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A LONGITUDINAL STUDY OF THE OCCIPITAL ALPHA RHYTHM IN NORMAL CHILDREN: FREQUENCY AND AMPLITUDE STANDARDS*

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A. INTRODUCTION

Studies by Lindsley (5, 6) and Smith (8, 9, 10, 11) have shown that in awake infants the occipital alpha rhythm usually first appears by the third or fourth month at a frequency of three to four per second. Once established the frequency of the waves increases with age, rapidly during the first year but slower thereafter until a relatively stabilized adult level is attained usually sometime before the end of the twelfth year. Weinbach (14) has fitted an exponential growth equation to the early data of the above investigators and has more recently (15) called attention to the fact, as has also Lindsley (6), that the growth in frequency of the waves with age follows essentially the same curve as does brain weight in children.

The purpose of the present report is to show the trends of development of both frequency and amplitude of the occipital alpha waves as a function of age in a large group of normal children studied longitudinally for a period of two to three years. Because of the recent widespread clinical application of the electroencephalograph and the growing tendency to classify waves as abnormal if their frequency or amplitude is above or below a certain range, it seems desirable to present these data for possible use as standards for comparison. Such standards are particularly valuable in dealing with the electroencephalograms of children since the frequency of the alpha waves varies with age and an alpha frequency abnormally low for an adult might be well within the normal range for a child.

In order to compare children and adults it is necessary to present some data for the latter. In a previous study (6) I reported that

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the frequency of the occipital alpha rhythm in 75 adult subjects, 52 men and 23 women ranging in age from 17 to 64 years, averaged 10.2 and ranged from 8 to 13 per second. These data are in essential agreement with other adult norms (12, 2, 7, 4), (see also 3, 1). To my knowledge the only data on mean amplitude that have been published are those by Travis and Knott (12) on 19 normal college students. Using a bipolar technique (occipital to motor area) they found the amplitude for the group ranged from 12 to 31 microvolts with a mean of 19 microvolts. From some analyses now being made in this laboratory which will be published later it may be stated that the mean amplitude of occipital alpha waves (bipolar recording) for 25 college students is 13 microvolts with a range from 5 to 24 microvolts. The latter data will be used for comparison since the method of recording (both electrodes over occipital region) is comparable to that used in the present study.

B. Technique

The apparatus and procedure have been described in detail in an earlier study (6). Briefly, two matched amplifiers and a Westinghouse type *PA* oscillograph were used to record simultaneously on photographic paper the electrical activity of the two occipital regions. Bipolar recording methods were used throughout, the two electrodes of each pair of leads being separated by five centimeters. The electrodes were placed just posterior to the parieto-occipital fossa in a line parallel with, but five centimeters lateral to, the mid-line. The electrodes consisted of small gold discs, eight millimeters in diameter, each sunk in a small bakelite block and attached to the head by means of bandages. An electrode jelly served as the conducting medium between the scalp and the electrodes.

All subjects, except the very young infants who lay on a cot, sat comfortably in a dark and relatively sound-proof room with eyes open. Several short records were made at random intervals during a 15- to 30-minute period after the subject had become adapted to the experimental situation.

In analyzing the records for frequency and amplitude of the alpha waves all of the readable records for each subject, consisting of a series of random samples (usually three or more meters), were used. The peak to peak amplitude of all alpha waves was measured and converted into average peak microvolts. The sensitivity of the

recording system permitted adequate measurement of waves of the order of two to three microvolts. Frequency determinations were never made on a series of waves unless there were at least four rhythmic waves in a sequence.

C. Subjects

The subjects for this study were 132 normal, white children ranging in age from one month to sixteen years. Of this group, 76 were boys and 56 were girls. Most of these children were members of a much larger group whose growth and development was being studied regularly by the staff of the Associated Foundations of Western Reserve University under the direction of the late Professor T. Wingate Todd. Only children of good health were included in the program and the group was admittedly a "selected" one inasmuch as the majority of the children came from homes well above the average, culturally and economically.

