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## Original Article

# Differentiating Autistic Children With Quantitative Encephalography: A 3-Month Longitudinal Study

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## ABSTRACT

The present study used a single-channel quantitative electroencephalographic (EEG) assessment to differentiate autistic children from normal control subjects. One hundred five normal and 17 autistic children participated in the study. In addition to amplitude measures of the frequency bands of delta, theta, alpha, sensorimotor rhythm, and beta and the theta to beta ratio, intra- (6 minutes) and intersessional (3 months) consistencies were also examined. The results indicated that autistic children showed significantly higher quantitative EEG amplitudes in many of the frequency bands than normal children; furthermore, their quantitative EEG activities were found to be relatively unstable within a 6-minute session compared with normal children. Discriminant function analyses revealed that absolute sensorimotor rhythm and beta amplitudes were the best predictors that correctly differentiated autistic children from normal children in the present sample, with a high accuracy rate of 95.2%. In addition, quantitative EEG measurements of normal and autistic children were found to be generally consistent across the 3-month period. (*J Child Neurol* 2006;21:391–399; DOI 10.2310/7010.2006.00094).

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Electroencephalography (EEG) has been a useful clinical diagnostic tool to measure the brain's electrophysiologic processes in humans. Empirical studies have demonstrated that patient groups with different neurologic and psychiatric disorders differed from normal individuals in one or more EEG spectral characteristics.<sup>1</sup> For example, EEG measures have been found to differentiate patients with depression,<sup>2-5</sup> schizophrenia,<sup>6-8</sup> stroke,<sup>9</sup> structural brain lesions,<sup>10,11</sup> and dementia<sup>12-17</sup> from normal controls.

EEG studies on children with neurologic disorders also showed that their quantitative EEG measurements were different from those of normal children. Specifically, children at risk of neurologic disease were found to have significantly higher slow-wave activities,<sup>18</sup> and learning-disabled children were found to have significantly higher activities in all bands.<sup>19</sup> Children with attention-deficit hyperactivity disorder (ADHD) were found to have higher theta and alpha activities,<sup>20</sup> and several studies have reported that children with ADHD demonstrated a higher theta to beta ratio than normal children.<sup>21,22</sup> Using this ratio, different research groups were able to classify children with different subtypes of ADHD, as well as normal controls, with high accuracy.<sup>23-25</sup>

Relatively fewer studies have been done on the quantitative EEGs of autistic individuals, and the findings are relatively less consistent than those on other disorders. Cantor et al studied 11 low-functioning autistic children (mean IQ = 37.45) aged between 4 and 12 years (mean age 7.89 years, SD = 2.0 years) using relative and total power measurements and found that autistic children showed more relative slow-wave, less relative alpha, and higher total power than normal children.<sup>26</sup> On the other hand, in Dawson et al's study using absolute power on 28 low-functioning autistic children (IQ = 60) aged between 5 and 18 years (mean 11.0 years, SD 4.0 years), it was found that autistic children demonstrated reduced slow-wave and alpha activities.<sup>27</sup> More recently, Daoust et al's study on nine autistic individuals (IQ  $\geq$  80) aged 12 to 53 years (mean 22.2 years, SD 4.1 years) found that autistic individuals showed lower absolute beta amplitude in the occipital area and higher absolute theta amplitude in the prefrontal area.<sup>28</sup> The different findings in these studies might be related to the methodologic differences in the studies. Whereas Cantor et al measured relative and total power,<sup>26</sup> Dawson et al used absolute power,<sup>27</sup> and Daoust et al used absolute amplitude.<sup>28</sup> In addition, whereas both Cantor et al and Dawson et al enlisted young children and adolescents as participants,<sup>26,27</sup> Daoust et al's participants ranged from adolescence to adulthood.<sup>28</sup> Furthermore, autistic participants in the three studies differed in their levels of functioning, which ranged from severely impaired,<sup>26</sup> to mildly impaired,<sup>27</sup> to low normal average.<sup>28</sup> These methodologic and participant differences have made it difficult to compare the findings.

Given that there are relatively few studies on the quantitative EEG profile of autistic children, the major purpose of the present study was to examine whether autistic children show differences in quantitative EEG profiles from normal children. With respect to

the inconclusive findings in past studies as a result of the use of different quantitative EEG measures, the present study examined both the absolute and relative amplitudes of autistic children. With respect to the findings of Monastra et al on the theta to beta ratio as an "attention index,"<sup>24,25</sup> the present study also examined whether this index is sensitive to autistic children, who also show attentional problems.<sup>29,30</sup> It should be noted, however, that although attentional problems are the central symptoms in ADHD, the attentional problems shown by autistic children are secondary to their social and language impairments.<sup>31</sup> In addition, there is a qualitative difference between the attentional deficits between children with ADHD and autistic children, in which children with ADHD show inattentiveness and impaired sustained attention,<sup>31</sup> whereas autistic children's impairments are more in selective attention.<sup>32</sup> Hence, it is anticipated that the theta to beta ratio characteristic of ADHD might not be observed in autistic children. In addition, the present study aimed to examine the issue of consistency in autistic children's EEGs across time. This was examined from two perspectives: intrasessional variability within the 6-minute recording time and intersessional consistency across a 3-month test-retest period. Reliability across time is critical in establishing the validity of an assessment technique; however, there are relatively few studies on this issue.<sup>24,33,34</sup> Hence, repeated measures were taken of the quantitative EEG measures of the participants in the present study to examine whether these were consistent in normal and autistic children.

