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# Electroencephalographic changes in children with attention deficit hyperactivity disorder

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## Abstract

**Background** Attention deficit hyperactivity disorder (ADHD) is the most prevalent psychiatric disorder in children who experience delayed language development. This work aimed to study electroencephalographic (EEG) changes in children with ADHD and establish a strategy for prompt identification and suitable management in the future.

**Methods** This descriptive cross-sectional study was conducted on 100 children aged between 5 and 12 years old, both sexes, diagnosed with ADHD according to DSM-V Criteria, diagnosed as ADHD children with the Arabic version of Conner's Parent Rating Scale. Psychometric evaluation by intelligence quotient (IQ) using Stanford Binet Intelligence test. The Receptive Expressive Arabic Language Scale was used to assess language profile.

**Results** There was a significant negative correlation between the severity of ADHD and IQ scores. There was an insignificant negative correlation between ADHD and scaled receptive language score and scaled expressive language score. There was an insignificant positive correlation between ADHD and scaled expressive language score. There was a significant difference between EEG changes and combined subtype of ADHD and scaled score of receptive language ($P < 0.05$). There was an insignificant difference between (EEG changes and language development), the scaled score of expressive, total language, and the scaled score of language.

**Conclusions** EEG has clinical utility in the diagnosis of ADHD. The results of EEG analysis in children with ADHD have been quite important, and this novel methodology could offer supplementary factors to strengthen its diagnostic impact.


**Keywords** Electroencephalography, Attention deficit hyperactivity disorder, Intelligence quotient, Language

## Background

Among neurodevelopmental disorders, attention deficit hyperactivity disorder (ADHD) is reportedly the most prevalent [1]. Approximately 3–8% of school-aged children in the general community exhibit all three hallmark symptoms of inattention, impulsivity, and hyperactivity [2]. As per the Diagnostic and Statistical Manual of Mental Disorders-V (DSM V), there are three distinct forms of ADHD: mainly inattentive, mostly hyperactive/impulsive, and mixed [3]. Males manifest ADHD at significantly higher rates than females. ADHD is thought to affect boys at a rate two to three times higher than girls. Girls are referred for examination and treatment up to nine times less frequently than boys. This might be attributed to the fact that males with ADHD show more externalizing hyperactive disruptive behavior than their female counterparts. Girls usually tend to cluster in the inattentive subtype [4].

Children with ADHD have delayed language development at a rate of 48.6%, making it the most common

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psychiatric condition among children with delayed language development [5].

The co-occurrence of ADHD and epilepsy has been the subject of numerous theories. The majority of children with ADHD who are in preschool while school age is linked to epilepsy [6]. ADHD is a serious possibility in children with epilepsy. The comorbidity of ADHD symptoms is seen in 20% of children with epilepsy [7].

ADHD electroencephalography (ECG) has been around for over 75 years with Jasper et al. (1938) [8] presenting a cluster of "behavior problem children" with slowed EEG rhythms at fronto-central sensors, a possible sign of aberrant brain function characterized as extremely unpredictable, impulsive, and hyperactive.

Recorded across front-central electrodes, the most robust EEG characteristic linked to ADHD is an increase in the power of slow waves (4–7 Hz "theta") and a reduction in the strength of rapid waves (14–30 Hz "beta"). The theta/beta ratio may also be used to quantify this effect [9].

Children with epilepsy and ADHD may struggle socially and behaviorally as they grow up [10].

Children with epilepsy have a better quality of life when their behavioral issues are diagnosed and treated correctly, although psychosocial factors do not contribute significantly to ADHD etiology but represent an important role in the severity and persistence of ADHD symptoms [11].

This research aimed to study electroencephalographic changes in children with ADHD to prepare for future intervention in the form of early diagnosis and appropriate management.

