Maturation Patterns of EEG Basic Waves of Healthy Infants under Twelve-months of Age

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MIZUNO, T., YAMAUCHI, N., WATANABE, A., KOMATSUSHIRO, M., TAKAGI, T., IINUMA, K. and ARAKAWA, Ts. *Maturation Patterns of EEG Basic Waves of Healthy Infants under Twelve-months of Age*. Tohoku J. exp. Med., 1970, 102(1), 91-98. — A simplified method for an evaluation of maturation patterns of the EEG waves of healthy infants under 12 months of age was reported. The EEG basic waves were divided into 10 bands according to frequency ranges (I-X bands). An averaged integrated voltage was calculated at each of the frequency bands (I-E%, II-E%, ... X-E%). When 'R' = (E% of VIII + E% of IX) / (E% of II + E% of III) was calculated and plotted against the age in months, a linear figure was obtained which demonstrated a maturation pattern of the EEG basic waves of infants with advance in age. — EEG, frequency analysis, maturation pattern of EEG.

The present study was attempted to establish a simplified method for an evaluation of maturation patterns of the EEG basic waves of infants under 12 months of age, by using a frequency analyzer so specially adapted that the basic waves of EEG were divided into 10 bands according to the frequency range (Arakawa *et al.*, 1969(a); Arakawa *et al.*, 1969(b)).

METHODS AND MATERIALS

The infants subjected to the present study consisted of 10 infants who were selected as being 'clinically' healthy on the basis of the following clinical criteria: They were born to healthy parents after an uneventful pregnancy and delivery. Neonatal history revealed none of asphyxia, cyanosis, convulsion, severe jaundice and other abnormalities. Five infants (Cases 1-5) were breast-fed, four (Cases 6-9) were artificially fed, and one (Case 10) was placed on a mixed feeding. Weaning was done uneventfully when the infants were 5-6 months old. Physical examination, measurement of body weight, height, circumference of the head and chest were performed monthly at a Well-Baby-Clinic of our Hospital and those whose body weight deviated from the zone of the mean value ± 2 standard deviations for the corresponding age (Report from the Department of Welfare, Japan, 1960) were excluded.

Estimation of an integrated voltage at each of the EEG frequency bands

The EEG recording was performed in the same way as described in the preceding papers of ours (Arakawa *et al.*, 1969(a); Arakawa *et al.*, 1969(b)). A 12 channel electroencepha-

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TABLE 1. *Physical development of Case 1 (F.Y. ♀)*

Age (months and days)	Body weight (g)	Height (cm)	Circumference of head (cm)	Circumference of chest (cm)	Diet
Birth	3,510				Mother's milk
1-16	5,530	56.0	37.8	36.5	
4-16	(112%)*	(103%)*	(102%)*	(98%)*	
	8,000	66.0	42.5	42.2	+ Rice-gruel, soy bean soup, vegetables
5-27	8,570	67.5	43.7	43.0	
7- 7	9,040	71.0	45.0	45.0	
8- 4	9,180		45.5	47.0	
9- 2	9,560	71.0	45.5	45.0	+ Rice, butter
10-15	9,500	73.5	45.7	46.5	
11-11	9,860	75.0	46.7	46.0	
12-10	10,220	77.2	46.0	45.5	
	(120%)*	(106%)*	(102%)*	(101%)*	

*() shows % of the standard values reported from the Department of Welfare, Japan, in 1960.

Note. Holding up the head, 3 months; sitting, 5 1/2 months; standing, 7 months; walking, 11 months.

TABLE 2. *Physical development of Case 2 (O.N. ♀)*

Age (Months and days)	Body weight (g)	Height (cm)	Circumference of head (cm)	Circumference of chest (cm)	Diet
Birth	3,220				Mother's milk
1- 4	4,500	53.5	35.5	37.5	
	(100%)*	(98%)*	(93%)*	(100%)*	
2- 2	5,520	57.0	38.0	39.0	
3- 6	6,400	60.2	40.0	42.5	+ Rice-gruel, egg -yolk, vegetables
4- 3	7,100	63.0	41.0	45.0	
5- 1	7,780	65.5	42.0	44.0	
5-28	8,050	67.5	43.0	46.5	+ Fish
6-26	8,170	70.2	43.5	46.5	
8- 2	9,170	72.0	44.5	47.0	
8-27	9,740	72.5	44.5	45.0	
9-27	9,850	71.8	45.0		
12-6	10,400	75.5	46.5	49.0	
	(122%)*	(98%)*	(103%)*	(109%)*	

()*, cf. Table 1

Note. Holding up the head, 3 months; sitting, 5 months; standing, 6 months.

lograph (Toshiba-St-2477-A) was used and disc electrodes were placed on the scalp according to the 10/20 international system. The EEG at the rest with closed eyes from the right occipital area was recorded on a magnetic tape using a 4 channel data recorder.