## MATERIALS AND METHODS

### Participants

One hundred twenty-two volunteers participated in this study, with 105 normal controls (44 boys and 61 girls) and 17 autistic children (14 boys and 3 girls). Although there was a higher percentage of girls in the normal group compared with the autistic group, *t*-tests on all quantitative EEG baseline measurements indicated no significant gender effect (all *P*s > .05) on any of the measures under study. Given that the male to female ratio of autism is about 4:1,<sup>31</sup> the uneven number of male and female participants in the present autistic sample reflected the unequal gender distribution of the disorder. Children in the autistic group were recruited from special educational centers in Hong Kong, and children in the normal control group were recruited from a local kindergarten and a local primary school. All autistic children were diagnosed based on the criteria in the *Diagnostic and Statistical Manual of Mental Disorders, 4th Edition*,<sup>31</sup> and no comorbidity of other brain disorders, such as epilepsy, prenatal or postnatal abnormalities, or other neurologic disorders, was reported by any parent. The normal children were without any history of neurologic disorders, head trauma, behavioral and emotional abnormalities, and mental retardation. Visual observation of the head shapes and sizes of the children did not suggest malformations in the autistic group or a noticeable difference in sizes between the autistic and normal control groups. All participants were not under medication at the time of assessment. The autistic and normal control groups did not differ in age, but the normal control group had a significantly higher IQ than the autistic group (Table 1).

Consent was obtained from the parents of all children prior to the testing. Before data collection, the examiner explained to the children (or in the case of the autistic group, the parents as well) the assessment procedure and informed them of their rights to terminate their participation at any time during the assessment. The protocol was approved by the Joint Chinese University of Hong Kong-New Territories Eastern Cluster Clinical Research Ethics Committee and conducted according to the Declaration of Helsinki.

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Table 1. Demographic Characteristics of the Autistic and Normal Children

Demographic Characteristics	Normal Children (n = 105)		Autistic Children (n = 17)		Independent t-Tests		
	Mean (95% CI)	SD	Mean (95% CI)	SD	t	df	Significance
Age (yr)	7.76 ( $\pm 0.39$ )	2.04	7.12 ( $\pm 1.04$ )	2.18	1.20	120	.233
IQ	109.51 ( $\pm 2.97$ )	15.53	92.00 ( $\pm 9.95$ )	20.93	4.04	109	.000

CI = confidence interval.

## Procedure

The children were tested individually in a quiet room by a trained research assistant at baseline. The Test of Nonverbal Intelligence – 3 (Form A)<sup>35</sup> was first administered to the child to measure his or her general intellectual functioning. Then the quantitative EEG profile of the child was measured using the BrainMaster System Type 2E Module (BrainMaster Technologies, Oakwood Village, OH) using a Quadrature filter<sup>36</sup> with a rolloff of 36 dB per octave, at a sampling rate of 120 samples/second and a bandpass filter from 1 to 40 Hz. The BrainMaster was particularly useful for this clinical population because saline was used for conduction and could be applied beforehand on the equipment. Continuous data were collected from a one-channel output at the estimated FpZ location (International 10-20 system)<sup>37</sup> referenced to the ears. FpZ, the midline electrode in the frontal area, was chosen as the site for electrode placement because this locus records frontal activity. Given that there have been reports on frontal lobe abnormalities in autistic children,<sup>38–40</sup> abnormal EEG signals will be more likely to be observed in this region, if any.

Data were collected for six continuous minutes, during which the child was asked to sit quietly on a chair in the eyes-open resting condition. As the vigilance state of the participant is likely to affect the EEG, the examiner was monitoring the child throughout the 6-minute recording period and made sure that the child was alert, eyes open, and resting throughout. Electro-oculogram and electro-myogram were not recorded to increase the compliance of the autistic children. This was considered acceptable because the standard procedure of using the BrainMaster does not require electro-oculogram or electromyogram recording because the recording software has a built-in detector, which automatically detects and excludes signals at threshold amplitude. Visual inspection of the data confirmed that eye blinks and large movements have been detected and thereby excluded from the data.

All participants were invited to be retested again after 3 months, and a subgroup of 50 children (normal controls = 43, autistic group = 7) voluntarily participated in the second assessment (retest) (Table 2). To ensure the comparability of the retested group and the nonretested group, *t*-tests had been conducted on all baseline measurements for both the autistic and the normal sample. The results indicated that all quantitative EEG baseline measures between the two groups were comparable (all *F*s > .05), both for the autistic and the normal sample. The procedure of the retest was the same as that at baseline except that the Test of Nonverbal Intelligence – 3 was not administered.

## Data Analyses

The EEG signals were recorded onto a notebook computer, digitized, and filtered to give absolute amplitude measurements for five frequency bands: delta (1–3 Hz), theta (4–7 Hz), alpha (8–12 Hz), the sensorimotor rhythm (12–15 Hz), and beta (15–20 Hz). Although four of the five frequency bands are customary in quantitative EEG clinical studies, the sensorimotor rhythm was found to be associated with epilepsy and ADHD<sup>41</sup> and is commonly used in neurofeedback studies.

The recording software generates absolute amplitudes in a minute-by-minute manner. This resulted in six mean absolute amplitudes for each frequency band, which were entered into a standard statistical software

package for computations of the other measures. The relative amplitude of a frequency band was computed by dividing its absolute amplitude by the sum of the absolute amplitudes of the five frequency bands and converted into a percentage, and the theta to beta ratio was computed by dividing absolute theta by absolute beta amplitude. This yielded, for each participant, 11 quantitative EEG measures (absolute delta, theta, alpha, sensorimotor rhythm, beta; relative delta, theta, alpha, sensorimotor rhythm, beta; and theta to beta ratio), which were used in the following analyses.

