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Developmental Characteristics of EEG Spectral Analysis in Children with Developmental Disabilities

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Summary.—Developmental transition of EEG spectra to alpha band of 14 children with developmental disabilities (from 7 yr. and 3 mo. to 16 yr. and 1 mo. of age in the first EEG recording: *M*=13.2, *SD*=2.6; 6 girls and 8 boys) was studied by auto-power spectrum analysis longitudinally. The results showed the mean age (14.1 yr. to 14.8 yr. in the four regions of the frontal, central, parietal and occipital regions) for subjects and their mean frequency (4.2 Hz to 4.7 Hz in the 4 regions) at which EEG shift started from theta band, and those means (15.1 yr. to 15.7 yr. and 9.5 Hz to 9.6 Hz in the 4 regions) at which EEG shift reached the alpha band. EEG research on healthy children has shown that approximately 10 years old is a critical age for developmental transition of EEG spectra to alpha frequencies (Katada *et al.*, 1981; Benninger *et al.*, 1984). It is suggested that the present study showed the delay of the critical age in children with developmental disabilities when compared to healthy children reported by Katada, *et al*. (1981) and Benninger, *et al.* (1984).

Key words：developmental characteristics, EEG spectral analysis, children with developmental disabilities

EEG research on healthy children has shown that approximately 10 years old is a critical age for developmental transition of EEG spectra to alpha frequencies (Katada, Ozaki, Suzuki, & Suhara, 1981; Beninnger, Matthis, & Scheffner, 1984). On the other hand, none of studies on developmental disabilities have clarified such a critical age for EEG transition to alpha band. We expected the delay of the critical age in children with developmental disabilities when compared to healthy children. This study had examined developmental transition of EEG spectra in children with developmental disabilities, particularly focusing on transition to alpha frequencies. Then, we compared the present data with normative outcomes in previous studies reported by Katada, *et al.* (1981) and Benninger, *et al*., (1984) (e.g., years of delay).

METHOD

Subjects

Subjects for the longitudinal EEG recordings were 14 children (6 girls and 8 boys) with developmental disabilities. The specific composition of the subjects is noted in Table 1. The group mean of IQ scores was 49.5 (*SD*=12.2). WISC-III for children

Table 1 Sex, etiology, IQ, age of EEG recording of subjects.

Subject No	Sex	Etiology	IQ	Age of EEG recording (yr. & mo.) 2003	2004	2005	2006
1	F	Down's syndrome	62	7: 3	8: 2	9: 3	10: 3
2	M		55		10:10	11: 9	12:10
3	M				10:11	11:11	12:11
4	M		42	9: 1	11: 0	12: 0	12:11
5	F		29	10:11	13: 0	13:11	14:11
6	F		56			14: 1	15: 1
7	M		44	13: 1	14: 1	15: 0	16: 0
8	M		79		14: 2	15: 1	16: 1
9	F	Down's syndrome	38			15: 4	16: 4
10	M		49		14: 6	15: 5	16: 5
11	M		43		15: 5	16: 5	17: 4
12	M		47		15: 7	16: 6	17: 6
13	F		50		15: 8	16: 8	17: 8
14	F		49		16: 1	17: 3	18: 0

(1998) was administered to the subjects by consulting psychologists who did not know of the subject's EEG data collected during resting arousal on the first EEG recording. In the subject 3, IQ value was not obtained, since the subject could not do the test. EEG recording in this study was performed repeatedly once a year at April to July for 2 or 4 years. The first record of each subject was made from 7 yr. to 16 yr. (*M*=13.2, *SD*=2.6). Subjects for whom doctors made the diagnosis of etiologically known and some subjects with unknown developmental disabilities were chosen. Two subjects had known etiologies of Down's syndrome (n=2). The remaining 12 subjects had unknown etiologies. Subjects 3, 11 and 12 had history of convulsion of once or twice during the infancy. However, they became healthy and no convulsion during childhood. Now, they were healthy and no medication for the convulsion. They were chosen to be free of medication and no epilepsy. They were the product of uncomplicated pregnancies with uneventful deliveries. They had no behavioral disabilities. They did not have abnormal clinical background EEG, epileptiform or paroxysmal discharge and asymmetry in the left and right hemispheres. They were attending a school in special education for children with developmental disabilities.