The EEG basic waves were divided into 10 bands according to frequency ranges by means of a frequency analyzer specially adapted as follows: I band, 2-2.4 c/s; II band, 2.4-2.88 c/s; III band, 2.88-3.46 c/s; IV band, 3.46-4.15 c/s; V band, 4.15-4.98 c/s; VI band, 4.98-5.97 c/s; VII band, 5.97-7.17 c/s; VIII band, 7.17-8.60 c/s; IX band, 8.60-10.3 c/s, and X band, 10.3-12.4 c/s.

An integrated voltage at each band was an average for 12 epochs of the 5 sec. period

TABLE 3. *Physical development of Case 3 (O.Y. ♂)*

Age (months and days)	Body weight (g)	Height (cm)	Circumference of head (cm)	Circumference of chest (cm)	Diet
Birth	2,820				Mother's milk
1-5	4,540 (96%)*	54.7 (98%)*	38.0 (100%)*	36.5 (93%)*	
2-10	5,600	57.5	39.5	40.5	
3-7	6,300	61.4	41.2	41.0	
4-4	7,000	65.6	42.0	45.0	
5-10	7,430 (100%)*	67.5 (103%)*	43.5 (100%)*	45.5 (105%)*	

()*, cf. Table 1

Note. Holding up the head, 4 months.

TABLE 4. *Physical development of Case 4 (K.K. ♂)*

Age (months and days)	Body weight (g)	Height (cm)	Circumference of head (cm)	Circumference of chest (cm)	Diet
Birth	3,080				Mother's milk
1-3	4,690 (99%)*	54.5 (98%)*	37.8 (99%)*	36.0 (97%)*	
2-8	5,770	57.7	39.0	41.0	
3-5	6,270	61.0	40.0	39.0	
4-2	7,290	61.7	42.0	43.0	
5-0	7,610	65.0	43.0	43.0	+ Rice-gruel, apples and Egg-yolk
5-27	7,800	65.7	43.0	43.0	
6-25	8,600	67.9		42.2	
7-29	8,610	70.0	44.0	43.5	+ Fish and meat
9-24	9,100	70.0	45.0	43.8	
11-0	9,390	73.4	47.0	46.0	
11-28	9,700 (106%)*	74.0 (99%)*	46.0 (100%)*	47.5 (103%)*	

()*, cf. Table 1

Note. Holding up the head, 2 months; sitting, 5 months; standing, 11 months.

TABLE 5. *Physical development of Case 5 (T.Y. ♀)*

Age (months and days)	Body weight (g)	Height (cm)	Circumference of head (cm)	Circumference of chest (cm)	Diet
Birth	3,600				Mother's milk
1-15	5,380 (114%)*	56.7 (104%)*	38.5 (104%)*	39.0 (104%)*	
3-9	6,750	63.2	41.3	39.0	+ Soy bean soup, fruit
4-14	7,480	65.1	41.5	44.5	
5-11	7,810	67.5		46.0	+ Cereals
6-9	8,270	67.0	42.5	41.0	
7-15	9,030		45.5	44.0	
8-10	9,310 (120%)*	71.0 (104%)*	45.7 (105%)*	45.5 (104%)*	

()*, cf. Table 1

Note. Holding up the head, 2 months; sitting, 4 months.

TABLE 6. *Physical development of Cases 6 (Y.Y. ♀)*

Age (months and days)	Body weight (g)	Height (cm)	Circumference of head (cm)	Circumference of chest (cm)	Diet
1-16	4,580 (101%)*	54.4 (101%)*	38.5 (103%)*	37.0 (99%)*	Dried powdered milk
2-14	5,190	57.3	40.2	37.5	
3-11	5,780	60.2	41.3	39.0	+ Soy bean soup,
4- 8	6,280	64.5	41.5	41.7	rice gruel
5-13	6,520	64.6	42.5	42.0	+ Egg yolk
6-10	6,890	65.0	43.0	43.0	
7- 8	6,660	66.3	43.0	40.7	+ Rice, fish
8-12	7,270	69.3	44.5	42.5	
10- 9	7,500	69.0	45.0	43.0	
11-20	7,880 (93%)*	71.6 (100%)*	44.0 (99%)*	44.5 (100%)*	