Whenever possible, brain potentials were recorded from each child when he came for his regular serial examination, every three months (dating from birth) for the first year, semi-yearly from one to five years of age and yearly (within one week of the birthday) thereafter. In all but 11 of the 132 subjects two or more serial brain potential examinations were made, and in 42 three or more examinations were made during a period of two to three years. In the case of some infants records were obtained at monthly intervals.

D. Results

In 12 infants an occipital alpha rhythm was present at three months of age. During the next few months the frequency and amplitude of the alpha waves increased and the rhythm became more persistent. As may be seen in Table 1, which shows the average, median, and range of frequency and amplitude for each age level, the average frequency at the onset of the rhythm at three months was 3.9 per second (range 3.3 to 4.7) and the average amplitude was 37 microvolts (range 10 to 48). By the end of the first year the average frequency had increased to 6.3 per second and the average amplitude to 52 microvolts. This represents more than a 60 per cent increase in frequency and more than a 40 per cent increase in amplitude during the first year. During the succeeding years the frequency continued to increase but by smaller and smaller annual

TABLE 1

GROUPED DATA SHOWING AVERAGE, MEDIAN, AND RANGE OF FREQUENCY AND AMPLITUDE OF THE OCCIPITAL ALPHA WAVES

Age	Frequency per second				Amplitude in microvolts			
	No.	Av.	Med.	Range	No.	Av.	Med.	Range
3 months	12	3.9	4.0	3.3- 4.7	9	37	38	10-48
6 months	10	4.5	4.5	4.0- 4.8	6	42	41	28-60
9 months	10	5.8	5.9	5.3- 6.3	10	50	52	26-68
12 months	9	6.3	6.5	5.5- 7.0	8	52	48	34-84
18 months	11	6.8	6.8	5.3- 7.4	9	43	42	22-62
2 years	17	7.0	6.8	5.0- 9.6	13	49	51	24-68
2½ years	9	7.1	7.2	6.3- 7.7	8	45	44	28-62
3 years	8	7.5	7.5	4.3- 8.5	5	51	54	38-60
3½ years	12	8.0	7.6	6.5- 9.6	10	32	33	16-46
4 years	10	7.7	7.8	6.0- 9.2	9	27	24	19-40
4½ years	10	7.9	7.9	7.3- 8.8	8	29	27	16-52
5 years	15	8.4	8.5	7.3- 9.4	16	31	30	12-74
6 years	20	8.6	8.5	7.3-10.3	14	27	28	16-42
7 years	20	9.0	9.3	7.9-10.0	17	25	22	12-44
8 years	15	9.3	9.2	7.3-10.3	12	21	20	14-36
9 years	18	9.3	9.4	8.4-11.4	15	21	22	10-34
10 years	22	9.4	9.3	8.0-11.6	18	19	16	10-34
11 years	31	9.8	9.9	8.0-12.0	21	20	16	10-44
12 years	31	10.2	10.3	8.0-12.0	27	20	20	10-42
13 years	36	10.3	10.2	8.0-12.1	28	19	16	8-36
14 years	22	10.3	10.3	8.7-12.2	19	18	17	7-34
15 years	13	10.3	10.5	8.9-12.6	9	14	14	6-22
16 years	8	9.9	10.0	9.0-11.0	3	13	12	10-16
	369				294			
Adults	75	10.2	10.3	8.0-13.0	25	13	13	5-24

increments until the average for adults (10.2 per second) was first attained as an average at 12 years of age. The amplitude on the other hand did not increase above the average at one year of age, but remained about the same until three years of age. Between three and four years of age the amplitude dropped sharply (see Figure 3) from an average above 50 microvolts at three years to below 30 microvolts at four years. From four years on the amplitude decreased very gradually until the adult average (13 microvolts) was reached at about 15 to 16 years of age.