The spectral profiles of autistic and normal children were examined separately for the absolute amplitudes, relative amplitudes, and theta to beta ratio. Intrasessional variability was tested separately for each of the 11 quantitative EEG measures using analysis of variance (ANOVA) with repeated measures, with the six 1-minute data as the within-groups factor and diagnoses as the between-groups factor. In addition, a variability index was derived for each of the 11 quantitative EEG measures by taking the average of the 6 minutes of data and computing the standard deviation. The greater the standard deviation from the mean, the greater the variability in that quantitative EEG measure. Intersessional consistency was tested separately for the autistic group and the normal control with the subgroup of 50 children using paired *t*-tests to compare the 11 quantitative EEG measures and the 11 corresponding quantitative EEG variability indices at baseline and at the 3-month retest. Finally, two discriminant function analyses were performed on the 11 quantitative EEG measures and the 11 corresponding variability indices. For each discriminant function analysis, a model was constructed using data from half of the sample and validated using data from the other half of the sample. This validation design was considered more stringent than using the 3-month retest data in that sample independence could be maintained and hence increase the external validity of the classification function.<sup>42</sup>

## RESULTS

### Spectral Profile

The quantitative EEG spectral profiles of the autistic and normal children (Table 3) were analyzed using multivariate ANOVA, and the multivariate results indicated that the autistic group had significantly different absolute (eta squared = .59) and relative (eta squared = .40) amplitudes than the normal children. For the absolute amplitudes, post hoc univariate analyses indicated that the autistic group had significantly higher amplitudes in all five frequency bands than the normal children. The differences remained highly significant even after adjusting for multiple comparisons (*P* < .005) and with large effect sizes (eta squared, delta = .16; theta = .35; alpha = .36; sensorimotor rhythm = .42; and beta = .19). For the relative amplitudes, post hoc analyses revealed that only the relative sensorimotor rhythm difference was significant with moderate effect size (eta squared = .09), suggesting that the multivariate difference was likely to be contributed by the sensorimotor rhythm, with minimal effects from the other frequency bands. The autistic group was also found to have a significantly higher theta to beta ratio than the normal children, with a small effect size (eta squared = .04).

Table 2. Demographic Characteristics of the Retested and Nonretested Groups

Demographic Characteristics	Retested			Nonretested			Independent t-Tests		
	Mean (95% CI)	SD	n	Mean (95% CI)	SD	n	t	df	Significance
Normal children									
Age (yr)	8.99 ( $\pm$ 0.51)	1.70	43	6.92 ( $\pm$ 0.46)	1.83	62	-5.89	103	.000
IQ	107.02 ( $\pm$ 5.63)	18.84	43	111.61 ( $\pm$ 2.95)	11.87	62	1.43	92	.155
Autistic children									
Age	7.38 ( $\pm$ 2.08)	2.81	7	6.94 ( $\pm$ 1.09)	1.76	10	-0.40	15	.696
IQ	92.29 ( $\pm$ 16.93)	22.85	7	91.80 ( $\pm$ 12.86)	20.75	10	-0.05	15	.964

CI = confidence interval.

### Intrasessional Variability

ANOVA with repeated measures was performed on the 6-minute measure of each frequency band (absolute and relative) and the theta to beta ratio. Figure 1 shows the absolute amplitudes of all frequency bands by minute, and Figure 2 shows the relative amplitudes of all frequency bands and the theta to beta ratio by minute. The results indicated significant diagnosis  $\times$  minute interaction effects for the absolute amplitudes in delta ( $F(5,116) = 3.04$ ,  $P = .013$ ), alpha ( $F(5,116) = 6.61$ ,  $P < .001$ ), sensorimotor rhythm ( $F(5,116) = 3.06$ ,  $P = .012$ ), and beta ( $F(5,116) = 2.85$ ,  $P = .018$ ); for the relative amplitudes of alpha ( $F(5,116) = 2.40$ ,  $P = .041$ ) and beta ( $F(5,116) = 2.49$ ,  $P = .035$ ); and for the theta to beta ratio ( $F(5,116) = 2.30$ ,  $P = .049$ ). The pattern of higher variability in the amplitudes as shown by the autistic group appears to be sustained across the 6-minute period, whereas the normal control group showed a relatively more stable pattern across time. In addition, these patterns appear to be quite consistent over the different frequency bands, particularly in the absolute amplitudes. The results remained highly significant for the absolute alpha amplitude after adjusting for familywise error ( $P < .005$ ).

The variability index, derived by taking the average of the 6 minutes of data and computing the standard deviation, of all absolute and relative amplitudes was analyzed using multivariate ANOVA with post hoc univariate analyses (Table 4). Multivariate results indicated that the autistic and normal control groups differed in both absolute (eta squared = .45) and relative (eta squared = .14) amplitudes. Post hoc univariate results indicated that autistic children showed overall greater variation in the frequency bands than normal control subjects, and the differences were significant for absolute delta ( $F(1,120) = 17.89$ ,  $P < .001$ ), absolute theta

( $F(1,120) = 51.03$ ,  $P < .001$ ), absolute alpha ( $F(1,120) = 86.74$ ,  $P < .001$ ), absolute sensorimotor rhythm ( $F(1,120) = 57.17$ ,  $P < .001$ ), absolute beta ( $F(1,120) = 34.06$ ,  $P < .001$ ), relative delta ( $F(1,120) = 7.06$ ,  $P = .009$ ), and relative sensorimotor rhythm ( $F(1,120) = 16.90$ ,  $P < .001$ ). After adjusting for multiple comparisons ( $P < .005$ ), the variability differences remained significant for all five absolute frequency bands and relative sensorimotor rhythm.

### Intersessional (Test-Retest) Consistency

Although the normal control group showed higher consistency across the 3-month retest period in both absolute and relative amplitudes and the theta to beta ratio than the autistic group (Table 5), paired *t*-tests demonstrated significant differences only on absolute alpha and the theta to beta ratio after correction for familywise error ( $P < .005$ ). Thus, both the normal control and autistic groups demonstrated reasonably reliable test-retest results in a 3-month interval. Intersessional consistency was also examined for the variability indices (Table 6). The results indicated that all variability indices were very stable for both the autistic and normal control groups over the 3-month period.