## Methods

This descriptive cross-sectional study was conducted on 100 children aged between 5 and 12 years old, both sexes, diagnosed with ADHD rendering to DSM-V Measures [12], diagnosed as ADHD children with the Arabic version of Conner's Parent Rating Scale (CPRS) [13] at Phoniatric unit, Minya university hospital from the period between March 2020 to august 2021. The research was done after approval from the Ethical Committee Minya University Hospital, Minya, Egypt (approval code: 219/02/2021). The family of the patient provided informed written consent.

Children less than 5 or older than 12 years, associated neuropsychiatric disorders and associated hearing impairment or any brain insults were excluded from this study.

### Preliminary diagnostic procedures

The parental interview and history, spanning prenatal to postnatal periods, along with developmental milestones and childhood illnesses, precede examinations covering neurological and ENT aspects. Additionally, subjective Auditory Perceptual Assessment (APA) evaluates language and speech.

### Clinical diagnostic aids

The audiological assessment encompassed middle ear evaluation via immitancemetry, which includes tympanometry and recording of acoustic reflex thresholds, along with hearing evaluation. Depending on the child's age, hearing assessment utilizes one of the following methods: free field audiometry and Behavioral Observational Audiometry (BOA), pure tone audiometry (conditioned play or conventional audiometry), and auditory brainstem response (ABR). Psychometric evaluation by intelligence quotient (IQ) using the Stanford Binet Intelligence test [13]. The Arabic version of the PRS: this scale underwent translation into Arabic and subsequent validation [14].

### Language test

The REAL scale (Receptive Expressive Arabic Language Scale) was employed to evaluate the language profile of children in the study. This scale comprises multiple tests designed to assess receptive and expressive Arabic language abilities in children aged 5–12 years old. Each test functions as an independent assessment, providing its own scaled score, confidence interval, decibels, and quartiles. The outcomes of the REAL scale offer insights into the severity of language difficulties as follows: A language standard scaled score of 86 or above indicates age-appropriate language skills, while scores ranging from 78 to 85 suggest mild language delay. Moderate language delay is indicated by scores falling between 70 and 77, and a score at or below 70 signifies severe language delay [15].

### Electroencephalogram

All children diagnosed with ADHD underwent comprehensive evaluations, including sleep EEG recordings, overseen by a pediatric neurology instructor. The EEG recordings were meticulously scrutinized to identify epileptiform activity, considering its type, location, and laterality. Notably, all participants were medication-free during the testing period, with those on anti-epileptic medications ceasing usage at least 12 h before assessment.

### Statistical analysis

All statistical analyses were conducted utilizing SPSS, version 20. The initial data-cleaning process involved identifying missing values and invalid responses. Descriptive statistics were employed to present quantitative data, with means and standard deviations utilized, while qualitative data were depicted through frequency distributions. Proportions were compared using the chi-square test and Fisher exact test, whereas the Student's *t*-test was employed for comparing two means, and the ANOVA test for comparing multiple means. A significance level of $p < 0.05$ was adopted for all analyses, and two-tailed tests were conducted throughout.

## Results

Demographic data, neonatal, infant, and medical history are shown in Table 1.

According to Stanford-Binet intelligence scales, below-average scores were found in 72% of ADHD cases, and Average scores were found in 28% of ADHD cases. According to CPRS of ADHD, subtypes were found to be 28% of combined types, 48% of the hyperactive type, and 24% of the inattentive type. Mild ADHD symptoms were found in 28% of cases, moderate symptoms were found in 48% of cases and severe were found in 24% of ADHD cases. Sleep EEG was obtained from all of the patients diagnosed with ADHD. EEG findings were found to be normal in 46% (46/100) of the cases and abnormal in 54% (54/100). Focal EEG changes were found in 38% of cases with EEG changes and Generalized EEG changes were found in 16% of Cases with EEG changes. According to Real Scale Arabic Language, 76% of cases were found to be delayed in receptive language score, 78% in expressive language score, and in74% in total language score (Table 2).

There was a significant difference between EEG changes and the combined subtype of ADHD and scaled score of receptive language ($P < 0.05$). There was an insignificant difference between.

EEG changes and, the scaled score of expressive and total language (Table 3).

