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VISUAL BEHAVIOUR IN THE NEWBORN BABY

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ABSTRACT

The corneal reflection technique, used both with adults and newborn babies, was investigated. Previous researchers have assumed that the centre of the pupil represents the line of sight. It is shown, both experimentally and theoretically, that this assumption is mistaken, and that optical divergence of the eyes does not imply an inability by newborn babies to fixate binocularly. Binocular fixation by the newborn was demonstrated, both to stimuli presented at different distances from the eyes, and to different types of stimuli. Although instances were found in which newborns were not converging, it is concluded that normal newborn babies have the ability to fixate binocularly, and that they will demonstrate this ability when an appropriate stimulus is presented.

CONTENTS

CHAPTER 1

1. **INTRODUCTION** Until recently, attempts to evaluate the perceptual abilities of the newborn baby have been hampered by the absence of readily available response measures. However, since about 1960 an increasing number of responses has become measurable, and a growing number of studies use neonates as subjects. An understanding of early processes of perceptual development and cognitive growth can only be gained by a detailed specification of the infant's visual world. The simple questions that have been asked are, what is the nature of the infant's visual world and what are the dimensions of stimulation that mediate preferences for some forms of stimulation over others? Since there is little chance for learning to have occurred in the period specified as newborn (from 0-10 days of age, i.e., the time usually spent in hospital from birth), it may be assumed that differential attention to stimulus objects reflects innate perceptual abilities.

A major step towards an understanding of the visual perception of the infant was the development of a simple corneal reflection technique for measuring visual fixations (Fantz, 1956). The research embodied in this thesis arose from calibration runs with a corneal reflection method which can be seen as a direct extension of the method suggested by Fantz.

Excellent reviews of research into the visual capabilities of the newborn and young infant can be found in Hershenson (1964, 1967), Kagan (1970), and Bond (1972). Consequently, a comprehensive literature review will not be presented here. In this chapter, mention will be made of research that is directly relevant to, or has directly influenced, the research presented later in the thesis; the concluding section outlines the research aims.

2. MEASURES OF VISUAL ATTENTION AND VISUAL PATTERN PREFERENCES One way of investigating the infant's perceptual abilities is to measure differential durations of visual fixations among a class of stimuli varying along some specified dimension (for example, wavelength, size, amount of contour, number of elements). For discriminations to be manifested by the neonate a functional, albeit immature, visual system is necessary. Hershenson (1967), reviewing the available electrophysiological evidence, concluded that there is "little doubt that the visual system is intact and functional at birth." (p329).

Stirnimann (1944; cited in Fantz, 1961, and Bond, 1972) held cards up to the eyes of infants 1-14 days of age and observed that they "preferred" (i.e., spent more time looking at) patterned cards over plain colours. In place of unaided observation the method of recording visual fixations that has been most often used is that of Fantz (1956). Two stimuli, A and B, are presented, usually some 10 to 15 inches above the supine infant's eyes, and a small observation hole is located between the stimuli. The stimuli are sufficiently well-lit that they can be seen reflected from the cornea of the eyes. To quote Fantz: "when the eyes are directed toward an object, the image of that object overlaps the pupil as viewed through the observation hole. This overlap of reflected image and pupil is the criterion of fixation." (1956, p14). The stimuli, A and B, are presented an equal number of times to left and right (to counteract position preferences) and if one is significantly preferred to the other this may be used to infer some perceptual structure. Thus "... if an infant consistently turns its gaze toward some forms more often than toward others, it must be able to perceive form." (Fantz, 1961, p67). Another method of investigating preferences using this corneal reflection technique is sequential rather than paired presentation of the stimuli.

While the amount of time spent looking at each of the stimuli has been the commonest dependent variable in this context, derivatives of the total fixation time have been used by some investigators, for example, longest fixation, length of first fixation, number of (discrete) fixations, latency to first fixation, (Lewis, Kagan and Kalafat, 1966). Responses other than visual fixation that have been used as measures of attention to visual stimuli include heart rate, sucking, suppression of movement, smiling.

Using these measures of visual attention, those aspects of stimulation to which the infant is most responsive have been investigated. One of the most explored dimensions has been that of "complexity" (defined variously in terms of redundancy, randomness, variety, or number of elements). A number of studies has shown that subjects prefer a given level of complexity and that the preferred level increases with age. Brennan, Ames and Moore (1966) found that, with position preferences controlled for, 3-week-old infants looked most at the least complex of three checkerboard patterns (2 x 2, 8 x 8, 24 x 24); 8-week-old infants preferred the intermediate level, and 14-week-old infants preferred the patterns in increasing order of complexity. Consistent with these findings other researchers have reported that the neonate and young infant prefer low levels of complexity (Hershenson, 1964; Greenberg and O'Donnell, 1972; Greenberg and Weizmann, 1971; Fantz, 1958; Miranda, 1970). An exception to these studies was reported by Horowitz, Paden, Bhana, Aitchison and Self (1972). They carried out two longitudinal and one cross-sectional studies of infants from 3 to 14 weeks of age, and found that "not a single subject in either of the longitudinal groups (10 infants in all) displayed the Age x Complexity shift reported by Brennan et al."

However, the large number of stimuli used in the test session (six checkerboards and one gray square) may have influenced the results because of the large exposure time per session: seven stimuli were presented for 120 seconds each, a total of 14 minutes per session, an amount of time that may have taxed the attentive powers of these young infants.

"Complexity" is not a unitary dimension. By varying the number of elements in a checkerboard one is also varying such features as the amount of contour (defined in terms of the total amount of border contained in the figures), the number of angles, and the size of the individual elements. When these dimensions have been varied independently of complexity the results have suggested that they may be more salient dimensions of stimulation than complexity per se. Karmel (1969), using a paired-comparison design, presented 2 different arrangements (random vs redundant) of 2-dimensional grid patterns with black and white elements of different sizes (⅛in, ½in, 1in and 2in squares) to human infants aged between 3 and 5 months. He suggested that an inverted-U function relating preference to the square root of the amount of contour appeared to be the best description of the looking behaviour, and that a complexity continuum was not useful in describing either the preferences or the shifts in preference with age. Other evidence (reviewed by Kagan, 1970, p828) supports the contention that contour is a more salient dimension of stimulation tha~~t~~n complexity.

Also using a paired-comparison design Miranda and Fantz (1971) varied the size and number of elements (squares) independently to see whether size (larger elements) or complexity (fewer elements) resulted in more fixations by newborn infants. A preference for size to be prepotent over number was found, their most attractive stimulus being two black 2in squares, which was also the largest stimulus shown their subjects.

Karmel, White, Cleaves and Steinsiek (1970), measured averaged evoked potentials to the same stimuli Karmel (1969) had used, presented as light flashes. The physiological responses are described by functions similar to those obtained behaviourally, i.e., they were independent of redundancy of pattern, and displayed an inverted-U relation with the amount of contour (reported in Bond, 1972, and Kagan, 1970). Similarly, Harter and Suitt (1970), who measured visually-evoked cortical potentials from one infant from 21 to 155 days of age in response to checkerboard-patterned light flashes, found that the largest amplitude responses "were evoked by relatively large checks during the first month of life and progressively smaller checks as the infant matured." (p235).

There seems, therefore, to be some agreement that a potent stimulus for the newborn baby is a square, or arrangement of squares, each element subtending approximately 10° visual angle (the stimulus most preferred by the youngest Ss of Brennan et al. was a 2 x 2 checkerboard, each element being 3 inches square, presented 18 inches from the Ss' eyes; an identical stimulus arrangement was preferred by Hershenson's Ss. In Miranda's (1970) study the optimal stimulus was a single square of 2 inches side, and in his 1971 study was two squares of 2 inches side, in both cases presented at a distance of 12 inches). The similarity of the behavioural and physiological findings has suggested to Karmel, and Bond (reported in Bond, p236) that the preferences are related to neuronal activity of contour-encoding cells in the visual system, and that some optimal receptive field size characteristic determines behavioural preference at a particular age.

3. VISUAL ACUITY, VISUAL PURSUIT and ACCOMMODATION A useful technique for testing the visual acuity of infants is to record following (pursuit) movements of the eyes to targets of various sizes. Under some stimulus conditions the optokinetic responses (optokinetic nystagmus, or OKN) are involuntary, and the angular size of the smallest target that elicits the response is used as a measure of visual acuity.[1] The objective measures of visual acuity provided by OKN correlate well with the Snellen equivalent (Reinecke and Cogan, 1958).[2] Using this technique, Gorman, Cogan and Gellis (1957), obtained 93 positive responses from their sample of 100 newborns to a black and white striped pattern, each interval of which subtended an angle of 33.5 minutes of arc, which corresponds to a Snellen notation of 20/670. Dayton, Jones, Aiu, Rawson, Steele and Rose (1964), reported the OKN response in 9 of 18 newborn subjects to targets with a Snellen equivalent of 20/150. Kiff and Lepard (1966), reported that a visual acuity of 20/820, as recorded by the OKN response, is obtained by the majority of premature infants, after reaching a weight of 4lb.

Footnote[1] The optokinetic nystagmus response is a reflex which is elicited when a subject views a moving target such as detectable black and white stripes.

Footnote[2] Snellen letters have been used clinically for over a century for specifying visual acuity. The letters are so constructed that the thickness of the line segments (i.e., of the critical details) of each letter is one-fifth the width or height of the whole letter. A subject is said to have 20/20 vision if the total size of the smallest letter he can recognise at 20 feet subtends at the eye a visual angle of 5 min of arc, and therefore that of the critical detail, 1 min of arc (Lit, 1968, p29).

The neonate's ability to accommodate to stimuli at different distances has not been fully investigated. Haynes, White and Held (1965), reported that the newborn infant's accommodation system is "locked on" at a particular distance (median 19cm), and that, consequently, images of targets nearer or farther away are proportionately blurred. Hershenson (1967), criticized this finding on the grounds that the target may have been an inadequate stimulus for accommodation at the different distances employed, i.e., that it may not have been resolved by the young infant at the farther distances. These criticisms still apply; thus, the data suggest that stimuli at a near distance can be accommodated to, but are inconclusive regarding focusing on stimuli at farther distances. In this context, White, Castle and Held (1964, p354) note that "visual stimuli closer than 7 inches are rarely fixated" by the infant younger than $1\frac{1}{2}$ months, a finding they attribute to the infant's inability to focus on very near objects, since a "test object at 5 inches produces a badly blurred image on the retina." Results from an experiment reported later in this thesis support this suggestion.

Fantz, Ordy and Udelf (1962), reasoned that the OKN data on visual acuity in infants did not necessarily reflect the same visual acuity levels available for pattern perception. Those structures which are important in the mediation of pattern perception, for example, the central retina and the cortex, are not necessary for the reflexive OKN responses in the adult, and therefore possibly not also in the infant. Using the infant's known preference for patterned vs. plain stimulation they presented infants with stimulus pairs consisting of striped vs. uniform gray members. Infants under 1 month of age were able to resolve lines of $\frac{1}{8}$ inch at 10 inches, a Snellen equivalent of 20/800, which is in reasonable agreement with the OKN data. They also found the same level of acuity when the stimulus patterns were presented at 5, 10 and 20 inches from the eye. Thus, the newborn baby seems equipped with sufficient resolving power to be responsive to stimulation within at least some range of distance.