Procedure

Since subject 1 in the present report could not close her eyes on instruction, and whenever she closed her eyes, she was asleep, EEG sample taken while resting in the arousal state with the eyes open was analyzed in the subject.

Polygraph recordings {electroencephalogram (EEG; gain:5mm/50 μV, low frequency filter: 0.3 sec, high frequency filter: 60 Hz), electrooculogram, electrocardiogram, respiration, and electromyogram} were carried out in the experimental room after a conventional lunch for 20-30 minutes. EEGs recorded from the F3-A1, C3-A1, P3-A1 and O1-A1 (or F4-A2, C4-A2, P4-A2 and O2-A2) leads were analyzed. The EEG was bandpass filtered (0.39-100 Hz) and digitized with a sampling rate 200 Hz. The subjects closed their eyes on instruction. The experimenter and polygraph machine were located in the room next to the subject's bed. Those who scored the EEG tracing had no knowledge of the intelligence quotient of the subject. No sedatives were used. All subjects were free of medication.

Analysis of EEG

EEG in a wakeful and resting state was chosen for spectrum analysis. A tape recording was simultaneously made with the conventional EEG recordings. EEG spectra from the left or right hemispheres were processed by means of a Fast Fourier Transformation (FFT) algorithm for real valued series. Two point five second epochs were chosen as samples for analysis. The total duration of the EEG samples was 30sec. to 2 minutes and the spectral frequency resolution was 0.391 Hz. Finally, an average auto-power spectrum was calculated from 12 to 48 epochs.

Delta, theta and alpha levels were 0.5 to 3 Hz, 4 to 7 Hz and 8 to 13 Hz. For statistical analysis of the results, ANOVA followed by Tukey's test was used for the comparison between electrode derivations the mean age and the mean dominant EEG frequency, respectively.

RESULTS

Averaged auto-power spectra of subject's EEGs were often composed of multiple peak components. We called the maximum peak the dominant component according to Katada, *et al.* (1981), and analyzed the dominant component.

Figure 1 shows examples of EEG auto-power spectra obtained from subject 7 which were followed up longitudinally. The first and second EEG recording of the subject was obtained at 13 years and 1 month, and 14 years and 1 month of age. The 2.7 Hz component appeared as the dominant one, and the 4.7 Hz component appeared as the subordinate one in frontal region in these recordings. The 4.7 Hz component appeared, moreover, as the dominant one in the central, parietal and occipital regions. The third and fourth EEG recording of the subject was obtained at 15 years and 16 years of age. The 10.2 Hz component in the third EEG and the 10.6 Hz in the fourth EEG appeared as the dominant one in all of the four regions.

Figure 2 illustrates the frequency of the dominant peak of EEGs in the frontal, central, parietal and occipital regions for subjects followed with after several years.

The most crucial results would be mean age of subjects and their mean dominant EEG frequency at which the EEG shift started from EEG bands below alpha, and those means at which the EEG shift arrived at the alpha band. Table 2 showed the mean age for subjects and their mean dominant EEG fre-

Table 2 Mean age for subjects and their mean EEG frequency at which EEG shift started from theta band, and those means at which EEG shift reached the alpha band.

