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ABSTRACT

This study examined behavioral correlates of the rapid central nervous system changes occurring in the first 4 months of life. It was hypothesized that during the early months of infancy, visual preference would occur as a function of quantitative dimensions of the stimuli (size) which could be mediated at a subcortical level. It was further hypothesized that when primitive reflex measures showed a diminution, thus signifying integration between cortical and subcortical structures, visual preference should shift to qualitative stimulus dimensions (curved versus straight elements) mediated at a cortical level. Sixteen infants participated in the behavioral study, in which they were tested at home seven times: at 2, 5, 8, 11, 13, 15, and 17 weeks of age. One of these infants also had his EEG measured seven times during the first 3 months of his life. Visual fixation of all infants was compared for five sizes of a bull's-eye pattern paired with an intermediate-sized horizontally striped pattern, and five sizes of the striped pattern paired with the intermediate-sized bull's-eye pattern. On the same day that visual behavior was assessed, the strength of seven reflexes was measured. Results showed that all of the primitive reflexes were present and normal or strong in the 2-week testing and weak or absent by the 17-week testing. Findings also showed that while young infants clearly had a preference for larger stimuli, their fixation preferences by 8 weeks of age seemed determined much less by the size of the stimuli, and they clearly showed a preference for curvature by the time they were 11 weeks old. (JMB)

Nervous System Development and Pattern Preference in Infants

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NERVOUS SYSTEM DEVELOPMENT AND PATTERN PREFERENCE IN INFANTS

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The purpose of this study was to examine behavioral correlates of the rapid central nervous system changes occurring in the first four months of life. This research originates directly from Lindsley's (1936, 1938, 1939) early developmental work on the human EEG and is designed to test the hypothesis that cortically mediated visual behaviors are absent in the first few months of infancy. Lindsley was one of the first to note that toward the end of the third month after birth, the EEG in occipital areas changes dramatically. The occipital EEG of the neonate is relatively flat and arrhythmic, but during the third month a prominent 50 uv. rhythm of 3-4 Hz emerges. Lindsley suggested that the beginning of organized rhythmic activity in occipital areas may signify the onset of integrated cortical activity in these regions. It may be only at this period that visual behavior comes under the control of the cortex. Thus, until the third month visual behavior may be mediated primarily at a subcortical level.

While systematic attempts to test this hypothesis by measuring infant behavioral capacity before and after the onset of rhythmic occipital EEG activity have not been undertaken, investigations of neonatal EEG in subsequent decades have continued to suggest the functional significance of the onset of rhythm in posterior regions (Dreyfus-Brisac, Samson, Blanc, & Monod, 1958; Ellingson, 1967). Research on neurological development of the infant cortex at the cellular level indicated that cortical cell myelination and dendritic branching show little progress during the first month of life, but undergo marked maturational change during the second and third months (Conel, 1939; 1941, 1947). This burst of neurological development immediately precedes the onset of occipital alpha activity.

The development of the capacity to function as a cortically integrated organism, as signaled by the emergence of organized rhythms in the occipital lobes, can be used as a perspective from which to examine behavioral development. Given the infant's dramatic increase in neurological potential around the age of three months, this should be a critical period in which to observe behavioral changes. The onset of occipital rhythmic activity corresponds with a time of change in neonatal reflex patterns. At approximately 3 to 4 months, many reflexes drop out of the infant's behavioral repertoire (Fiorentino, 1972; Scheibel & Scheibel, 1964; Taft & Cohen, 1967) due to increasing cortical inhibition of lower centers. As reflex arcs exist below the cortical level, before integration between subcortical and cortical centers, stimulation of the infant elicits an involuntary response. As maturing cortical centers become integrated with subcortical areas, primitive reflex behavior is inhibited, and voluntary responses emerge. The infant thus progresses to a neurologically more mature, integrated state. This disappearance of primitive reflexes is a clear behavioral sign indicating the development of the central nervous system.

Lindsley and Wicke (1974) inferred the lack of cortical functional integration in infant behavior prior to three months from the reflex behavior of infants born without a cerebral cortex. Although these infants do not live more than three months, while alive they exhibit the same reflex development as a normal newborn of the same age. This suggests the lack of cortical integration in the normal neonate.

The inference that visual behavior is mediated at a subcortical level in the first months of life was also made by Bronson (1974) based on his interpretation of the neurophysiological and behavior literature on early infancy. Bronson devised a model of neonatal visual development involving visual pathways through the superior colliculus and pulvinar as well as through the lateral geniculate to areas 17, 18, and 19. Bronson argued that the pathways through the superior colliculus and pulvinar comprise a secondary visual system and develop earlier and are myelinated sooner than the geniculo-striate pathways (comprising the "primary visual system").