The mode of pursuit shown by the infant when visually following a moving object may depend on the nature of the stimulus. In the OKN response typically elicited in the adult, after fixating the object the eyes follow the movement of the object smoothly to the periphery of the field of fixation, and then jerk quickly back to take up fixation on the next object. When the moving stimulus shown the neonate has been a series of black and white stripes the presence of both forms of eye movement is usually reported. Thus, McGinnis (1930), after analyzing the newborn's following responses to a striped stimulus, concluded that "the ability to make these two types of ocular movements (i.e., smooth pursuit, and saccades) is present from birth" (p379). Similar comments are made by Doris and Cooper (1966, p33), Brazelton, Scholl and Robey (1966, p287), and Gorman, Cogan and Gellis, who noted that in the usual positive response there is "a slow, smooth following movement (corresponding approximately to the motion of the striped paper) to the limit of excursion, and a swift (righting) saccadic movement; the eye going back to a more central position. The above cycle recurred rhythmically" (1957, pp1090-1091). Smooth pursuit movements do not appear to be made, however, to the movement of a discrete stimulus. Dayton and Jones (1964) analyzed the oculomotor reflex (defined as that reflex "responsible for the placement and maintenance of the image of an object on the fovea" p1152), to a series of black dots drawn over a plexiglass canopy. Only one dot was present in the visual field at a time. The eyes' line of sight of newborns and young infants fell behind in tracking the target and following responses consisted of a series of refixations, apparently made to correct for slippage of the image from the fovea as the object moved across the visual field. The amplitude of the refixations fell off with age.

The temporal lag, the eyes moving a fraction of a second after the target has passed the line of vision, has also been noted by Barten, Birns and Ronch (1971, p316). Similarly, White, Castle and Held (1964), whose stimulus was a red circle moved slowly across the visual field, state that, up to $1\frac{1}{2}$ months of age, "pursuit consists of a series of jerky fixations of the red circle which brings its image to the foveal area" (p353). After $1\frac{1}{2}$ months of age a new form of visual pursuit may appear during which "tracking is continuous over wide sectors (up to 90°) of the stimulus path" (p354). These remarks seem to suggest that there are two modes of pursuit, smooth vs. jerky, which are separately elicited depending upon both the type of stimulus and the age of the infant. An alternative, and perhaps more likely hypothesis, is that the two forms of pursuit fall along a continuum, and that the "jerky pursuit" is a consequence of the neonate's inability to maintain a constant fixation on a discrete stimulus, a result of poor visual acuity which "would allow for greater slippage before detection could occur" (Hershenson, 1967, p329). The greater the number of cues available to keep the image of the moving target aligned on the fovea, the more likely is a smooth form of pursuit to be made. Unfortunately, the available literature on visual pursuit does not allow an adequate test of the alternatives.

4. DETERMINANTS OF INFANT VISUAL ATTENTION The purpose of most psychological studies into the perceptual capacities of the neonate is to determine, for theoretical and descriptive purposes, the infant's maximum perceptual capabilities. To do this, the neonate must obviously be in the optimal attentive state for the demonstration of such capabilities; reports of perceptual limitations in infants from studies in which the babies have not been fully awake, or have been fussing, throughout the experimental session can be misleading. The present section reviews the more important variables affecting infants' attention, including both organismic and stimulus variables.

(a) State The state of the subject is his momentary position along some arousal, or activity continuum (or continua). Most investigators have relied upon behaviour rating scales to assess the state of the neonate. The exact criteria utilized varies from author to author (Ashton, 1973, pp7-8, in his review of the state variable in neonatal research, gives a number of the different classifications of state). A commonly used scale is that of Wolff (1959, 1965), who describes six states of arousal: regular sleep, irregular sleep, drowsiness, alert inactivity, alert activity, and crying. The state of alert inactivity is of most interest: the infant in this state is "fully awake but quiet rather than excited; his respirations are regular at a rate of 50-60 per minute; his eyes are wide open, shiny, and capable of conjugate eye movements, and he makes visual and auditory pursuit movements to appropriate objects. The limbs, trunk and face are relaxed... and the baby is not struggling, fussy or crying." (Wolff, 1965, p816). Additionally, periods of alertness rarely occurred during the first months unless the infant had recently eaten, a conclusion supported by Giacoman's (1971) finding that visual attending was greater in satiated Ss than hungry Ss. Visual attention is almost exclusively confined to the state of alert-inactivity. Even when the infant is classified as being in another state, visual attentive behaviour is normally accompanied by a reduction of ongoing motor activity, and is characteristic of a state of vigilance (Stechler and Latz, 1966, p524).

Some other organismic factors that may affect the capacity of the newborn to attend to visual stimuli are (a) complications of pregnancy and delivery, (b) medication given to the mothers before delivery, and (c) parity. A discussion of these factors is to be found in Bell (1963).

(b) Orientation One other factor that may qualitatively affect the neonate's ability to demonstrate his maximum perceptual capacities is whether he is upright or not. Bower (1971), presented experimental evidence suggesting that the supine (i.e., horizontal) baby is not fully awake, regardless of whether the eyes are open. The full form of an adaptive avoidance response to approaching objects only occurred when the subjects (infants from 6 to 20 days of age) were upright; infants on their back, more than 40 of them, did not even blink. However, when the infants were held upright or semi-upright, the defensive response (they pulled their heads back and put their hands between their face and the approaching object), was "accompanied by distress and crying so intense that the experiment had to be terminated." (1971, p32). The apparatus used by the present author, and described in detail later in this thesis, enables eye fixation position to be recorded in the newborn while the S is held in an upright position.

(c) Stimulus factors Stimulus factors (other than variations in patterning), that affect the duration of attention, and may result in differences in attention to patterns, are the size of the stimulus and the distance at which it is presented. McKenzie and

Day (1972) presented evidence to show that the duration of visual fixation of solid objects varies as a function of object distance. In their second experiment the stimuli were cubes presented at distances from 30cm to 90cm. With the real size and the angular size of the object held constant, infants in two age ranges, from 6 to 12 weeks, and from 13 to 20 weeks, spent much more time looking at the object at the nearest distance, with a linear decline in fixation time as the object distance increased. The reason for these findings is unclear; since no interaction of age and distance was observed, a lack of accommodative ability on the part of the younger Ss will not account for the results. Whether the duration of fixation on 2-dimensional objects similarly varies as a function of distance is not known. That the infant under $1\frac{1}{2}$ months will seldom fixate objects closer than 7 inches has been noted previously.

The size of the stimulus object may also affect the infant's attentive processes. Tronick (1972) presented infants from 2 to 10 weeks, who were seated in an infant seat, with a fixation object which was a brightly coloured rectangular object at an approximate distance of 16 inches. When the infant was deemed to be looking at the fixation object a similar object was presented peripherally. The criterion of a "look" was a definite shift in gaze to the peripheral object and a brief fixation of it. The largest angular separation of the two objects that elicited a look was operationally defined as the infant's effective visual field. The size of the infant's visual field determined in this way was, in the 2-week-old infant, quite small, 15° to either side of the line of regard. Of course, the absence of a fixation response to objects greater than 15° in the 2-week-old infant does not necessarily mean that the object is not visually available; alternative explanations of the results in terms of the muscular effort required to respond, for example, are possible. However, the findings do have implications for two areas of research: (i) form perception and (ii) the nature of the attentive process, both of which are discussed below.

(i) Implications for form perception Where fairly precise specification of the area of a stimulus fixated by the newborn is available the results suggest that visual scanning is limited to a small portion of the stimulus (Salapatek and Kessen, 1966). Also, as mentioned in a previous section of this chapter, a potent stimulus for the newborn is a square, or arrangement of squares, with each element subtending approximately 10° visual angle - an angular size that, if Tronick's (1972) finding is correct, would keep all portions of a single square in view no matter which part of it S looked at. Hershenson (1967) suggested that a requirement for the operational demonstration of form perception could be a response to the whole figure: this may be possible only if the stimulus is sufficiently small for the neonate to view it as a whole.

(ii) Implications concerning the nature of the attentive process The growth of the effective visual field with age may account for the change from an obligatory to a voluntary looking pattern in infants. Several investigators have reported that the young infant appears to be "captured" by stimuli; thus, Ames and Silfen (reported in Hershenson, 1967), note that "while the older infant may be capturing stimuli with his looking behaviour, the young infant is being captured by the stimuli." White, Castle and Held (1964) similarly note that "the infant maintains one direction of gaze for prolonged periods." (p353), and Horowitz, Paden, Bhana and Self, working with infants from 3 to 14 weeks of age, found that looking durations of over 2 minutes were very common. Tronick (1972) suggests that the change to a more active and voluntary looking pattern is a quantitative, rather than a qualitative, change, attributable to the growth in the visual field which would make previously ineffective portions of the stimulus available to be looked at.

In a study reported by Haith (1968; more formally presented by Kessen, Salapatek and Haith, 1972), newborn babies were shown a vertical edge; when this edge was presented 3 inches to the left of the centre of the visual field one form of visual scanning observed was repetitive horizontal movements across the edge (whether this is characteristic of most, or all, infants is not known because of limitations of their recording procedure: see Kessen et al., 1972). Also, neonates fixating stimuli, even though only a small portion of the visual field is usually viewed, typically move their eyes at least once each second, and probably more than once each second (Salapatek and Kessen, 1966; Salapatek, 1968). These findings are difficult to reconcile with suggestions of "blank looking" in the neonatal period. Possibly the reduced motility and the vigilance-like state that accompany visual attention belie the possibility that the form of the visual scanning, although confined to a small angular area, may be active. Those recorded periods of genuine "blank looking" - periods in which no change of gaze occurs at all, which may last up to 30 sec. (Tronick and Clanton, 1971, p1481) could well be transitory changes of state.

5. <u>CONJUGATE EYE MOVEMENTS AND BINOCULAR FIXATION</u> The single, unified image of normal binocular vision is dependent upon accurate binocular fixation, both eyes being positioned so that each fovea is centred under the image of the object of regard. Binocular fixation entails a two-fold requirement: (i) the integrated activity of both

the intra- and extra-ocular neuromuscular systems so that the eyes move in a co-ordinated and conjugate fashion, and (ii) accurate monocular fixation by either eye allowing for simultaneous binocular fixation of the object of regard.

The first of these two abilities is well documented in the newborn. According to Wolff (1965), the infant in the state characterized as "alert inactivity" is capable of conjugate eye movements and he makes visual and auditory pursuit movements to appropriate objects. Dayton, Jones, Steele and Rose (1964), found that conjugate movements of the eyes were shown in electro-oculographic tracings when newborns followed a series of black dots: "each eye in the process of pursuit moved simultaneously in the direction of the target; both eyes moved over the same period of time. The similarity of the tracings indicates close conjugation of the eyes in the newborn period"(p874). Greenman (1963), analyzed the visual following responses of 127 infants within 24 hours after birth.. In the 95% of infants who followed, "conjugate deviation of the eyes occurred in all instances". (p75).

Conjugation in the presence of stationary targets is less clear. Hershenson (1964, 1965) photographed ocular orientations at a rate of 10 frames per second, when subjects were judged to be looking directly at a stimulus screen by an observer. Immediately above each stimulus was an infrared light, and the degree of conjugate movement was reflected in the degree to which the relative shifts in size and direction of the corneal reflex positions corresponded. The mean correlation observed was 0.87, with a range from .84 to .90, which is good evidence for a high degree of conjugate movement. Wickelgren (1969), photographed neonates' eyes to three stimulus conditions: a permanently on light centred in front of the eyes, a blinking centre light, and repeating series of 3 horizontal lights at different light durations. She reported that conjugate eye movements occurred approximately 50% of the time in all conditions, "quite a high frequency when one considers the large number of alternatives to conjugate eye movements" (p482). It seems likely that, given the newborn's poorer visual acuity, some small degree of independent movement of the eyes is possible before detection and correction of a slippage of the image from the fovea can occur. This could allow for some small amounts of nonconjugate eye movements, without at the same time implying either poorer muscular coordination than in the adult, or the absence of binocular fixation.

Conjugate eye movements and binocular fixation are distinguishable as two separate activities. The eyes can move together without necessarily being directed at the same point in space. Developmentally it has often been assumed that the newborn baby is incapable of binocular fixation. Ling (1942), showed supine babies of various ages a black disc, 2 inches in diameter, which moved radially in depth from 3 inches to 36 inches above the infants' eyes. She photographed the eyes and determined the position of the irides in relation to each other, and reported that, developmentally, the first fixations on the object are monocular, the non-fixating or resting eye being either closed or only partly open. Additionally, she reported "the absence of binocular fixation until about the end of the second month." (Ling, 1942, p271; also reported in Gesell, 1950).