	Frontal				Central				Parietal				Occipital			
	Age, yr.		Fre-Quency Hz		Age, yr.		Fre-quency Hz		Age, yr.		Fre-Quency Hz		Age, yr.		Fre-Quency Hz	
	M	SD	M	SD	M	SD	M	SD	M	SD	M	SD	M	SD	M	SD
		N=6				N=6				N=9				N=11		
Theta	14.4	1.3	4.3	0.7	14.1	1.3	4.7	0.4	14.3	1.6	4.3	0.6	14.8	1.4	4.2	0.7
		N=6				N=6				N=10				N=11		
Alpha	15.4	1.4	9.6	0.6	15.1	1.3	9.5	0.6	15.2	1.6	9.5	0.8	15.7	1.4	9.6	0.7

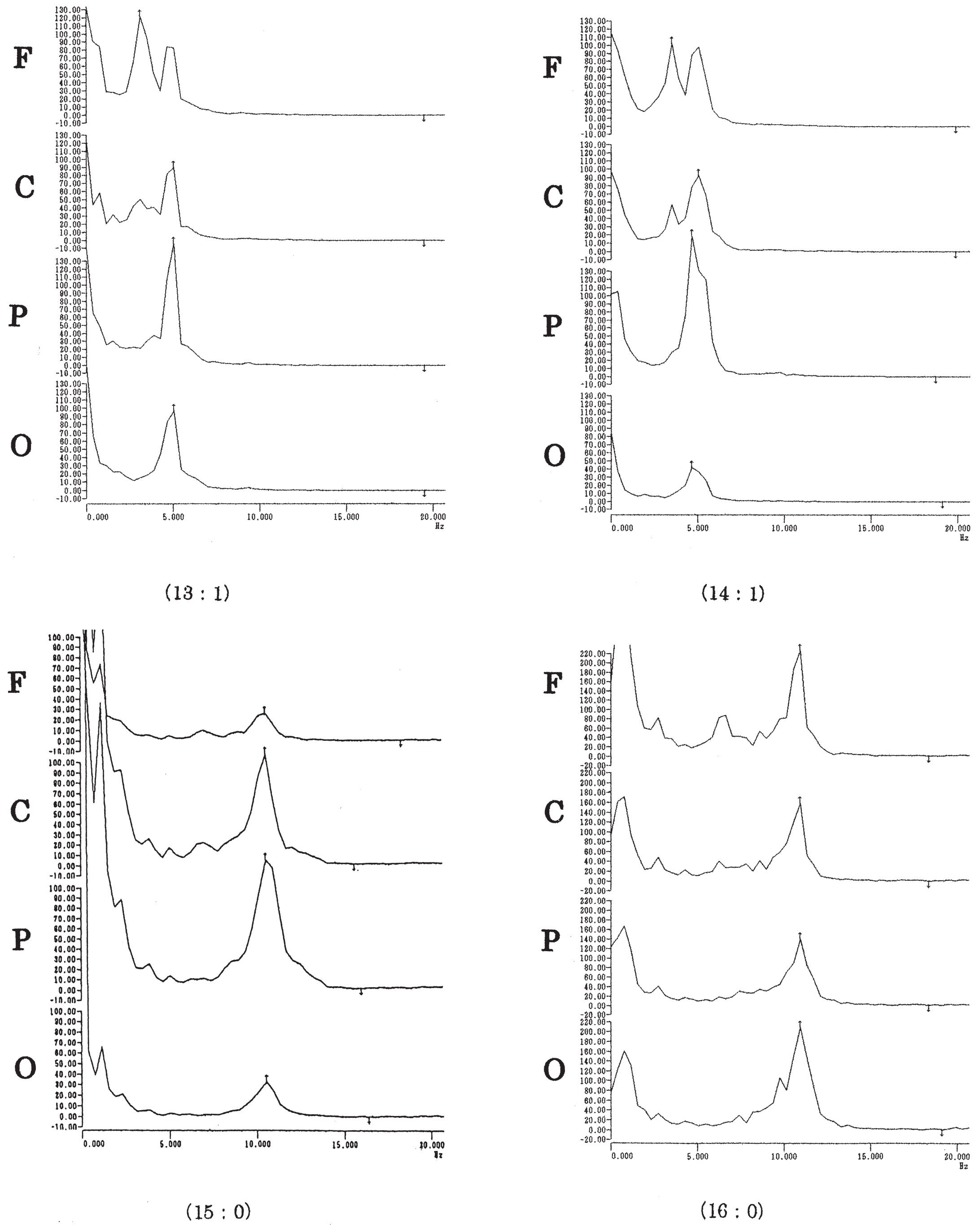

Figure 1 Example of averaged auto-power spectra from the same subjects that were followed up longitudinally. Numbers in parentheses indicate the age of EEG recording. Thus, (13:1) means 13 years and 1 month. F: frontal region, C: central region. P: parietal region, O: occipital region.