The data for all subjects included in Table 1 are plotted in Figures 1 and 2. The measurements at successive examinations are connected by lines to show the trend of frequency and amplitude changes as a function of age for individual subjects and to show the distributions for the group as a whole. The curves of average

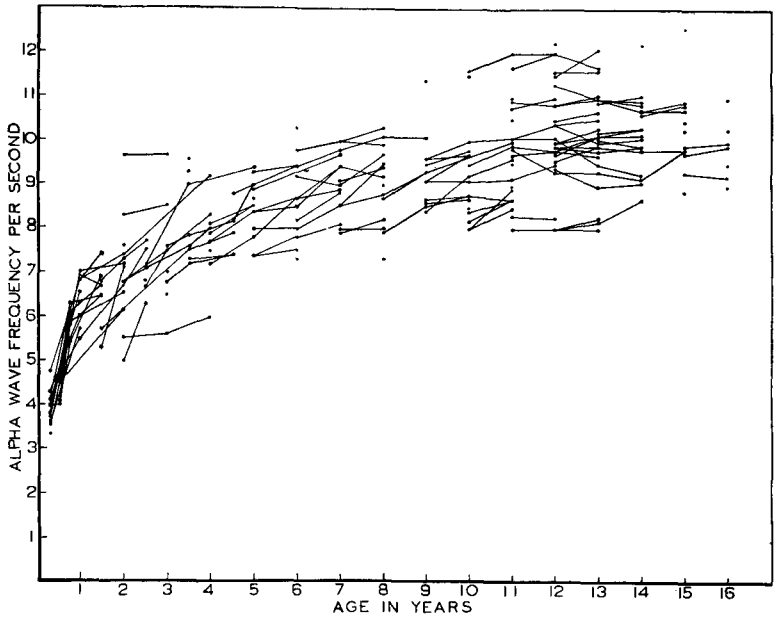

FIGURE 1

INDIVIDUAL CURVES OF OCCIPITAL ALPHA FREQUENCIES REPRESENTING 369 SEPARATE EXAMINATIONS ON 132 DIFFERENT SUBJECTS

frequency (heavy solid line) and average amplitude (heavy dotted line) are plotted in Figure 3. Also shown in this figure are some curves of frequency and amplitude (thinner solid and dotted lines) for individual subjects representative of various age levels. These will be seen to follow the same trend as the curves of average frequency and amplitude for the groups. Further evidence that the serial or longitudinal measurements on individuals correspond essentially with the cross-sectional data for the group is shown in Table 2 where the successive and amplitude measurements for the 42 children studied three or more times during a period of three years are given.

1. *Frequency*

To return to the changes in frequency of the occipital alpha rhythm as a function of age, let us turn again to Table 1 and Figures 1 and 3.

TABLE 2

SERIAL DATA SHOWING FREQUENCY PER SECOND (ABOVE) AND AMPLITUDE IN MICROVOLTS (BELOW) OF THE OCCIPITAL ALPHA WAVES

Age in months:		3	6	9	12	18	24	30	36	42	48	54	60	72	84
Subj.	Sex														
1	M	(4.9)	4.5	6.3	6.5	(6.9)	(7.0)	(7.0)	7.3						
		(64)	60	62	57	(51)	(51)	(44)	32						
2	M	4.7			6.8	7.4									
		36			38	30									
3	M	3.7			6.9	6.7									
		36			34	38									
4	F	4.0	4.6		7.0		7.2								
		10	28		38		66								
5	M	4.0		5.4	6.0	6.5									
		38		64	84	62									
6	F	4.0	4.0	5.4		6.9									
		—	—	50		36									
7	F	4.3	4.8	6.1		6.7									
		12	38	36		22									
8	M	3.5	4.5				6.2								
		36	44				68								
9	M		4.1	5.9			6.6								
			36	54			60								
10	M		4.7		5.5		6.7	7.5							
			46		38		54	40							

TABLE 2 (*continued*)

Age in months		3	6	9	12	18	24	30	36	42	48	54	60	72	84
11	M					6.8 58	7.3 48	7.7 48							
12	M						6.8 60	7.1 48		7.6 46	8.0 40				
13	F						5.5 56		5.6 44		6.0 36				
14	M							6.7 44	6.7 —		6.5 24	8.3 30			
15	F								4.3 60	4.5 —			7.3 74		
16	M								7.6 54	7.8 —		8.2 34	9.0 32		
17	M										7.7 22		8.3 20	8.7 24	
18	M											8.8 48	9.0 —	8.4 —	
19	M												8.0 36	8.0 42	8.5 44
20	F												8.5 14	8.5 16	9.4 22
21	M												7.4 40	7.8 28	8.1 30