Examining the behavioral data in infancy, he concluded that the discriminations which infants have been shown to be capable of performing in the first two months of life could be mediated by the secondary system, and he believed that the primary system was not functional until the third month of life.

There is considerable evidence available from studies of neurophysiological development and of the development of EEG, behavioral reflexes, and visual behavior that dramatic changes occur in the second and third months of life. However, relationships among these variables in the developing individual have not been examined. A major reason that such studies have not been undertaken in infancy is that few techniques for the accurate measurement of infant behavior had been developed until the last decade. We undertook the present longitudinal study using some of these recently developed measures of fixation, following, discrimination, habituation, and preference to study the relationship between visual development and development of the nervous system. Behaviors which could be mediated subcortically as well as behaviors requiring cortical control were included to test the hypothesis that infant behavioral capacity changes around the time that cortical and subcortical structures become integrated.

The data involving visual discrimination and preference will be reported here. This portion of the longitudinal study involved a paradigm devised by Ruff and Turkewitz (1975) to measure qualitative and quantitative aspects of infants' visual response. We hypothesized that during the first months of infancy, preference would occur as a function of quantitative dimensions of the stimuli (size) which could be mediated at a subcortical level. When primitive reflex measures ~~showed~~ a diminution, thus signifying integration between cortical and subcortical structures, visual preference should shift to qualitative stimulus dimensions (curved vs. straight elements) mediated at a cortical level.

Method

Subjects

Fifteen infants, ten females and five males, participated in the behavioral study for the first four months of their lives. Following the Lindsley tradition of longitudinal EEG testing of his own children, the sixteenth subject, the first author's son (JTP), was tested in the behavioral paradigm and also had his EEG measured during the first three months of his life. All infants were full-term (mean gestational age of 40.5 weeks; range of 39-42 weeks) and had an Apgar score of 9 or above.

Apparatus

Stimuli were presented in a fiberboard table-top viewing apparatus, composed of three panels. The infant faced the rear panel and was surrounded on the front and both sides to block out interfering visual stimuli. The mother was seated before the table on which the white viewing screen was placed with her back toward the rear panel with her infant held at her shoulder. This placed the infant on eye level with the stimuli at a distance of approximately 12 inches. The openings for the stimuli were 11 x 11 inches, and the distance between these openings was 3 inches. Fixations were observed from behind the stand through a ¼-inch hole between the stimuli, and fixation time was recorded by the experimenter. The stimuli could not be seen by the experimenter when they were in place, so the experimenter was blind as to which stimuli were being fixated. A cardboard flap on the inside of the apparatus covered the stimuli until they were presented. Fixations were timed by a Lafayette clock-counter, and presentations were timed using a prerecorded cassette with timed signals to indicate the beginning and end of each trial.

Stimuli

The stimuli were the same as used by Ruff and Turkewitz (1975) and were five different sizes of each of a bull's-eye and striped configuration. The bull's-eye was comprised of 12 curvilinear segments and the horizontal stripes were comprised of 12 straight segments arranged in two columns. Size was varied by designing bull's-eyes and stripes of five different total areas. The dimensions of the two patterns are presented in Table 1. A bull's-eye and horizontal stripe pattern of the same size were equated for number of segments, length of segments, and overall black/white ratio. Contour was the same for stimuli of the same size. Each stimulus presentation included two stimuli, a bull's-eye and a horizontal stripe stimulus. All five sizes of the bull's-eye pattern were paired with the intermediate-sized striped pattern, and all five sizes of the striped pattern were paired with the intermediate-sized bull's-eye pattern. Hence, there were ten possible stimulus pairs. Since the bull's-eye/stripes pair of intermediate size was common to both series, there was a total of nine different pairs presented.

Insert Table 1 about here

Procedure

Each infant was tested at home seven times: at two, five, eight, eleven, thirteen, fifteen, and seventeen weeks of age. The mother was asked to sit with her back to the apparatus and hold her infant so that he or she could look over the mother's shoulder. The nine stimulus pairs were shown in the same random order to all subjects and then shown again in a different random order with the positions of the stimuli reversed. Thus, the two stimulus types appeared equally on the left and the right throughout the 18 trials, appearing four times on the left in one order and five times on the left in the other order. Each pair was presented twice to the infant for 5 seconds, so the total possible viewing time for each stimulus was 10 seconds. The experimenter observed the direction of the infant's gaze through the small viewing hole and recorded the direction and duration of each fixation. Fixations were recorded on the basis of the observer's judgment of the direction of gaze and not by corneal reflection. Neither the experimenter nor the mother could see the stimuli. Interrater reliability for this procedure was found by Ruff and

Birch (1974) to be .95.

