

Quantitative EEG Analysis in Children with Attention Deficity/Hyperactivity Disorders

Dikkat Eksikliği/Hiperaktivite Bozukluğu Olan Çocuklarda Kantitatif EEG Analizi

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SUMMARY

Attention deficit hyperactivity disorder (AD/HD) in children and adolescents is characterized by excessive restlessness and extremely poor concentration span, resulting in impulsive and disruptive behaviour. Increased slow wave activity and decreased beta activity, predominantly in posterior regions, have been reported in AD/HD. We performed this cross-sectional study to determine and compare hemispheric and regional differences in children with AD/HD and age-sex matched children by using the quantitative EEG (QEEG) analysis. We evaluated 24 children with AD/HD who were diagnosed by DSM-IV criteria and 21 age-sex matched controls. The clinical evaluation and EEG analysis, during the baseline and hyperventilation, had been performed by the same specialist. Visual analysis of EEG records did not show any important abnormality, but QEEG analysis performed decreased theta activity during basic state, decreased delta, increased alpha and beta activities during hyperventilation. Hemispheric asymmetry, a relationship between wave frequencies (delta and theta), and male gender and age, especially in left frontotemporal regions, have been seen in children with AD/HD.

As for conclusion, QEEG analysis can be accepted as a beneficial technique providing objective and physiologically based data currently available for clinical assessment, and some features can be added to the neurobiological basis of AD/HD. (*Nöropsikiyatri Arşivi* 2007; 44: 19-27)

Key words: Attention deficit hyperactivity disorders (AD/HD), quantitative EEG, delta power, slow wave asymmetry, regional difference.

ÖZET

Çocuk ve ergenlerde dikkat eksikliği hiperaktivite bozukluğu (DEHB) aşırı huzursuzluk ve dikkat aralığının çok dar olması ile karakterize olup dürtüsel ve yıkıcı davranışlara yol açan bir tablodur. DEHB olan çocuklarda posterior bölgelerde hakim olmak üzere yavaş dalga aktivitesinde artış ve beta aktivitesinde azalma sıklıkla bildirilmiştir. Bu kesitsel çalışmayı DEHB tanısı alan çocuklar ve kontrollerde kantitatif EEG analizi kullanarak ortaya çıkan değişiklikleri saptamak ve gerek hemisferik, gerekse bölgesel farklılıkları karşılaştırmak amacı ile gerçekleştirdik. Biz DSM-IV'e göre DEHB tanısı alan 24 çocuk ve 21 yaş -cins uyumlu kontrolü değerlendirdik. Aynı uzman tarafından istirahat durumunda ve hiperventilasyonda klinik değerlendirme ve EEG analizi yapıldı. EEG kayıtlarının görsel olarak değerlendirilmesinde herhangi bir anormallik saptanmadı ancak KEEG analizinde istirahat durumunda teta aktivitesinde azalma, hiperventilasyonda ise beta ve alfa aktivitelerinde artışa eşlik eden delta aktivitesinde azalma kaydedildi. DEHB tanısı alan çocuklarda hemisferik asimetri, sol frontotemporal bölgede hakim olmak üzere dalga frekansları ile (delta ve teta) erkek cinsiyeti ve yaş arasında anlamlı ilişki saptandı.

KEEG analizinin DEHB'nun klinik değerlendirmesinde objektif ve fizyolojik temelli veri sağlayan yararlı bir yöntem olarak kullanılabileceği ve hastalığın nörobiyolojik temeline katkısı olacağı sonucuna varıldı.

Anahtar kelimeler: Dikkat eksikliği hiperaktivite bozukluğu (DEHB), kantitatif EEG, delta power, yavaş dalga asimetrisi, bölgesel fark. (*Archives of Neuropsychiatry* 2007; 44: 19-27)

Introduction

Attention-deficit/hyperactivity disorder (AD/HD) refers to a variable cluster of hyperactivity, impulsivity and inattention symptoms, affecting the normal cognitive and behavioural functioning of the individual (4). Although AD/HD is characterized by decreased attention span and impulsivity, increased motor activity can also be a clinical feature in some individuals (17).

According to the DSM-IV, the disorder has 3 main types: predominantly inattentive (AD/HDin), predominantly hyperactive-impulsive (AD/HDhyp), and combined type (AD/HDcom) (2). AD/HD is one of the most common disorders that can be treated by a psychiatrist (7). The prevalence has been estimated approximately 3 to 5% at school-age children in DSM-IV, and has been reported as 3-6% in studies based on the DSM-IV criteria (2,15,23).

Among the investigational approaches to AD/HD patients EEG is a common method, providing information about the electrical activity of the brain and the scalp recorded signal provides a diffuse picture that underlying activity. By this recording method, valuable information about the brain with high temporal resolution can be elicited. So the EEG is a useful method that achieves information on the background activity of the brain and indexes the substrate of cognition and behaviour (4). Although no specific EEG pattern has been identified, excessive background slow activity and rare paroxysmal activity have been reported in these patients (17).

Different abnormalities have been reported about EEG changes in AD/HD patients in recent studies. Although the EEG findings of AD/HD and control groups have been compared with each other in these studies, most of them did not identify the nature of the abnormalities exactly. But increased activity of delta and theta bands were the most common findings seen in this methodology which was commonly consisted in digital EEG reports (4).

A newer technique, computerized power spectral analysis, permits the topographic representation and statistical analysis of EEG. The use of digital EEG has been recommended by the American Academy of Neurology and the American Association for Clinical Neurophysiology. Proposed indications for quantitative EEG (QEEG) include epilepsy, cerebrovascular diseases, dementia, postconcussion syndrome, cranial trauma, learning disorders, attention deficit hyperactivity disorder, schizophrenia, depression, alcoholism, drug dependence, and criminal psychiatry (20). The calculation of absolute and relative power estimates is the most commonly used form of QEEG in AD/HD (18). Increased slow wave activity and lack of alpha attenuation have been shown in children with deficient attention in the absence of conduction disorders, when compared with the normal population (17).

