

Quantitative EEG in children with learning disabilities: analysis of band power

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ABSTRACT

In order to better understand the mechanisms of learning disabilities it is important to evaluate the electroencephalogram parameters and their relation to the results of the Wechsler Intelligence Scale. Thirty-six children with complaints of learning disability were studied. Electroencephalograms were carried out while awake and resting, and the values for absolute and relative powers calculated. The results were compared with those of 36 healthy children paired with respect to age, gender and maternal scholastic level. In the group with learning disabilities, the absolute (in the delta, theta and alpha 1 bands) and relative (theta) power values were higher and the relative power alpha 2 value significantly lower at the majority of the electrodes in relation to the control group. There was a high positive correlation in the children with learning disabilities between the relative power alpha 2 and the verbal, performance and total IQ values. These quantitative electroencephalogram findings in children with learning disabilities have a clear relation with psychological measurements and could be due to brain immaturity.

Key words: quantitative EEG, EEG maturation, frequency analysis, cognition, intelligence quotient.

Quantitative electroencephalogram (qEEG) studies in children with learning disabilities have shown alterations, such as an increase in the absolute power in the delta and theta bands¹⁻³, reduction in alpha activity⁴ and reduction in alpha and beta activity, and also poor spatial differentiation⁵. The differences in qEEG results between the various studies must have been due, in greater part, to the different characteristics of the casuistry studied. Children with severe reading/writing disabilities had more delta activity in frontal-temporal regions and those with less intense disabilities had more theta activity (absolute and relative) and less relative alpha activity⁴. In the follow-up of these children the abnormalities tended to decrease, suggesting the importance of maturity factors⁶.

When the learning disability was associated with mental deficiency the alterations were more accentuated than in those without such deficiency, although these children also showed more slow activity than normal children⁷. With respect to dyslexia, the initial expectation that qEEG variables could discriminate healthy individuals from those with dyslexia⁸, failed to be confirmed by other authors⁹. Children with attention deficit/hyperactivity disorder (ADHD) show a greater contingent of slow activity and less beta¹⁰⁻¹³, although the clinical use of qEEG in ADHD has still to be confirmed¹⁴. Recently there has been renewed interest in studying the relationship between qEEG variables and IQ measurements. Elevated correlation was observed in children between aspects of qEEG and coefficients of the intelligence test (WISC)^{15,16}. A study of the relationship between qEEG variables and IQ could provide greater knowledge about the biological aspects related to learning disabilities. It is possible that diversified performance in the tests could have different neuronal activity substrates and could consequently be associated to different qEEG aspects.

The proposal of this study was to analyse brain electrical activity frequency in children with learning disabilities but without evident neurological risk factors, and to evaluate the relationship of qEEG to the IQ measurements (WISC-III).

METHOD

Casuistry - Thirty-six schoolchildren, aged between 8 and 11, with complaints of learning disabilities (group LD), from the outpatients clinic for learning disabilities of the Speech Therapy Clinic of PUC-Campinas were studied, who attended the following inclusion criteria:

1. absence of a history of neurological or psychiatric problems (personal antecedents or close relatives suffering from epileptic

fits, cranial-encephalic traumatism with loss of consciousness, encephalitis, reduced mental capacity, amongst others);

2. normal neural-psychomotor development;
3. normal neurological examination;
4. normal hearing;
5. normal or corrected sight;
6. absence of cognitive deficit (total IQ above 70 on the WISC-III).