More recent studies have supported this early finding. Hershenson (1964), photographed newborn babies' eyes when the Ss were thought to be looking at the stimulus (either a square or a checkerboard) with at least one eye. The corneal reflections of either the stimulus, or of infrared marker lights whose position relative to the stimulus was known, were used in determining the fixation position of both eyes, and it was found " that to a large extent the newborns were fixating the stimulus with both eyes" (p275). However, as each stimulus was 6 inches square it was possible that the Ss' eyes were looking at different parts of the same stimulus, and that true convergence was not present. Using a similar corneal reflection technique, but one which was thought to provide a more precise measure of looking, Wickelgren (1967, 1969) tested this possibility. Some nominal convergence was found, i.e., where the two eyes were both directed at the same stimulus panel. The eyes "converged" (in her 1967 study) 70% of the time to a striped vs. gray stimulus, 42% of the time to a red vs. gray stimulus, and 9% of the time to a single, centrally presented, blinking light. These findings are misinterpreted by Hershenson who suggested that he (Hershenson) "probably measured the convergence and conjugation that Wickelgren found more or less frequent over longer periods of time depending upon the nature of the stimulus" (1967, p30). In fact, according to Wickelgren, this nominal convergence is illusory; it occurred when the two eyes were actually directed to different parts of the stimulus panel. In fact, the neonates' eyes <u>always</u> diverged, i.e., the right eye always looked to the right of the position the left eye was fixating, this divergence ranging from 2.61 inches to 5.22 inches at the stimulus plane in her 1967 study, and was an average of 4.5 inches for the three stimulus conditions in her 1969 study. In the two studies the eyes-to-stimulus distances were, respectively, 14 inches and $9\frac{1}{2}$ inches; thus the separation of the two eyes ranged from 10.6° to 25.3° visual angle. She suggests that "observer judgments based on one eye, particularly when both eyes are open, are unlikely to be a meaningful indication of newborn stimulus discrimination and preference" (1967, p84).

Similar reports of an inability to fixate binocularly in the neonate and young infant are to be found in the literature. Greenberg and Weizmann (1971), whose criterion of fixation was the reflection of the pattern on the pupil of the infant's eye reported that "several 8-week-old Ss had difficulty focusing binocularly on the patterns. In this situation the lead-eye was observed - the eye in which a pattern was reflected wholly within the pupil during the first few seconds of the first trial" (p237). Salapatek and Kessen (1966, 1969) have reported instances of visual scanning by the neonate in which fixations parallel the actual stimulus figure, but are displaced from it by several degrees. In both of these studies both of the subjects' eyes were open, and their explanation of the off-contour looking is based on the supposition that "the unrecorded eye was directly on target while the recorded eye, divergent from but conjugate with the unrecorded eye, aped the movement of the unrecorded, on-target eye, but with a line of sight constantly displaced from target" (1969, p26).

The presumed absence of binocular fixation until the 6th week of life has led at least one medical investigator, concerned with the systematic ocular examination of newborns, to ignore instances of manifest strabismus: "At birth, fixation is monocular; at this time strabismus does not call for any treatment. Binocular vision becomes constant only between the 6th week and the 6th month" (Leroy, Leroy and Leroy, 1971; translated from the original French).

The only evidence of which the author is aware that suggests the possibility of binocular fixation in the newborn period is somewhat indirect. Miranda (1970), using the visual preference method (as Fantz's technique is sometimes called), presented various stimuli to full-term and premature infants, and recorded fixations from the right eye only. His argument is as follows: Wickelgren's results show convergence of the two eyes whenever either eye looks at a contralateral stimulus (i.e., when the left eye looked right, the right eye was invariably recorded as looking also at the right stimulus). Thus, preferences can be determined unambiguously from contralateral responses. Miranda found that preferences were the same from contralateral and from ipsilateral fixations, thus refuting (he claims) Wickelgren's argument that observation of a single eye can lead to spurious results. However, since Wickelgren found that the right eye always looked farther to the right than the left eye, if the left eye were looking right, the right eye must also have been looking to the right: Miranda's argument could be refuted in turn if there were instances in which the right eye was looking to the right of the right stimulus panel, and the left eye was looking at the stimulus panel. This variable of the eyes' position is not allowed for in Wickelgren's studies; possibly, when the right eye was looking so far to the right to be "off" the right stimulus panel the photographic image would not be scorable. (The same line of reasoning applies, of course, when the left eye looks to the left of the left stimulus panel). On logical grounds, therefore, Miranda does not seem to have proved his point.

Nevertheless, a major part of the research presented in this thesis is concerned to show that convergence is, in fact, to be found in the newborn, and that its reported absence by previous investigators, together with evidence of off-contour looking, may be an artefact resulting from inappropriate scoring procedures. As an illustration, Figure 1.1 is a photograph taken directly from an article by Fantz (1961). Part of the original figure caption reads "In this case, with the reflection over the centre of the infant's eye, the reflected object

Figure 1.1 From Fantz (1961). For explanation see text

is being fixated... Because this young infant's binocular coordination is poor, only the right eye is fixating the object." Evidence will be presented to show that a stimulus can be directly fixated without its reflection being seen by an observer to be located directly over the centre of the pupil, and that the optical divergence of the eyes reported by Wickelgren, and illustrated in Figure 1.1, is compatible with binocular fixation.

6. DEVELOPMENT OF THE CORNEAL REFLECTION TECHNIQUE FOR USE WITH INFANTS, AND ASSOCIATED RESEARCH FINDINGS The simple corneal reflection technique originated by Fantz was described previously. Although this technique can give some indication of the infant's ability to discriminate between stimuli, it has obvious limitations. For example, when it is reliably shown that an infant looks longer at a cross than a circle this tells us very little about form perception: we cannot safely conclude that the baby is making a whole-form discrimination of the cross from the circle; it may be that he is only looking at one of the angles formed at the centre of the cross. After demonstrating differential fixations between a number of stimuli differing in hue and pattern Fantz (1963, p297) commented that "specification of the prepotent configurational variables is unwarranted at this time." Two major attempts have been made to secure more direct evidence concerning those stimulus dimensions to which the newborn is most responsive. The first concerns the selection of criteria for establishing relevant dimensions. The second results from the development of a procedure which permits fairly accurate location, from moment to moment, of where on a stimulus the infant is fixating.

Hershenson (1967), and Hershenson, Kessen and Munsinger (1967), suggest that one may assert that there is a stimulus dimension that could have generated the response if a transitive ordering of "preference" is found among a minimum of three stimulus pairs. The three demands upon the relations among the elements of an ordered set (Huntington's postulates) are:

1. If $A \neq B$, then either $A < B$ or $B < A$
2. If $A < B$, then $A \neq B$
3. If $A < B$ and $B < C$, then $A < C$

Two problems are encountered with this approach. The first is that the demonstration of quantitative differences along one measure of preference, for example, duration of looking, need not imply that one has manipulated a single stimulus dimension. Hershenson (1964) presented newborns with stimulus pairs differing in brightness. The stimuli were patches of light projected onto 6 inch square stimulus screens, and the different levels of luminance were (a) 3.56, (b) 35.6, and (c) 356 apparent foot candles. A transitive ordering of preference in the order $b > c > a$ was found which indicates "that brightness is a discriminable dimension of stimulation for the newborn and that there is an inverted-U shaped relationship between brightness and fixation preferences." An alternative interpretation of these results could be that the dim stimulus was too dim to be seen by the newborns; the brightest stimulus, although preferred to no stimulus, was too bright and caused some aversive responses; the intermediate stimulus was easily seen and was looked at in preference both to no stimulus and a too-bright stimulus. Thus, it seems possible that the basis of discrimination used by the subject may be a qualitative one which is reflected in a quantitative ordering along the measure of preference employed: transitivity of preference, that is, does not necessarily imply that one has manipulated a unitary stimulus dimension.

An additional failing of all quantitative measures of preference is that the failure to manifest a preference among two or more stimuli does not mean that the stimuli are not discriminated as being different by the subject. When spontaneous visual preference does not produce clear evidence of discrimination at least two other procedures may be used:

(1) Response to novelty Where stimuli A and B are to-be-discriminated, stimulus A is presented successively for a series of familiarization trials. Stimulus B is then presented, paired with A; the non-familiarized stimulus may then elicit increased looking, (i.e., Saayman, Ames and Moffett, 1964). A similar procedure is to present stimulus A as before until the duration of looking has significantly decreased; stimulus B is then presented alone and a response recovery effect is looked for.

(2) Operant training method An operant conditioning technique, employing usually a head-turning response maintained by social reinforcement, can provide a sensitive index both of discrimination and of stimulus generalization, (i.e., McKenzie & Day, 1972; Bower, 1966).

A complementary procedure to measures of preference and discrimination, recently developed, is to present stimuli and record which parts of the stimuli are fixated by the infant: "It is only through a detailed study of ocular responses in the newborn child that critical questions about the nature of perceptual development can be resolved" (Salapatek and Kessen, 1966, p155). Salapatek and Kessen reported the development of a photographic corneal reflection technique to record eye fixation changes in the newborn baby. The method was developed from a technique first described for use with monkeys by Cowey (1963), and a later modification using closed-circuit infrared television has been described by Haith (1969). Advantages over other methods of recording visual behaviour are, (1) photography provides a permanent and more reliable record of fixations than is possible with unaided observation of a baby's eye, (2) the use of infrared light permits much lower levels of stimulus intensity than would otherwise be possible, and (3) complete immobilization of the head is not required.

The infrared lights are positioned around the stimulus, and reflections of the lights are clearly visible on the photographed image of the eye. Consequently, the position of the stimulus within the lights is easily inferred from the developed photographs as its position relative to the lights is known. Thus, the (inferred) corneal reflection of the stimulus itself can be superimposed on each film frame, and the technique is therefore similar to others in which an image of the stimulus display is visible on the photographed image of the eye (e.g., Mackworth and Otto, 1970). A photograph of the eye is taken once every second (or more often) and each film frame is scored by finding which portion of the stimulus display is reflected from the exact centre of the pupil - this, it is assumed, is the portion of the stimulus display that is being foveally fixated at that moment in time: Salapatek (1969, p20) states "the center of the pupil (is) assumed to represent the line of sight."

From studies using this technique a number of conclusions regarding the infant's visual scanning strategies may be drawn. In the absence of a clearly defined stimulus fixations are widely distributed throughout the visual field in a broad, mainly horizontal, scan. When a geometrical figure, such as a triangle, is presented, newborns' ocular orientation tends to cluster, especially near the vertices of the triangle (Salapatek and Kessen, 1966). This ability of a form to capture the neonate's visual attention has been well documented (Salapatek, 1969; Salapatek and Kessen, 1969). An innate first instruction to an awake newborn confronted with a simple geometric figure appears to be "the instruction to localize the figure in space... across many successive exposures of the figure, even up until the infant closes his eyes" (Salapatek and Kessen, 1969, p18).

A second, though less unanimous finding concerns the newborn's selective fixation of single vs. multiple features of the stimulus. Salapatek et al's (1966) finding was that newborns looked at only part of the stimulus triangle, usually a vertex. The preference for angles over sides was also reported by Nelson (1969). In an experiment reported in 1968 Salapatek presented all possible combinations of black and white, solid and outline circles and triangles of 3 magnitudes. Overall, about half of the 72 subjects looked at less than 50% of the presented figure. In a later study Salapatek and Kessen (1969) gathered data from 5 newborns who were presented a large black solid equilateral triangle for extended periods of time. Some subjects alternated between selection of a single feature for viewing and selection of more than one feature, but there was no convincing evidence that multiple-feature selection was a function of exposure or age. In another study, however, Salapatek (1969) reported that younger infants exhibited a tighter form of scan than older ones, i.e., fixations fell within a narrower portion of the visual field in the presence of a geometrical figure, and most of their visual scan was concentrated on a very limited portion of the stimulus panel. A problem of interpreting these data concerns the size of the stimulus figures which, in the studies reported above was usually quite large (in Salapatek and Kessen's 1966 study the stimulus triangle was 8 inches to a side, with an eye-to-stimulus distance of 9 inches). As discussed in an earlier section of this chapter, the selection of single features may be a consequence of a limited field of view rather than a consequence of an inability to perceive form.