The aim of this cross-sectional case control study was to determine hemispheric and regional differences in children with AD/HD, and age and sex matched normal children by using QEEG analysis, to evaluate the hyperventilation response as a measure of cerebral maturation, and to evaluate the contribution of new statistical techniques.

Methods

Subjects

This was a cross-sectional case control study performed in collaboration with the departments of Child and Adolescent Psychiatry, Neurology, and Biophysics at the Hospital of the Mersin University School of Medicine. Study population was 24 children or adolescents with AD/HD, aged 7 to 16 years, and 21 age and sex matched children as a control group. All participants were right-handed as indicated by positive laterality quotients on the Edinburgh Handedness Inventory administered at the time of testing (21). The mean score was 19.4 ± 2.0 in the

AD/HD group and 17.9 ± 1.9 in the control group. There was not any statistical difference between the two groups ($p > 0.05$). The patients with AD/HD were diagnosed according to the criteria of DSM-IV-TR by the same child and adolescent psychiatry specialist (FT). All children were living with their families and those under the care of juvenile or adoptive agencies were excluded. The subjects with a history of febrile or afebrile convulsions, central nervous system infections, cerebrovascular diseases, cranial trauma, any chronic or psychoactive drug use, other psychiatric disorders (e.g., mental retardation, learning disorders, obsessive compulsive disorder, and tics disorders), and metabolic diseases were not included. None of the subjects were receiving any medication during or prior data acquisition. All participants had normal hearing sensitivity bilaterally, defined by hearing thresholds of 20 dB HL or better at octave frequencies of 250 to 8000 Hz (1,13). The subjects with focal neurological deficits and any findings of neuroimaging procedure were not included in this study.

Informed written consent was obtained from the legal guardians of the subjects. Test and control subjects were matched by demographic variables.

Electroencephalographic Analysis

Computerized EEG recordings were obtained by using Medelec Profile 40-channel digital EEG equipments (Oxford-England) from 19 scalp points, according to the International 10-20 system nomenclature via Ag-AgCl plated disk electrodes with a commercial EEG paste (Nihon Kohden Elefix paste). The following 12 channels (O1-P3, P3-T5, T5-T3, T3-F7, F7-F3, F3-Fz, Fz-F4, F4-F8, F8-T4, T4-T6, T6-P4 and P4-O2) and Ag-AgCl disk electrodes (Medelec, Oxford, England) were used for the data collection. The maximum resting condition for 8 to 10 minutes at room temperature was obtained for each subject during the procedure. The reference electrode was placed at the midline. The electrode impedance was carefully kept below 5 k Ω . Hyperventilation was used as standardized activation method (22). Only antihistaminic drugs were used for sedation, which has no effects on EEG recordings. The filtering interval, frequency, and amplitude of the device were adjusted at 10 to 59 Hz, 30 mm/sec, and 100 mV, respectively. The recordings were evaluated visually, and analyzed quantitatively by the same neurologist (A.O.) and biophysicist (U.C.), who were blind to the clinical diagnosis of the subjects.

Baseline activity and hyperventilation response were quantitatively evaluated. Data were subsequently segmented into the consecutive 2-second epochs. Epochs that were contaminated by blinks, eye movements, and movement related artefacts, were excluded from the analysis using a rejection criterion of ± 100 μ V on any channel. These criteria produced artifact free data, as verified by direct visual inspection of the raw data. Each epoch was then baseline corrected and tapered over the entire 2 seconds using a Hannig window. Channel by channel calibrations were performed prior to the testing of each patient. Distributions of basic EEG waves by frequency (i.e. delta [0.5-3 Hz],

theta [3.5-8 Hz], alpha [8.5-12 Hz], and beta [12.5-30 Hz]) were recorded. For each montage, distributions obtained at two different states (baseline and hyperventilation response) were compared between the patient and control groups. Additionally, general distribution patterns and hemispheric asymmetries of each waveform were determined irrespective of the montage distributions. Data were pooled across electrode sites within anterior (right=F8/F4, left=F7/F3) and posterior (right=T6/P4, left T5/P3) regions to examine these regional differences directly.

Statistical Analysis

All raw data were explained as mean $\pm$ standard deviation and differences more than 5% were accepted as significant. A variance analysis model using six factors was used to analyse quantitative data. These factors and their levels were in the following order: montage (twelve channel), procedure (background activity and hyperventilation response), waveforms (delta, theta, alpha, beta), groups (patients and controls), hemispheres (right and left), and regions (anterior and posterior).

Relative power has been calculated for each waveform independent from montage. Relative power is represented by the percentage of the power in a given frequency band that is re-

lated to total power across all frequency bands. Relative delta power, for example, is equal to (absolute delta power/absolute delta power+ absolute theta power+ absolute alpha power+ absolute beta power)x 100. Also we performed theta/alpha and theta/beta ratios for each region. In order to evaluate the correlation between clinical variables and electrophysiological data, we performed Pearson correlation analysis for each waveform and montage during state and hyperventilation.

Results

Of the 24 subjects in the AD/HD group, 4 were female (16.6%) and 20 were male (83.3%) with a mean age of 11.16 $\pm$ 2.59 years (range 7 to 14 years). The control group included seven females (33.3%) and 14 males (66.7%) with a mean age of 10.8 $\pm$ 2.3 years (range 6 to 15 years). All subjects were right-handed, however four children with AD/HD had family history of left-handedness. None of the subjects had any signs of epilepsy and other central nervous system disorders. Other developmental and neurological examinations of subjects were in the normal ranges.