Procedures

1. Anamnesis about data referring to the pregnancy, birth, neonatal period, neural-psychomotor development, sleep, feeding, sociability, toys, school life, social-economic level, personal and family pathological antecedents. Questionnaire for the teachers with questions about student behaviour and performance.
2. Raven test for progressively coloured matrixes - instrument standardised and adapted to Brazilian reality, designed to measure general intelligence.
3. Digital electroencephalogram - register of electrical brain activity. Exam carried out to provide an analysis of the brain electrical activity. The EEG was obtained for 200 samples per second with a resolution of 12 bits and 0.5 and 35 Hz filters, using the Braintech 3.0 equipment (EMSA Equipamentos Médicos). Impedance was maintained below 10k Ω . 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 10-20 international 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 cleft, with the objective of evaluating eye movements. The inter-connected auricular electrodes served as the reference. Registration was done during three periods, alternating two minutes resting with the eyes closed with two minutes with the eyes open. Hyperventilation was carried out for three minutes.
4. Quantitative EEG - mathematical data processing of the brain electrical activity so as to highlight certain components in a quantitative mode. For the qEEG, 18 to 26 epochs were selected while awake and resting (eyes closed), each of 2.56s. After applying the quick Fourier transform, the absolute and relative powers were studied in the following frequency bands: delta (up to 3.9 Hz), theta (4.29 to 7.8 Hz), alpha (8.2 to 12.5 Hz), alpha 1

(8.2 to 9.8 Hz), alpha 2 (10.15 Hz 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, $Y = \log(R/1-R)$ ¹⁷.

5. School performance test (SPT) - This is a psychometric instrument, favourably considered by the Psychological Tests Evaluation System (Brazilian Federal Council Of Psychology), which offers an evaluation of the fundamental capacities for school performance in writing, reading and arithmetic, in an objective form. The test was conceived to evaluate schoolchildren in the 1st to 6th grades of schooling, and standardised within the reality of the Brazilian school system¹⁸. In a very broad manner, the SPT indicates which school learning areas have been preserved or prejudiced in the examinee.

6. Wechsler Intelligence Scale for Children - WISC III - This is a clinical instrument, applied individually, to evaluate the intellectual capacity of children between 6 and 16 1/2 years of age. It is composed of various subtests, each measuring a different aspect of intelligence and is used to verify the cognitive performance of the subjects in qualitative and quantitative terms. This scale proposes problems that permit an appreciation of the capacity of the subjects with respect to memory, attention, action planning, spatial orientation and other aspects connected to mental functioning. It is composed of two types of evaluation: that of cognitive performance as related to the verbal aspect, and that of cognitive performance as related to the non-verbal aspect, that is, to performance or carrying out of an action.

7. Traditional neurological examination.

Data analysis - The sample was composed of a control group (CG) of "healthy" children, paired according to age, gender and scholastic level of their parents. These children had no history of neurological (for example personal antecedents or close relatives suffering from epileptic seizures, cranial-encephalic traumatism with loss of consciousness, encephalitis, reduced mental capacity) or psychiatric problems, showed normal neural-psychomotor development, normal neurological and electroencephalographic examinations, an absence of cognitive deficit in the Raven progressive matrixes test, had never repeated a school year and presenting performance compatible with their age and school grade in the SPT.

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 for paired samples).

Correlation between aspects of WISC (verbal IQ, performance IQ and total IQ) and the qEEG parameters was also studied, using Pearsons correlation analysis.

The level of significance was 0.05, but since evaluations were carried out relative to 15 electrodes, and taking into account the possibility of alpha error inflation, the level of 0.0033 ($0.05/15=0.0033$) was also considered by the Bonferroni correction.

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

RESULTS

[Table 1](#) shows the distribution of the individuals with complaints of learning disability according to age and gender. All the children showed inferior performances in the total SPT or its subtests.

Table 1. Distribution of the 36 children according to age and gender.

Age (years)	Masculine		Feminine		Total	
	Nº	%	Nº	%	Nº	%
8	4	11.1	1	2.8	5	13.1
9	11	30.5	2	5.5	13	34.2
10	6	16.7	3	8.3	9	28.9
11	5	13.9	4	11.1	9	23,7
Total	26	72.2	10	27.7	36	100

[Table 2](#) shows the values for the absolute delta, theta and alpha 1 powers for the group of children with learning disabilities (LD) and the control group (CG), and the value for p in the respective comparisons (t test for paired samples).

Table 2. Values for the absolute delta, theta and alpha 1 powers for the groups of children with learning disability (LD) and the control group (CG) and the value for p in the respective comparisons.