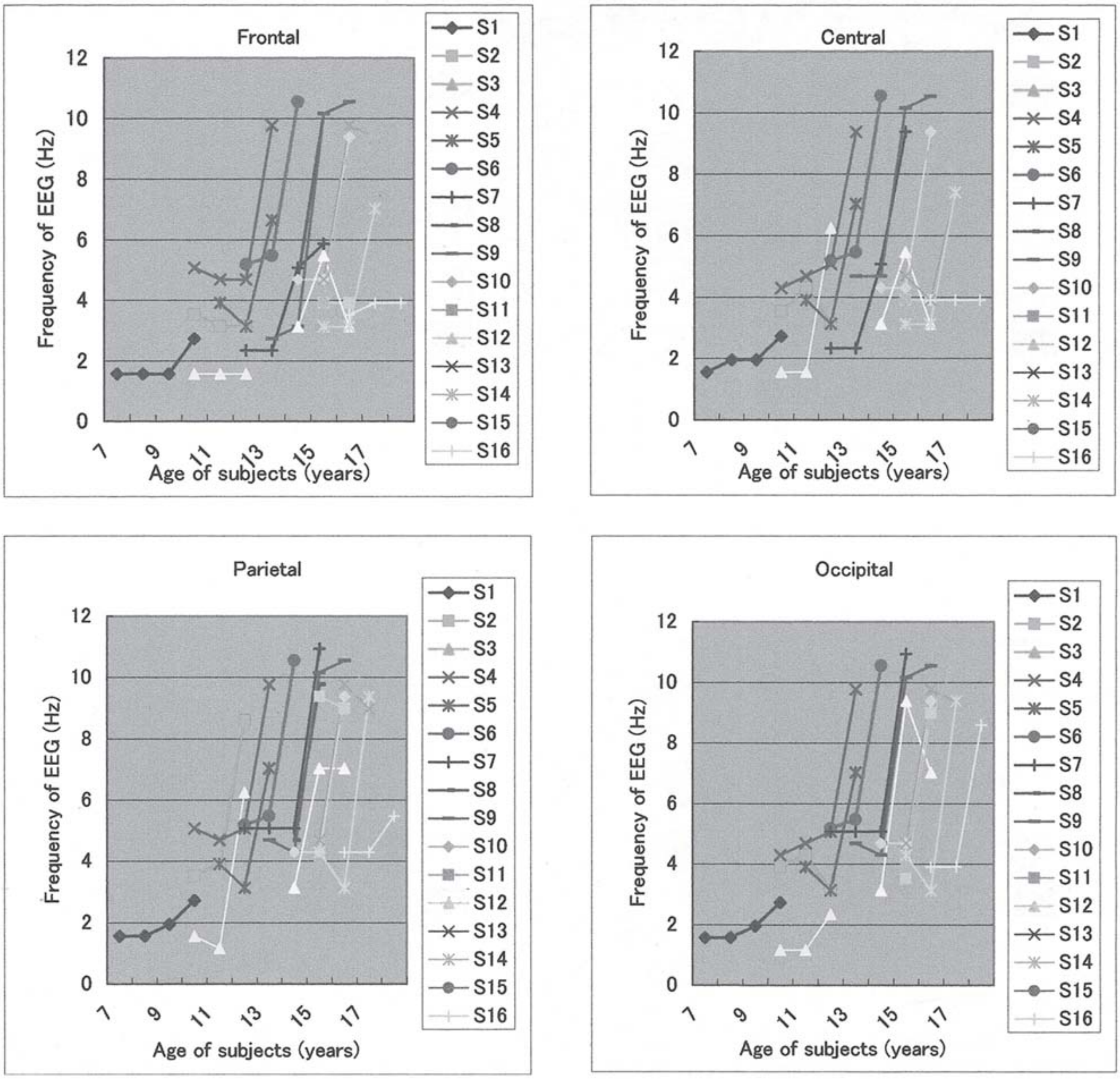

Figure 2 Longitudinal changes in the dominant frequency (a peak of the spectrum) in the EEG of the frontal, central, parietal and occipital regions. Points for the same subjects are connected by a straight line and the same color. Subjects of the Table 1 were changed from the S5-S14 to S7-S16. Then two new subjects (S5, S6) were added.

quency at which EEG shift started from theta band, and those means at which EEG shift reached the alpha band. The EEG shift started from the theta band (4.2-4.7 Hz) at 14.1 yr. to 14.8 yr. in the four regions of the frontal, central, parietal and occipital regions. The EEG shift reached the alpha band (9.5-9.6 Hz) at 15.1 yr. to 15.7 yr. in the four regions. We statistically compared between electrode derivations the mean age and the mean dominant EEG frequency, respectively. Analysis of variance revealed no significant differences between the electrode derivations the mean age and the mean dominant EEG frequency, respectively.

Subject 4 showed sizeable increases in dominant EEG frequency at 13 or younger. The age and the dominant EEG frequency at which the EEG shift started from the theta band were 12 yr. and 4.7 Hz in the frontal region, and 5.1 Hz in the central, parietal and occipital regions, and those values at which the dominant EEG frequency reached the alpha band were 12.9 yr. and 9.4 Hz in the central region, and 9.8 Hz in the frontal, parietal and occipital regions. However, subjects 9, 10 and 14 did not show sizeable increases in EEG frequency until age 15 or older. Their ages and dominant EEG frequencies at which the EEG showed the delta and theta bands were 16.3 yr. and 3.9 Hz in the frontal and central regions in subject 9, 16.4 yr. and 3.1 Hz in the frontal and central regions in subject 10, and 18 yr. and 3.9 Hz in the frontal and central regions, and 5.5 Hz in the parietal region in subject 14.

DISCUSSION

Since we had no age and sex-matched controls, results obtained by Katada, *et al*. (1981) and Benninger, *et al*. (1984) were referred to as normal data.