TABLE 2 (*continued*)

Age in months		72	84	96	108	120	132	144	156	168	180	192
Subj.	Sex											
22	F	9.2	9.0	9.7								
		32	32	16								
23	F	9.4	9.8	10.1								
		16	18	20								
24	F	9.8	10.0	9.9								
		18	20	16								
25	F	8.5	8.8	9.3								
		26	24	26								
26	M				8.7	8.8	8.7					
					22	20	24					
27	M					9.1	9.2	9.5				
						12	10	10				
28	M					11.6	12.0	12.0				
						16	14	10				
29	M						8.0	8.0	8.0			
							18	20	28			
30	F						10.1	10.4	10.5			
							—	22	22			
31	F						10.9	10.8	11.1			
							16	26	20			
32	F						11.7	12.0	11.7			
							14	14	16			
33	M						9.7	9.8	9.7			
							30	30	12			
34	M						10.8	10.3	10.3			
							34	28	28			
35	F						10.1	10.1	9.5			
							12	14	18			

TABLE 2 (*continued*)

Age in months		72	84	96	108	120	132	144	156	168	180	192
36	M							8.0	8.2	8.7		
								—	24	24		
37	F							10.8	11.0	10.8		
								14	20	12		
38	M							9.9	9.8	9.9		
								12	22	12		
39	F							11.3	11.0	10.9		
								14	8	10		
40	M							10.4	10.0	10.1		
								18	18	16		
41	M								10.4	10.2	10.8	
									14	10	10	
42	M								11.0	10.7	10.9	
									16	18	16	

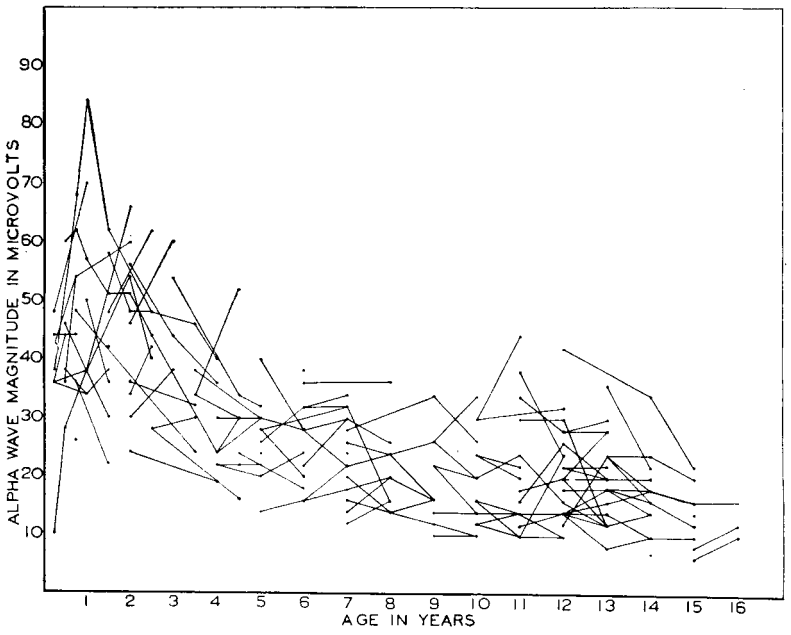

FIGURE 2

INDIVIDUAL CURVES OF OCCIPITAL ALPHA AMPLITUDES REPRESENTING 294 SEPARATE EXAMINATIONS ON 132 DIFFERENT SUBJECTS

Although the average for adults (10.2 per second) is first attained as an average by the children comprising the twelve-year-old group, one notes that the lower limit (8.0 per second) of the adult range of frequencies is first exceeded by the average of the group at five years of age. The median at this age indicates that 50 per cent of the children at five years of age have alpha frequencies exceeding the lower limit of the adult range. Except for one perhaps spurious case with a frequency of 9.6 per second at two and again at 3.5 years of age (see Figure 1) the lower limit of the adult range is first exceeded by a few subjects at three years of age. Thus, although one can be fairly sure that if the frequency of a child's alpha rhythm is below eight per second it will increase further, it is difficult to predict how much it will go beyond eight per second. From the data in Table 1 it appears that the average, median, and essential