There was an insignificant difference between the severity of ADHD and IQ, receptive language score, expressive language, and total language score (Table 4).

There was a significant negative correlation between the severity of ADHD and IQ scores. There was an insignificant negative correlation between ADHD and scaled total language scores (Table 5).

## Discussion

ADHD is recognized as the primary neurobehavioral disorder in children, marked by persistent traits of hyperactivity, impulsivity, and inattentiveness [16].

The incidence of EEG alterations was observed to be greater in the combined type of ADHD compared to other subtypes. Epileptic EEG findings in this study were most commonly observed in the combined type (44.4%), then the hyperactive type (37.03%), and the inattentive type (18.5%). This agrees with another study in Turkey which found that in the captivating realm of ADHD research, investigation unveiled a compelling narrative: 21.9% of cases bore the electric crackle of epileptic abnormalities, while 15.2% pulsed with the dynamic rhythm of non-epileptic discharges. There were EEG alterations with focal discharges in 14.5% of cases [17].

In this study, 72% of ADHD cases were below-average IQ and 28% were with average IQ with a significant *P* value (0.047) below (0.05). These results attributed to that ADHD can affect children's ability to focus and this can significantly hinder their ability to accomplish various

**Table 1** Demographic data, neonatal, infant, and medical history of the studied cases

| | | ***N* = 100** |
|---|---|---|
| Age (month) | | 89.70 ± 29.74 |
| Sex | Male | 66(66.0%) |
| | Female | 34(34.0%) |
| Order | First | 4(4.0%) |
| | Second | 32(32.0%) |
| | Third | 28(28.0%) |
| | Fourth | 36(36.0%) |
| Consanguinity | | 58(58.0%) |
| Neonatal history | | |
| Maternal history | | 3(3%) |
| Type of labor | Normal | 72(72.0%) |
| | SC | 28(28.0%) |
| Weight at birth | Normal | 40(40.0%) |
| | Low birth weight | 60(60.0%) |
| Resuscitation | | 51(51.0%) |
| Cyanosis | | 57(57.0%) |
| Icterus | | 63(63.0%) |
| Infant history | | |
| Feeding | Breastfeeding | 56(56.0%) |
| | Artificial | 22(22.0%) |
| | Both | 22(22.0%) |
| Family history of ADHD | | 82(82.0%) |
| Subjective impression of hearing | Good | 100(100.0%) |
| | Poor | 0(0.0%) |
| Inner language | Developed | 100(100.0%) |
| | Not developed | 0(0.0%) |
| History of seizure | | 18(18.0%) |
| Medical history | | |
| History of drug for ADHD | | 54(54.0%) |
| Duration of treatment(month) | | 3.48 ± 3.95 |
| History of previous language therapy | | 72(72.0%) |

Data are presented as mean ± *SD* or frequency (%). *CS* Cesarean section, *ADHD* attention deficit hyperactivity disorder

**Table 2** Case evaluation

| | | ***N*** **= 100** |
|---|---|---|
| I.Q | Below average<br>Average<br>Above average | 72(72.0%)<br>(28.0%)<br>0(0.0%) |
| Audiological evaluation | Normal | 100(100.0%) |
| | Abnormal | 0(0.0%) |
| Conners | Combined | 28(28.0%) |
| | Hyperactive | 48(48.0%) |
| | Inattentive | 24(24.0%) |
| EEG | Normal | 46(46.0%) |
| | Mild focal changes | 38(38.0%) |
| | Generalized changes | 16(16.0%) |
| Receptive language score | | 103.16 ± 45.76 |
| Scaled score of receptive language score<br>Normal<br>Delayed | | 76.46 ± 15.20<br>24(24.0%)<br>76(76.0%) |
| Expressive language score | | 156.70 ± 69.56 |
| Scaled score of expressive language score<br>Normal<br>Delayed | | 78.48 ± 10.12<br>22(22.0%)<br>78(78.0%) |
| Total language score | | 253.42 ± 76.09 |
| Scaled score of total language score<br>Normal<br>Delayed | | 78.36 ± 12.89<br>26(26.0%)<br>74(74.0%) |
| Delayed language development | Normal | 26(26.0%) |
| | Delayed | 74(74.0%) |