Table 1. Demographic features, clinical characteristics, and subtype of children with ADHD

Subjects	ADHD-subtype	Age (years)	Sex (F/M)	First degree psychiatric disorders	The age of diagnosis (years)
1	Combined	10	M	OCD	7
2	Combined	13	M	-	8
3	Combined	9	M	Depression	7
4	Combined	12	M	Alcohol dependent	9
5	Combined	11	M	Chronic motor tic disorder, depression	6
6	Inattentive	16	M	-	8
7	Inattentive	10	M	Alcohol dependent	7
8	Inattentive	8	M	-	7
9	Combined	11	M	OCD	7
10	Combined	16	F	-	8
11	Combined	9	M	OCD	6
12	Inattentive	13	M	AD/HD	7
13	Hyperactivity-Impulsivity	13	M	-	7
14	Combined	16	M	OCD, generalized anxiety disorder	8
15	Combined	9	M	-	7
16	Combined	9	M	Depression	7
17	Combined	12	M	-	8
18	Inattentive	8	F	Alcohol dependent	7
19	Inattentive	7	F	-	6
20	Combined	9	M	-	8
21	Hyperactivity-Impulsivity	12	M	Alcohol dependent	9
22	Combined	14	M	Chronic motor tic disorder, alcohol dependent	8
23	Inattentive	10	M	-	7
24	Inattentive	11	F	-	7

F : Female, M : Male, OCD: Obsessive compulsive disorder

The mean age at the time of AD/HD diagnosis was 7.33 ± 0.81 years in patient group. All of the subjects had the DSM-IV criteria for AD/HD (4). Seven of the 24 subjects had inattentive subtype. These include difficulty in paying attention, problems in completing works at school or home, difficulty in following, and losing or forgetting things such as homework instructions. On the other hand, 2 of subjects had hyperactivity and impulsivity subtype including fidgeting, feeling of restlessness, difficulty in waiting turn and interrupting others. And 15 subjects had combined type involving a combination of the other two types (details can be seen in table 1).

Electroencephalographic Evaluation

Five AD/HD patients and one of the control subjects had benign EEG abnormalities as parieto-occipital slow waves, although none of the subjects had epileptiform EEG abnormalities and a history of convulsion.

As the the general distribution of the waveforms had been analysed irrespective of the montage, the most prevalent waveform was found to be delta ($48.0 \pm 19.8\%$) at the background activity. It was followed by theta ($21.7 \pm 11.1\%$), alpha ($19.8 \pm 14.5\%$) and beta ($9.6 \pm 7.0\%$). As shown in table 2 and 3, increased frequency of alpha waves and decreased delta activity during the hyperventilation in the children with AD/HD had been seen when compared with the controls.

As the EEG recordings of AD/HD group for each montage had been compared with the recordings of the control group, it was seen that the frequency of beta was significantly increased in the left occipital ($7.3 \pm 4.4\%$ versus $5.3 \pm 2.7\%$, $p=0.05$), decreased in the left temporal ($17.0 \pm 9.5\%$ versus $24.3 \pm 11.5\%$, $p=0.03$) and left frontal ($7.7 \pm 4.2\%$ versus $13.3 \pm 7.6\%$, $p=0.005$) regions during basic state analysis. Also basic state recordings revealed important increased alpha (14.7 ± 5.1 versus 11.5 ± 5.1 , $p=0.050$) and beta (13.6 ± 7.4 versus $9.4 \pm 6.2\%$, $p=0.050$) activities on left frontal region and increased theta activity (26.6 ± 12.9 versus $19.7 \pm 10.7\%$, $p=0.050$) on the left temporal region. On the other hand, the frequency of beta significantly increased in the child-

ren with AD/HD ($7.7 \pm 4.8\%$) compared to the controls ($5.4 \pm 2.8\%$) on the left parietal region at hyperventilation ($p=0.050$). Decreased alpha activity (13.3 ± 10.8 versus $24.4 \pm 20.2\%$, $p=0.027$) on the left frontal region and increased alpha activity ($25.2 \pm 14.9\%$ versus $15.6 \pm 10.5\%$, $p=0.022$) on the right temporal region were seen as hyperventilation responses, when compared with each other (see figures 1 and 2).

EEG analysis of resting state revealed increased frequency of theta ($23.7 \pm 11.0\%$ versus 19.0 ± 10.4 , $p=0.019$) and delta ($59.7 \pm 16.4\%$ versus $52.6 \pm 19.5\%$, $p=0.014$) activity in left frontal region more than the right frontal region in AD/HD group. Basic state analysis also showed increased frequencies of delta ($46.5 \pm 20.4\%$ versus 39.2 ± 16.9 , $p=0.007$) and beta activities ($7.7 \pm 5.1\%$ versus $7.3 \pm 4.4\%$, $p=0.050$), and decreased frequencies of theta ($20.6 \pm 10.4\%$ versus $26.5 \pm 12.6\%$, $p=0.002$) and alpha activities ($25.5 \pm 17.6\%$ versus 26.9 ± 16.8 , $p=0.050$) in the right occipital region in AD/HD group. Hyperventilation recordings of the children with AD/HD revealed a significant decrease in the theta activity ($25.5 \pm 18.5\%$ versus $27.8 \pm 18.9\%$, $p=0.050$) and increase in the alpha activity (15.8 ± 14.1 versus 11.7 ± 10.4 , $p=0.003$) in the right frontal regions. None of the frequencies of other waveforms revealed significant difference between the two hemispheres.