Haith (1968), using infrared closed circuit television which enables recording in absolute darkness was able to record the newborn's ocular response to light extinction. In many cases, an apparently sleeping infant opened his eyes widely and began to scan actively in the dark. Thus, there is an orienting response to light offset. He suggested that the newborn may be regarded as an organism equipped with some innate "programming instructions" that direct his scanning: (a) if alert and light is not too bright, open up; (b) if eyes open, but see no light, search; (c) if see light but no edges, keep searching; (d) if see edges, hold and cross.

All investigators using this corneal reflection technique have used the centre of the pupil as the best indication of the point of fixation. This assumption derives directly from the earlier work of Fantz whose criterion of fixation, as noted earlier and illustrated in the previous section (Figure 1.1) was the reflection of the stimulus over the centre of the infant's eye. However, during preliminary calibration runs with a similar technique it was noticed that there are often marked and consistent disparities between the centre of the pupil and the fixation point. The first series of investigations carried out by the author explored the disparities further, using adults and newborn babies as subjects. An explanation of the causes of these effects requires a detailed consideration of the relevant anatomical structures of the eye, and of the physiological optics of the corneal reflection technique. The early investigations with the technique, and the explanations for the disparities found, are given in chapters 2, 3, and 4. In addition there are a number of implications of these findings for research carried out by previous investigators. These are detailed more fully in chapter 4. However, perhaps the major implication concerns the newborn's ability to fixate binocularly (reviewed in the previous section of this chapter). Chapters 6 and 7 of this thesis describe the further studies carried out to determine whether or not the neonate is able to converge, and to which types of stimuli.

CHAPTER 2

THE CORNEAL REFLECTION TECHNIQUE: TESTING SEQUENCES WITH ADULTS

When the apparatus for recording eye position changes in newborns had been constructed, several testing sequences were carried out to determine the accuracy of the corneal reflection technique. Other users (Haith, 1968, 1969; Kessen, 1967; Kessen, Salapatek and Haith, 1972; Nelson, 1969; Salapatek, 1968 and 1969; Salapatek and Kessen, 1966, 1969 and 1973; Wickelgren, 1967 and 1969), have made the assumption that this particular technique is accurate in placing the line of sight to within a few degrees of visual angle when used with newborns. The testing sequences described below show that this may not be the case.

The apparatus, general procedure, and scoring protocol employed were similar for all these sequences, and these are therefore described first.

Apparatus and Photography A photograph of the specially constructed apparatus is shown in Figure 2.1A (the recording camera was not in position when this photograph was taken). Figure 2.1B is a diagrammatic representation of the same apparatus, used in the early experimentation with neonates. The same apparatus (with the obvious exclusion of the head and hip restraining cot) was used in the testing sequences with adults. The stimuli (described individually for the testing sequences) were placed over a $9\frac{1}{2}$ inch diameter hole cut out of a 16 x 26 inch aluminium stimulus screen. Six marker lights (Bausch and Lomb Nicholas illuminators) were mounted above the screen[1].

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[1] Footnote Initially only four illuminators were used: this was later changed to six as with more peripheral fixations by the subject there was often an insufficient number of clear reflections for scoring purposes.

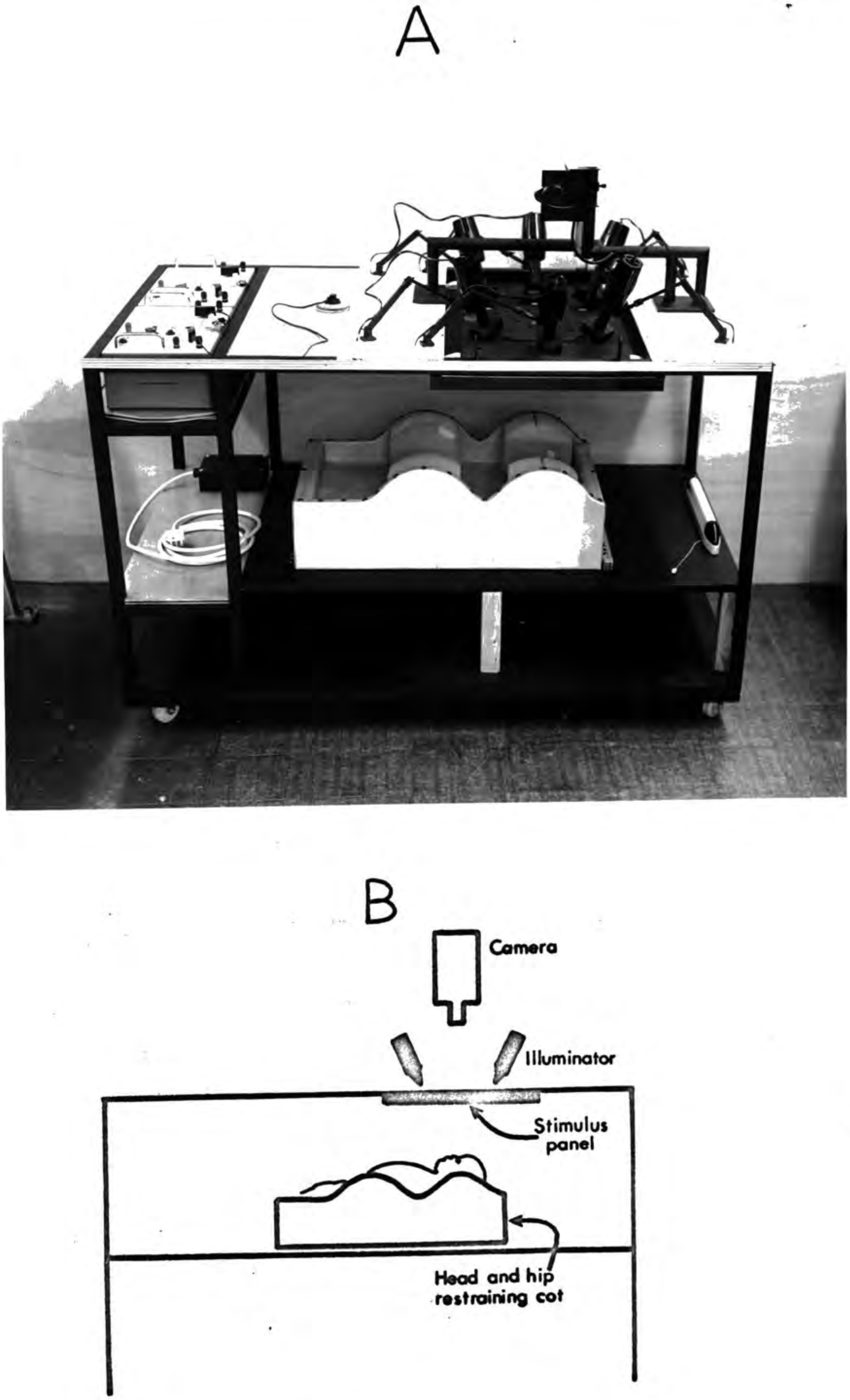


Figure 2.1 Photograph (A) and diagram (B) of the apparatus used with adults, and in the first series of experiments with newborns.

A condenser in the lamphousing of these illuminators spotlights a narrow beam of light on the area the illuminator is directed at. The light source is a 6.5v., 2.75 Amp. tungsten filament lamp bulb. When in operation the illuminators were connected to labpacks and were run at 6v. to preserve bulb life.

Kodak Wratten 87c and Corning CS 7-69 filters were placed in front of the illuminators. The transmission curves of these filters are shown in Figure 2.2. The 87c filters cut off the wavelengths below 800nm, and the CS 7-69 filters cut off the wavelengths below 700 nm and above 1000 nm. The shaded area of this Figure indicates the wavelengths that can pass through both filters. The light from these illuminators passed through six $\frac{3}{4}$ inch holes punched out of the stimulus screen, and converged at the position of the subject's eye (10 inches below the stimulus screen). Whilst the eye is most sensitive to the wavelengths between 350nm and 750 nm, radiation above and below these wavelengths can be detected, although the energy demand increases as the wavelength is made longer or shorter (Bartlett, 1965). Thus, although the filters cut off light below 800 nm, the bulb filaments of the illuminators were visible to the adult as a dull, reddish glow. The luminance of each bulb filament was 0.16ft.L., measured with an exposure photometer. Each $\frac{3}{4}$ inch hole was positioned 6 inches from the centre of the $9\frac{1}{2}$ inch diameter hole in the stimulus screen. The bulb filaments of the illuminators were $4\frac{1}{2}$ inches behind the stimulus plane and at this distance the beam-width of each light was $\frac{3}{4}$ inches in diameter. Accurate aiming of each reference light was achieved by ensuring that the beam of light passed centrally through the $\frac{3}{4}$ inch hole in the stimulus screen and that, with S correctly positioned, all the beams of light encircled his eye. Two of the illuminators were positioned to left and right of the sheet; the

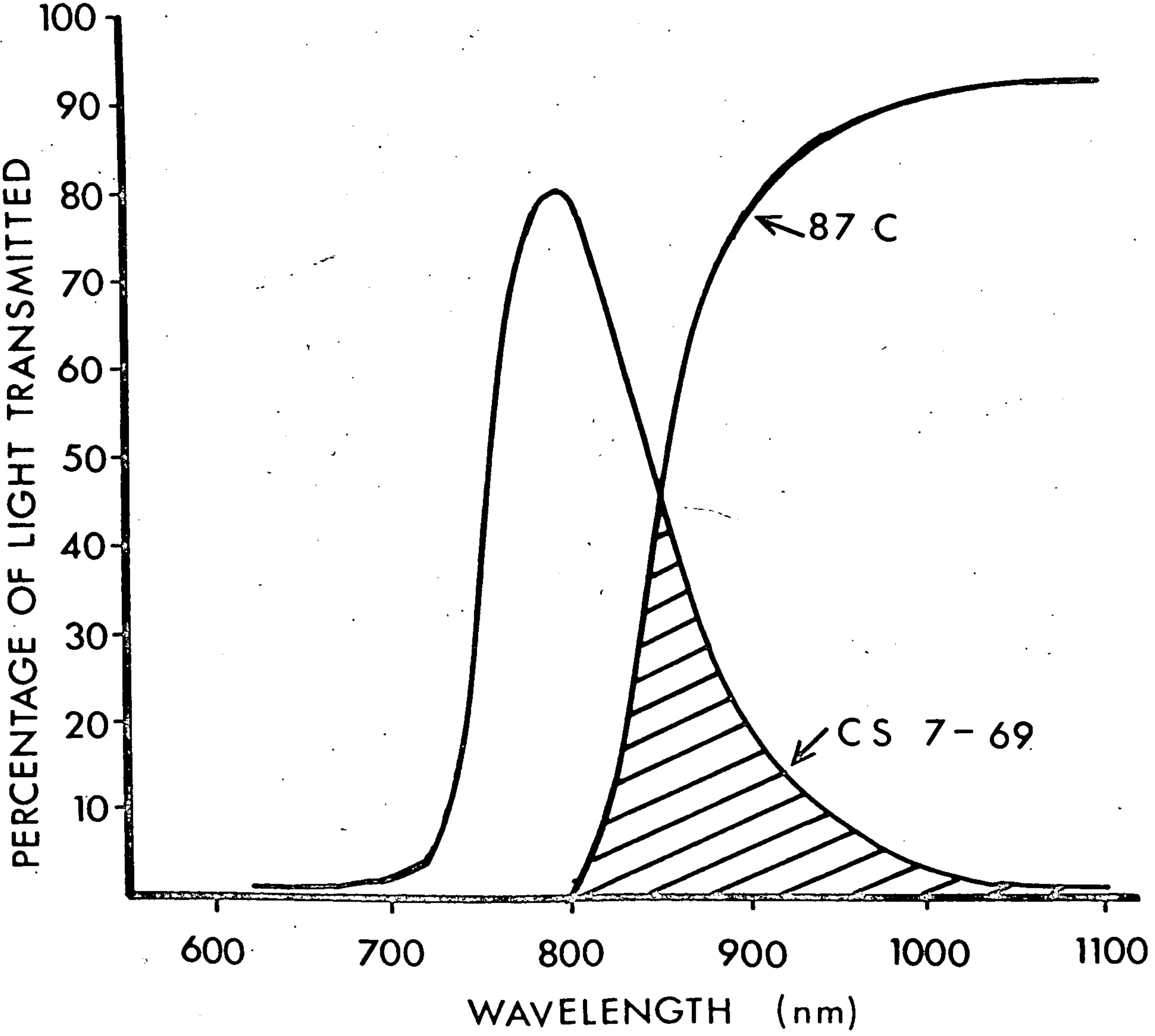


Figure 2.2 Transmission curves for Kodak Wratten 87c and Corning CS 7-69 filters

remaining four were diagonally placed.

