Austin Child & Adolescent Psychiatry

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Research Article

Comparison of Quantitative Electroencephalography (qEEG) Indices in Children with Attention Deficit-Hyperactivity Disorder and Healthy Children

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Received: July 22, 2016; **Accepted:** September 20, 2016; **Published:** September 22, 2016

Abstract

Background: Electroencephalographic (EEG) indices provide objective and useful measures of ongoing brain activity. They may have a role in ADHD diagnosis. This study aims at evaluating the findings of quantitative EEG (QEEG) in children with ADHD.

Methods: In this cross-sectional controlled study, 30 male children with ADHD aged 6-12 years were compared with 30 male age-matched healthy children. The QEEG was performed in all participants and the data with regard to the brain waves were compared between the two groups.

Results: Regarding the band type, generalized decrease in absolute power of “high-beta” waves was found in the ADHD group. The power ratio of alpha, beta, delta and theta waves to high-beta wave were increased in the ADHD group in decreasing order. The recorded waves from the frontal, parietal and occipital lobes, with different absolute power between the two groups, were demonstrated to have a significant preponderance in children with ADHD. This preponderance was in favor of the control group in the temporal lobe. There was not a significant difference in central region between the two groups.

Conclusion: According to our results, generalized decrease in absolute power of “high-beta” waves was a constant finding in ADHD children.

Keywords: Attention deficit/hyperactivity disorder; ADHD; Electroencephalography; Quantitative

Introduction

Attention Deficit Hyperactivity Disorder (ADHD) is one of the most common reasons for referral of youth to out-patient child and adolescent psychiatric clinics, with many adverse outcomes and complications [1]. This accounts for the necessity of accurate and timely diagnosis of the disorder and the subsequent administration of appropriate treatment. In the existing diagnostic systems, pathological behaviors are the basis for the diagnosis of this disorder [2]. Such a diagnostic procedure has major drawbacks; first, relying on behavioral indicators and caregivers’ reports or even medical observations may be subject to cultural requirements, and expectations, tolerance levels or even the personal condition of the evaluator [1]. On the other hand, similar behaviors might have different underlying causes that essentially allow one to question whether the disorder is identical in nature [3]. The stated flaws in the diagnostic system as well as attempts towards finding a more accurate treatment based on the underlying pathology have led researchers to examine brain functions under such a condition. In this regard, one of the critical research lines has been in the field of Electroencephalography (EEG). In the past 30 years, EEG has been repeatedly used to find differences between healthy children and those with ADHD, which has yielded significant results. These results consist mainly of an increase in slow-wave activity and a decreased activity of the high-frequency waves [3,4]. However, the results of these studies were heterogeneous [5-7]. On the other hand, as the symptoms of the psychiatric disorders may have a cultural nature, obtaining similar objective results among Iranian patients to what has been obtained in the aforementioned studies would help up verify the identical nature of what is known and treated as ADHD in Iran with that in the other countries. So, we carried out the present study with the aim of investigating the quantitative EEG (QEEG) indices in Iranian children with ADHD.

Materials and Methods

In this cross-sectional controlled study, 64 children ranging from 6-12 years of age were enrolled in two groups: 32 male children with ADHD were selected through convenience sampling method and 32 male age-matched healthy children (control group) were enrolled randomly from the city. Finally, two patients from each group withdrew from the study and investigations were conducted on 30 remaining patients in each group. The research setting was the Imam Reza Hospital’s EEG Center, Tabriz-Iran. The case group consisted of 30 boys with ADHD and no history of psychiatric drug treatment, based on initial clinical diagnosis of children performed by a child and adolescent psychiatrist. To rule out IQ Problems, children were referred to a clinical psychologist to undergo an IQ test by The *Wechsler Intelligence* Scale for Children (WISC). In case of absence of intellectual disability, a neurologist would visit the patients. If there were no signs of neurological or physical illnesses, a psychiatry resident would confirm the diagnosis ADHD through semi-structured

Citation: Malek A, Shahrokhi H, Amiri S, Ayromlou H, Safaiyan A and Nasiri M. Comparison of Quantitative Electroencephalography (qEEG) Indices in Children with Attention Deficit- Hyperactivity Disorder and Healthy Children. Austin Child Adolesc Psychiatry. 2016; 1(1): 1003.