Neurological Assessment

On the same day that visual behavior was assessed, the strength of seven reflexes was measured. These reflexes are described in Table 2. The experimenter (KMG) was trained by a pediatric neurologist to elicit the reflexes, and they were scored on a four-point scale devised by Parmelee (1971; Sigman, Kapp, Parmelee, & Jeffrey, 1973). On the Parmelee scale a reflex is scored as absent (0), weak (1), normal (2), or strong (3). Since there were seven reflexes tested, a total score indicating the greatest possible immaturity was 21.

Insert Table 2 about here

Electroencephalographic Measurement

In one male infant, JTP, EEG as well as visual and reflex behavior was measured. EEG assessments were made when JTP was two, five, seven, eight, nine, ten, and eleven weeks old, and behavioral assessments were made at two, five, seven, eight, eleven, and thirteen weeks. Grass silver-silver chloride cup electrodes were attached with Grass electrode cream to sites measured as O_1, O_2, and C_2 according to the 10-20 system and referenced to linked earlobes. EEG was recorded on a Beckman Type R dynograph with inputs to a Vetter Model A FM tape recorder.

Results

As anticipated, neurological development as measured by reflexes, proceeded rapidly in this four-month period in infancy with all of the primitive reflexes present and normal or strong in the two-week testing and weak or absent by the 17-week testing. This result is shown in Figure 1, which presents reflex scores over the four-month period for 15 infants. The most dramatic change in the nervous system as assessed by primitive reflexes occurred between the fifth and eighth week, when mean

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Insert Figure 1 about here

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reflex score dropped from 16.0 to 9.3. Twelve of the 15 infants showed the greatest maturational change in reflexes at this point in their development. The remaining three showed the greatest neurological score change between the 8 and 11-week testing.

Changes in visual responding as a function of age were examined in a 2 x 4 x 7 analysis of variance testing the effects of stimulus pattern (bull's-eye vs. horizontal stripes), stimulus size (intermediate, reference stimuli were not included in analysis), and age on fixation time. All three effects were statistically significant as was the age x size interaction and the age x pattern interaction. Infants fixated more at older than at younger ages ($F = 2.97$; df = 6, 98; $p < .01$), they preferred larger stimuli ($F = 29.0$; df = 3, 98; $p < .01$), particularly when they were younger ($F = 4.41$; df = 18, 294; $p < .01$), and they preferred bull's-eyes to horizontal stripes ($F = 73.0$; df = 1, 98; $p < .01$), only when they were older ($F = 6.09$; df = 6, 98; $p < .01$).

The effect of age and stimulus size on fixation is shown in Figure 2. Young infants clearly had a preference for larger stimuli as they fixated the two largest stimuli four times as long at the two-week testing and twice as long at the five-week testing as they fixated the two smallest stimuli. The intermediate stimulus, not shown in Figure 2, was fixated an intermediate length of time between fixation time for the largest and smallest stimuli. Post hoc comparisons using the Scheffe test indicated that the differences between the largest and smallest stimuli and between the second largest and second smallest stimuli were both statistically significant at the .01 level of confidence at the two-week testing and at the .05 and .10 levels, respectively, at the five-week testing. By the eight-week testing the infants were not preferentially viewing stimuli on the basis of size as the differences between fixation time were not statistically significant. At the eleven-week

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Insert Figure 2 about here

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testing the largest stimulus was preferred over the smallest stimulus at the .05 level, but there were no significant preferences on the basis of size at the .05 level of confidence after that session. Thus, the data suggest that size is a salient stimulus characteristic for young infants, but by the time they are eight weeks of age their fixation preferences seem determined much less by the size of the stimulus. It was also at this eight-week testing that we observed the greatest change in nervous system maturation as indexed by primitive reflex score.

Fixation preference as a function of stimulus pattern is shown in Figure 3.