A 16mm Pathe Webo M cine camera was mounted with the camera lens at a 90° angle to, and directly above the centre of the $9\frac{1}{2}$ inch diameter hole in the stimulus screen. The camera was fitted with a small Crouzet electric motor which, when switched on, caused the camera to record at a speed of one frame per second with an exposure time of $\frac{1}{8}$ sec. The film used was Kodak High Speed Infrared film (HIE 430). Photographs were taken at a diaphragm opening of f11, through a 75mm lens. The field of view of the camera was approximately $1\frac{1}{2} \times 1\frac{1}{4}$ inches and the exposed film was normally developed for high contrast using Kodak's developer D19.

Procedure Each (adult) S was positioned on his back in the apparatus with one eye 10 inches below the centre of the hole in the stimulus screen, and within the field of view of the camera. In the testing sequences the subject(s) was usually asked to fixate each of a series of numbered points marked on sheets of clear acetate that were placed over the hole in the stimulus screen. Three or four photographs were taken of the S's eye as he looked at each of the required points. The procedure was, in some sequences, repeated with the S's other eye being photographed.

Scoring The scoring procedure differed in detail between testing sessions. Essentially, however, each film frame was projected by a 16mm analyzing projector onto a scaled-down copy of a print showing the relative positions of the marker lights. The image size of each frame was altered until the reflections of the marker lights in the eye fitted the template positions of the print copy. Each frame was initially scored by finding the position of the centre of the pupil relative to the reflections of the marker lights, and marking this on the template. Three or four identical frames were available of each

S fixating each required point. Figure 2.3 illustrates the scoring procedure: the photograph is of an adult's eye taken with S fixating a point located somewhere near the centre of the stimulus array. The six reflections of the marker lights can clearly be seen encircling the pupil of the eye.

When S was fixating around the central region there was little or no apparent distortion of the marker lights, and all six reflections were used in determining the position of the pupil centre. With peripheral fixations, however, some distortion of the marker lights is apparent. This is shown in Figure 2.4 and takes the form of a displacement outward of those marker lights farthest from the fixation area. With peripheral fixations, therefore, the reflected marker lights nearest the centre of the pupil were used in determining the relative position of the pupil centre, and reflections of the more extremely located lights were ignored. In this context it is important to note that the purpose in most of the testing sequences was to determine the pupil centre's position <u>in relation to the corneal reflection of the fixated target</u>. The reflections of the target were not visible on the film; each target position was therefore inferred from its expected location within the marker lights. However, in a short experiment (testing sequence 6,below) it appeared that estimating the target position within the marker lights did not give rise to any additional error. The discrepancies reported later would therefore seem to be unaffected by the distortion of the marker lights mentioned, and are not a function of, say, the distance between the marker lights.

<u>Testing Sequence 1</u> The stimulus set initially was a series of 69 numbered points spaced at equal 1 inch intervals along an acetate sheet 9½ inches in diameter (this sheet was placed over the hole in the

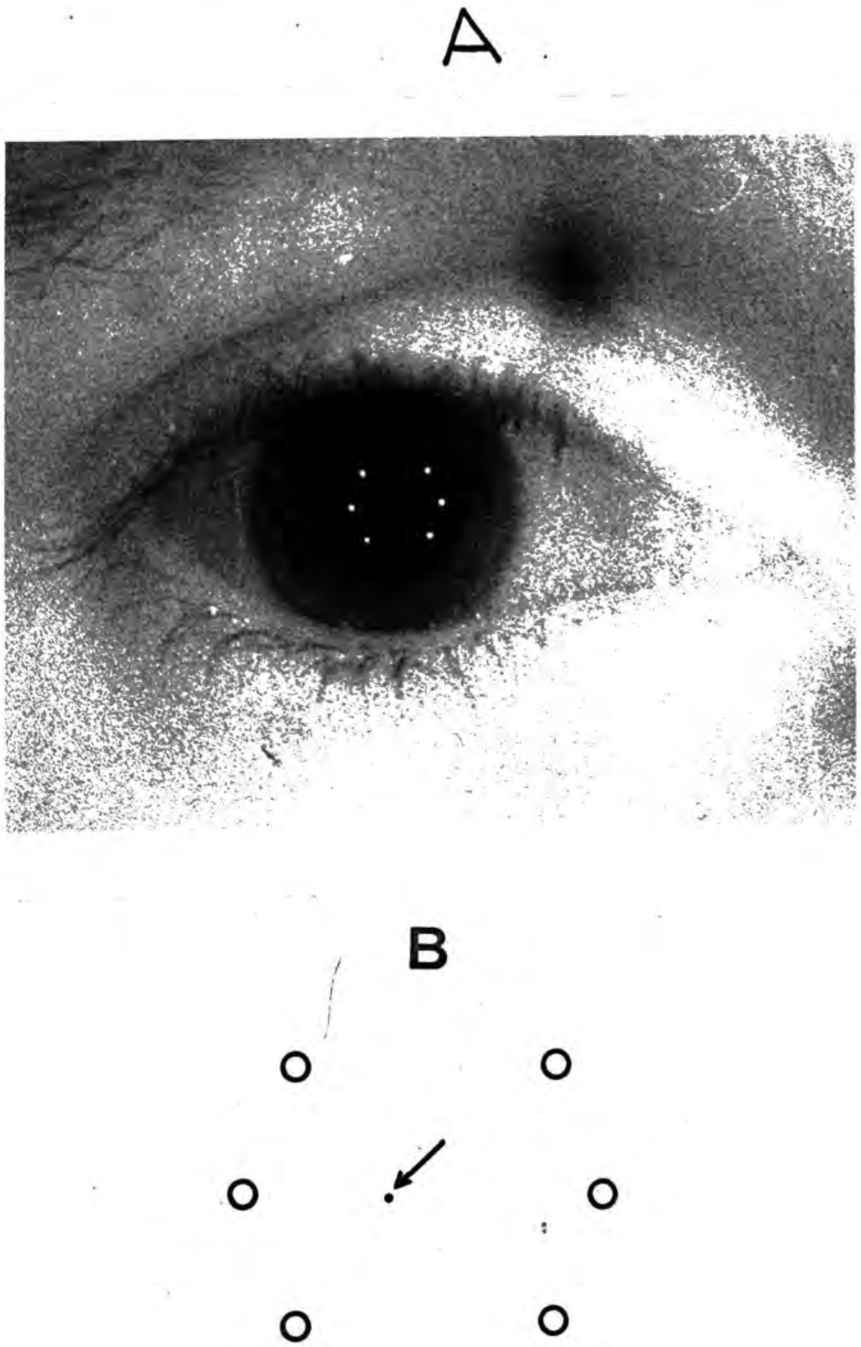


Figure 2.3 To score the film the photographed image of the eye (A) is enlarged until the six reflections of the marker lights, which can be seen encircling the pupil of the eye, fit the template (B). The position of the centre of the pupil (arrowed in B) is then marked.

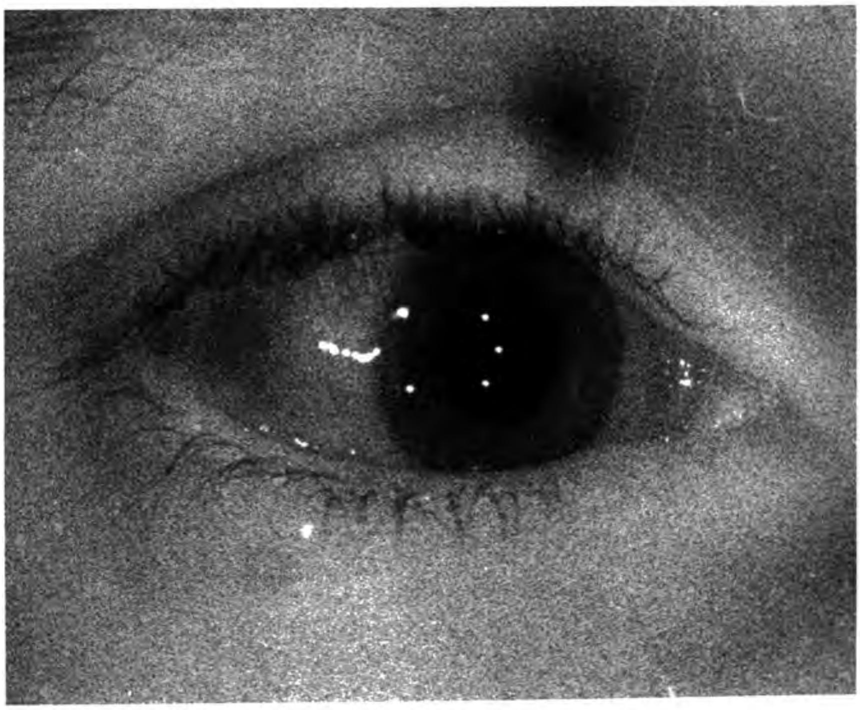


Figure 2.4 Photograph of an adult's right eye, taken when S was fixating a point to the left of centre, within the marker lights. Note that the corneal reflections of the marker lights farthest from the fixation point are displaced outwards.

stimulus panel). The points were fixated in turn by one S (AS) whose right eye was photographed. As a subject looks at different parts of the stimulus field the centre of the pupil relative to the position of the marker lights changes. Thus, each separate fixation is characterized by a unique configuration of pupil centre and marker lights' reflection. This fact was used by Cowey (1963) who photographed subjects' eyes looking at each of 99 fixation points. The developed photographs of the separate fixations constituted his "standard reference photographs"; later fixations were matched by scanning the array of "standards" until the appropriate one was found. A less tedious procedure was adopted for scoring results from the first testing sequence: the positions of the centre of the pupil for successive fixations were fitted to the scoring template, and a "fixation map" was constructed. Figure 2.5 shows a "fixation map" made in this manner. The successive positions of the pupil centre form an orderly sequence within the marker lights.

The subject then fixated again each of the 69 points, this time in a predetermined random order. The film of these fixations was projected onto the "fixation map" and a judgment was made of which points S had been fixating. This judgment was made "blind", i.e., the order in which the points had been fixated during the "random" trial was not known. This blind judgment was later compared with the actual order of fixation, and the two were in perfect agreement.

This procedure was repeated with a second subject (MR); this time the stimulus was an array of 89 points, spaced $\frac{1}{8}$ inches apart - a separation that is approximately 5° visual angle at the eye-to-target distance (10 inches). 50 of the numbered points were re-fixated, and the "blind judgment" correctly identified 49 of these. The remaining one was incorrectly judged because of a difficulty in determining the pupil centre for that fixation.

