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EPILEPTIFORM ABNORMALITIES AND QUANTITATIVE EEG IN CHILDREN WITH ATTENTION-DEFICIT/HYPERACTIVITY DISORDER

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Abstract – There is much controversy about the importance of the electroencephalogram (EEG) in assessing the attention-deficit/hyperactivity disorder (ADHD). The objective of this study was to assess the use of EEG and quantitative EEG (qEEG) in ADHD children. Thirty ADHD children and 30 sex- and age-matched controls with no neurological or psychiatric problems were studied. The EEG was recorded from 15 electrode sites during an eyes-closed resting condition. Epileptiform activity was assessed, as were the absolute and relative powers in the classical bands after application of the Fast Fourier transform. Epileptiform activity was found in 3 (10%) ADHD children. As compared to the controls, the ADHD group showed significantly greater absolute delta and theta powers in a diffuse way, and also greater absolute beta power and smaller relative alpha 1 and beta powers at some electrodes. A logistic multiple regression model, allowed for 83.3% sensibility and specificity in diagnosing ADHD.

KEY WORDS: attention-deficit/hyperactivity disorder, EEG, children.

Atividade epileptiforme e eletrencefalograma quantitativo em crianças com transtorno de déficit de atenção/hiperatividade

Resumo – Há controvérsias sobre a importância do eletrencefalogama (EEG) na avaliação do transtorno de déficit de atenção/hiperatividade (TDAH). O objetivo deste estudo foi avaliar, em crianças com TDAH, o EEG digital e quantitativo. Foram estudadas 30 crianças com TDAH e 30 sadias, sem evidências de problemas neurológicos ou psiquiátricos e pareadas por idade e gênero. Foi registrado o EEG em 15 posições de eletrodos, durante repouso e olhos fechados. Foi realizada pesquisa de atividade epileptiforme e feita análise de freqüências nas faixas clássicas, após aplicação da transformada rápida de Fourier. Foi encontrada atividade epileptiforme em 3 (10%) crianças com TDAH. O grupo TDAH teve, em relação ao grupo controle, significativamente, maior potência absoluta delta e teta, de modo difuso, assim como maior potência absoluta beta e menor potência relativa alfa 1 e beta, em alguns eletrodos. Um modelo de regressão múltipla logística possibilitou sensibilidade e especificidade de 83,3% no diagnóstico de TDAH.

PALAVRAS-CHAVE: transtorno de déficit de atenção/hiperatividade, EEG, infância.

The attention-deficit/hyperactivity disorder (ADHD) is one of the commonest behavioral disorders in childhood. Due to advancing knowledge with respect to the prevalence, natural history, genetics, biology and treatment of ADHD, a greater number of patients are now receiving adequate treatment. The diagnosis of ADHD is based on the DSM IV[1] criteria of which the essential characteristic consists of a persistent pattern of lack of attention and/or hyperactivity-impulsivity more frequent and serious than that typically observed in individuals with an equivalent developmental level. Some symptoms of hyperactivity and impulsivity should be present up to 7 years of age. Some compromise due to the symptoms should be present in at least two contexts (e.g. at home or at school or work) and there should be evidence of interference in the social, academic or occupational functioning for that level of development. The assessment procedure should consist of a review of the medical history, development and family, and an examination of the intellectual functions and academic performance.

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Scales such as that of Conners[2] about behavioral aspects and continued execution tests may be useful in the assessment. However, due to limitations, these tests and scales cannot be considered diagnostic[3]. There is current concern with respect to exaggeration in the diagnosis of ADHD and consequent exposition of many children to unnecessary medical treatment. Thus the search continues for better accuracy in the diagnosis using objective procedures. Since ADHD is considered to be the result of a brain dysfunction and the electroencephalogram (EEG) assesses brain function, it is natural that this method be examined with respect to this clinical condition.

Electroencephalogram and ADHD

EEG studies in children with ADHD are searching for data with respect to various brain function aspects. One of the alterations that can occur in an EEG is that of epileptiform activity (EA), characterized by electrographic elements that correspond to the recording of excessive neuronal discharge and abnormal components of the basic epilepsy mechanism. EA can occur with less frequency in non-epileptic individuals. A greater recording of EA has been described in ADHD children than in normal children[4].

Although it only occurs in a small proportion of ADHD children (about 6%), EA could be a factor in the origin of the attention deficit [5,6,7], and thus pharmacotherapy with the objective of reducing EA could eventually produce benefit with respect to this behavior[8].