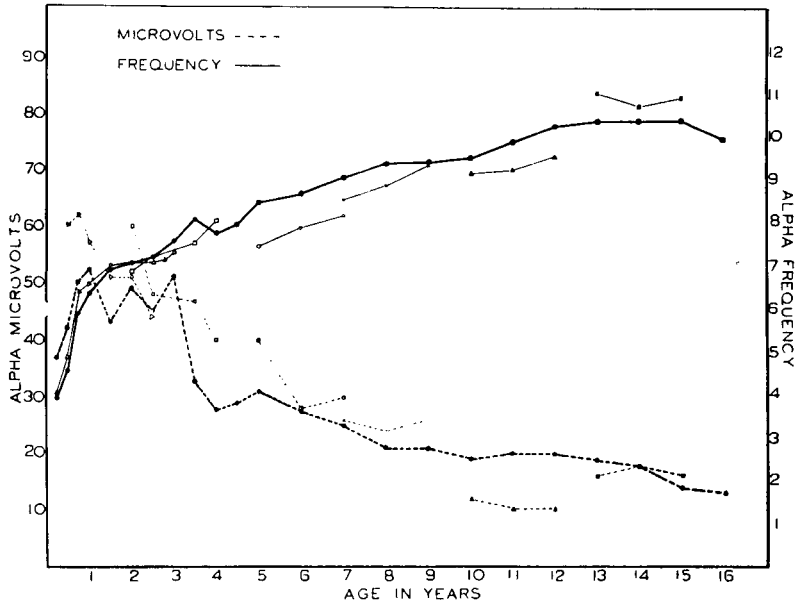

FIGURE 3

CURVES OF MEAN FREQUENCY (HEAVY SOLID LINE) AND MEAN AMPLITUDE (HEAVY DOTTED LINE) FOR ALL SUBJECTS

The thin lines solid and dotted marked by symbols) are curves of frequency and amplitude for individual subjects studied three or more times.

range of the adult is first reached by the 12-year-old group. A glance at Figure 1 reveals also that most of the individual curves of frequency have flattened out and show relatively little rise beyond the age of 12.

Observation of Figure 1 where serial frequency measurements for individual subjects are plotted shows that the frequencies for most age levels are fairly well distributed. The range of frequencies is relatively narrow during the first year, despite the fact that the largest increments in frequency occur during this period. After one year of age the range increases, but except for an occasional subject it does not exceed 2.5 cycles per second until 10 years of age; thereafter the range is almost equal to that of the adult group. At ages two, three, and four (see Figure 1), the frequency measurements

for three children deviate considerably from the rest of the group. Although there were no obvious abnormalities it is perhaps significant to note in connection with these frequency deviations that all three children were rated as somewhat emotionally unstable, i.e., their behavior at home and in the research examinations was characterized by excessive timidity, flightiness, distractableness, temper tantrums, and other indications of poor adjustment. The child with the lowest frequencies at two, three, and four years of age was also one year below the weight standards for her age at three years and had an essentially borderline mental classification (*IQ* 81). One can only speculate as to whether the frequency deviations, probably associated in some way with variations in brain growth and development, are also associated with the behavior characteristics of these children. It would have been interesting to follow them farther and learn whether with increasing age the frequency would approach the range of the group or continue to deviate from it.

2. *Amplitude*

One notes on looking over the individual data in Table 2 and in Figure 2 that during the first year, while the occipital alpha rhythm is becoming better established, the amplitude in some of the infants increases and reaches a maximum between the end of the first and second years. In others it seems to have its full magnitude when first observed at three or four months of age and begins to decrease almost immediately. The individual curves of amplitude (Figure 2) show that the general trend is downward after one year of age. This is shown also in Figure 3, but here the curve of average amplitude for the group shows a marked decline in amplitude between three and four years of age. After four years of age the decline is more gradual and the average adult level is reached by the average of the group at 15 to 16 years of age.