Data are presented as mean ± SD or frequency (%). *IQ* intelligent quotient, *EEG* electroencephalography, *ADHD* attention deficit hyperactivity disorder

**Table 3** EEG changes according to CPRS, scaled language scores (receptive. expressive, total)

| | | **EEG changes** | | | ***P*** |
|---|---|---|---|---|---|
| | | **Normal (*n*=46)** | **Epileptic changes (54)** | | |
| Conners | Combined | 4(8.7%) | 24(44.4%) | | <0.0001* |
| | Hyperactive | 28(60.9%) | 20(37.03 %) | | |
| | Inattentive | 14(30.4%) | 10(18.5 %) | | |
| Language test (Real scale) | | Normal (n=46) | | Epileptic changes (n=54) | |
| Scaled score of receptive language | Normal | 16(34.8%) | | 8(14.8%) | 0.013* |
| | Delayed | 30(65.2%) | | 46(85.2%) | |
| Scaled score of expressive language | Normal | 12(26.1%) | | 10(18.5%) | 0.127 |
| | Delayed | 34(73.9%) | | 44(81.5%) | |
| Scaled score of total language | Normal | 14(30.4%) | | 12(22.2%) | 0.118 |
| | Delayed | 32(69.6%) | | 42(77.8%) | |

Data are presented as Mean ± *SD* or frequency (%). *Significant *p*-value <0.05, *EEG* Electroencephalography, *ADHD* Attention deficit hyperactivity disorder, *CPRS* Conner's parent rating scale

routine tasks and affect cognitive abilities. Moreover, in children with hyperactive ADHD, the inclination toward television viewing could elucidate this observation, as many mothers turn to television as a means to manage their children's hyperactivity and mitigate disruptive behaviors. However, it is worth noting that television offers passive stimulation, which may impact cognitive functions. This is in agreement with another study done by Antshel et al. (2010) [18] who discovered that individuals possessing high IQs alongside ADHD were more

**Table 4** Severity of ADHD according to IQ score, the scaled score of receptive language, the scaled score of expressive language, and total language

| | | Severity of ADHD | | | P |
|---|---|---|---|---|---|
| | | Mild (n=28) | Moderate (n=48) | Sever (n=24) | |
| IQ | Below average | 18(64.3%) | 32(66.7%) | 22(91.7%) | 0.047* |
| | Average | 10(35.7%) | 16(33.3%) | 2(8.3%) | |
| Scaled score of receptive language | Normal | 8(28.6%) | 12(25.0%) | 4(16.7%) | 0.080 |
| | Delayed | 20(71.4%) | 36(75.0%) | 20(83.3%) | |
| Scaled score of expressive language | Normal | 8(28.6%) | 10(20.8%) | 4(16.7%) | 0.078 |
| | Delayed | 20(71.4%) | 38(79.2%) | 20(83.3%) | |
| Scaled score of total language | Normal | 8(28.6%) | 14(29.2%) | 4(16.7%) | 0.082 |
| | Delayed | 20(71.4%) | 34(70.8%) | 20(83.3%) | |

Data are presented as Mean ± *SD* or frequency (%). * Significant *p*-value <0.05, IQ: Intelligent Quotient, *ADHD* Attention deficit hyperactivity disorder

**Table 5** Correlation between severity of ADHD, IQ, and the scaled score of total language

| | ADHD | |
|---|---|---|
| | r | *P* |
| IQ | -0.225 | 0.024* |
| Scaled score of total language | -0.060 | 0.555 |

r Pearson coefficients, *significant *p*-value <0.05, *IQ* Intelligent Quotient, *ADHD* Attention deficit hyperactivity disorder

prone to experiencing decreased cognitive functioning. In contrast to this study, a study by Wood et al. (2011) [19] demonstrated no association between ADHD and diminished IQ levels. Lower intelligence quotient scores and the apparent correlation between ADHD and lower cognitive performance might not solely indicate reduced intelligence. Rather, it could stem from impaired working memory and slower processing speed, as proposed by a 2014 study conducted in Germany on 116 ADHD cases [20].

