable attention levels compared to the control group, with significant differences in most game levels. The setup demonstrated potential as a prescreening tool for attention disorders.

TABLE 1: List of literature reviews that include consumer-grade EEG devices for NDD diagnosis purposes

This table presents a selection of literature reviews that include consumer-grade EEG devices for the diagnosis of neurodevelopmental disorders (NDDs), highlighting key methodologies and findings.

List of Abbreviations.

ADHD: Attention Deficit Hyperactivity Disorder;
ADHD-C: Attention Deficit Hyperactivity Disorder-Combined
ADHD-I: Attention Deficit Hyperactivity Disorder – Inattentive
BCI: Brain Computer Interface
CARAS-R: Conners' Continuous Auditory Response Test, Revised
CATA: Continuous Auditory Test of Attention
CPT: Continuous Performance Task
DBDRS: Disruptive Behavior Disorder Rating Scale
EEG: Electroencephalographic
FC: Functional Connectivity
K-CPT: Kiddle Continuous Performance Taks
PSD: Power Spectrum Density
SAM: *Self-Assessment Manikin*
SCP: Slow Cortical Potentials
SLP: Speech Language Pathologist
TD: Typically developing

*Stuttering is part of the Specific Learning Disorders (SLD)

CONSUMER-GRADE EEG

The devices used in the articles included in this review were mainly from 4 commercial companies:

Artise Biomedical Co., Ltd. (n=1), g.tec (n=1), NeuroSky (n=2), Neuroelectronics (n=1), or other devices developed internally device by researchers (n=3). The Artise Biomedical Co., Ltd. device used was a wireless 32-channel EEG cap with semi-dry sponge electrodes. The g.tec system described was the g.Nautilus EEG headset with 16 active electrodes (only eight electrodes were used in the article). The Neurosky device cited was the the MindWave headset with one active electrode. Finally, the studies conducted by Chen and al., used a novel eight-channel wearable EEG system acquisition device with eight semi-dry electrodes called hygroscopic sponge electrode sensors.

These devices differ technologically in their electrode count, use of saline gel or solution preparation or no conductive medium. CG-EEG devices can capture key brain signals, including quantitative EEG (qEEG) and event-related potentials (ERP). qEEG measures the brain's continuous electrical activity detecting brainwave frequencies (delta, theta, alpha, beta, gamma), each associated with cognitive and physiological functions such as focus, relaxation, or alertness. In NDD, abnormal patterns may emerge linked to attention or executive functioning issues. The studies included in this review, all focused on qEEG measures, using techniques like Power Spectral Density (PSD) and relative power analyses to explore neural activity in task and resting-state conditions.

While the preprocessing and artifact removal techniques, such as Independent Component Analysis (ICA), are similar to those used in traditional EEG, ERPs, on the other hand, are time-locked brain responses to specific stimuli, used to study sensory and cognitive processing. Atypical ERP responses, such as delays or reduced amplitudes, can signal impaired cognitive processing or sensory integration difficulties common in conditions like autism and ADHD. These signals help identifying neurophysiological biomarkers, improving diagnosis and early intervention for NDD.

NEUROPSYCHOLOGICAL TESTING & PROTOCOLS

Neuropsychological testing provides valuable insights into cognitive and attentional processes in individuals with NDD. Relevant tests include the Continuous Performance Test (CPT), and the Continuous Auditory Test of Attention (CATA), which in combination with EEG measures improve diagnostic accuracy, by providing objective, real-time data on brain activity that can corroborate the findings from neuropsychological assessments. This multi-modal approach helps to better differentiate.

Wireless wearable EEG was used to quantify brain dynamics during various attention-related tasks, in preschool children diagnosed with ADHD and typically developing (TD) children: the Kiddie Continuous Performance Test (K-CPT),[15-17] the CPT[18] and the Conners Continuous Auditory Test of Attention (CATA).[18] Sustained and selective attention and impulsivity were assessed in children aged 6 to 12 years using the Test of Perception of Differences (CARAS-R), but not during electroencephalographic measures.[19] Task-related stimuli were used during EEG recordings, such as visual stimuli in the K-CPT and CPT or auditory stimuli in the CATA, integral to neuropsychological tests. Only one study[20] combined simple visual stimuli, including fixation on a smiling face and a dynamic attention task with morphing colored shapes with eyes-open (EO) and eyes-closed (EC) resting-state recordings while another one combined simple visual stimuli in a clinical setting, where participants viewed images, described their thoughts, and expressed emotions with EEG, speech, and behavioral responses.[21] Finally, interactive tasks, such as gamified paradigms,[19] engaged children in dynamic, real-time scenarios that highlighted attentional variability and impulsivity, offering valuable data for pre-screening attention disorders.