### Differentiating Autistic Children With Quantitative EEG Measures

Given that both the amplitude and the variability measures were significantly different between the autistic and the normal control groups, two sets of discriminant function analyses were done using the amplitude measures and the variability measures to examine if these variables can differentiate autistic from normal children. In the discriminant function analysis of the amplitude measures, half of the sample (normal children = 53, autistic children

Table 3. Multivariate Analysis of Variance and Post hoc Univariate Comparisons of Quantitative Electroencephalographic Spectral Profiles Between Autistic and Normal Children

Spectral Profiles	Normal Children (n = 105)		Autistic Children (n = 17)		MANOVA and Post hoc Tests		
	Mean (95% CI)	SD	Mean (95% CI)	SD	F	df	Significance
Absolute amplitudes ( $\mu$ V)							
Delta	155.96 ( $\pm$ 4.95)	52.82	233.61 ( $\pm$ 28.95)	60.89	32.84	5, 116	.000
Theta	61.06 ( $\pm$ 3.00)	15.68	95.29 ( $\pm$ 9.35)	19.66	22.99	1, 120	.000
Alpha	38.12 ( $\pm$ 1.44)	7.51	56.31 ( $\pm$ 6.32)	13.29	64.78	1, 120	.000
Sensorimotor rhythm	19.12 ( $\pm$ 0.97)	5.05	33.83 ( $\pm$ 4.97)	10.45	66.78	1, 120	.000
Beta	20.96 ( $\pm$ 1.10)	5.75	30.16 ( $\pm$ 5.15)	10.83	86.39	1, 120	.000
Relative amplitudes							
Delta	51.65 ( $\pm$ 1.05)	5.50	50.85 ( $\pm$ 2.55)	5.36	19.27	4, 117	.000
Theta	20.85 ( $\pm$ 0.37)	1.92	21.89 ( $\pm$ 0.90)	1.89	0.31	1, 120	.580
Alpha	13.58 ( $\pm$ 0.64)	3.37	12.89 ( $\pm$ 0.88)	1.85	4.26	1, 120	.041
Sensorimotor rhythm	6.59 ( $\pm$ 0.21)	1.08	7.59 ( $\pm$ 0.68)	1.42	0.64	1, 120	.410
Beta	7.33 ( $\pm$ 0.34)	1.78	6.79 ( $\pm$ 0.84)	1.77	11.39	1, 120	.001
Theta to beta ratio	3.05 ( $\pm$ 0.13)	0.70	3.48 ( $\pm$ 0.35)	0.73	1.38	1, 120	.243
Theta to beta ratio					5.55	1, 120	.020

CI = confidence interval; MANOVA = multivariate analysis of variance.

Sphericity was checked using the Mauchly's Sphericity Test, and the Greenhouse-Geisser adjusted statistics were reported where the sphericity assumptions were violated.

= 9) was randomly selected for inclusion in a stepwise model. The model was then cross-validated using the jackknife procedure and further validated with the other half of the sample (normal children = 52, autistic children = 8). The initial analysis yielded two measures, the absolute sensorimotor rhythm and absolute beta amplitudes, that could reliably predict diagnosis (Wilk's lambda = .40,  $\chi^2$  ( $df=1$ ) = 54.34,  $P < .001$ ), with an overall correct classification rate of 95.2%. The sensitivity was 77.8%, and the specificity reached 98.1%. The jackknife procedure yielded the same classification rate of 95.2%, indicating that the function was stable. Using the second half of the sample to validate the discriminant function, the classification rate was comparable at 95.0%, with a sensitivity of 87.5% and a specificity of 96.2%. Thus, the discriminant function using absolute sensorimotor rhythm and beta amplitudes was able to predict diagnosis in the present sample, with satisfactory classification rates with high reliability. Given that the current diagnosis of autism involves the clinician's relatively subjective clinical judgment and reports from caregivers, the quantitative EEG technique might provide a relatively objective method in diagnosing the disorder, which could serve as an easy-to-administer complement to the current methods of diagnosis. However, more studies are needed to further examine the sensitivity and specificity of this technique in discriminating between normal children and children with other neurodevelopmental disabilities.

The results of the discriminant function analysis on the quantitative EEG variability indices showed that absolute alpha variability alone could correctly classify 90.6% of normal children and 77.8% of autistic children, resulting in an overall classification rate of 88.7% (Wilk's lambda = .59,  $\chi^2$  ( $df=1$ ) = 31.15,  $P < .001$ ) (Figure 3). The jackknife cross-validation procedure yielded the same results. In the validation analysis using the second half of the sample, the correct classification rate was 90.0%. The specificity was 94.2%, and the sensitivity was 62.5%.

## DISCUSSION

The present study aimed to examine the quantitative EEG profile of autistic children and to find out whether it has distinctive characteristics that differentiate it from a group of age-matched normal children. Absolute and relative amplitudes, theta to beta ratio, and consistency measures were examined and compared between autistic and normal children. Autistic children were found to have significantly higher absolute amplitudes in all frequency bands, higher relative amplitude in sensorimotor rhythm, a higher theta to beta ratio, and higher intrasessional variability in the absolute amplitudes and relative sensorimotor rhythm than normal children. Entering the amplitude and variability measures into discriminant function analyses yielded a highly satisfactory classification rate of 95.2% using the absolute sensorimotor rhythm and absolute beta amplitude measures and a classification rate of 88.7% using the variability index of the absolute alpha. Although it is too early to generalize the present findings with reference to the inconsistent findings from previous studies and a lack of other patient groups for clinical differential diagnoses, the results from the present study nevertheless serve to provide some initial evidence to support the development of the clinical utility of quantitative EEG parameters as a potentially useful screening tool for differentiating autistic children from normal children. Future studies should be done with a larger sample size to increase generalizability and to include different patient groups to establish the differential diagnostic ability of this technique.