Quantitative electroencephalogram (qEEG) and ADHD

Advances in computer technology and the creation of programs have made it possible to register EEG digitally using analogical-digital transformation. Since it uses numbers, the digital EEG allows for quantitative analyses (qEEG) such as the composition of the electrical brain activity frequencies (frequency analysis). Segments of the recording free of artifacts are chosen, and the Fast Fourier Transform applied, this being a mathematical process that identifies the various frequency bands (delta, theta, alpha and beta) on the qEEG, from the temporal series of the original digital EEG data.

Various qEEG studies were carried out with individuals suffering from ADHD, assessing different parameters using a variable number of electrodes in patients with their eyes open and closed, both at rest and when carrying out activities[9,10]. In studies with ADHD children at rest with their eyes closed, differences have been observed in relation to normal controls, such as an increase in the delta and theta powers[11], increase in theta[12], increase in theta and decrease in beta[13,14] and increase in theta and decrease in alpha and beta[15].

qEEG in ADHD diagnosis

Various research studies have assessed the value of qEEG in ADHD diagnosis. Monastra et al. (1999, 2001)[16,17] affirmed that qEEG data allow for differentiation between ADHD children and normal children with a specificity of 94% and sensibility of 90%. Other studies indicate the value of qEEG in ADHD diagnosis[7,18,19], but there is still not sufficient evidence to use qEEG as a routine diagnostic method[20]. Although qEEG obtained with children with their eyes open or carrying out tasks were less trustworthy in the test-retest than those registered at rest with the eyes closed[21], only one study of the sensibility and specificity under this functional condition was found[19].

Thus the objective of the present research was to study ADHD children using digital and quantitative electroencephalograms, determining their diagnostic value at rest with the eyes closed.

METHOD

Thirty schoolchildren in the 8 to 11 year-old age range suffering from the attention-deficit/hyperactivity disorder according to the DSM-IV-TR[1] criteria, referred by the outpatients sections of the Infancy & Adolescence Psychiatry Department and the Pediatric & Neurological Pediatric Department of (HMCP PUC-Campinas), were included in this study.

All the children were free of medication at the time of testing, and those taking methylphenidate were taken off this medication for at least 12 h prior to the assessment.

The following procedures were carried out: medical history, psychiatric evaluation and traditional neurological examination; Conner's Parent and Teacher Rating Scales; Wechsler Intelligence Scale for Children (WISC-III); digital and quantitative EEG.

The dEEG was recorded with a resolution of 12 bits, 0.5 and 35 Hz filters and 200 samples per second, using the Braintech 3.0 equipment (EMSA Equipamentos Médicos). Impedance was maintained below 10 kΩ. The exam was carried out with the child in the dorsal decumbent position in an ambient of silence with reduced luminosity. The electrodes were placed according to the International 10-20 System, with the use of an additional two electrodes placed 1 cm below (left side) and above (right side) the external angle of the eyelid, with the objective of evaluating eye movements. The inter-connected ear lobe electrodes served as the reference. Recording was carried out during three periods, alternating 2 minutes rest with the eyes closed with two minutes with the eyes open. The type, location and side of epileptiform activity were assessed.

Eighteen to 26 epochs were selected for the qEEG while awake and resting (eyes closed), each lasting 2.56s. Epochs with more than 100 μV on the electro-oculogram were excluded from the means. After applying the Fast Fourier Transform, the absolute and relative powers of 15 electrodes (F4, F3, C4, C3, T4, T3, T6, T5, P4, P3, O2, O1, F0, C0 and P0) were studied in the follow-

ing frequency bands: delta (up to 3.9 Hz), theta (4.29 to 7.8 Hz), alpha (8.2 to 12.5 Hz) and beta (above 12.89 Hz). To obtain the normal distribution, the values for absolute power (X) were substituted by their logarithms, Y=log (X), and the relative power values (R) transformed by Logit, Y=log(R/1-R).

Data analysis

Thirty children made up the control group (CG) of "healthy" children, paired with the study group according to age, gender and the scholastic level of their parents. These children had no history of neurological (for example personal antecedents or close relatives suffering from epileptic fits, head injury with loss of consciousness, encephalitis or reduced mental capacity) or psychiatric problems, showed normal neurological and intellectual development, normal neurological and electroencephalographic examinations, an absence of cognitive deficit in the Raven progressive matrixes test, had never repeated a school year and presented performance compatible with their age and school grade in the School Performance Test.

A comparison was made between the study group and the control group with respect to the absolute and relative powers in the delta, theta, alpha and beta bands of the qEEG (T-test).

The Ethics in Research Committee of FCM-PUC-Campinas, organ recognized by the Brazilian National Commission on Ethics in Research (CONEP/MS) approved the project.

Table 1. Distribution of the 30 ADHD children, and similarly of the control group, according to age and gender.