)*, cf. Table 1

TABLE 7. *Physical development of Case 7 (M.S. ♂)*

Age (months and days)	Body weight (g)	Height (cm)	Circumference of head (cm)	Circumference of chest (cm)	Diet
Birth	2,920				Dried powdered milk
1- 6	4,400 (93%)*	53.7 (96%)*	39.0 (102%)*	38.0 (100%)*	
2- 4	5,800	57.9	39.5	42.0	+ Fruit
3- 1	6,550	62.0	41.5	40.7	
3-28	7,100	64.0	42.2	42.0	+ Rice gruel, egg yolk
5- 3	7,970	66.3	43.5	45.0	+ Cereals, fish
6- 0	8,510	68.0	44.0	45.5	
6-28	8,750	71.0	45.0	45.5	
8- 4	8,740	72.4	45.0	46.0	
9- 6	9,530	73.5	45.7	47.3	
10- 6	10,000 (115%)*	73.4 (101%)*	46.7 (102%)*	45.5 (100%)*	

()*, cf. Table 1

Note. Holding up the head, 3 months; standing, 9 months.

at each of the frequency bands. The averaged integrated voltage for the I band was calculated according to the following formula:

$$E\%(I) = \frac{I^2}{I^2 + II^2 + \dots + X^2} \times 100$$

RESULTS AND DISCUSSION

Physical development

Measurements of body weight and height during the period of this study remained within a zone between +2 and -2 standard deviations as compared

TABLE 8. *Physical development of Case 8 (Y.K. ♂)*

Age (months and days)	Body weight (g)	Height (cm)	Circumference of head (cm)	Circumference of chest (cm)	Diet
Birth	3,060				Dried powdered milk
1-12	4,740 (100%)*	53.3 (96%)*	37.6 (99%)*	37.0 (99%)*	
2-10	5,630	58.3	39.7	39.0	+ Fruit
3-7	6,500	59.8	41.5	43.0	
4-4	7,240	64.5	43.0	44.0	+ Rice-gruel, egg-yolk + Soy bean soup, fish
5-9	8,000	68.0	43.5	45.0	
6-6	8,370	68.2	44.8	45.6	
7-11	8,950	70.0	45.2	44.5	
8-15	9,100 (109%)*	72.8 (104%)*	46.0 (103%)*	44.5 (100%)*	

()*, cf. Table 1

Note. Holding up the head, 2 months; sitting, 7 months.

TABLE 9. *Physical development of Case 9 (K.C. ♀)*

Age (months and days)	Body weight (g)	Height (cm)	Circumference of head (cm)	Circumference of chest (cm)	Diet
Birth	3,340				Dried powdered milk
1-4	4,400 (98%)*	5.40 (99%)*	36.0 (97%)*	37.0 (99%)*	
2-9	5,950	62.5	39.5	40.0	+ Fruit, soy bean soup
4-1	6,540 (102%)*	64.7 (104%)*	41.0 (100%)*	41.0 (99%)*	

()*, cf. Table 1

Note. Holding up the head, 4 months.

TABLE 10. *Physical development of Case 10 (Y.N. ♂)*

Age (months and days)	Body weight (g)	Height (cm)	Circumference of head (cm)	Circumference of chest (cm)	Diet
Birth	2,880				Mothers' milk and dried powdered milk
0-29	4,260	53.3	36.7	36.0	
1-27	5,600 (119%)*	59.5 (107%)*	39.0 (102%)*	40.5 (107%)*	+ Rice-gruel, egg-yolk, fish and vegetables
2-24	6,500	60.8	41.5	44.0	
4-26	8,250	69.2	43.5	45.0	
5-24	8,470	70.4	44.5	46.0	
6-28	8,850	71.7	45.5	47.0	
7-25	9,100	73.2	45.5	45.0	
8-12	9,230	72.8	46.0	47.0	
10-26	9,570 (111%)*	77.2 (107%)*	46.5 (102%)*	47.0 (104%)*	

()*, cf. Table 1

Note. Sitting, 6 months.; standing 10 months.