In addition to neuropsychological tasks, clinical questionnaires such as the Disruptive Behavior Disorders Rating Scale (DBDRS) were completed by both parents and teachers in the different studies.[15-18] Alternatively, the K-SADS-PL interview and the ADHD Rating Scale-IV (ADHD RS-IV) in McCabe et al[20] were also administered to parents, to differentiate participant groups and provide a comprehensive understanding of cognitive and behavioral symptoms. To classify typically developing (TD) children from ADHD children, attention was evaluated through clinical and neuropsychological assessments, in combination with excessive daytime sleepiness (EDS) using the Children's Self-Report Sleep Patterns - Sleepiness Scale (CRSP-S).[20] Sustained and selective attention, as well as impulsivity, were assessed in children aged 6 to 12 years with the Test of Perception of Differences (CARAS-R), not during electroencephalographic measures.[19] Al-Nafjan et al[21] assessed stuttering severity in fifteen children using the Stuttering Severity Instrument (SSI), focusing on duration, frequency of stuttered syllables, and physical concomitants to cluster participants

into groups based on stuttering severity, rather than identifying EEG biomarkers.

The diversity in these assessments highlights the range of methods used to evaluate attention in children with ADHD (and potentially other disorders). The combined use of neuropsychological testing, questionnaires, and neural biomarkers identified through wireless EEG system open the way towards improved diagnosis and monitoring treatment outcomes in NDD children.

IDENTIFICATION OF BIOMARKERS

Several EEG-based biomarkers have shown potential for improving the diagnosis of NDD, particularly in the case of ADHD (Table 1).

Increased delta power and reduced alpha and beta power during slow-rate tasks were reported as significant neural biomarkers of ADHD.[15-17] Children with ADHD showed significantly increased delta power and decreased alpha power, particularly in central and parietal regions when evaluated with slow-rate tasks as compared to TD.[17] Moreover, significant correlations were found between EEG power and K-CPT performance, highlighting the potential for task-based EEG to monitor ADHD-related behaviors and serve as a real-time diagnostic tool.

Task-related EEG dynamics were explored in preschoolers with ADHD, distinguishing between high (ADHD-H) and low (ADHD-L) cognitive proficiency, using wireless EEG headsets during slow-rate and fast-rate tasks.[15] ADHD children showed increased delta power during tasks suggesting a developmental lag and cognitive proficiency modulated EEG patterns, with ADHD-L children exhibiting more pronounced delta and theta power changes. Their findings suggest that slow-rate task-related neural dynamics differentiate ADHD groups from typically developing (TD) children, while fast-rate dynamics unravel ADHD heterogeneity. McCabe et al[20] explored EEG characteristics in ADHD subtypes, finding increased delta and theta power in ADHD-Combined (ADHD-C) compared to ADHD-Inattentive (ADHD-I) and TD children, reflecting symptom severity. While inconsistent with previous research, they also observed elevated frontal alpha power in ADHD-C. Importantly, excessive daytime sleepiness (EDS) moderated EEG effects, particularly in ADHD-C, where high EDS was linked to reduced alpha and beta power. These findings suggest that task-related brain dynamics, rather than resting-state EEG, better capture the attentional dysfunction in ADHD.

Attention performance differences were also reported between ADHD and control groups using the GokEvolution EEG-BCI game application that is based on real-time neurofeedback.[19] Children with ADHD exhibited lower and more variable attention scores during the task than TD children, supporting the potential of EEG coupled with a gamified BCI-based interventions for tracking and modulating attentional biomarkers. These differences were particularly observed in the theta and beta frequency bands, with ADHD children showing a higher theta/beta ratio, a well-established marker of attentional dysfunction.

Functional connectivity deficits could also serve as potential biomarkers for ADHD when observed during neuropsychological testing. Differences in alpha and theta functional connectivity (FC) in the temporal region, were observed between ADHD and TD groups, particularly under CPT and CATA conditions.[18]

Only one study addressed the identification of biomarkers for diagnostic purpose in children with speech disorders by combining clinical data and EEG signals.[21] Investigators found a relationship between EEG-measured emotional states, and the treatment but did not identify specific neural signatures that could serve as biomarkers for diagnostic purposes. However, they highlighted potential overlaps between EEG and visual tools for measuring emotions, such as the Self-Assessment Manikin (SAM) and Speech Language Pathologist (SLP) evaluations.

Discussion

Consumer-grade electroencephalography devices offer significant opportunities for exploring brain activity in children due to their ease of use, quick setup, and reliance on widely available wireless protocols for signal capture. However, very few studies reported their use in clinical and pediatric settings with only 7 out of the 51 retrieved manuscripts meeting criteria for inclusion.