Age	Boys		Girls		Total	
(years)	Nº	%	Nº	%	Nº	%
7	3	12.5	0	0	3	10.0
8	8	33.3	1	16.6	9	30.0
9	8	33.3	2	33.3	10	33.3
10	3	12.5	2	33.3	5	16.6
11	2	8.3	1	16.6	3	10.0
Total	24	80	6	20	30	100

RESULTS

Table 1 shows the distribution of the 30 ADHD children, which was identical to that of the control group with respect to age and gender.

In the WISC-III evaluation, all the children showed an IQ above 70 and the means and standard deviations were as follows: total IQ, 94.5±19.9; verbal IQ, 96.3±19.3; performance IQ, 93.8±17.9.

Digital electroencephalogram

Epileptiform activity was registered in 3 (10.0%) of the ADHD children, in small numbers and short duration.

The characteristics of the EA in these 3 cases were, respectively: 1 – spikes showing their main projections in the left and median parietal regions, either spontaneous or evoked by tapping the right foot; 2 – generalized spike-wave complexes at 3-4 Hz, lasting for 1 second; 3 – spikes

Table 2. Mean values for the absolute delta, theta and alpha 1 powers of the ADHD and control (CG) groups of children, and the value for p in the respective comparisons.

Electrode	Absolute delta			Absolute theta			Absolute alpha 1		
	ADHD	CG	p	ADHD	CG	p	ADHD	CG	p
T3	131.4	106.4	0.000**	110.9	93.5	0.029*	52.0	48.7	0.409
T5	152.9	144.4	0.288	157.4	145.8	0.310	89.2	99.8	0.359
F3	182.4	154.6	0.000**	163.2	140.9	0.017*	71.2	66.9	0.519
C3	181.9	155.1	0.001**	166.8	147.7	0.033*	86.7	79.9	0.312
P3	192.9	172.5	0.016*	192.4	176.2	0.146	117.1	110.9	0.520
O1	206.2	192.6	0.253	225.9	205.4	0.279	170.5	197.7	0.183
T4	135.9	105.3	0.000**	116.1	93.7	0.002**	57.8	48.4	0.027*
T6	178.2	143.9	0.001**	182.4	151.9	0.022*	130.7	106.7	0.084
F4	188.9	154.9	0.000**	167.6	144.4	0.004*	72.2	68.1	0.456
C4	183.0	155.5	0.000**	168.4	149.7	0.030*	88.5	83.3	0.464
P4	199.2	171.0	0.003*	196.3	175.7	0.076	123.4	111.43	0.229
O2	219.5	192.16	0.061	232.8	210.5	0.218	195.3	203.2	0.987
F0	201.1	166.0	0.000**	192.1	160.0	0.003*	77.2	71.3	0.287
C0	218.9	186.4	0.000**	204.1	190.5	0.203	93.1	89.1	0.513
P0	211.3	184.2	0.005*	211.4	195.7	0.307	124.8	118.7	0.475

T-test, *p<0.05; **p<0.003.

Table 3. Mean values for the absolute alpha 2 and beta powers of the ADHD and control (CG) groups of children, and the value for p in the respective comparisons.

Electrode	Absolute Alpha 2			Absolute Beta		
	ADHD	CG	p	ADHD	CG	p
T3	45.6	41.6	0.246	87.8	84.0	0.307
T5	63.9	64.3	0.956	94.4	93.7	0.869
F3	59.1	52.1	0.147	104.4	92.3	0.061
C3	68.3	60.1	0.126	99.0	86.6	0.030*
P3	79.6	70.2	0.130	109.2	100.5	0.156
O1	102.0	105.3	0.873	120.6	122.6	0.793
T4	51.3	41.4	0.016*	91.2	83.2	0.114
T6	87.1	68.5	0.082	106.3	96.0	0.101
F4	60.1	59.0	0.205	112.7	94.9	0.014*
C4	70.5	60.3	0.097	101.8	90.0	0.029*
P4	82.0	70.5	0.077	110.9	99.9	0.065
O2	110.5	103.8	0.689	125.4	126.4	0.994
F0	62.6	54.4	0.047*	116.7	95.5	0.004*
C0	66.1	60.7	0.215	111.3	94.7	0.012*
P0	75.8	68.2	0.135	108.4	95.6	0.039*

*T-test, *p<0.05

Table 4. Electrode sites and frequency ranges showing significant differences between the ADHD and control groups.

Electrode	Relative power				
	Greater in the ADHD group		Smaller in the ADHD group		
	delta	theta	alpha 1	alpha 2	beta
O1	*		*		
T6					*
F4			*		
CZ	*				

T-test, *p<0.05

in the right frontal-temporal region. These children did not suffer from epileptic fits.

Results of the qEEG: comparison between the ADHD and control groups

Tables 2 and 3 show the values obtained for the absolute powers for the ADHD and control groups, and also the values for *p* in their comparison (T-test).