diagnostic interview using Kiddie Schedule for Affective Disorders and Schizphrenia – Present & Lifetime version (K-SADS-PL) [8] and look for other psychiatric disorders. In the absence of any intervening psychiatric disorders, the child was introduced to undergo QEEG. 30 healthy male children (control group) in the same age range were selected from the city of Tabriz using a multi-stage sampling method. These children were selected and added to the present study from a concurrent ongoing epidemiological study of child and adolescent psychiatric disorders in Tabriz, Iran, based on the results of the initial screening as the healthy children. The health of this group was verified through diagnostic psychiatric interview using Kiddie-SADS and neurological examinations. Quantitative EEGs in this group were conducted with the same conditions as those in the case group. 10 artifact-free traces, prepared through the standard mode, were selected for quantitative analysis. Based on the frequency band, waves were divided into Delta (1-3.5 Hz), theta (4-7.5 Hz), Alpha (8-12 Hz), beta (12.5-25 Hz) and high beta (25.5-30 Hz) groups. The locations of the recorded waves included the frontal, central, parietal, occipital, and temporal lobes. Moreover, the closed/open eye condition was considered at the time of recording. Waves were analyzed with regard to three aspects: Absolute power (AB), Relative power (RE), and Power ratio (PR). This research has been approved by the Ethics Committee of Tabriz University of Medical Sciences. The obtained data were expressed in the form of mean ± standard error (Mean ± SE), as well as frequency and percentage. The statistical software used in this study was SPSS™ version 15. Comparisons were made *via* Independent Samples T-test. Results with P<0/05 were regarded as statistically significant.

Results

30 male children with ADHD (case group), and 30 healthy male children (control group), were included in the study. The mean age of children in the control group was 10.5±0.2 years, and the mean age of the case group was 10.0±0.2 years. In this regard, there were no statistically significant differences between the two groups (p=0/114).

QEEG analyses for absolute power of waves are summarized in Table 1 with statistically significant differences between the two groups. In this regard, the mean absolute power of beta waves in the temporal lobe, and that of the delta waves in the frontal lobe were higher in the case group compared to the control group. The mean absolute power of high beta waves in the central, frontal, and the temporal regions were higher in the control group than the case group.

QEEG analyses for power ratio of waves are summarized in Table 2 with statistically significant differences between the two groups. In this regard, the mean power ratio of alpha to high beta waves in the frontal and occipital lobes, beta to high beta in the central, frontal, occipital and parietal lobes, delta to beta in the frontal lobe, delta to high beta in the frontal lobe, and theta to high beta in the parietal, central, frontal, and the occipital lobes were higher in the case group than the control group. The mean power ratio of delta to alpha waves and delta to theta waves in the central region was higher in the control group.

QEEG analyses for relative power of waves, with statistically significant differences between the two groups are summarized in Table 3. In this regard, the mean relative power of delta waves in the occipital lobe, and high beta in the central, frontal, occipital, parietal and temporal lobes were higher in the control group compared to the case group.

Table 1: Quantitative EEG analyses for absolute power of waves (included only those with statistically significant differences between the two groups).

Waves	Control (n=30) Mean ± SE	ADHD (n=30) Mean ± SE	p- Value
Beta T^4 Open eye	8.9± 0.7	11.6 ± 1.0	0.042
Delta F^8 Open eye	36 ± 2.9	45 ± 2.7	0.027
High Beta C^3 closed eye	0.5 ± 0.1	0.4± 0.0	0.01
High Beta C^3 Open eye	0.5 ± 0.1	0.3 ± 0.0	0.06
High Beta C^4 closed eye	0.5 ± 0.1	0.3 ± 0.0	0.009
High Beta C^4 open eye	0.5 ± 0.1	0.3 ± 0.0	0.005
High Beta F^3 closed eye	0.9 ± 0.1	0.7 ± 0.1	0.036
High Beta F^3 open eye	0.9 ± 0.1	0.7 ± 0.1	0.036
High Beta F^4 closed eye	1 ± 0.1	0.7 ± 0.1	0.033
High Beta F^7 open eye	2.3 ± 0.2	1.7 ± 0.1	0.018
High Beta F^Z closed eye	0.8 ± 0.1	0.4 ± 0.0	0.004
High Beta F^Z open eye	0.7 ± 0.1	0.4 ± 0.0	0.004
High Beta T^6 closed eye	2.2 ± 0.2	1.5 ± 0.1	0.003
High Beta T^6 open eye	2.5 ± 0.3	1.7 ± 0.1	0.015

Table 2: Quantitative EEG analyses for power ratio of waves (included only those with statistically significant differences between the two groups).