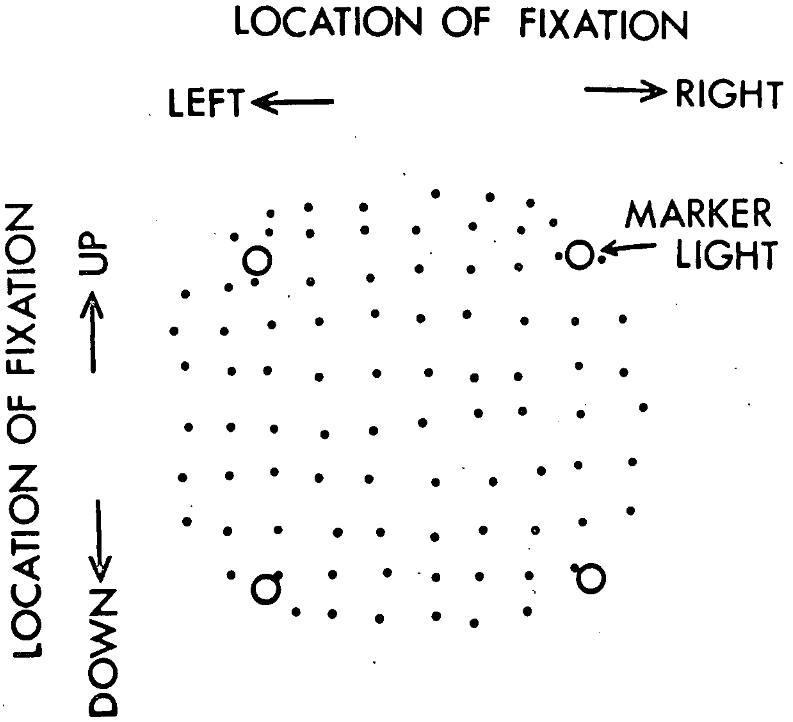


Figure 2.5 Individually determined fixation map for one S (MR), whose left eye was recorded from. Only 4 marker lights were in position when this fixation map (and also the one shown in Figure 2.6) was derived. Note how the positions of the pupil centre for successive fixations form an orderly sequence within and around the marker lights. Departures from regularity are most probably the result of slight irregularities in the anterior surface of the cornea which forms the reflecting surface.

Thus, when the stimulus was a grid of points arranged 5° apart in horizontal and vertical rows the maximum error involved was less than half the angular distance between two points on a diagonal (i.e., close to $3\frac{1}{2}^{\circ}$) 98% of the time. This applies when an individually determined fixation map is available for the subject's viewing eye. Cowey (1963) also reports this degree of accuracy to apply.

However, for these subjects it was noticed that the centre of the pupil was often displaced from the inferred location of the target. Two other subjects viewed selected points on the array and fixation maps were derived; these subjects showed similar displacements. The fixation map derived from one S (whose right eye was the viewing eye) is shown in Figure 2.6.

To determine the nature of the distortions, and to test for any other potential error factors, further testing sequences were carried out.

Testing Sequence 2

Subjects and procedure The subjects were 10 adults, ages 16-38 years. Each subject was asked to fixate the central point on the acetate sheet, and six Ss were additionally asked to fixate a further 12 points (less in one case) randomly chosen from the whole fixation area. Both eyes were separately photographed for each fixation.

Scoring and results 145 of these fixations were available for analysis. Having initially located the pupil centre for each fixation, its deviation (if any) from the target position was read off from a scaled-down photographic transparency which could be fitted over the original print copy and which showed the known target positions within the marker lights. 116 of these 145 fixations were not correctly identified, i.e., for these 116 fixations the centre of the pupil was located $2\frac{1}{2}^{\circ}$ or more from the target position. If the centre of the

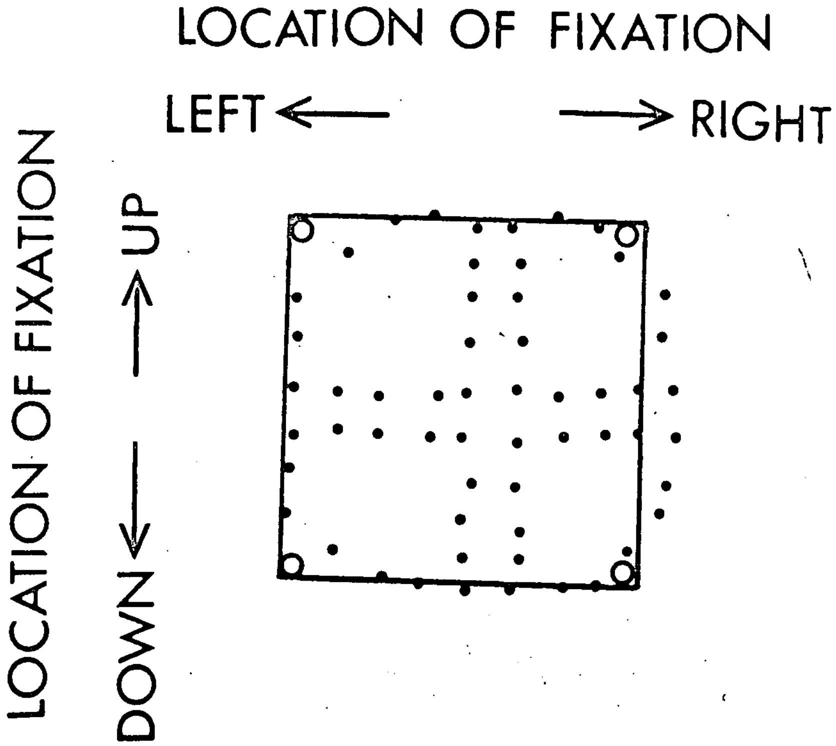


Figure 2.6 Fixation map for subject FG (right eye). If the centre of the pupil represents the line of sight the positions of the pupil centre would have been contained within the square drawn around the marker lights. The errors are greatest for this S when the right eye looks to the right. For subject MR, whose fixation map is shown in Figure 2.5, the most overlap occurs, and the errors are greatest, when the left eye looks to the left.

pupil were the best indication of the line of sight this analysis would have correctly identified the fixation position most of the time: clearly, it did not. Further analysis showed that errors for the left eye were predominantly instances in which the pupil centre was located to the left of its expected position; for the right eye most errors were in the opposite directions.

The results for each subject are presented graphically in Figures 2.7 and 2.8, for the left and the right eyes. The points represent the horizontal (Figs. 2.7A 1 & 2 and B 1 & 2) and vertical (Figs. 2.8A 1 & 2 and B 1 & 2) disparities found between the scored position and the position the subject was asked to fixate. In all four graphs the horizontal axis through zero represents coincidence of the target and the pupil centre. In Figures 2.7A 1 & 2 and B 1 & 2 the abscissa represents the horizontal component of the difference between the target position and the central point. The vertical axis gives the displacement, positive values indicating displacement to the right. Data from the 4 subjects who were asked only to fixate the centre point are not shown in these Figures. The horizontal displacements scored for these subjects were, for the left eye, 1.38 inches, 0.62 inches, 1.0 inches, and 0.88 inches, and, for the right eye, 1.25 inches, 0.75 inches, 1.25 inches, and 1.12 inches (the displacements for the left eye are to the left, and for the right eye are to the right, for these 4 Ss). In Figures 2.8A 1 & 2 and B 1 & 2 the vertical component is considered and positive scores represent displacement upward. No systematic interactions between horizontal and vertical coordinates were found. In the central region 0.18 inches corresponds to 1° of visual angle; a slightly greater figure applies in the periphery. The average horizontal and vertical disparities are presented in Figures 2.9A and 2.9B, respectively, and

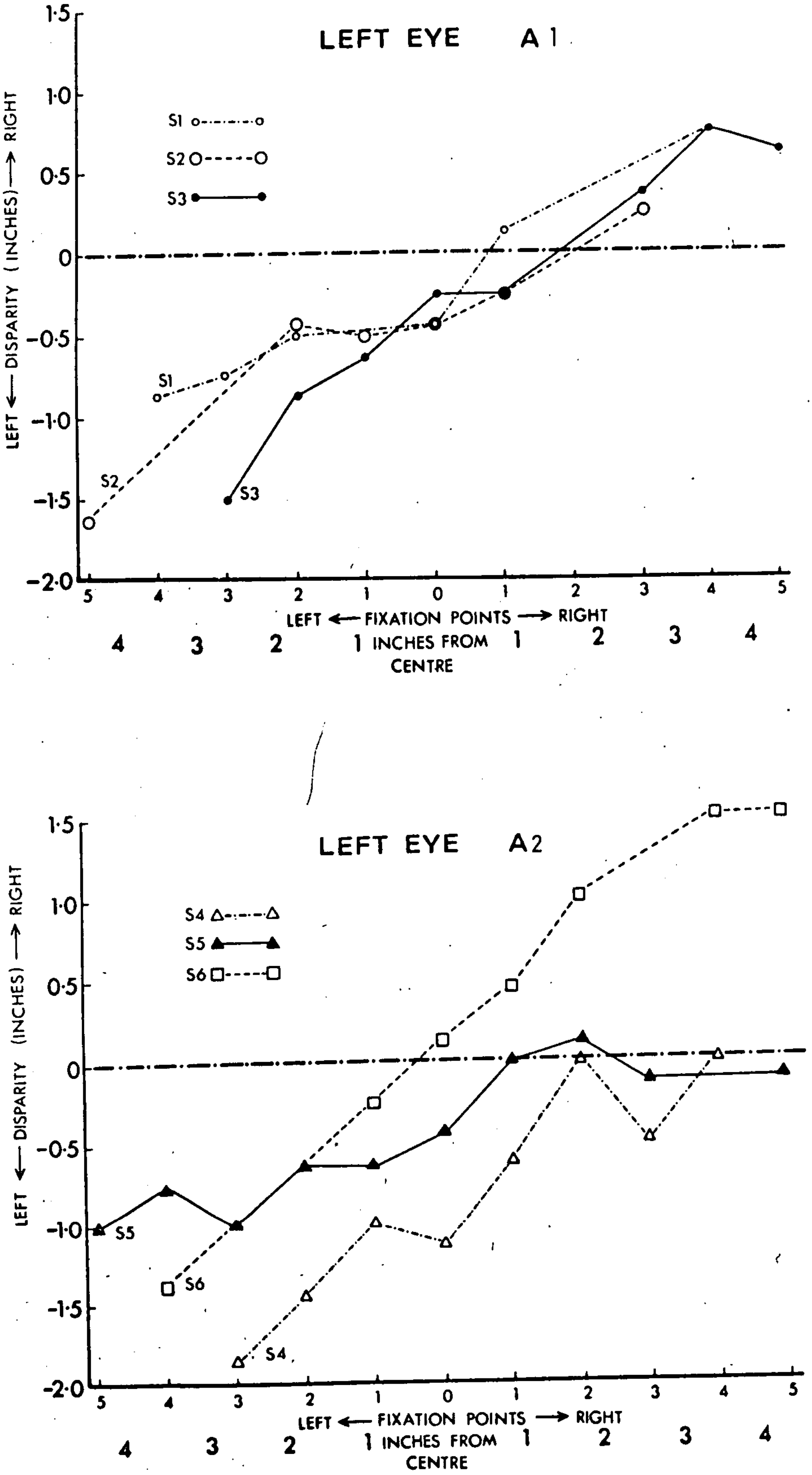


Figure 2.7A (1 and 2). Horizontal displacements found for the left eye of each subject.