Insert Figure 3 about here

During the first two test sessions at two and five weeks there was virtually no difference in preference for horizontal stripes or bull's-eyes. These were the same two sessions in which there was a clear preference for stimuli on the basis of size. At eight weeks, five of the fifteen infants began to show some preference for bull's-eyes, but the effect was not statistically significant. By eleven weeks the preference for bull's-eyes was evident in 12 of the 15 infants, and post hoc Scheffe tests indicated that the effect was significant at the .05 level as it was for all of the subsequent testings. Throughout the period of the study infants showed about the same amount of looking time for the horizontal stripes, but they significantly increased the amount of time they fixated bull's-eyes. The first testing session after the five-week session on which infants showed an increased fixation time for / bull's-eyes was the eleven-week session. Thus, infants did not appear to discriminate differences between patterned stimuli in the first two months of life, but by the time they were eleven weeks they were clearly showing a preference for curvature.

Neurological maturation in the sixteenth subject, JTP, for whom there is longitudinal EEG data, was similar to neurological maturation in the other 15 Ss except that JTP's scores were somewhat lower from the initial testing on. Since his gestational age was 42 weeks, he would be expected to have a more mature nervous system.

He still showed the greatest change in neurological score between the five and eight-week testing. Additionally, JTP preferred the largest over the smallest stimuli in the initial test sessions, and he first showed a clear preference for bull's-eye stimuli at eight weeks.

While JTP showed a clear preference for curvature at the age of eight weeks, he did not have organized rhythmic activity in his EEG at the eight or nine-week testing. It was not until the ten-week testing that the occipital rhythm of 3-4 Hz appeared. Sample EEG tracings at five, nine, and ten weeks for this subject are presented in Figure 4. While the onset of the occipital EEG rhythm at 10 weeks was earlier than published reports of mean age at which the rhythm appears, it was still preceded by clear behavioral evidence of preference for curvature.

Insert Figure 4 about here

Discussion

The results of this study suggest that there is a shift in the manner in which infants respond to visual stimuli between eight and eleven weeks of age, and this shift is preceded by rapid changes in neurological maturation as indexed by the disappearance of primitive reflexes. The greatest decline in reflex strength took place between five and eight weeks, while the shift in visual behavior began to become apparent at eight weeks and was clear by eleven weeks. These results add to a growing body of literature (Fantz & Fagan, 1975; Karmel, Hoffmann, & Fegy, 1974; Harter, Deaton, & Odom, 1977; Ruff & Turkewitz, 1975) demonstrating that infants younger than 9 to 10 weeks discriminate stimuli on a different basis from infants 11 weeks or older. Younger infants differentiate on the basis of the size of the stimulus while older infants differentiate on the basis of qualitative characteristics of pattern elements. Young infants treat stimuli of the same pattern but of different size as different stimuli, while older infants attending to pattern characteristics of stimuli respond to preferred pattern elements regardless of size.

Ruff and Turkewitz (1975) argued that such results could not be explained simply on the basis of acuity differences between young and older infants. The stimuli used by Ruff and Turkewitz were those used in the present investigation, and the segment width of even the smallest segment was well above the threshold of the youngest infant. Since preference occurred even between two stimuli a great deal above acuity threshold (e.g., between the largest and the intermediate stimulus), it is unlikely that acuity is the cause of the preference shift.

The explanation favored by Ruff and Turkewitz and by the present investigators involves changes in the central nervous system. Lindsley suggested that subcortical and cortical structures are not integrated at birth and that the infant functions on a subcortical level until the third month of life. Bronson (1974) suggested that the secondary visual system, involving the superior colliculus and pulvinar and characterized by poor foveal vision and greater sensitivity to peripheral stimulation, may pred[illegible]ate in the control of infant visual behavior during the first two months of life. The primary visual system is relatively immature until the end of the second month when it supercedes the secondary system. Functional capacity in this geniculo-striate system provides the neurological basis for pattern vision which emerges at this time. Bronson argues that patterns of myelinogenesis and neuronal growth in the infant cortex follow the order in which information is processed in his model. Subcortical structures such as the superior colliculus and lateral geniculate mature earlier than the cortex. Thus, visual behaviors which can be mediated at a subcortical level appear in young infants, while behaviors requiring cortical control emerge only after the cortex is functional.

While Bronson suggested histological measures to index the onset of function in the cortex, Lindsley suggested that the onset of rhythmic occipital EEG might signify the integration of cortical and subcortical structures and hence the onset of functional cortical capacity. Bronson's criteria for cortical control cannot be measured in normal human infants while Lindsley's can. Longitudinal data on one subject suggested that the geniculo-striate system is functionally involved in behavior before the onset of organized rhythmic activity in that system. Stimulus preference based on pattern discrimination occurred two weeks before the appearance of the occipital rhythm. This suggests that while the rhythmic activity is closely associated with the onset of cortical function, it does not pace or precede that function.