Waves ratio	Control (n=30) Mean ± SE	ADHD (n=30) Mean ± SE	P-Value
Alpha / High Beta F_Z closed eye	11.6± 1.6	18.7 ± 3.0	0.043
Alpha / High Beta O_1 closed eye	56.3 ± 7.3	81.9 ± 8.3	0.025
Alpha / High Beta O_1 Open eye	29.9 ± 3.6	41.9± 4.7	0.046
Beta / High Beta C_3 closed eye	7.1 ± 0.5	8.7 ± 0.6	0.02
Beta / High Beta C_4 closed eye	7.1 ± 0.5	8.8 ± 0.5	0.038
Beta / High Beta C_4 Open eye	7 ± 0.5	8.7 ± 0.5	0.031
Beta / High Beta C_Z closed eye	6.3 ± 0.3	8 ± 0.5	0.006
Beta / High Beta C_Z Open eye	6 ± 0.3	7.6 ± 0.5	0.009
Beta / High Beta F_3 Open eye	6.3 ± 0.4	7.4 ± 0.4	0.048
Beta / High Beta F_4 closed eye	6.3 ± 0.4	7.5 ± 0.5	0.038
Beta / High Beta F_4 Open eye	5.9 ± 0.4	7.4 ± 0.4	0.012
Beta / High Beta F_Z closed eye	6.9 ± 0.5	9 ± 0.7	0.02
Beta / High Beta O_1 closed eye	11.3 ± 0.7	14 ± 0.9	0.022
Beta / High Beta P_4 closed eye	9.3 ± 0.7	11.6 ± 0.7	0.022
Beta / High Beta P_4 Open eye	8.7 ± 0.6	11 ± 0.7	0.024
Beta / High Beta P_Z closed eye	8.3 ± 0.5	10.5 ± 0.7	0.023
Beta / High Beta P_Z Open eye	8.1 ± 0.5	10.3 ± 0.7	0.008
Delta / Alpha C_Z closed eye	2.9 ± 0.3	2.2 ± 0.2	0.043
Delta / Alpha C_Z open eye	3.2 ± 0.3	2.5 ± 0.2	0.049
Delta / Beta F_8 closed eye	3.5 ± 0.2	2.5 ± 0.2	0.026
Delta / High Beta F_7 Open eye	20.2 ± 1.5	26.8 ± 2.5	0.031
Delta /High Beta F_8 closed eye	23.6 ± 1.8	32.8 ± 2.3	0.007
Delta / High Beta F_8 Open eye	20.5 ± 1.5	29 ± 2.1	0.002
Delta / High Beta F_Z Closed eye	24.7 ± 2.3	31.5 ± 2.5	0.049
Delta / theta C_Z Closed eye	1.7 ± 0.1	1.3 ± 0.1	0.047
Delta / theta C_Z Open eye	1.8 ± 0.1	1.2 ± 0.1	0.018
Delta / theta F_8 Open eye	2 ± 0.1	2.3 ± 0.1	0.032
theta / High Beta C_3 closed eye	10.3 ± 1.0	13.2 ± 1.0	0.029
theta / High Beta C_3 Open eye	9.2 ± 0.8	12.5 ± 1.0	0.017
theta / High Beta C_4 closed eye	10.2 ± 1.0	13.6 ± 1.0	0.041
theta / High Beta C_4 Open eye	9.2 ± 0.9	13 ± 1.0	0.007
theta / High Beta C_Z closed eye	16.1 ± 1.6	21.6 ± 1.9	0.028
theta / High Beta C_Z Open eye	15 ± 1.4	19.6 ±1.8	0.046
theta / High Beta F_4 closed eye	11.1 ± 1.0	15.1 ± 1.6	0.036
theta / High Beta F_4 Open eye	9.6 ± 0.9	13.6 ± 1.4	0.015
theta / High Beta F_7 closed eye	11.6 ± 0.9	15.7 ± 1.7	0.034
theta / High Beta F_7 Open eye	9.9 ± 0.8	12.9 ± 1.2	0.047
theta / High Beta F_8 closed eye	12.6 ± 1.2	16.8 ± 1.2	0.028
theta / High Beta F_Z closed eye	15.2 ± 1.6	21.2 ±1.8	0.016
theta / High Beta F_Z Open eye	14.7 ± 1.3	19.5 ± 1.6	0.022
theta / High Beta O_2 Open eye	16.3 ± 1.2	20.6 ± 1.7	0.046
theta / High Beta P_4 closed eye	15.9 ± 1.3	21.7 ±2.2	0.028
theta / High Beta P_4 Open eye	13.5 ± 1.2	17.2 ±1.5	0.039
theta / High Beta P_Z Open eye	17.9 ± 1.6	23.3 ±2.1	0.046

Table 3: QEEG analyses for relative power of waves (included only those with statistically significant differences between the two groups).