Based on the studies included in the review, alpha and delta power signals in the parieto-central brain region extracted from most CG-EEG offer consistent biomarkers for attention and for ADHD in children, while though other biomarkers independent of the NDD conditions show less agreement, likely due to the signal quality during acquisition. However, reliable ERPs were reported in several studies with CG-EEG devices in adults[22] and children.[23] Furthermore, both spectral analyses in EEG, such as resting-state, and event-related potentials (ERPs) such as N170, N200, P300 waves[22-26] were comparable to those observed with clinical EEG systems, known as the « gold standard ».[10]

Interestingly, most of the studies reported have attempted EEG biomarker identification for NDD diagnosis through a multimodal approach that combines electrophysiological measures, neuropsychological testing, and behavioral and cognitive questionnaires.[15-18] With over 90% diagnostic accuracy, this multimodal approach highlights the importance of combining methods for ADHD diagnosis[16] and offers a more comprehensive framework for understanding the complexities of neurodevelopmental conditions in youth.[27] ‘

Using CG-EEG for diagnosing NDD in children poses several limitations. While offering accessibility and convenience, their reduced number of sensors and lower spatial resolution result in less precise localization of brain activity and decreased sensitivity to subtle neural changes. Their signal quality is more susceptible to artifacts and environmental interference, potentially impacting data reliability. The interpretation of EEG data from these devices can vary due to differences in specifications, electrode placement and complicate reproducibility across studies. CG-EEG studies often have small sample sizes, leading to reduced statistical power and limiting the generalizability of findings. Finally, these devices

sometimes lack regulatory validation as clinical systems, raising concerns about their safety, reliability, and diagnostic validity.

To enhance the use of CG-EEG devices in NDD diagnosis, future efforts should focus on optimizing electrode placement, reducing movement and noise artifacts, and improving signal quality with dry and semi-dry electrodes. Standardized protocols and shared guidelines would facilitate their integration into large-scale studies, while also enabling naturalistic condition studies "out of the laboratory," like those in Serrano-Barroso's work, combining EEG with video games to maximize engagement and the ecological validity of the assessments.[19]

In summary, CG-EEG devices could support clinicians in diagnosis of children with ADHD or stuttering and monitor over time brain activity patterns associated with attention, arousal, and emotional regulation in these children. They could also help monitor EEG changes, providing insights into intervention effectiveness and guiding treatment adjustments. Clinicians should consider integrating CG-EEG data with other clinical information and standardized assessments to ensure multimodal, comprehensive and accurate diagnostic evaluation of NDD in children.

However, these challenges must be addressed to ensure reliable, ethical, and valid use in pediatrics and further research is needed to fully assess their clinical utility.

Beyond the hardware challenges, the challenges of CG-EEG reside in the application and performance of modeling algorithms such as deep neural network (DNN), as used by Al-Nafjan.[21] This classifier analyzed EEG data coupled with other signal types, such as speech and behaviors, that resulted into enhancing the understanding of emotional and cognitive processes. Techniques like Support Vector Machines (SVM), Convolutional Neural Networks (CNN), and Long Short-Term Memory (LSTM) networks, could improve the interpretation of brain-computer interfaces' signals to ease the NDD classification and detection, especially with analysis combining heterogenous data.[28]

To optimize the application of CG-EEG devices for NDD, future research should address hardware variability and protocols standardization. Integrating advanced machine learning methods, alongside multi-modal data could improve diagnostic accuracy. Finally, large-scale validation studies are needed to establish the clinical reliability of these devices, fostering their integration into routine pediatric healthcare.

Conclusion

Consumer-grade electroencephalography devices represent a promising opportunity for the assessment of neurodevelopmental disorders in children, offering increased accessibility, portability, and ease of use compared to traditional clinical EEG systems. Our mini review highlights their potential in identifying neural biomarkers associated with NDD, particularly ADHD, and underscores their clinical relevance in understanding the underlying mechanisms of these disorders. Despite key limitations - such as reduced spatial resolution, susceptibility to artifacts and the need of standardized protocols - CG-EEG has demonstrated encouraging results, particularly when integrated into a multimodal approach combining neuropsychological testing and behavioral assessments, which enhances its effectiveness and clinical utility. Importantly, these findings provide clinicians and researchers with valuable information on potential neural markers that could aid in early intervention planning, including individualized training and educational programs. CG-EEG paves the way for more comprehensive and ecologically valid diagnostic approaches. Future research should focus on refining signal processing techniques, improving machine learning algorithms for data interpretation, and validating these devices in larger clinical cohorts to establish their reliability in routine practice. Addressing these aspects will be essential to fully leverage CG-EEG as a viable tool to support diagnosis and intervention in pediatric populations.

Conflicts of Interest Statement

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