In Figure 2 it will be noted that after four years of age only two subjects show amplitude measurements above 40 microvolts. It will also be noted that most of the individual curves represented here show a downward trend after four years of age.

3. *Relationship between Frequency and Amplitude*

From the individual curves of frequency and amplitude shown in Figures 1 and 2 and from the curves of the averages of frequency

and amplitude for all subjects in Figure 3 it appears that there is essentially an inverse relationship between frequency and amplitude. If this were true it would agree with the results of a study by Travis and Knott (13) which showed a low positive relationship ($r = 0.40$) between the amplitude and duration (the reciprocal of frequency) of 10 alpha waves taken at random from the records of 19 subjects. Actually in the present study, however, the relationship does not seem to be a direct one, for when correlations were made between frequency and amplitude with age held constant (i.e., at any one age level) no significant relationships were found. For example the rank difference correlations between frequency and amplitude at age seven and eleven were respectively, 0.20 and 0.01. Thus, although frequency and amplitude of the occipital alpha waves vary inversely as a function of age (frequency increasing and amplitude decreasing) there appears to be no direct relationship between the two; the variations of both are probably due to independent factors. The possible nature of these factors will be discussed later.

4. *Longitudinal Records*

To illustrate the manner in which the occipital alpha rhythm develops and changes in frequency and amplitude with increasing age during the early years samples of the records from a child studied 16 times during the first three years of life are presented in Figure 4. These are tracings of the actual records equated for time and magnitude. Records were made regularly each month for the first year of life and at irregular intervals thereafter until three years of age.

Although beta waves and occasionally other doubtful rhythms (mainly random waves) of low amplitude appeared earlier, the first persistent alpha rhythm began at four months of age as may be seen in Figure 4. The average frequency of the waves at onset of the rhythm was 4.0 per second and the average amplitude 64 microvolts. Thereafter the frequency increased, reaching an average of 7.3 per second at three years of age, and the amplitude decreased to 32 microvolts. The serial frequency and amplitude data for this child (subject No. 1) are given in Table 2. The values in parentheses have been placed under the nearest age classification in the table; the actual age for each of these examinations is given opposite the records in Figure 4. The data for this child are plotted in Figure 3