Electrode	Absolute Delta			Absolute Theta			Absolute Alpha 1		
	LD	CG	p	LD	CG	p	LD	CG	p
T3	125.02	105.19	0.001**	114.60	89.55	0.000**	59.97	46.71	0.002**
T5	157.70	139.40	0.003**	167.23	134.41	0.001**	111.21	97.63	0.127
F3	179.79	151.09	0.000**	174.40	129.37	0.000**	81.76	65.28	0.006*
C3	178.42	153.19	0.000**	186.12	141.52	0.000**	106.14	82.48	0.007*
P3	194.92	171.42	0.003**	211.53	167.50	0.002**	129.87	114.10	0.079
O1	192.07	179.84	0.209	211.31	190.34	0.177	180.16	190.47	0.222
T4	126.43	103.54	0.000**	114.28	89.39	0.000**	61.56	48.28	0.001**
T6	169.18	138.47	0.001**	178.19	137.92	0.001**	129.05	104.05	0.033*
F4	185.32	150.85	0.000**	173.21	134.20	0.000**	81.85	66.85	0.007*
C4	178.16	153.20	0.000**	178.51	142.98	0.001**	107.27	84.10	0.012*
P4	192.02	166.43	0.015*	207.63	166.76	0.006*	138.82	111.98	0.017*
O2	187.87	182.47	0.369	205.63	196.34	0.339	189.70	189.85	0.409
Fz	198.61	160.23	0.000**	194.78	148.09	0.000**	90.27	71.11	0.001**
Cz	207.85	180.45	0.000**	220.11	171.81	0.000**	111.53	88.99	0.004*
Pz	218.92	181.24	0.004*	235.16	186.67	0.006*	145.75	119.60	0.023*

*p<0.05; **p<0.003

Observe that the absolute delta, theta and alpha 1 powers were statistically greater for the majority of the electrodes for the LD group, and that the differences were highly significant ($p < 0.0033$) in the delta and theta bands.

[Table 3](#) shows the values for the relative theta and alpha 2 powers for the LD and CG groups as well as the values for p in the comparisons.

Table 2. Values for the absolute delta, theta and alpha 1 powers for the groups of children with learning disability (LD) and the control group (CG) and the value for p in the respective comparisons.

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*p<0.05; **p<0.003

For various electrodes, in a statistically significant way, there was greater relative theta power and lesser relative alpha 2 power for the LD group.

No statistically significant differences were found between the LD and CG groups for the absolute total alpha and beta powers or for the relative delta, theta and beta powers.

[Tables 4](#) and [5](#) show the values for Pearsons correlation coefficient and for p with respect to the relationship between the qEEG variables and the WISC III quotients.

Table 4. Pearson's correlation coefficients between the absolute and relative alpha 1 powers and the IQ of WISC-III, and the respective p values.

Electrode	Absolute Alpha 1 power				Relative Alpha 1 power	
	Verbal IQ		Total IQ		Verbal IQ	
	Coefficient	p	Coefficient	p	Coefficient	p
T3	-0.17	0.031*	-0.09	0.590	-0.14	0.380
T5	-0.41	0.012*	-0.37	0.023*	-0.37	0.022*
F3	-0.32	0.051	-0.19	0.257	-0.29	0.081
C3	-0.40	0.014*	-0.34	0.040*	-0.39	0.016*
P3	-0.44	0.006*	-0.34	0.037*	-0.46	0.004*
O1	-0.46	0.004*	-0.39	0.016*	-0.53	0.001**
T4	-0.31	0.066	-0.25	0.133	-0.20	0.230
T6	-0.45	0.005**	-0.35	0.032*	-0.41	0.011*
F4	-0.36	0.028*	-0.24	0.152	-0.36	0.027*
C4	-0.39	0.018*	-0.30	0.067	-0.41	0.013*
P4	-0.48	0.003**	-0.42	0.011*	-0.51	0.001**
O2	-0.42	0.009*	-0.30	0.072	-0.47	0.003**
Fz	-0.37	0.024*	-0.24	0.144	-0.33	0.044*
Cz	-0.49	0.002**	-0.38	0.021*	-0.49	0.002**
Pz	-0.49	0.002**	-0.39	0.018*	-0.48	0.003**

Pearson: *p<0.05; **p<0.0033.

Table 5. Pearson's correlation coefficients between the relative alpha 2 power and the verbal, performance and total IQ quotients from the WISC-III, and the respective p values.