We intend to examine the EEG and behavioral development sequences in additional infants before generalizing the conclusion that occipital rhythmic activity onset is not associated with the onset of cortically mediated visual behavior. However, since the visual and reflex data of JTP closely paralleled data collected in 15 other infants, we anticipate replication of EEG results. This leads us to speculate about the behavioral significance of the onset of occipital rhythm. Are there more complex behaviors which accompany or follow onset of this organized rhythm, or does the rhythmic activity only emerge after an interaction of cortical maturation and visual experience with appropriate elements? This intriguing question has arisen from Lindsley's early work on the ontogeny of the EEG, and we are continuing research in our laboratory to pursue this issue he raised.

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Table 1

Physical Measurements of Stimuli

Stimuli	Area in sq. in. (cm^2)	Length of segment in in. (cm)	Length of contour in in. (cm)	Contour density[a]
Size 1	9.75(62.89)	1.25 (3.2)	30 (76)	3.08
Size 2	22.50(145.13)	1.88 (4.8)	45 (114)	2.00
Size 3	30.75(198.34)	2.56 (6.5)	61 (155)	1.98
Size 4	50.25(324.11)	3.25 (8.3)	78 (198)	1.56
Size 5	70.60(455.37)	4.00(10.2)	96 (244)	1.36

[a] Area divided by length of contour.

(Ruff & Turkewitz, 1975)

Table 2

Reflexes Evaluated over the First Four Months of Life

Reflex	Description
1. rooting	Stroking the corner of the mouth and moving the finger laterally across the cheek causes the baby to move his tongue, mouth, and head towards the stimulated side
2. sucking	Elicited by placing a finger or a nipple in the infant's mouth
3. palmar-mental	Produced by pressure on both of the infant's palms; infant opens mouth and closes eyes.
4. grasping	Infant's automatic grasp is used to pull him to sit by placing a forefinger in each of the infant's palms (evaluation of motor maturity)
5. tongue retrusion	Infant responds by pushing out tongue whenever hard object is placed in mouth
6. stepping reflex	In standing position, infant held under arms and inclined forward, takes rhythmical steps characterized by heel strike
7. withdrawal reflex	Legs extended, soles of feet stimulated results in extension of toes followed by pulling legs to torso