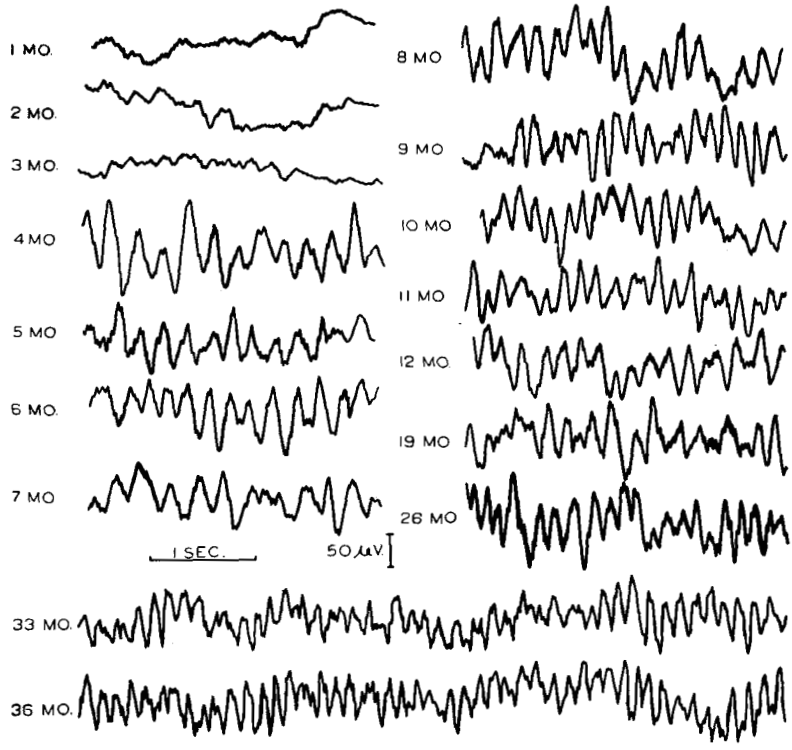

FIGURE 4

PANTOGRAPH TRACINGS (EQUATED FOR TIME AND MAGNITUDE) OF THE OCCIPITAL BRAIN POTENTIAL RECORDS FROM A CHILD STUDIED SERIALLY DURING THE FIRST THREE YEARS OF LIFE, SHOWING THE ONSET OF THE OCCIPITAL ALPHA RHYTHM AT FOUR MONTHS (FREQUENCY 4.0 PER SECOND; AMPLITUDE 64 MICROVOLTS) AND ITS SUBSEQUENT DEVELOPMENT TO THREE YEARS OF AGE (FREQUENCY 7.3 PER SECOND; AMPLITUDE 32 MICROVOLTS)

as the individual curves marked by open triangles. This represents one of the cases in which the amplitude was at a maximum when the alpha rhythm was first observed; after nine months of age it decreased consistently. Frequency increased almost exactly according to the average for the group up to the age of three years. The

pattern of the activity remained essentially the same throughout with the alpha waves present practically 100 per cent of the time.

E. Discussion

Both the longitudinal and the grouped data presented here confirm the earlier cross-sectional findings of Lindsley (5, 6) and Smith (8) on the increase in frequency of the occipital alpha waves as a function of age. They are also in close agreement with the results of the more intensive serial studies of Smith (9, 10) on very young children.

The onset of the occipital alpha rhythm sometime around the third to fourth month in infants is undoubtedly associated with the development of certain functional capacities of the visual area. The increase in frequency of the waves with age is probably associated with some aspect of growth and development of the brain since the data on brain growth in children assembled from different sources by Weinbach (15) and Lindsley (6) were found to follow similar developmental trends.

Changes in amplitude of the alpha waves with increasing age may in some way be related also to growth and reorganization of patterns of activity in the brain, but the changes in amplitude with age observed in this study, since they bear no direct relationship to the changing frequency, might be interpreted in another way. Travis and Knott (13) interpreted the relatively low positive relationship they found between amplitude and duration of alpha waves as evidence of a common factor underlying variations in frequency and amplitude. They assumed that the underlying factor was the number of neurones forming an active gradient; thus, the greater the number of cells active, the greater the magnitude and duration of the resulting potential wave.

The increase in the amplitude of the alpha waves found in some but not all subjects during the first year or two may well be due to the activity of more and more functional units, but the low resistance pathway afforded by the unclosed fontanelles probably accounts for the high amplitude of the alpha waves during the first three years. The usual age for the closing of the anterior fontanelle (the end of the second year) coincides fairly closely with the sharp drop in the magnitude of the alpha wave which occurs during the third year. The fact that this drop is so sharp and is unaccompanied by any corresponding change in the frequency of the waves suggests that

its cause is extrinsic to the brain itself. It is perhaps not unreasonable to look upon the continued gradual drop in amplitude after four years of age as due in part to increased resistance offered by an increased thickness of the scalp and skull during the succeeding years. If these factors do operate in this way to cause an apparent decrease in amplitude it is obvious that any direct relationship which might obtain between amplitude and frequency as functions of brain growth and development would probably be over-shadowed.

F. Summary

A study of the frequency and amplitude of the occipital alpha rhythm in 132 children ranging in age from one month to sixteen years of age has been made, and the data grouped for use as standards. Frequency measurements are based on 369 and amplitude on 294 separate examinations at the various age levels. Serial or longitudinal observations were made on most subjects and show that the changes in frequency and amplitude with increasing age for individuals confirm those established for the group, cross-sectionally. The alpha rhythm once established increases rapidly in frequency during the first year but more slowly thereafter until the adult average is first reached as an average by the 12-year-old group. Amplitude of the alpha waves increases during the first year or two but drops sharply during the third year and more gradually thereafter until the adult average is reached at about 15 to 16 years of age. The changes in frequency and amplitude of the alpha waves as a function of age are not directly related.

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