Note that the absolute delta and theta powers were significantly greater for the ADHD group at the majority of electrodes as compared to the control group (Table 2).

The absolute alpha 1 (Table 2), alpha 2 and beta (Table 3) powers were greater for the ADHD group, but only reached a significant level at a few electrodes.

With respect to the relative powers, at the majority of the electrodes the means were greater for the relative delta and theta powers, and lower for the alpha 1, alpha 2 and beta powers in the ADHD group as compared to the control group, but statistical significance was only found for some of the delta (O1, C0), alpha 1 (F4, O1) and beta (T6) electrode positions (Table 4).

Table 5. Classification between the ADHD and control groups according to the absolute delta T4 and absolute theta F0 and C0 powers (logistic multiple regression).

	Forecast by the model	
Observed	ADHD	Control
ADHD	25	5
Control	5	25

Sensibility=83.3%, Specificity=83.3%.

The qEEG and discrimination between the ADHD and the controls

A multiple logistic regression analysis allowed for the correct classification of 83.3% of the cases (Table 5) as from the data for the absolute F7 and T4 delta powers. The sensibility and specificity were 83.3% in the classification of the ADHD group.

DISCUSSION

Epileptiform activity on the EEG – The finding of epileptiform activity (EA) in 3 (10%) of the ADHD children is similar to the values of 6.1% and 5.6% found in the literature[4,5] and higher than that found in healthy children (2%-3%)[22,23].

The EA could be a factor generating the attention-deficit[5-7] and one of the mechanisms could be the occurrence of transitory cognitive impairment during the EA[24].

In a recent paper on the evaluation of children with rolandic epilepsy and EA, transitory cognitive impairment was only shown in a small percentage of the children, and in these cases there were no cognitive or behavioral impairments[25]. These findings suggest that transitory cognitive impairment is not an important factor in the genesis of behavioral alterations in children with ADHD.

The clinical use of routine EEG in children with ADHD seems to be limited and its recommendation would depend on the suspicion of epileptic manifestations.

qEEG in the comparison between the ADHD and control groups – In the present research the absolute theta power was shown to increase in a diffuse way, but preserving the posterior regions in agreement with the literature[13,14,26].

The finding of a diffuse increase in the delta power, as found in the present study, has been less frequently pointed out[11].

It is possible that the relatively low socio-economic level of various children in the present study could have been a causal factor in the increase in delta activity, similar to that described by Harmony et al. (1990)[27] in healthy children with low socio-cultural stimulation.

The increase in the relative delta power in the left occipital region is in agreement with the increases in delta power in posterior regions described by some other authors[15,26,28].

The smaller relative alpha and beta powers observed in the present research have also been described previously[15,26,28].

It is known that in the development of a healthy child, there is a tendency for the absolute powers in the delta and theta bands to decrease with age, and the relative alpha power to increase[23].

Based on these data, one of the ADHD models based on the qEEG is the maturational lag model of ADHD. On the other hand, since alterations in EEG are frequently very stable and considering that different sub-groups exist within the ADHD, the hypothesis of a developmental deviation model has been raised[28].

Nevertheless, these models do not appear to adequately explain the complexity of ADHD[18].

qEEG in the diagnosis of ADHD – In the present research, the children were assessed at rest with their eyes closed, since this is a simpler situation showing trustworthiness in the test-retest[21].

The model was reached with the absolute delta T4 and theta powers in F0 and C0. Alterations in C0 and F0 in ADHD have already been pointed out in the literature[16].

The finding of 83.3% for both sensibility and specificity in the present research was similar to the values found by Magee et al. (2005)[19] in a study using similar procedures, of 89.0% and 79.6%, respectively.

In studies using other methods for the evaluation of qEEG, the values for sensibility and specificity found were 80.9%-74.00% by Mann et al.[12], 86.0%-98.0 by Monastra et al.[16]; and 83.1%-88.2% by Chabot & Serfontain[13].

Recent research has shown discordant results in the comparison between qEEG and psychiatric evaluation data and rating scales, with high[29] or low[30] values for sensibility and specificity.

One of the aspects limiting transposition of the sensibility and specificity values found in research studies is that the parameters of the qEEG may be particular for that research (ADHD versus normal) and not apply to new groups of patients for whom a differential diagnosis of different clinical conditions is carried out[20].

Another question refers to the negative predictive value, where a qEEG within normal parameters can, in about 20% of cases, correspond to the ADHD that will be diagnosed by other methods.

Nevertheless the EEG analysis has provided highly significant findings in children with ADHD, and new approaches to this procedure could provide additional elements to reinforce its diagnostic contribution.

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