The children with AD/HD showed significantly high delta activity in both of the posterior regions ($p=0.000$ for left and $p=0.001$ for right hemisphere) during basic state. Similar differences has been also shown during hyperventilation ($p=0.008$ for left and $p=0.004$ for right hemisphere). Theta frequency in children with AD/HD, was significantly higher in only left frontal region ($p=0.005$) than other side during basic state. Alpha frequency of children with AD/HD was also significantly lower in bi-frontal regions ($p=0.003$ for left frontal and $p=0.000$ for the right frontal regions) than posterior ones during the basic state, and in right frontal region ($p=0.001$) during hyperventilation. Similarly, beta activities of the bi-frontal regions were significantly high in the AD/HD group during the hyperventilation ($p=0.009$ for left and $p=0.05$ for right hemisphere).

Table 2. The comparison of the frequencies of basic wave forms at resting state and hyperventilation between the children with AD/HD and the controls

EEG Waves	ADHD (n=24)	Controls (n=21)	p
Delta-BA	$48.0 \pm 19.8\%$	$45.2 \pm 21.7\%$	0.195
Delta-HV	$45.5 \pm 19.7\%$	$48.9 \pm 18.5\%$	0.050
Theta-BA	$21.7 \pm 11.1\%$	$25.0 \pm 13.1\%$	0.013
Theta-HV	$25.1 \pm 14.8\%$	$26.0 \pm 14.8\%$	0.577
Alpha-BA	$19.8 \pm 14.5\%$	$19.6 \pm 15.2\%$	0.923
Alpha-HV	$19.9 \pm 14.6\%$	$15.2 \pm 14.3\%$	0.002
Beta-BA	$9.6 \pm 7.0\%$	$9.9 \pm 7.8\%$	0.635
Beta-HV	$9.3 \pm 6.7\%$	$8.0 \pm 5.5\%$	0.050

Note= Data are represented as mean±standard deviation; BA= Background activity; HV= Hyperventilation response; NS= Non significant ($p>0.05$)

Table 3. The comparison of the relative power of basic wave forms at resting state and hyperventilation between the children with AD/HD and the controls

EEG Waves	ADHD (n=24)	Controls (n=21)	p
Delta-BA	$48.1 \pm 19.7\%$	$45.2 \pm 21.6\%$	0.182
Delta-HV	$45.5 \pm 19.7\%$	$49.6 \pm 15.8\%$	0.036
Theta-BA	$22.1 \pm 11.5\%$	$25.0 \pm 13.3\%$	0.021
Theta-HV	$25.1 \pm 14.7\%$	$26.5 \pm 13.9\%$	0.352
Alpha-BA	$19.9 \pm 14.5\%$	$19.6 \pm 15.2\%$	0.861
Alpha-HV	$19.9 \pm 14.6\%$	$15.0 \pm 11.5\%$	0.001
Beta-BA	$9.7 \pm 7.2\%$	$9.9 \pm 7.7\%$	0.833
Beta-HV	$9.3 \pm 6.7\%$	$8.7 \pm 6.6\%$	0.433

Note= Data are represented as mean±standard deviation; BA= Background activity; HV= Hyperventilation response; NS= Non significant ($p>0.05$)

When all of the recordings have been evaluated together, relative power of main EEG waveforms during baseline, significantly decreased theta power in children with AD/HD compared with controls ($22.1 \pm 11.5\%$ versus 25.0 ± 13.3 , $p=0.02$) were seen during basic state (Table 3). Hyperventilation recordings showed significantly decreased delta power ($45.5 \pm 19.7\%$ versus $49.6 \pm 15.8\%$, $p=0.03$) and increased alpha power ($19.9 \pm 14.6\%$ versus $15.0 \pm 11.5\%$, $p=0.001$) in children with AD/HD compared with controls. Other waveforms did not show any significant difference in study groups. When compared with the absolute power, only beta activity of children with AD/HD has been changed in relative power analysis and this finding suggested the beneficial role of relative power calculation in borderline data.

Theta/alpha and theta/beta ratios have been calculated for each

montage during both of the basic state and hyperventilation. They also showed only significantly decreased theta/alpha ratio in the right frontal region (1.9 ± 1.3 versus 3.7 ± 4.0 , $p=0.04$) in AD/HD group compared with controls (see figure 3 and 4).

Correlation analysis showed a decrease in left temporal delta activity as the age increased (Pearson correlation: -0.476 , $p=0.019$) in children with AD/HD during basic state. This analysis also showed a significant correlation between male gender and left fronto-temporal delta activity (Pearson correlation: -0.462 , $p=0.023$ and Pearson correlation: -0.420 , $p=0.041$) during basic state in children with AD/HD. Correlation analysis also showed a significant correlation between male gender and left frontal theta activity (Pearson correlation: -0.416 , $p=0.043$) during basic state, and right temporal beta activity (Pearson correlation: -0.563 , $p=0.004$) during hyperventilation.

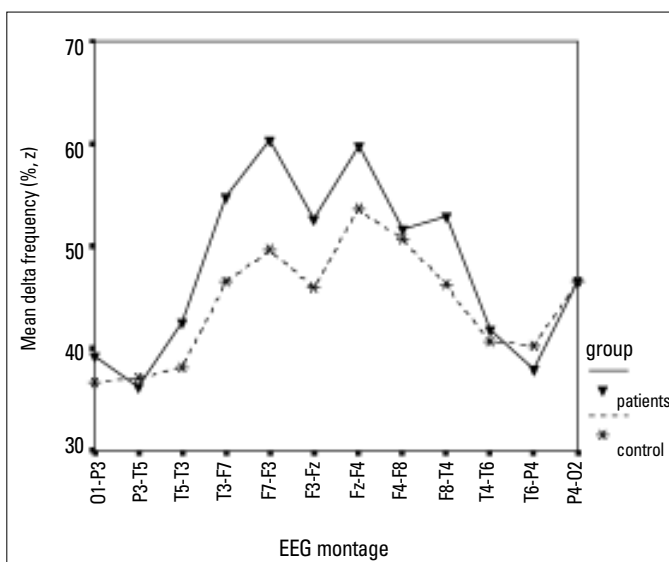


Figure 1 a. Brain mapping of delta activity of the patients and the controls during basic state