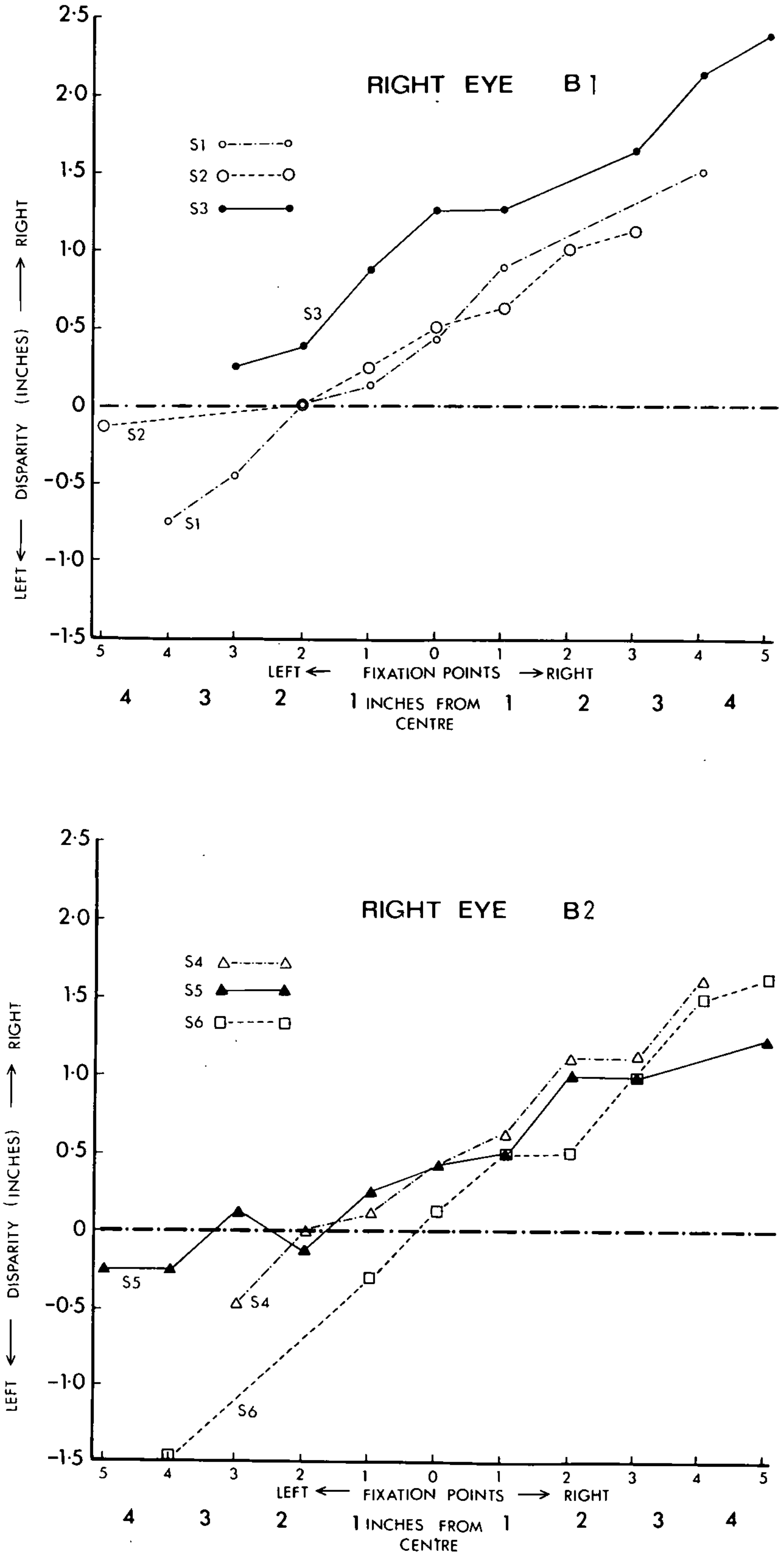


Figure 2.7B (1 and 2) Horizontal displacements found for the right eye of each subject.

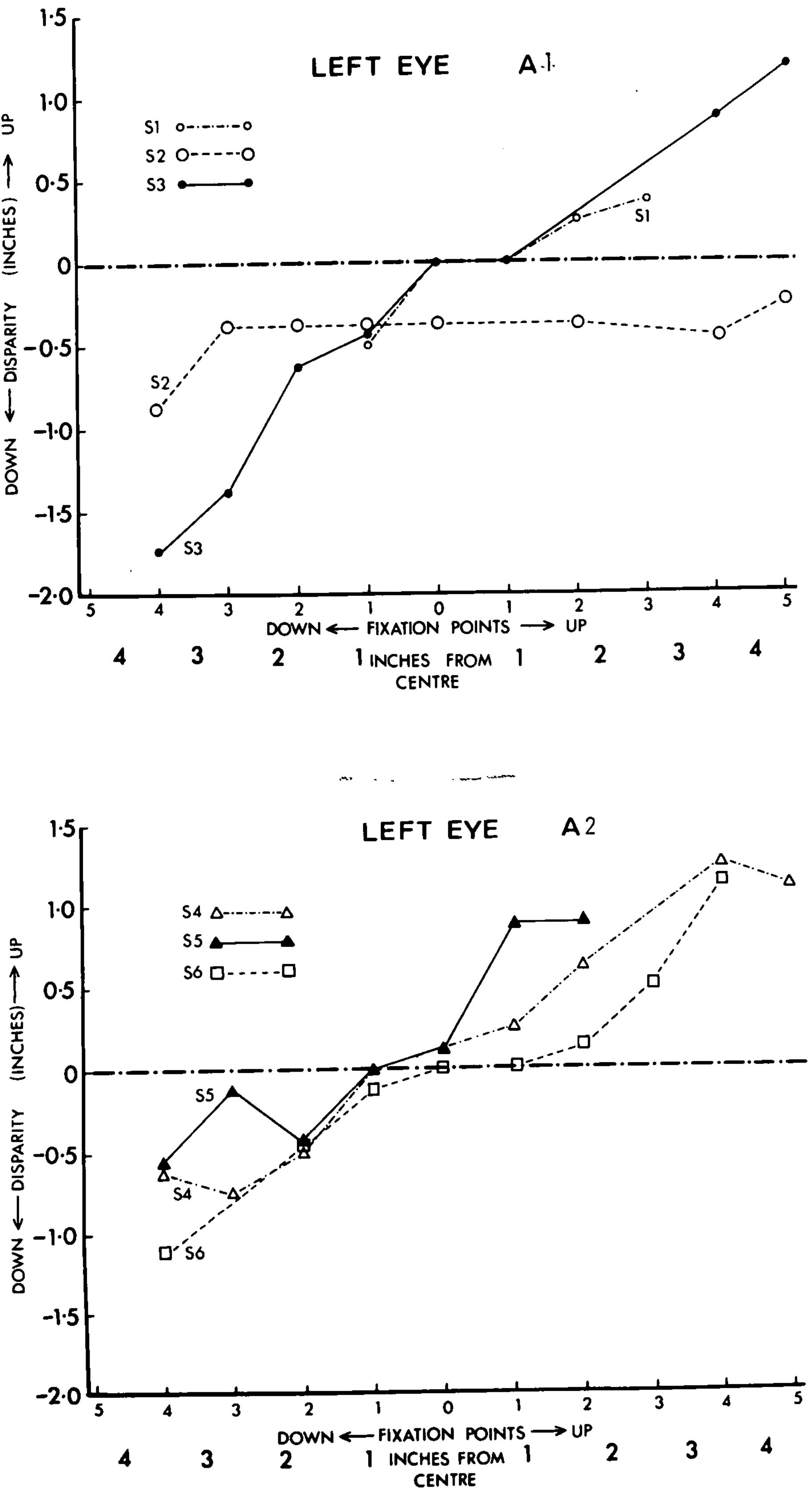
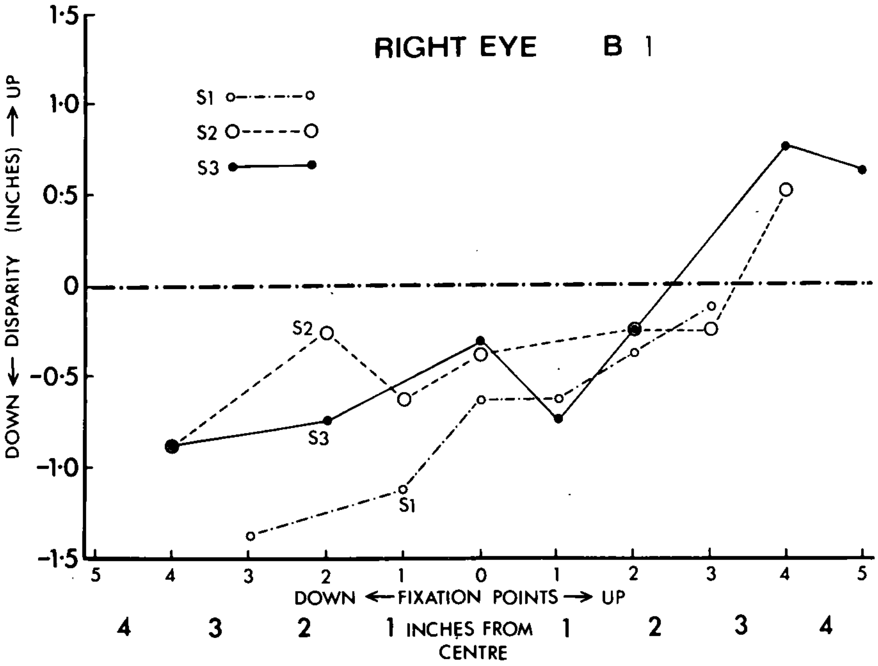


Figure 2.8A (1 and 2) Vertical displacements found for the left eye of each subject.



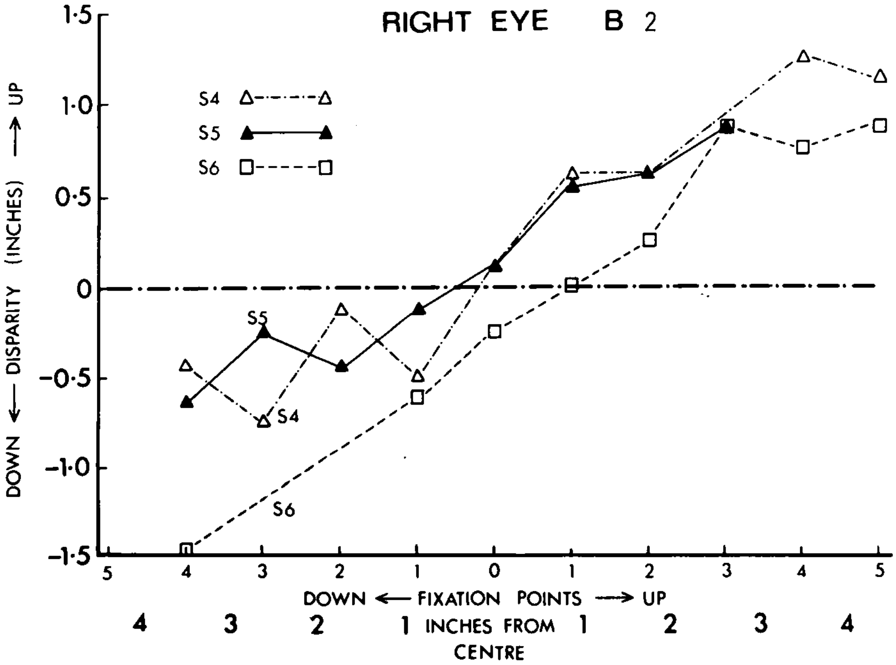


Figure 2.8B (1 and 2) Vertical displacements found for the right eye of each subject.