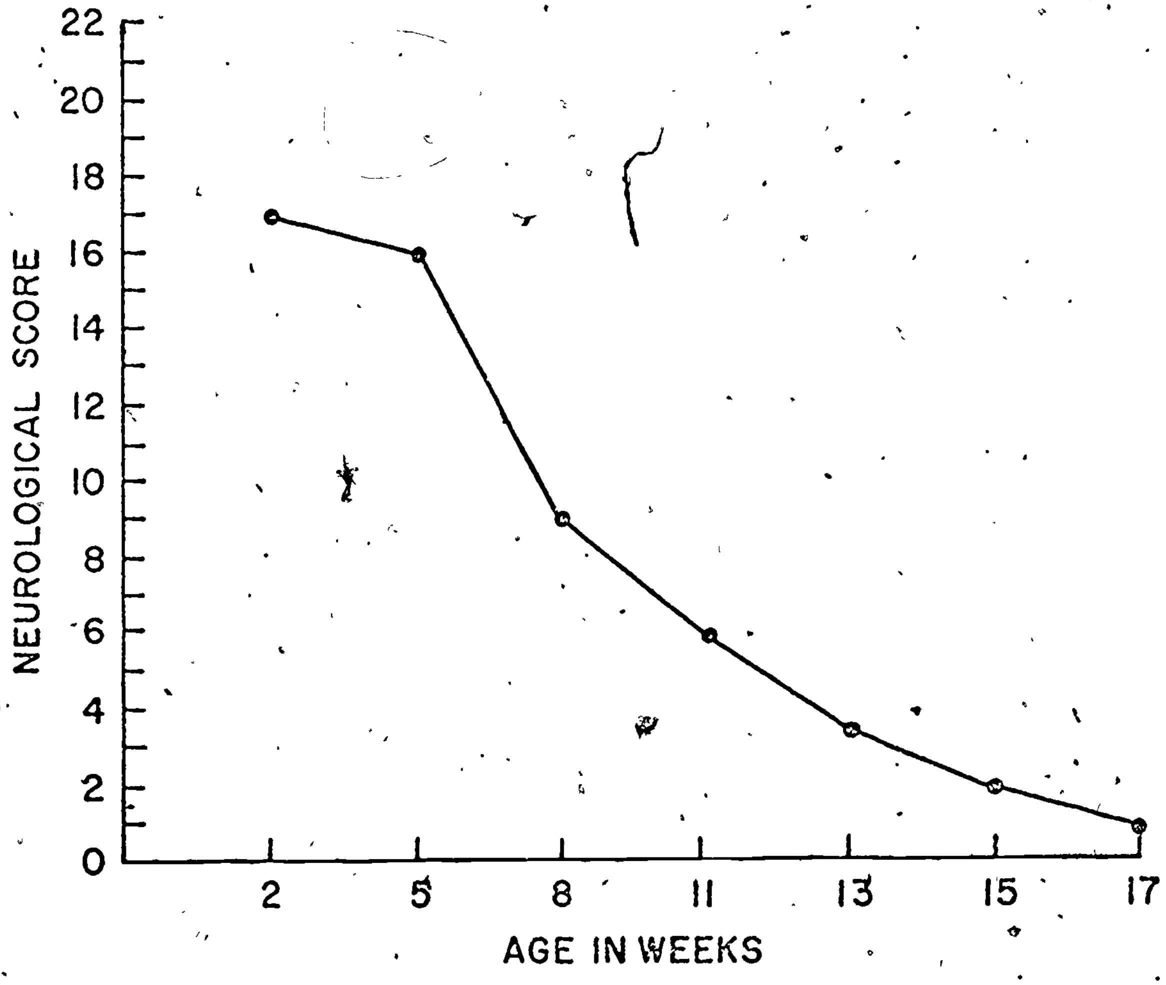
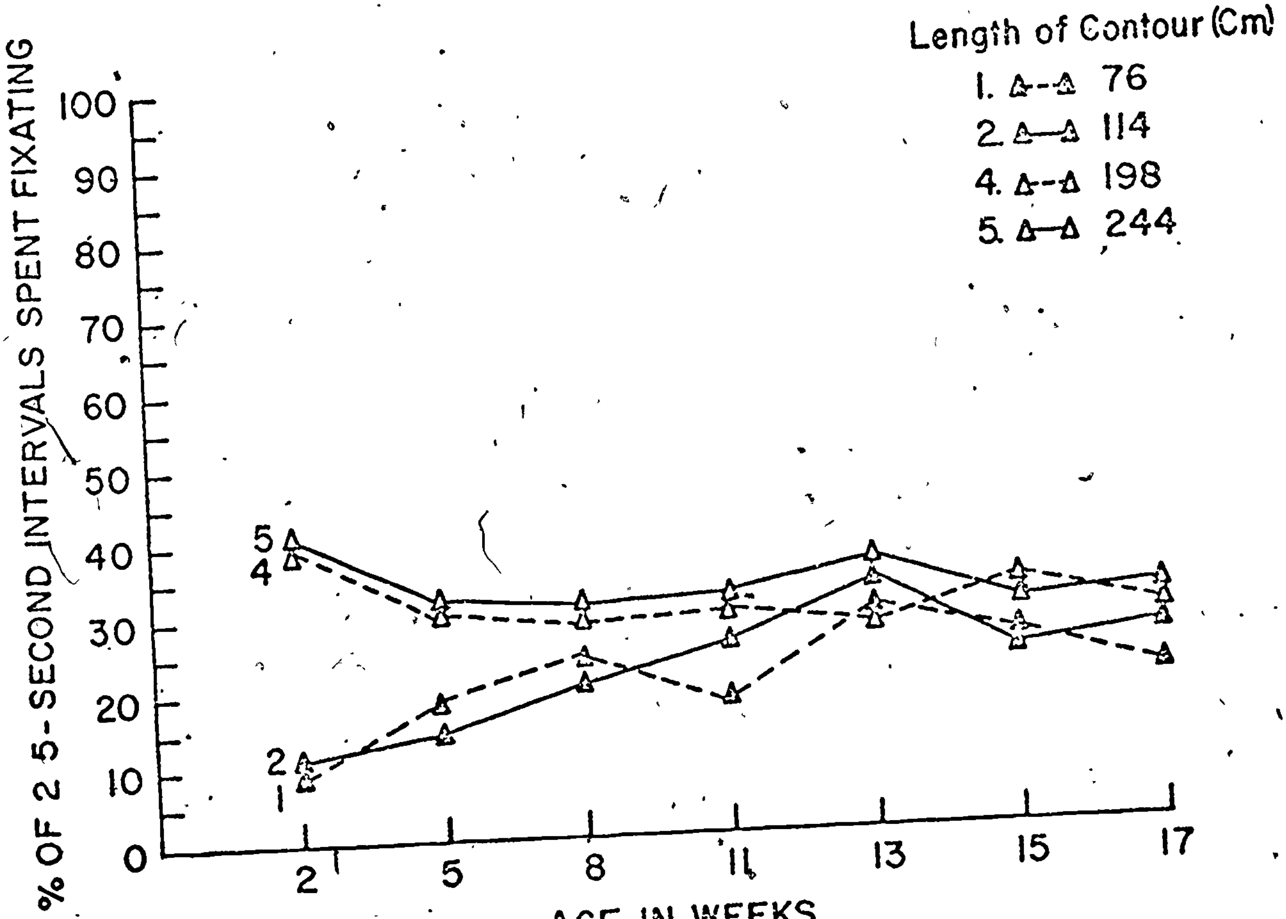