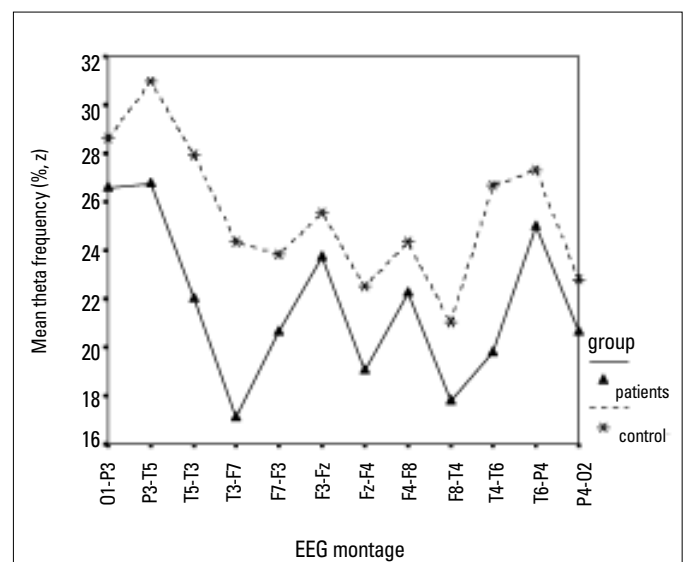


Figure 1 b. Brain mapping of theta activity of the patients and the controls during basic state

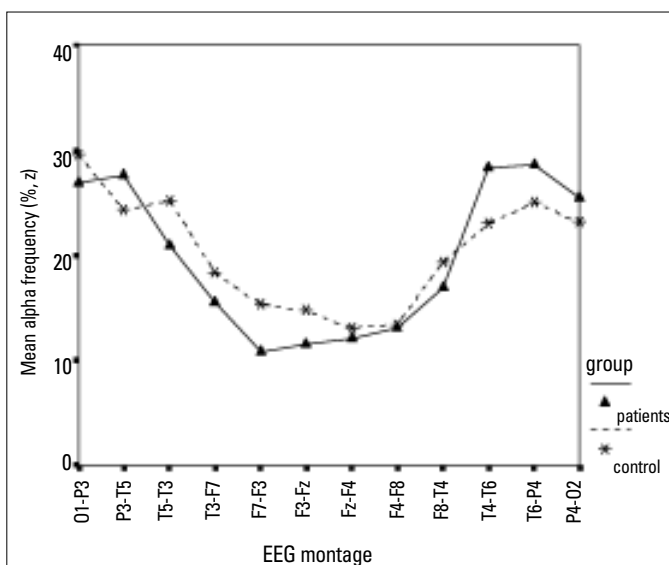


Figure 1 c. Brain mapping of alpha activity of the patients and the controls during basic state

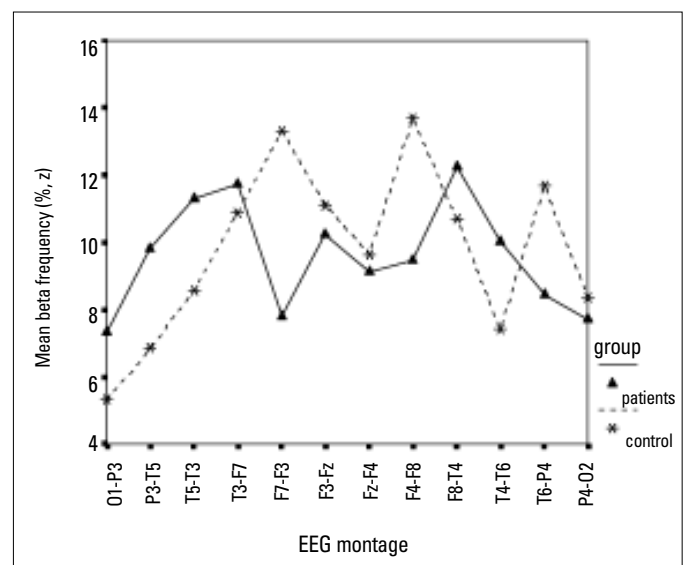


Figure 1 d. Brain mapping of beta activity of the patients and the controls during basic state

Discussion

In this study, significantly decreased theta power in basic state, and significantly decreased delta and increased alpha power during hyperventilation were seen in children with AD/HD, when compared with controls. Other statistical analysis also showed important clues of cerebral dysmaturation in children with AD/HD, especially in left fronto-temporal and right occipital regions.

In these patients, all the data support the maturational delay in brain functioning. In a longitudinal study, Satterfield reported more quickly decreased EEG power in control subjects than in hyperactive ones, as the age increased (24). Clarke reported elevated theta and reduced beta that supporting the maturational delay model in children with AD/HD (12). Hyper-

ventilation response could be accepted as a measure of cerebral maturation (22). In this aspect, we evaluated hyperventilation response as qualitatively. Our data suggested that with the increasing age, left temporal delta activity significantly decreased in children with AD/HD during basic state. This analysis also showed a significant correlation between male gender and left fronto-temporal delta activity during basic state, a significant correlation between male gender and left frontal theta activity during basic state, and right temporal beta activity during hyperventilation. Visual and quantitative analysis of EEG showed that, the ratio of hyperventilation response significantly decreased in children with AD/HD compared with controls. All of these results can be accepted as some clues of left fronto-temporal dysmaturation in children with AD/HD.