Although the present study attempted to shed some light on the discrepancy in the findings of Cantor et al,<sup>26</sup> Dawson et al,<sup>27</sup> and Daoust et al<sup>28</sup> through examining both the relative and absolute amplitudes, the results only partially supported the previous findings. Cantor et al found that autistic children showed higher relative slow waves, lower alpha power, and higher total power than normal children.<sup>26</sup> However, autistic children in the present study only showed higher total amplitude (amplitude being the square root of power), which was computed as the sum of the five absolute amplitudes. For the relative amplitudes, whereas Cantor et al found higher slow waves and lower alpha,<sup>26</sup> we found only higher sensorimotor rhythm for the autistic children. Our findings were also somewhat inconsistent with the findings of Dawson et al, who found that autistic children had reduced absolute power in the slow waves and alpha.<sup>27</sup> Our findings, on the contrary, indicated that autistic children had significantly higher, rather than lower, absolute slow waves and alpha amplitudes than normal children. A number of factors might play a role in the inconsistent results. Given that the autistic children participating in this and the previous three studies were different in their levels of functioning, it is conceivable that the varying levels of general functioning might be a factor for the discrepant findings. That is, whereas Cantor et al studied severely impaired autistic children and Dawson et al studied mildly impaired autistic children,<sup>26,27</sup> Daoust et al's autistic participants had close to normal functioning,<sup>28</sup> and the autistic children in the present study were considered high functioning. This difference could suggest that autistic children with different levels of cognitive functioning might have different quantitative EEG profiles. This appears to be supported by the fact that the present findings were more consistent with the study by Daoust et al, in which autistic individuals had a level of functioning much closer to that of the present study.<sup>28</sup> Further studies to compare the quantitative EEGs of autistic children with different levels of functioning might help shed light on this issue. In addition, it should not be overlooked that other possible sources might contribute to the differences because autistic children with different levels of functioning can have other related brain abnormalities that were not considered in previous studies. Care should be taken in future studies to examine and control for these other possible confounding factors. Autistic individuals in both the Daoust et al study<sup>28</sup> and the present study were found to show higher absolute theta amplitude in the prefrontal area, suggesting that prefrontal theta activity might be a more reliable quantitative EEG index for autistic individuals. On the other hand, Daoust et al did not find any difference in the prefrontal beta amplitude that was found in the present study to differentiate the autistic children from normal children with high accuracy.<sup>28</sup> A larger sample size should be recruited and other electrode locations examined to find out more about theta and beta activities and the sensorimotor rhythm in future studies.

To find out whether the theta to beta ratio, being an attention index as suggested by Monastra et al,<sup>24,25</sup> is sensitive to our sample of autistic children, we compared the theta to beta ratio between normal and autistic children. Our result on normal children (mean = 3.05) was consistent with that of Monastra et al's study (mean = 3.03).<sup>24</sup> It was also found that autistic children had a significantly higher theta to beta ratio than normal controls, although at a lower level (mean = 3.48) than that in children with ADHD, as reported by Monastra et al (mean = 7.70–8.49),<sup>24</sup> and was not found in the 3-month retest. On the one hand, this suggested that the theta to beta ratio might not be as stable as the other amplitude measures in differentiating autistic children. On the other hand, the theta to

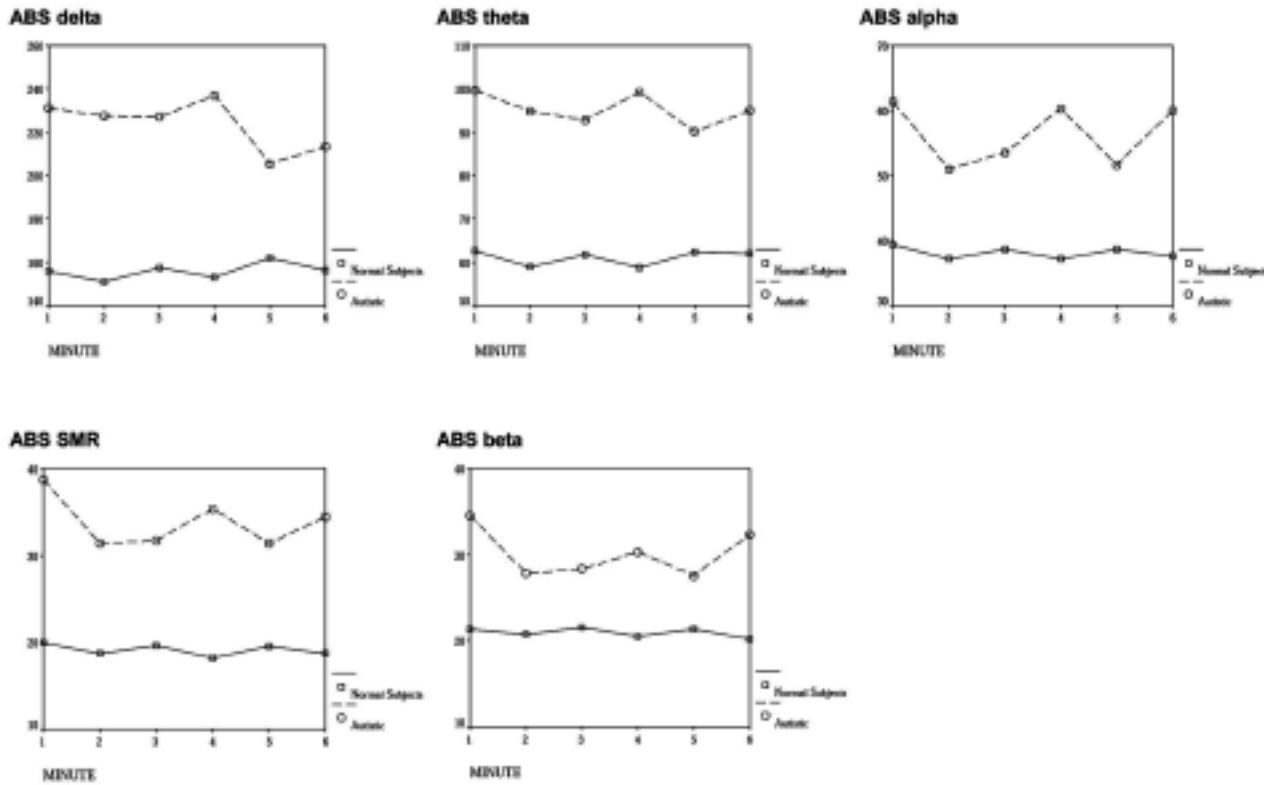


Figure 1. Profile plots of the intrasessional variability of the five absolute (ABS) amplitudes. The x-axis represents the 6-minute recording time for the different frequency bands; the y-axis represents the absolute amplitudes. SMR = sensorimotor rhythm.