Electrode	Verbal IQ		Relative Alpha 2 power Performance IQ		Total IQ	
	Coefficient	p	Coefficient	p	Coefficient	p
T3	0.35	0.035*	0.43	0.007*	0.43	0.008*
T5	0.35	0.036*	0.41	0.011*	0.42	0.009*
F3	0.48	0.003**	0.52	0.001**	0.57	0.000**
C3	0.33	0.046*	0.46	0.004*	0.43	0.008*
P3	0.35	0.034*	0.52	0.001**	0.47	0.003**
O1	0.27	0.102	0.35	0.036*	0.35	0.035*
T4	0.29	0.085	0.46	0.004*	0.42	0.010*
T6	0.36	0.030*	0.52	0.001**	0.49	0.002**
F4	0.49	0.002**	0.53	0.001**	0.58	0.000**
C4	0.20	0.230	0.49	0.002**	0.38	0.020*
P4	0.32	0.057	0.52	0.001**	0.45	0.005*
O2	0.28	0.097	0.40	0.014*	0.37	0.025*
Fz	0.50	0.002**	0.51	0.001**	0.57	0.000**
Cz	0.48	0.002**	0.54	0.001**	0.57	0.000**
Pz	0.40	0.014**	0.54	0.001**	0.51	0.001**

Pearson: * p<0.05 ; **p<0.0033.

There was negative correlation between the verbal IQ and the absolute and relative alpha 1 powers, whereas for the total IQ this negative correlation only occurred for the absolute power ([Table 4](#)).

As can be observed in [Table 5](#) a highly positive correlation was found between the relative alpha 2 power and the three WISC quotients (verbal, performance and total) for almost all the electrodes.

DISCUSSION

In the present study the children with learning disabilities presented greater absolute delta and theta powers than normal children, similar to that pointed out by other authors^{1,2,4}. With respect to the value of these findings, the present casuistry does not present previously reported characteristics such as a great association with alterations in the qEEG, mental retardation⁷ or risk factors commonly connected to brain injury⁴.

On the other hand, it must be remembered that in the process of brain maturation up to the adult stage, a progressive decrease in delta, theta and alpha 1 activities occur and also an increase in relative alpha 2 power^{17,19,20}, permitting the suggestion that the findings of increased delta, theta and alpha 1 powers in the children with learning disabilities corresponded to an immaturity of brain development, in agreement with the interpretation of Harmony et al.⁶, and well-founded in the evolutive study in which the qEEG abnormalities tend to disappear.

With respect to the localisation of these alterations, it was observed that in both the present study and that of Harmony et al.⁶, the occipital regions were not involved, possibly because the maturity of the brain electrical activity in these regions occurs much quicker than the referred to slow activities¹⁷ and in most cases would already have occurred in both the children with learning disabilities and the healthy ones.

Studies comparing the results of psychological tests and the qEEG variables are scarce^{15,16}. In the present study there was a highly positive correlation between the relative alpha 2 power and the total, performance and verbal IQ quotients. Such correlation can be explained by the fact that the alpha 2 power is associated with greater maturity of the brain electrical activity, as already shown in healthy children^{17,20}.

However the frequency of the alpha 1 fraction is immediately inferior to that of alpha 2 and its negative correlation with the IQ could signify lower brain maturity. This processes under normal conditions from the alpha 1 to the alpha 2 bands. This finding is very interesting and shows that the analysis of the traditional bands (total alpha) may be insufficient to detect differences in brain maturity or correlations with IQ.

The present findings agree with the experience of Schmid et al.¹⁵ that the frequency in the middle of the alpha band is highly associated with performance in the WISC-III. The fact that the correlations between the qEEG variables at the various electrodes and IQ were broad in their extension and sometimes in frequency bands could, in part, be due to the fact that the tests measured heterogeneous abilities^{15,16}.

Thus it was concluded that qEEG could provide subsidies concerning biological brain aspects involved in children with learning disabilities, in pointing out, for example, brain immaturity as one of the possible factors in the genesis of such disabilities. Other studies should analyse the value of qEEG in sub-groups of children diagnosed with learning disabilities.

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