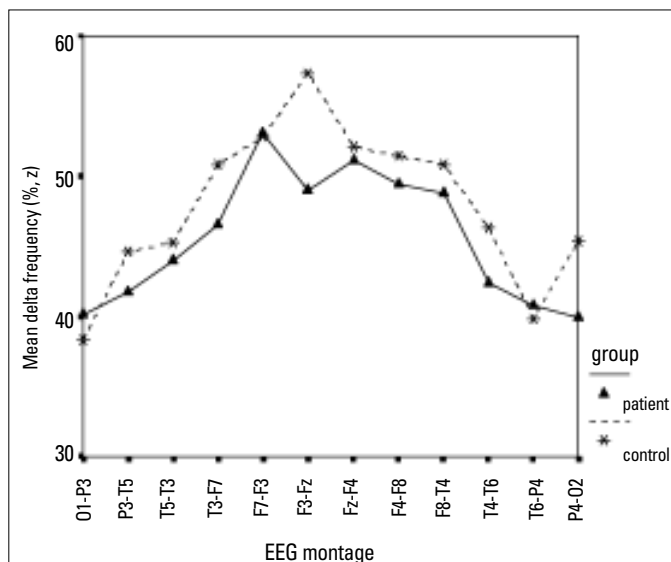


Figure 2 a. Brain mapping of delta activity of the patients and the controls during hyperventilation

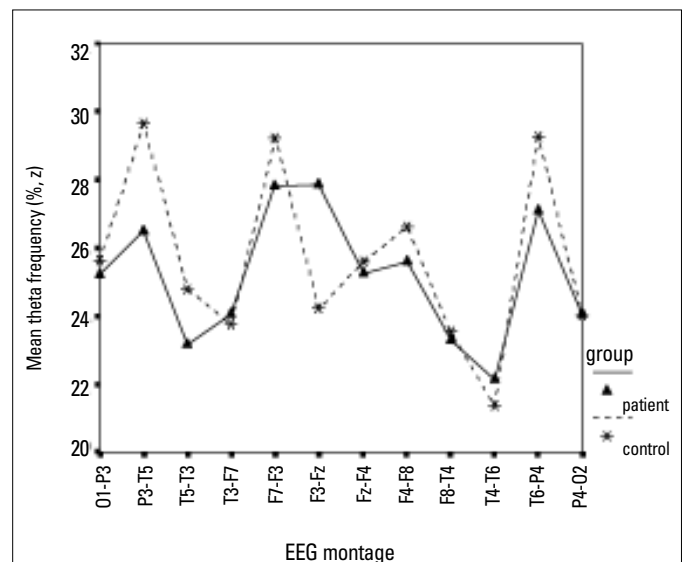


Figure 2 b. Brain mapping of theta activity of the patients and the controls during hyperventilation

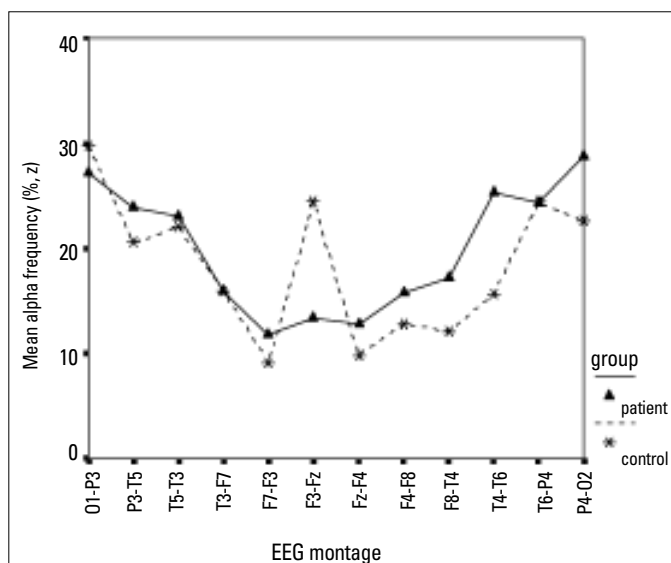


Figure 2 c. Brain mapping of alpha activity of the patients and the controls during hyperventilation

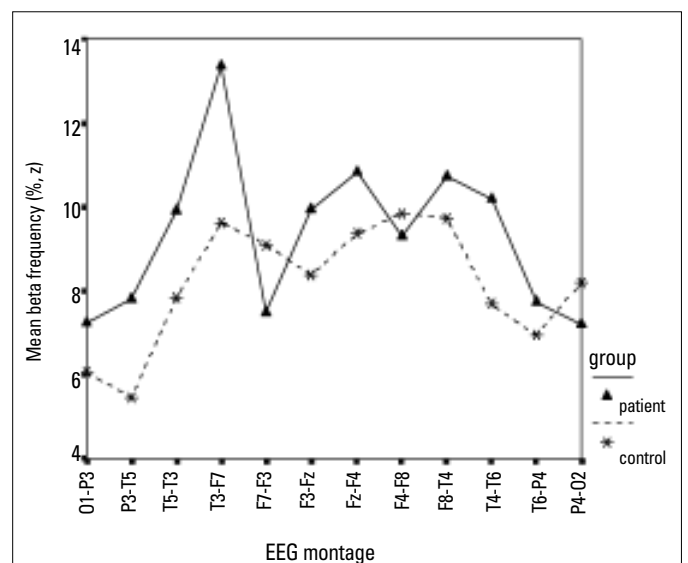


Figure 2 d. Brain mapping of beta activity of the patients and the controls during hyperventilation

Another hypothesis, named as developmental deviation model, AD/HD is conceptualized as resulting from an abnormality in the functioning of the CNS. Wikler and Bresnahan reported that hyperactive children were found to have increased slow wave activity compared with normal controls (5,25). In this aspect, our data also suggested this hypothesis. Most common waveform that had been seen in AD/HD children was delta ($48.0 \pm 19.8\%$) at the background activity, and followed by theta ($21.7 \pm 11.1\%$), alpha ($19.8 \pm 14.5\%$) and beta ($9.6 \pm 7.0\%$). Significantly increased alpha wave frequency and decreased delta activity were seen in children with AD/HD during the hyperventilation, when compared with the controls. The results suggest a possible combined developmental delay and cerebral dysmaturation hypothesis in the neurobiological basis of AD/HD.