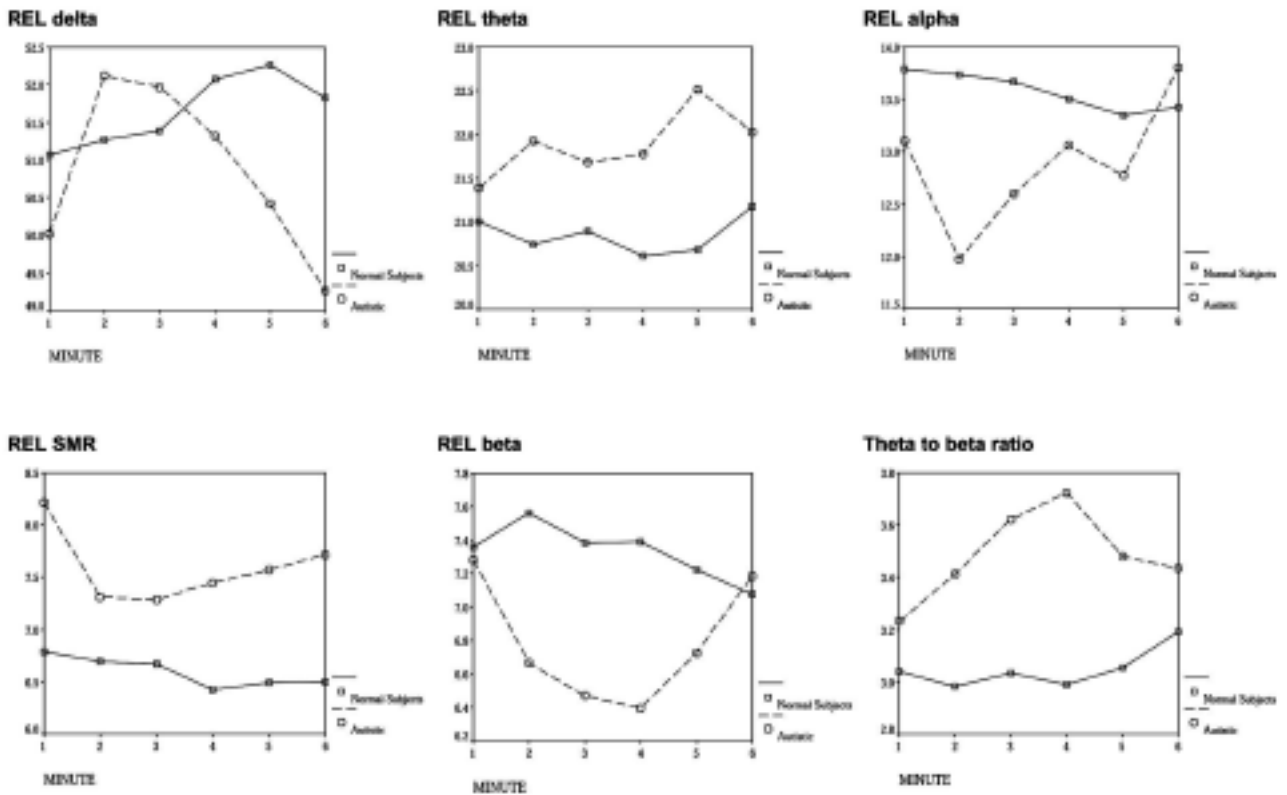


Figure 2. Profile plots of the intrasessional variability of the five relative (REL) amplitudes and the theta to beta ratio. The x-axis represents the 6-minute recording time for the different frequency bands; the y-axis represents the relative amplitudes and theta to beta ratio. SMR = sensorimotor rhythm.

**Table 4. Multivariate Analysis of Variance and Post hoc Univariate Comparisons of Intrasessional Variability Indices for the 11 Quantitative EEG Measures Between Autistic and Normal Children**

Variability Indices	Normal Children (n = 105)		Autistic Children (n = 17)		MANOVA and Post hoc Tests		
	Mean (95% CI)	SD	Mean (95% CI)	SD	F	df	Significance
Absolute amplitudes (µV)					18.81	5, 116	.000
Delta	27.61 (±2.67)	13.94	45.01 (±11.60)	24.41	17.89	1, 120	.000
Theta	9.72 (±0.98)	5.10	20.31 (±4.04)	8.49	51.03	1, 120	.000
Alpha	4.77 (±0.58)	3.02	14.16 (±3.44)	7.23	86.74	1, 120	.000
Sensorimotor rhythm	3.42 (±0.52)	2.70	9.79 (±2.62)	5.52	57.17	1, 120	.000
Beta	3.70 (±0.59)	3.09	9.36 (±3.04)	6.40	34.06	1, 120	.000
Relative amplitudes					3.77	5, 116	.003
Delta	3.44 (±0.26)	1.37	4.41 (±0.74)	1.55	7.06	1, 120	.009
Theta	1.86 (±0.17)	0.88	1.84 (±0.29)	0.61	0.01	1, 120	.923
Alpha	1.57 (±0.15)	0.77	1.78 (±0.40)	0.84	1.05	1, 120	.307
Sensorimotor rhythm	0.78 (±0.05)	0.28	1.15 (±0.29)	0.61	16.90	1, 120	.000
Beta	1.03 (±0.11)	0.55	1.28 (±0.42)	0.88	2.44	1, 120	.121
Theta to beta ratio	0.50 (±0.04)	0.21	0.63 (±0.19)	0.39	5.55	1, 120	.020

CI = confidence interval; MANOVA = multivariate analysis of variance. Sphericity was checked using the Mauchly's Sphericity Test, and the Greenhouse-Geisser adjusted statistics were reported where the sphericity assumptions were violated.

beta ratio might be sensitive in differentiating the different attentional deficits of ADHD and autistic children because the former, but not the latter, group demonstrated abnormality in this ratio.