TABLE 11. *Distribution of energy % at each of frequency bands of EEG of 'healthy infants'*

Age (months)	Case	Energy %										
		I	II	III	IV	V	VI	VII	VIII	IX	X	$\frac{\text{VIII}+\text{IX}}{\text{II}+\text{III}}$
1	4	13.7	12.1	17.4	13.7	12.1	9.1	7.7	5.4	5.4	3.4	0.36
	10	19.0	17.3	17.3	11.3	10.0	8.8	6.6	3.9	3.9	1.9	0.22
	Average	16.3	14.7	17.3	12.5	11.0	8.9	7.1	4.6	4.6	2.6	0.28
2	2	16.2	13.4	13.4	13.4	13.4	10.8	8.6	4.8	4.8	1.2	0.35
	4	27.3	17.0	17.0	9.2	7.6	7.6	7.6	2.7	2.7	1.2	0.15
	7	17.6	13.7	17.6	13.7	10.3	8.8	7.4	3.9	3.9	3.0	0.24
	10	29.4	18.0	16.1	8.0	8.0	5.6	6.7	2.7	3.6	2.0	0.18
	Average	22.6	15.5	16.0	11.0	9.8	8.2	7.5	3.5	3.6	1.8	0.22
3	6	16.7	13.8	16.7	16.7	13.8	8.8	6.7	2.2	3.4	1.2	0.18
	7	17.8	14.6	17.8	13.1	11.7	7.9	7.9	3.3	4.0	2.0	0.22
	10	15.1	15.1	16.5	19.3	8.3	9.3	6.4	4.1	2.3	3.5	0.19
	Average	16.6	14.4	17.0	16.3	11.2	8.6	7.0	3.2	3.2	2.2	0.20
4	3	17.2	17.4	17.0	13.7	9.8	7.1	6.6	4.3	3.7	3.2	0.23
	6	11.4	12.1	11.4	14.1	16.1	12.1	10.1	4.7	5.4	2.7	0.42
	7	16.1	11.7	16.2	15.9	13.6	10.2	7.1	2.2	5.1	2.0	0.26
	8	13.7	12.2	13.7	16.9	12.2	10.8	9.5	4.2	4.2	2.7	0.32
	9	8.4	12.5	12.1	13.9	13.9	15.3	12.3	5.3	3.5	2.7	0.35
	Average	13.3	13.1	14.0	14.9	13.1	11.1	9.1	4.1	4.3	2.6	0.30
5	3	11.9	10.4	13.4	18.5	15.0	10.4	9.1	4.6	3.8	3.0	0.35
	4	9.7	9.8	15.0	18.2	14.3	11.9	8.8	5.4	4.9	4.1	0.41
	8	9.2	9.2	11.5	18.3	18.3	11.5	10.3	5.4	3.8	2.6	0.44
	10	15.0	12.8	16.0	15.5	14.2	10.7	7.4	3.3	3.1	2.0	0.22
	Average	11.4	10.0	13.9	17.6	15.7	11.1	8.9	4.6	3.9	2.9	0.35
6	1	9.8	8.8	12.0	12.0	14.4	13.2	12.0	7.9	6.1	3.9	0.67
	2	8.6	7.9	9.4	14.0	19.4	16.0	10.3	6.4	4.6	3.5	0.63
	6	10.8	8.7	10.8	13.0	14.2	13.0	11.9	7.8	6.0	3.9	0.70
	7	10.1	10.1	11.6	16.8	16.8	14.9	8.7	4.2	4.2	2.5	0.41
	8	11.8	10.2	11.3	11.0	16.2	12.6	11.2	7.0	5.2	3.5	0.56
	Average	10.2	9.1	11.0	13.3	16.2	13.9	10.8	6.6	5.2	3.4	0.58
7	2	15.5	7.7	7.8	12.4	21.4	11.9	9.7	6.1	4.4	3.0	0.67
	4	7.7	6.2	11.1	16.6	14.7	14.0	16.0	6.9	4.0	2.7	0.63
	6	10.2	8.5	10.6	10.5	10.7	14.0	15.2	9.8	6.8	3.7	0.86
	8	10.0	6.5	8.3	15.7	25.0	13.6	8.8	5.8	4.0	2.4	0.66
	10	10.1	9.7	10.6	17.8	19.0	11.8	9.3	6.3	3.1	2.1	0.46
	Average	10.7	7.7	9.6	14.6	18.1	13.0	11.8	6.9	4.4	2.7	0.65
8	4	8.6	6.1	9.3	13.2	16.8	13.5	20.7	7.5	1.8	2.5	0.60
	5	7.9	7.0	8.3	9.4	14.9	18.6	15.3	9.9	4.4	4.3	0.93
	6	11.2	8.0	9.0	11.2	16.1	14.3	13.8	6.9	5.7	3.8	0.74
	7	7.9	7.4	8.0	8.4	13.3	12.6	22.6	12.6	3.1	4.2	1.01
	8	8.2	7.6	9.6	12.5	18.5	14.1	12.5	8.2	4.4	4.4	0.73
	10	8.9	8.7	10.3	13.1	22.3	14.4	9.5	6.6	3.0	3.3	0.50
	Average	8.7	7.4	9.0	11.3	16.9	14.5	15.7	8.6	3.7	3.7	0.75