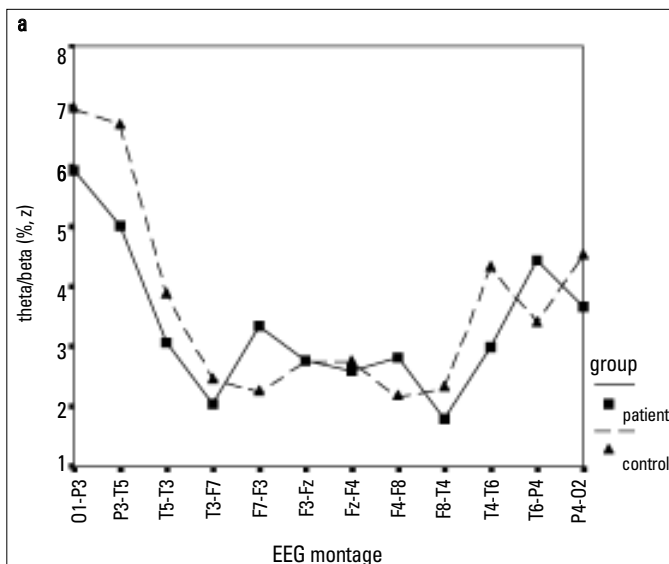


Figure 3a. Ratios of theta/beta activity for 12 standard EEG locations for 24 AD/HD children and 21 matched controls during basic state (a) and hyperventilation (b)

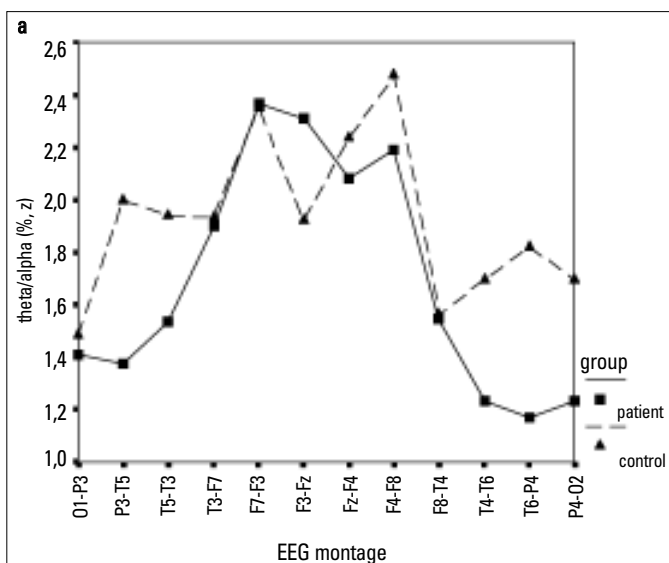


Figure 4a. Ratios of theta/alpha activity for 12 standard EEG locations for 24 AD/HD children and 21 matched controls during basic state (a) and hyperventilation (b)

As reported, relative power measures that have been recorded under an eyes-closed resting state can show good test-retest reliability (13). Callaway showed that hyperactive children had lower power in the alpha and beta bands than control subjects (6). Our AD/HD children had partially higher power of alpha but lower power of beta than controls. On contrary to our results, in a detailed subgroup analysis study, Clarke reported that all of the groups showed increased power levels across all sites in absolute and relative theta and reductions in relative alpha and beta (12). Increased activity of delta was predominantly in posterior regions of all subgroups. We did not evaluate subgroup analysis, because of restricted subject numbers. However, when compared with the designs and results of other studies, our data suggested similar results about absolute and relative power of basic EEG waveforms, except beta during hyperventilation.

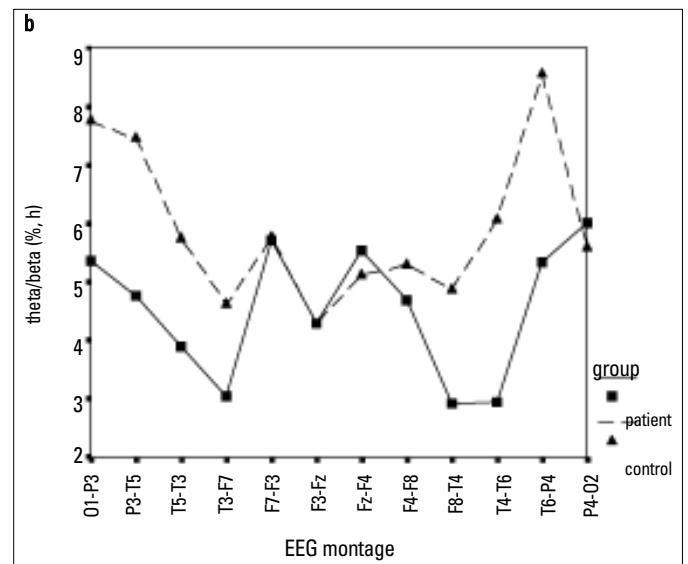


Figure 3b. Ratios of theta/beta activity for 12 standard EEG locations for 24 AD/HD children and 21 matched controls during basic state (a) and hyperventilation (b)