Profile analyses revealed that autistic children were found to have higher variability in all of the absolute activities within a 6-minute assessment. This finding is interesting when interpreted in light of Casanova et al's finding of an abnormal cortical minicolumnar structure in autistic children and their suggestion that the abnormality might result in irregular neuronal communications.<sup>43</sup> Since the EEG recorded from the scalp is a measurement of the neuronal electrical signals summated over a much larger area under the electrode

location, if the minicolumnar communication was irregular, in theory, they will be summated and could produce an irregular EEG, as observed in the present study, which, in turn, might manifest themselves in the diffuse and pervasive brain dysfunctions in autistic individuals. Although this is our speculation, similar views have been suggested by Courchesne et al, who, based on previous reports of brain overgrowth in autistic children in the first 2 years of life after which the growth was severely delayed, suggested that such abnormal development might lead to aberrant axonal connections in developing autistic brains.<sup>44</sup> Together with reports of reduced gray-matter volume in the frontal-striatal, parietal, and temporal net-

**Table 5. Amplitudes of the 11 Quantitative Electroencephalographic Measures in Autistic and Normal Children at Baseline and the 3-Month Retest**

Amplitudes	Baseline		Retest		Paired t-Tests		
	Mean (95% CI)	SD	Mean (95% CI)	SD	t	df	Significance
Normal children (n = 43)							
Absolute amplitudes (µV)							
Delta	152.34 (±16.38)	54.81	157.42 (±16.26)	54.40	-0.83	42	.409
Theta	59.30 (±4.78)	15.99	58.03 (±4.50)	15.07	0.54	42	.589
Alpha	36.98 (±2.20)	7.37	37.78 (±3.24)	10.83	-0.58	42	.562
Sensorimotor rhythm	18.56 (±1.34)	4.49	19.30 (±1.94)	6.49	-0.75	42	.455
Beta	20.85 (±1.40)	4.68	20.70 (±2.10)	7.03	0.13	42	.893
Relative amplitudes							
Delta	51.49 (±1.79)	5.98	52.76 (±2.12)	7.08	-2.00	42	.052
Theta	20.76 (±0.59)	1.98	19.99 (±0.64)	2.12	2.42	42	.020
Alpha	13.60 (±1.07)	3.59	13.35 (±0.99)	3.30	1.20	42	.237
Sensorimotor rhythm	6.59 (±0.32)	1.07	6.66 (±0.43)	1.45	-0.44	42	.663
Beta	7.56 (±0.52)	1.74	7.24 (±0.62)	2.09	1.39	42	.170
Theta to beta ratio	2.94 (±0.22)	0.72	3.00 (±0.23)	0.76	-0.76	42	.484
Autistic children (n = 7)							
Absolute amplitudes (µV)							
Delta	218.40 (±48.14)	64.98	189.68 (±51.36)	69.33	0.91	6	.397
Theta	91.08 (±16.08)	21.70	68.51 (±14.55)	19.64	3.00	6	.024
Alpha	51.25 (±7.32)	9.88	39.24 (±5.80)	7.83	5.05	6	.002
Sensorimotor rhythm	29.57 (±5.82)	7.86	23.16 (±4.30)	5.80	4.00	6	.007
Beta	24.98 (±4.09)	5.52	26.19 (±3.91)	5.28	-0.92	6	.393
Relative amplitudes							
Delta	52.16 (±2.40)	3.24	53.98 (±4.50)	6.07	-0.72	6	.499
Theta	22.13 (±1.47)	1.99	19.71 (±1.53)	2.06	3.32	6	.016
Alpha	12.60 (±1.15)	1.55	11.64 (±1.59)	2.15	0.97	6	.370
Sensorimotor rhythm	7.08 (±0.50)	0.68	6.76 (±1.07)	1.44	0.53	6	.618
Beta	6.04 (±0.54)	0.73	7.92 (±1.14)	1.54	-3.16	6	.019
Theta to beta ratio	3.82 (±0.51)	0.69	2.63 (±0.37)	0.50	4.85	6	.003

CI = confidence interval.