Waves	Control (n=30) Mean ± SE	ADHD (n=30) Mean ± SE	P-Value
Delta O1 Closed eye	25.2± 1.7	20.8 ± 1.4	0.048
High Beta C3 Closed eye	2.7 ± 0.3	1.9 ± 0.1	0.031
High Beta C3 open eye	2.8 ± 0.3	2.1± 0.1	0.04
High Beta C4 Closed eye	2.7 ± 0.3	1.9 ± 0.1	0.026
High Beta C4 open eye	2.9 ± 0.3	2 ± 0.1	0.027
High Beta Cz Closed eye	2.1 ± 0.2	1.6 ± 0.1	0.044
High Beta F7 Closed eye	2.1 ± 0.1	1.7 ± 0.1	0.024
High Beta C7 open eye	2.5 ± 0.2	2 ± 0.1	0.025
High Beta F8 Closed eye	2.1 ± 0.2	1.6 ± 0.1	0.018
High Beta F8 open eye	2.5 ± 0.2	1.8 ± 0.1	0.017
High Beta Fz Closed eye	2.1 ± 0.3	1.4 ± 0.1	0.012
High Beta Fz open eye	2 ± 0.2	1.5 ± 0.1	0.014
High Beta O1 Closed eye	1 ± 0.1	0.7 ± 0.1	0.009
High Beta O1 open eye	1.3 ± 0.1	1.1 ± 0.1	0.034
High Beta O2 Closed eye	1.1 ± 0.1	0.8 ± 0.1	0.018
High Beta P4 Closed eye	1.7 ± 0.2	1.2 ± 0.1	0.029
High Beta P4 open eye	2 ± 0.3	1.4 ± 0.1	0.032
High Beta T6 Closed eye	2 ± 0.3	1.3 ± 0.1	0.017
High Beta T6 open eye	2.7 ± 0.3	1.9 ± 0.1	0.026

Comparing waves in terms of the location where recording took place, the mean absolute power of high beta waves, alpha to delta and delta to theta mean power ratios, and the mean relative power of high beta waves in the central region were higher in the control group than the case group. The mean power ratios of beta to high beta and theta to high beta waves in the central region were higher in the case group compared to the control group.

The mean absolute power of beta waves in the frontal lobe was higher in the control group than the mean absolute power of delta waves. Power ratios of alpha to high beta, beta to high beta, delta to beta, delta to high beta, delta to theta, theta to high beta were higher in the case group compared to the control group in the frontal lobe.

In the occipital lobe, the mean relative powers of high beta and delta waves were higher in the control group compared to the case group. On the other hand, in the occipital lobe, the mean power ratios of alpha to high beta, beta to high beta, and theta to high beta, and the mean relative power of high beta were higher in the case group compared to the control group.

In the temporal lobe, the mean relative power of high beta was higher in the control group compared to the case group and the mean absolute power of beta waves was higher in the case group compared to the control group.

Discussion

In the present study we investigated the quantitative EEG findings in children with ADHD compared to healthy children. The results showed that the mean absolute power of high beta waves is significantly lower in ADHD children. In terms of location, the recorded waves from the frontal, parietal and occipital lobes, with different absolute power between the two groups, were demonstrated to have a significant preponderance in children with ADHD. This preponderance was in favor of the control group in the temporal lobe. There was not a significant preponderance in central region between the two groups in this regard. These results could help clinicians making definite diagnosis in complicated patients and might be an objective measure for controlling the course of disorder as well as response to treatment.