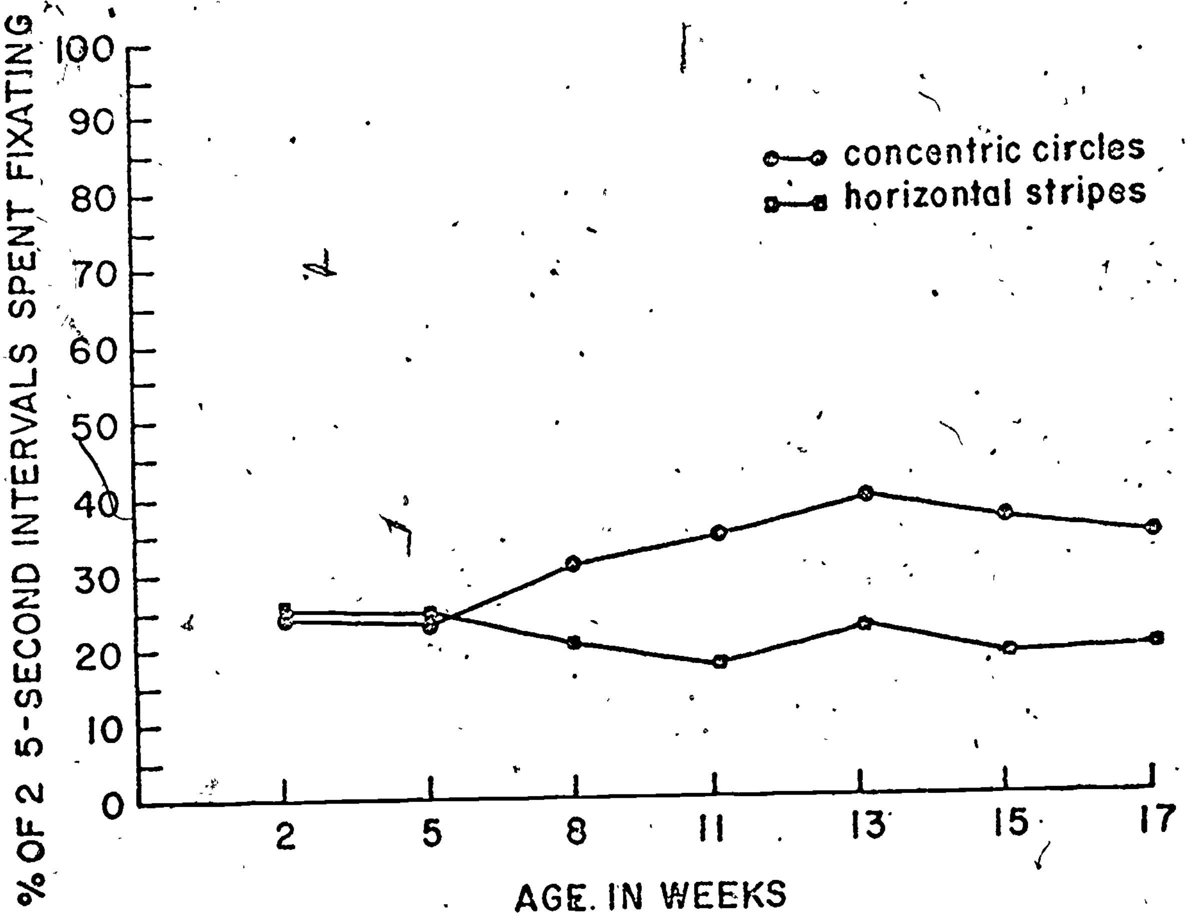