**Table 6. Intrasessional Variability Indices in Autistic and Normal Children at Baseline and the 3-Month Retest**

Variability Indices	Baseline		Retest		Paired t-Tests		
	Mean (95% CI)	SD	Mean (95% CI)	SD	t	df	Significance
<b>Normal children (n = 43)</b>							
Absolute amplitudes ( $\mu$ V)							
Delta	27.61 ( $\pm$ 4.76)	15.94	26.76 ( $\pm$ 4.87)	16.30	0.30	43	.767
Theta	9.72 ( $\pm$ 1.52)	5.10	9.42 ( $\pm$ 2.30)	7.69	0.44	43	.665
Alpha	4.77 ( $\pm$ 0.88)	3.02	5.02 ( $\pm$ 1.54)	5.14	-0.33	43	.743
Sensorimotor rhythm	3.42 ( $\pm$ 0.81)	2.70	3.64 ( $\pm$ 1.15)	3.86	-0.17	43	.866
Beta	3.70 ( $\pm$ 0.92)	3.09	4.10 ( $\pm$ 1.27)	4.24	-0.20	43	.846
Relative amplitudes							
Delta	3.57 ( $\pm$ 0.33)	1.09	3.48 ( $\pm$ 0.39)	1.31	0.38	43	.707
Theta	1.98 ( $\pm$ 0.31)	1.05	1.93 ( $\pm$ 0.24)	0.79	0.23	43	.816
Alpha	1.57 ( $\pm$ 0.21)	0.71	1.53 ( $\pm$ 0.24)	0.79	0.29	43	.776
Sensorimotor rhythm	0.80 ( $\pm$ 0.08)	0.26	0.84 ( $\pm$ 0.09)	0.30	-0.70	43	.488
Beta	1.12 ( $\pm$ 0.18)	0.60	1.02 ( $\pm$ 0.13)	0.45	0.91	43	.369
Theta to beta ratio	0.51 ( $\pm$ 0.07)	0.22	0.51 ( $\pm$ 0.06)	0.20	-0.04	42	.967
<b>Autistic children (n = 7)</b>							
Absolute amplitudes ( $\mu$ V)							
Delta	45.01 ( $\pm$ 18.08)	24.41	46.90 ( $\pm$ 14.32)	19.33	-1.19	6	.278
Theta	20.31 ( $\pm$ 6.29)	8.49	15.65 ( $\pm$ 7.17)	9.68	-1.10	6	.346
Alpha	14.16 ( $\pm$ 5.36)	7.23	10.72 ( $\pm$ 3.72)	5.02	-1.06	6	.332
Sensorimotor rhythm	9.79 ( $\pm$ 4.09)	5.52	6.28 ( $\pm$ 2.49)	3.36	-0.68	6	.522
Beta	9.36 ( $\pm$ 4.74)	6.40	6.59 ( $\pm$ 2.35)	3.17	-0.95	6	.380
Relative amplitudes							
Delta	3.72 ( $\pm$ 0.95)	1.28	4.37 ( $\pm$ 0.90)	1.22	-0.82	6	.444
Theta	1.72 ( $\pm$ 0.44)	0.60	2.18 ( $\pm$ 0.77)	1.04	-1.01	6	.353
Alpha	1.81 ( $\pm$ 0.82)	1.11	1.74 ( $\pm$ 0.27)	0.37	0.19	6	.853
Sensorimotor rhythm	0.83 ( $\pm$ 0.30)	0.41	0.90 ( $\pm$ 0.44)	0.59	-0.22	6	.832
Beta	0.85 ( $\pm$ 0.43)	0.58	1.38 ( $\pm$ 0.24)	0.32	-2.06	6	.085
Theta to beta ratio	0.64 ( $\pm$ 0.41)	0.55	0.57 ( $\pm$ 0.16)	0.21	0.35	6	.738

CI = confidence interval.

works<sup>39,45,46</sup> and in the cerebellar-frontal network,<sup>38</sup> evidence from recent morphologic studies does, indeed, point to the possibility of abnormal neuronal connections in the autistic brain. Hence, we believe that the notion of intrasessional variability might be worth

further investigation with autistic children, as well as children with other brain disorders that involve abnormal brain wiring. It would be very interesting to find out whether other patient groups would show similar variability in their quantitative EEGs.

Our findings and those of Monastra et al<sup>24</sup> on children with ADHD demonstrated that pediatric patient groups can be differentiated from normal controls using a simple quantitative EEG single-channel protocol, providing evidence to support the use of this measure as a reliable and sensitive diagnostic tool in assessing children with brain disorders. Recording the EEGs of young children, especially those with developmental disorders, is usually a great challenge because these children are, in general, less compliant and patient. The present findings are particularly encouraging because this method is simple enough for most young children, even those with impulsive tendency and hyperactivity. In addition, whereas Monastra et al reported high test-retest reliability on their quantitative EEG measurements over a 1-month period on children with ADHD,<sup>24</sup> our findings indicated that the quantitative EEG measurements of autistic children were consistent over a 3-month period. As reliability in measurement is critical in validating any assessment technique, the high test-retest consistency of the quantitative EEG measurements suggests that this assessment approach might have the potential to be developed into a valid and sensitive clinical assessment tool. Nevertheless, more studies are needed before any conclusion can be drawn.

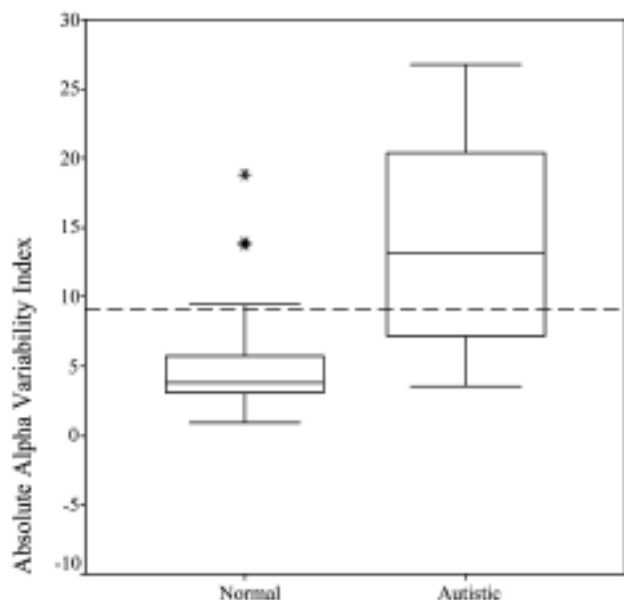


Figure 3. Boxplot showing the distribution of the autistic and normal control groups (entire sample) on the absolute alpha variability index. The line across the box represents the median. The bottom and the top of the box represent the first and third quartiles. Extreme cases are marked with asterisks. The dashed line represents the cutoff (value = 9.13), with cases above the line predicted as autistic and below the line predicted as normal.

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