Despite the numerous studies conducted in the field of EEG on children with ADHD, the reported results vary. The number of QEEG studies in this field is limited. Dykman et al. investigated the electrocortical frequencies in hyperactive, learning-disabled, mixed, and normal children. They could specify a multi-frequency component with highest loadings in frequencies from 16 to 20 Hz as well as 7 to 10 Hz to be sensitive to children with hyperactivity symptoms and learning disability [9]. Callaway et al. investigated the differences in EEG findings of 18 children with ADHD and 18 normal children. In this research, the power of beta was reported to be lower in hyperactive children compared to the control group [10]. Chabot and Serfontein reported differences in EEG findings among 407 children with ADHD compared to the control group. In children with ADHD the power of Theta wave was increased. Their records could distinguish normal children from those with ADHD with a high sensitivity and specificity. Both patterns of EEG slowing and an increase in EEG activity were noted in these children [11]. In another study, Lazzaro et al. investigated 54 male adolescents with ADHD and the same number of healthy adolescents. It was shown that the relative and absolute activity of alpha and theta increased and the relative activity of beta decreased [12]. Lazzaro et al. again reported an increase of theta activity in children with ADHD [13]. The result of our study on the decrease of power of high-beta waves in ADHD children was consistent with the above-mentioned studies. In this context, *via* considering the absolute power of the other waves, there were no significant differences between the two groups. The differences in the power ratio of waves (including the increased ratio of alpha, beta, delta, and theta to high beta in the case group) can be accounted for by considering the decreased power of high beta waves in the ratio denominator. Lazzaro et al. (1998) investigated differences in EEG findings between 26 teenage boys diagnosed with ADHD and the control group. The results indicated an increase in the power of theta and alpha waves in the frontal region and a decrease in the relative power of beta waves in the occipital region [14]. Considering the increase in the power of waves in the frontal lobe, the results of the stated study are consistent with the findings of the present study and can be an objective guide for clinical diagnosis, especially in presence of other comorbidities. However, we also showed the increase of the relative power of waves in the occipital region of patients. Clarke et al. studied the EEG differences between 20 children with ADHD, 20 children with ADHD and learning disability, and 20 healthy children. Results indicated that among the clinical groups, in comparison with the control group, the absolute and relative powers of alpha and beta waves were lower and the relative powers of delta and theta waves were higher. The group of patients in the posterior region had decreased absolute power of alpha and beta, and decreased relative power of delta, theta, and alpha waves. They also had a lower relative power of beta in the frontal region.

According to the results of this study, the ratios of theta/alpha, and theta/beta were able to differentiate case and control groups from each other [15]. Lubar calculated the ratio of theta/beta in 25 children with ADHD and 27 healthy children during the act of painting. In children with ADHD this ratio was higher than healthy children, but most of the differences were seen in the frontal lobe [16]. Ucles and Lorente reported that children with ADHD had a lower alpha/theta ratio than normal children in the occipital region [17].

As mentioned earlier, the results of the various studies in the field of QEEG findings in ADHD are highly varied. In summing up the results of various studies in this field, increased activity of the slow waves in the frontal region, increased power of the theta and delta waves and decreased power of alpha and beta waves in ADHD children and in comparison with healthy children are notable [18-24]. The results of the present study are also similar, in some aspects, to those reported above. However, we need to take into account that the status of the patients at the time of study in different studies can have a significant effect on the obtained results. Snyder and Hall conducted a meta-analysis, including the results of 9 studies of the quantitative EEG in 1498 ADHD children. They concluded that many of these studies have variable and unreliable results due to flaws in methodology (for example in retrospective studies) [25]. According to Clarke et al. many of the findings of QEEG in ADHD children are influenced by the concurrent brain pathological conditions. However, in their study the increase in the power of beta waves has been emphasized and dysfunction in the frontal lobe has been attributed for this [26].

Moreover, it has been previously shown that the results of EEG will vary according to the patients' eyes being open or closed [27]. In the present study, the results of EEG were recorded in both open and closed eyes. Moreover, the other reason for failure to achieve definite results in the area of QEEG findings in ADHD may be the nature of the ADHD itself and indeed its different subtypes [18]. According to Bresnahan et al. the predominant symptoms of ADHD may be related to the findings of the EEG, so that in the more hyperactive children the power of the beta is decreased; whereas in the more impulsive children the power of the theta is increased. Furthermore, they have raised the role of increasing age in QEEG findings in ADHD and showed a decrease in the extent of the reduction in relative beta activity in the ADHD groups [28].

There have been some limitations in the present study, including the lack of determining the differentiating cut-off points between the ADHD and healthy children groups due to the small sample size, not including female subjects, and not considering the role of different sub-types of ADHD on the results of the study.

Conclusion

According to our results, generalized decrease in absolute power of "high-beta" waves was a constant finding in ADHD children. These findings may be employed as a reference for future studies, determining factors for prognosis or for the treatment of ADHD.

Determining the appropriate cut-off points based on a careful distinction between different significant parameters among patients and healthy subjects with larger sample size is recommended. Also, similar studies are recommended for female children and different ADHD subtypes.

Acknowledgement

The authors are thankful to all parents and children participating in this study. The paper was adopted from doctoral dissertation of Dr Mahmoud Nasiri with the Reg. No. of 87/3-6/13 from Tabriz University of Medical Sciences.

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Austin Child Adolesc Psychiatry - Volume 1 Issue 1 - 2016
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Citation: Malek A, Shahrokhi H, Amiri S, Ayromlou H, Safaiyan A and Nasiri M. Comparison of Quantitative Electroencephalography (qEEG) Indices in Children with Attention Deficit- Hyperactivity Disorder and Healthy Children. Austin Child Adolesc Psychiatry. 2016; 1(1): 1003.