TABLE 11. *Continued*

Age (months)	Cases	Energy %										$\frac{\text{VIII}+\text{IX}}{\text{II}+\text{III}}$
		I	II	III	IV	V	VI	VII	VIII	IX	X	
9	1	11.3	9.8	9.6	9.7	10.7	11.7	14.8	9.5	8.1	4.8	0.90
	2	12.6	8.1	9.2	12.6	22.1	12.0	10.0	7.1	3.2	3.0	0.59
	7	11.2	10.6	10.6	10.3	12.4	12.2	13.1	9.8	4.9	5.1	0.69
	10	11.7	8.7	9.0	11.9	17.9	14.5	12.9	7.0	3.5	3.0	0.60
	Average	11.7	9.3	9.6	11.1	15.7	12.6	12.7	8.3	4.9	3.9	0.69
10	2	12.3	9.4	10.3	7.7	11.3	15.6	13.3	10.3	4.8	4.8	0.76
	4	8.7	8.7	6.8	10.7	15.4	15.4	18.1	8.7	3.8	3.8	0.80
	6	8.1	7.3	8.9	10.7	18.3	17.1	13.7	8.9	3.0	4.0	0.73
	7	9.6	6.9	9.6	12.8	14.5	14.5	12.8	11.1	3.6	4.6	0.89
	Average	9.6	8.0	8.9	10.4	14.8	15.6	14.4	9.7	3.8	4.3	0.79
11	1	7.1	7.1	7.9	9.6	12.5	12.9	14.0	14.5	7.2	7.3	1.44
	2	13.8	10.2	8.2	11.9	10.2	12.8	13.8	10.2	5.5	3.3	0.85
	10	10.7	7.9	8.3	15.0	16.8	12.7	12.2	8.8	4.5	3.1	0.82
	Average	10.5	8.4	8.1	12.1	13.1	12.8	13.3	11.1	5.7	4.5	1.01
12	2	12.7	7.6	7.3	19.8	12.3	9.6	11.3	10.0	5.9	3.6	1.06
	4	8.7	6.2	7.5	12.6	15.2	13.8	13.5	12.4	6.5	3.7	1.37
	6	7.6	6.8	9.4	15.5	17.0	13.8	13.2	9.7	4.4	3.0	0.87
	Average	9.6	6.8	8.0	15.9	14.8	12.4	12.6	10.7	5.6	3.4	1.10

Fig. 1. Distribution of the energy % (E%) at each of frequency bands of the EEG basic waves of healthy infants.

with the mean values reported in 1960 from the Department of Welfare of Japan.

The circumference of the head was found to be 99-100% of the standard values.

Fig. 2. Maturation pattern of the EEG basic waves in healthy infants expressed by maximum, average and minimum values of 'R'.

$$R = \frac{E\% \text{ of VIII} + E\% \text{ of IX}}{E\% \text{ of II} + E\% \text{ of III}}$$

Changes in the frequency pattern of the EEG basic waves of healthy infants with advance in age

Distribution patterns of E% at each of frequency bands of the EEG basic waves of the infants were shown in Table 11. Fig. 1 was drawn from the average values of E% at each of frequency bands of infants aged 3, 6 and 12 months, showing that there was a tendency to a decrease in E% at the II and III bands with a concomitant increase in that at the VIII and IX bands (cf. Fig. 1).

These changes in the distribution of E% at each of frequency bands according to the age of infants were more clearly demonstrated when $R = (E\% \text{ of VIII} + E\% \text{ of IX}) / (E\% \text{ of II} + E\% \text{ of III})$ was calculated and plotted against the age in months (Fig. 2), which might be used as a simplified figure for an evaluation of a maturation pattern of the EEG basic waves of healthy infants.

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