In the current study, a significant delay in language development in ADHD cases, the scaled score of receptive language was delayed in 76% of ADHD cases, the scaled score of expressive language was delayed in 78% of ADHD cases scaled score of total language was delayed in 74% of ADHD cases. This agrees with Geurts and Embrechts (2008) [21] who found delays in receptive and expressive language. An alternative interpretation suggests a shared neurological basis, as both ADHD and language disorders may arise from pathological changes, particularly involving the frontal lobe and basal ganglia [22].

In the current study, delayed language development was detected in 74% of ADHD cases. It is significantly higher in cases with EEG changes (77.7%) than in cases with normal EEG (69.6%). This phenomenon may be attributed to the intricate relationship between language development and active processes like hearing and listening. The delay in language development could stem from challenges in maintaining focused and sustained attention to auditory stimuli in the environment. Furthermore, negative parenting styles, characterized by neglect and unfavorable maternal comments, may exacerbate ADHD symptoms, hindering the child from experiencing a conducive environment for language development. Additionally, impairments in working memory, which are closely linked to language abilities, could also contribute to these delays. Delayed language development in ADHD children with EEG changes was higher in this study than in ADHD children without EEG changes, this may attributed to ADHD children with EEG changes having more slow waves (Theta waves) which is especially pronounced during reading and listening tasks. Furthermore, these findings led to the suggestion that under-arousal and maturational delay may serve as underlying pathophysiological mechanisms in ADHD [23]. Based on this ratio, it is crucial to consider language abilities during assessments of children with ADHD. Furthermore, incorporating ADHD screening tools can offer valuable insights when evaluating children with developmental language disorder (DLD).

Limitations of this study include that the sample size was relatively small. It was a single-centre study. So, we recommend routine EEG analysis for ADHD cases even if there is no history of seizures. In the follow-up stage, close monitoring of ADHD patients is essential. Consideration should be given to initiating antiepileptic therapy, particularly in cases where underlying risk factors and seizure occurrences are present.

## Conclusions

ADHD diagnosis requires a multifaceted approach, incorporating developmental history, rating scales, cognitive tests, and EEG analysis. No single method ensures complete accuracy, necessitating reliance on multiple data sources. EEG analysis yields significant insights into ADHD, with potential for further innovation. Enhancing diagnostic precision entails continued refinement of test batteries. Integrating EEG with other clinical measures optimizes diagnostic accuracy and understanding of ADHD in children.

**Abbreviations**

| | |
|---|---|
| ADHD | Attention deficit hyperactivity disorder |
| ABR | Auditory brainstem response |
| APA | Auditory Perceptual Assessment |
| BOA | Behavioral Observational Audiometry |
| CPRS | Conner's Parent Rating Scale |
| DLD | Developmental language disorder |
| DSM V | Diagnostic and Statistical Manual of Mental Disorders-V |
| EEG | Electroencephalographic |
| ECG | Electroencephalography |
| IQ | Intelligence quotient |
| REAL scale | Receptive Expressive Arabic Language Scale |

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**Authors' contributions**
All authors contributed to the study's conception and design. Material preparation, data collection, and analysis were performed by Z.K., A.O.S., and E.A.Z.. The first draft of the manuscript was written by M.A.E. and Z.K. All authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

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**Availability of data and materials**
The datasets used and analyzed during the current study are available from the corresponding author on reasonable request.

## Declarations

**Ethics approval and consent to participate**
The research was done after approval from the Ethical Committee Minya University Hospital, Minya, Egypt (approval code: 219/02/2021). The family of the patient provided informed written consent.

**Consent for publication**
Not applicable.

**Competing interests**
The authors declare that they have no competing interests.

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