EEG research on healthy children has shown that approximately 10 years old is a critical age for developmental transition of EEG spectra to alpha frequencies (Katada *et al*., 1981; Benninger *et al*., 1984). On the present study, the subjects on developmental disabilities had had 15 years old of such a critical age for the EEG transition to alpha band. The present study showed the delay of the critical age in children with developmental disabilities when compared to healthy children. It may be accepted that in part the retardation of the brain development, and the developmental change of the brain function in the developmental disabilities was indicated.

Subject 4 showed sizeable increases in EEG frequency at 13 or younger. However, subjects 9, 10 and 14 did not show such increases in EEG frequency until age 15 or older. Why do some subjects show sizeable increases in EEG frequency at 13 or younger compared with those that do not show such increases until age 15 or older? It is suggested that the subjects who showed sizeable increases in EEG frequency at 13 or younger reached at developmental stage of the brain. However, those that did not show such increases until age 15 or older did not reach at that stage of the brain.

Not withstanding varying etiologies and varying degrees of retardation of the present subjects, our main finding was the delay of critical age in children with developmental disabilities when compared to healthy children expected from studies of children without developmental disabilities.

Moreover, we had many methodological difficulties that are virtually inherent in this type of study: the heterogeneity of the subject sample, and the absence of direct control subjects without developmental disabilities. We would have to question our results if we had found marked differences between our subject group and control groups without developmental disabilities reported on in the literature that were at the same time inconsistent with previous reports of differences between subjects with and without developmental disabilities (such as the delay of critical age for the EEG transition to alpha band in subjects with developmental disabilities (Katada *et al*., 1981)). Despite methodological difficulties, however, our main findings show that the present study on developmental disabilities have clarified a critical age for the EEG transition to alpha band.

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