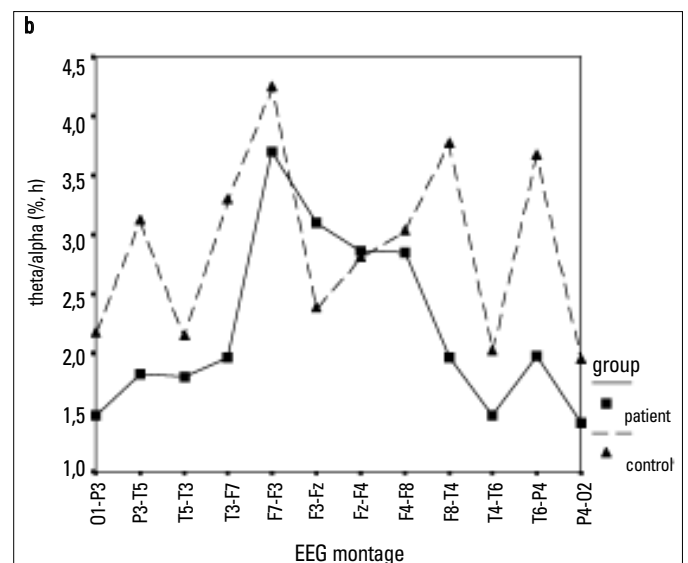


Figure 4b. Ratios of theta/alpha activity for 12 standard EEG locations for 24 AD/HD children and 21 matched controls during basic state (a) and hyperventilation (b)

lation. In this respect, we recommend the calculation of relative power, especially in borderline significance, by using this method. Otherwise the analyses of absolute and relative power were similar to the basic state and hyperventilation.

In the aspect of localisation, in their comprehensive studies Chabot and Serfontein reported that, children with AD/HD had an increased absolute and relative theta, primarily in the frontal regions and in the frontal midline (19). In other calculations had been used in the study by Clarke with a clinical and electrophysiological study. They reported that AD/HD children had less absolute and relative alpha and beta, more absolute theta, and more relative delta and theta than the control groups. These changes were seen predominantly in frontal regions. The theta/alpha and theta/beta ratios were also different between the clinical groups and the control group (9). In a controlled clinical study consisting of boys, Mann found that basic state EEG recordings of children with AD/HD revealed significantly increased theta activity in the frontal and central locations, and decreased beta in posterior and temporal locations (2). Depending on PET studies, these authors hypothesized that a possible close correlation between increased theta activity and decreased glucose metabolism supports the view that cortical activation may be decreased in AD/HD. Our regional analyses suggested most of these findings, such as important degree high delta activity on posterior regions, increased left frontal theta activity and low alpha activity on frontal regions. We suggest a possible role of left frontotemporal dysmaturation in neurobiological basis of AD/HD.

Inter-hemispheric asymmetries were found in the parietal and posterior temporal areas. Intra-hemispheric abnormalities were found to be with asymmetries between frontal/temporal and frontal/occipital regions (4). We evaluated hemispheric asymmetries during basic state and hyperventilation, and we suggested left fronto-temporal slow wave activity with nearly similar to the results of these conditions. We also evaluated the correlation among age, gender and EEG changes during both of these conditions. Our comprehensive analysis showed significant relationships among left fronto-temporal slow wave activity, and decreased age and male gender in this study group. In another aspect, Lazzaro studied 54 unmedicated adolescent male AD/HD patients and age and sex-matched normal control subjects, using simultaneously-recorded EEG and electro dermal measures in a resting eyes-open condition (21). Their findings supported that the continuation of increased slow wave activity in AD/HD adolescents show presence of a state of autonomic hypo arousal in this clinical group. We did not evaluate autonomic dysfunction and functional neuroimaging in our study design. We also did not include any neuropsychologic evaluation during EEG recordings. Although these pitfalls do not change our study aims, it can be accepted as some limitations of our study.

In the subgroup studies; Clarke found 15-20% of children with AD/HDcom had significantly elevated levels of beta activity in their EEG (10,11,12). This group was also found to have a behavioural profile slightly different from other children with AD/HDcom, with an increased rate of temper tantrums and mood behaviours. They also pointed out the importance of increased absolute and relative theta power in the frontal regions. Also, they suggested the presence of qualitative differences in frontal lobe function between the two AD/HD disorders. Our study group, 7 of the 24 children had inattentive subtype, 2 of the subjects had hyperactivity and impulsivity subtype, and 15 of the subjects had combined type involving a combination of other two types. As a limitation of the study, we did not perform the subgroup analysis, because of the restricted number of subgroups needing the divided analysis.

Both of the theta/alpha and theta/beta ratios also appear to be reliable measures to show differences between AD/HD and control subjects, as well as the differences between the DSM-IV types of disorder. None of these measures has greater sensitivity than the other, although the theta/beta ratio is preferred by some researchers (11). Monastra reported that the theta/beta ratio could discriminate AD/HD from control subjects with 86% sensitivity and 98% specificity (19). We also evaluated both of these ratios. However, we only determined significantly decreased theta/alpha ratio in right frontal region in children with AD/HD compared with controls. This result was not convenient with other results and previous data. So we do not recommend additional theta/alpha and theta/beta ratios in QEEG analysis of children with AD/HD.

Since AD/HD is considered to be a result of CNS dysfunction, and EEG provides a direct measure of brain functioning, QEEG appears to be a convenient tool in assessment of this disorder (4). It has been recommended that further researches and developments are needed for clinical use of EEG as a diagnostic tool in AD/HD. Our data also suggested these authors. As for conclusion, QEEG analysis can be accepted as a beneficial technique in providing objective and physiologically based data currently available for clinical assessment. By using QEEG new data can be added to the neurobiological basis of AD/HD.

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