FIG.I. Mean Neurological Score as a Function of Age.
(The higher the score, the lower the maturational level).



Mean Percent of Total possible time fixated (2 5-second intervals) as a function of Age for 4 stimuli of varying sizes collapsed across 2 pattern types.



Mean Percent of Total Possible Time Fixated (2 5-second intervals) as a function of Age for Concentric Circle and Horizontal Stripe Patterns collapsed across 4 stimulus sizes.

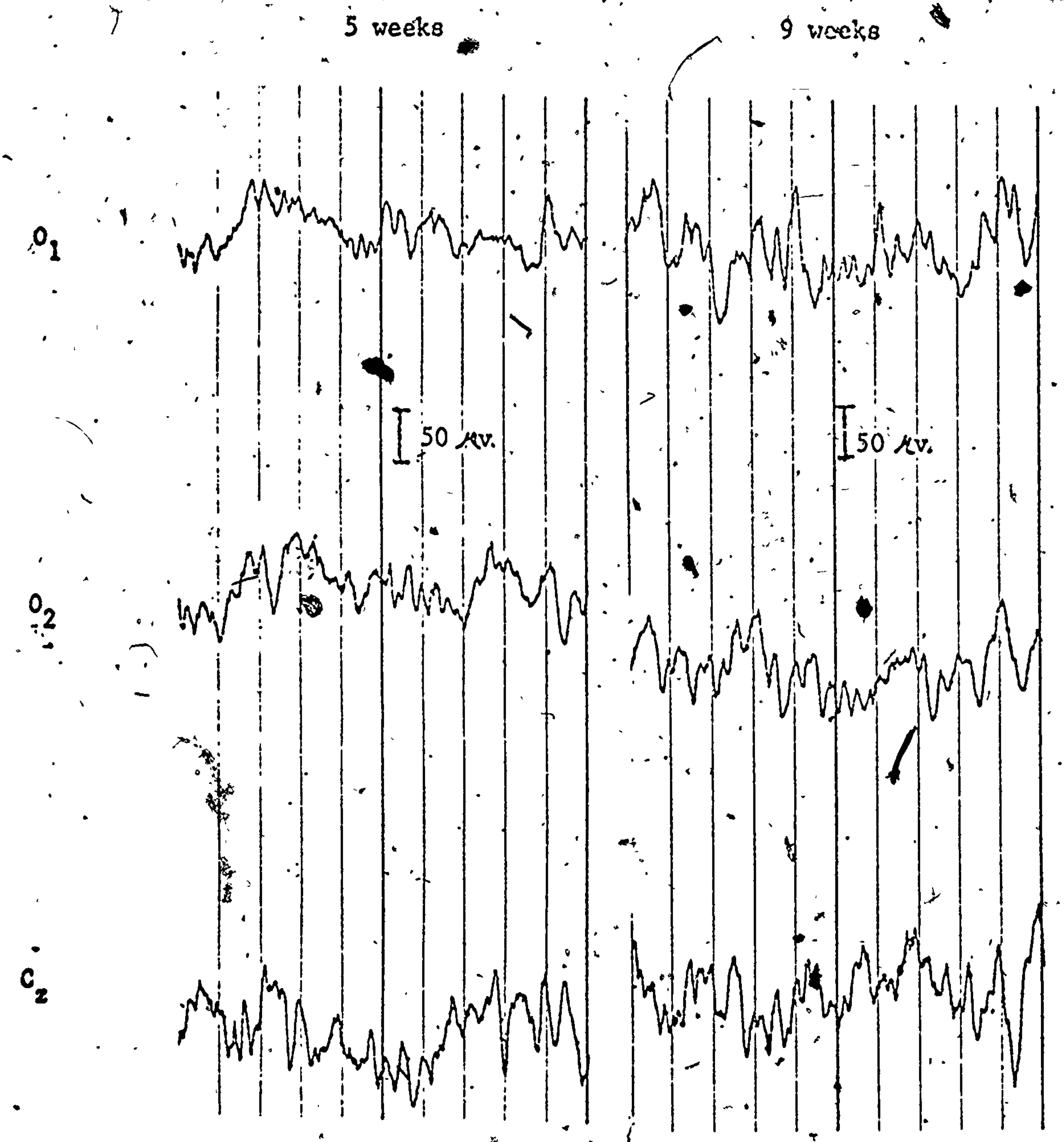


Figure 4. Characteristic EEG of JTP at five, nine, and ten weeks of age.
O_1 - left occipital, O_2 - right occipital, C_z - vertex.

10 weeks