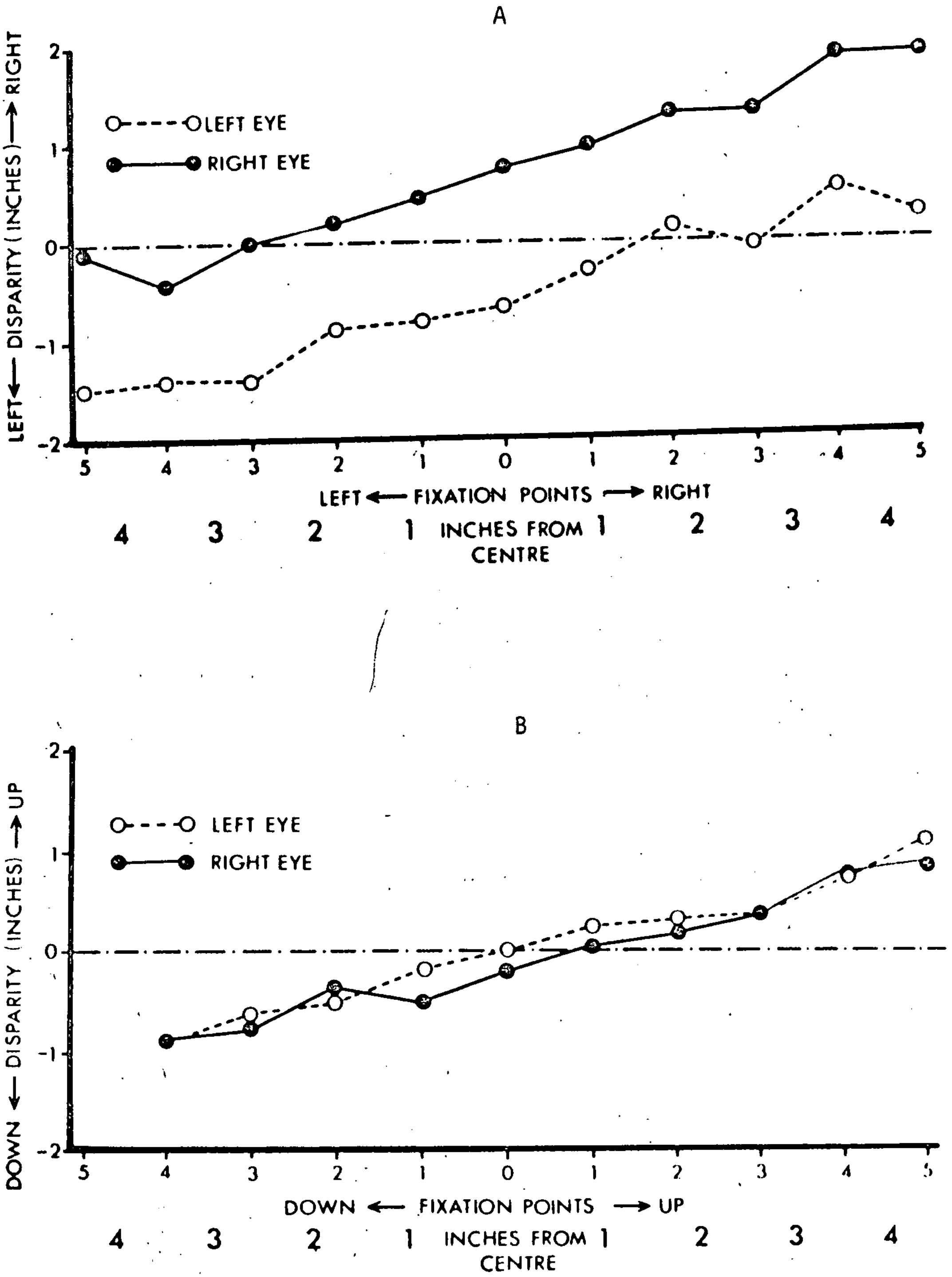


Figure 2.9 Average horizontal (A) and vertical (B) displacements found.

are derived from the data in Figures 2.7 and 2.8[2].

It is immediately evident that there are large discrepancies of the pupil centre from the fixation point. Even with central fixation the derived centre of the pupil is horizontally displaced by approximately 4° of visual angle. This displacement is to the right when S fixates with his right eye and to the left when S fixates with his left eye. A second effect is evident when S fixates away from midline. This is always in the direction away from the fixation point, (for example, when the subject fixates a point 4 inches above midline the average scored position indicates $4\frac{3}{4}$ inches above midline). Nevertheless, because of the central effect in the horizontal direction, it is possible for the overall disparity with off-axis fixation to be reduced (in most cases the pupil centre will approach the target position as the left eye fixates right, and the right eye fixates left). This second effect appears to be identical in all four directions, and equal for both eyes.

<u>Testing Sequence 3</u> The results presented above were taken from subjects fixating positions less than 25° from midline. Five Ss (two of whom had been Ss in T.S. 2) fixated the more peripherally placed marker lights, 6 inches to left and right of centre, whose filaments were visible as a dull, reddish glow, and also the centre point.

The off-axis effect, described in the previous testing sequence, causes an average change in the scored position of .865 inches as S moves his locus of gaze from the central position to a point 4.4 inches

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[2] Footnote The central horizontal disparities shown in Fig. 2.9A are the averages from all 10 Ss who fixated the centre point in the stimulus set.

from centre (fixation point 5 in Fig. 2.9A). The average change in the scored position as S fixated from the central position to the marker lights (6 inches from the central position), however, was .905 inches, an increase in the disparity resulting from the off-axis effect of .04 inches. Thus, the results from this testing sequence indicate that the off-axis effects seem to stabilize with more peripheral fixations.

<u>Testing sequence 4</u> One subject fixated the six marker lights and the central point on the acetate sheet three separate times with each eye, each time employing a different position of the head. A further subject fixated several of the numbered points under two conditions, (a) with the pupil of the eye contracted, and (b) with the pupil dilated. Pupil dilation and contraction were caused by switching off or on a fluorescent strip light above the apparatus.

No differences in the scored position of the pupil centre were found as a result either of head position or of the size of the pupil opening; thus, these variables do not appear to affect the disparities found.

<u>Testing sequence 5</u> Four subjects were used. Each was seated approximately 12 inches behind a ruler mounted horizontally, and at right angles to his line of sight. Figure 2.10 diagrams the arrangement. Each S fixated, separately with both eyes, three marked points on the ruler: the centre position and points 3 inches to left and right of centre. As S fixated the required position an observer (0), seated with his observing eye immediately behind the centre point of the ruler, moved a torch light until its reflection appeared (to 0) to occupy the centre of the pupil of the subject's viewing eye. The deviation of the actual location of the torch from the fixation position was read off by a second observer; two or three readings

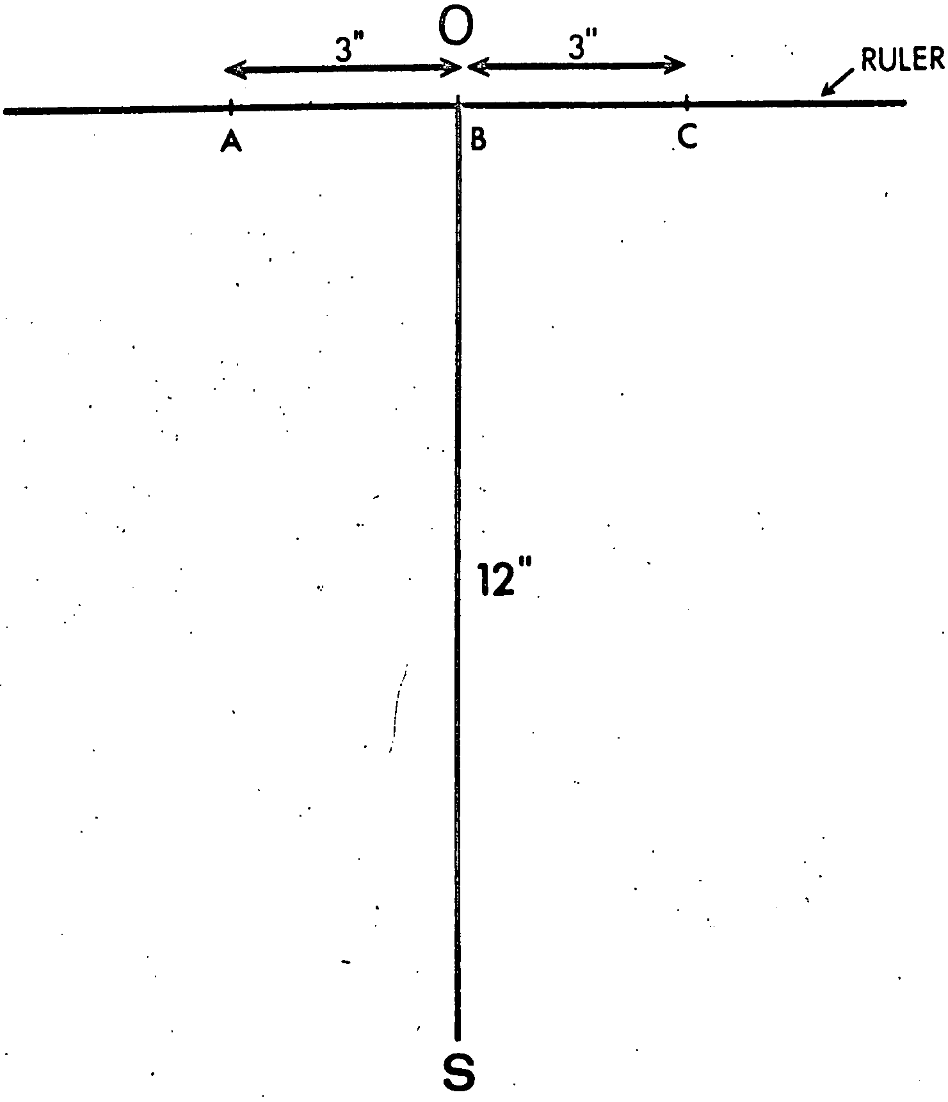

Figure 2.10 Each S was seated with his viewing eye approximately 12 inches from the centrally fixated target (B). A and C are the targets 3 inches to the left and 3 inches to the right. The observer (O) was seated with his observing eye immediately behind target B, along the S's line of sight when S fixated B.

were taken for each fixation position to ensure a fairly reliable estimate of the disparities.

The disparities found are given in table 2.1. Negative values indicate a displacement of the torch's location to the left of the subject's fixation position. A direct comparison of the magnitudes of these disparities with those reported in testing sequence 2 is not possible as the eye-to-target distance was not held constant for each subject. When a similar technique is used, with targets positioned on a perimeter, however, a fairly precise measure of the angle alpha may be derived (i.e., see Davson, 1950, p428)[3]. Nevertheless, the main effects are apparent from this table, and are in the same direction as those of testing sequence 2. When the left eye looked to the right of centre the torch light was held close to the point fixated; when the left eye looked to the left there was a large degree of error. The opposite is the case for the right eye. From this it can be concluded that the camera, or the scoring of the film, is not in some way at fault, as similar effects are found using a more direct observation of the eyes.

<u>Testing sequence 6</u> The distortion of the marker lights' position with peripheral fixations was noted earlier in the scoring section of this chapter. To determine what effect this might have a further subject (DB) was used. S was asked to fixate a number of positions radiating horizontally and vertically from the centre position on the acetate stimulus sheet. As S fixated each point a small torch, held at the fixation point itself, was shone by the experimenter into

Footnote[3] The optic axis of the eye diverges from the visual axis, the angle between the two being called the angle alpha.

TABLE 2.1

Displacement of torch light from fixation position (in inches)

FIXATION POSITION

(LEFT EYE)

	3" left of centre	Centre	3" right of centre
S1	-2.3	-1.35	0.3
S2	-2.0	-0.75	-0.38
S3	-2.6	-1.4	0
S4	-2.5	-1.38	-0.4
Average	-2.35	-1.22	-0.12

(RIGHT EYE)

	3" left of centre	Centre	3" right of centre
S1	0	0.75	1.1
S2	-0.5	0.88	1.0
S3	0.5	0.88	1.25
S4	0.1	1.1	1.7
Average	0.02	0.90	1.26

S's eye (the left eye was used). On the developed film the corneal reflection of the torch light, for each position fixated, was visible.

The film was analyzed in three ways:

(a) Normally: the deviation of the centre of the pupil from the inferred target location was found. This analysis was carried out using the reflections of the six illuminators, i.e., the reflections of the torch light were ignored.

(b) The deviation of the centre of the pupil from the corneal reflection of the torch light itself was found for each fixation position. For this analysis the reflections of the six illuminators were not used.

(c) For each separate fixation the position of the reflex of the torch light was found within the marker lights.

Results The deviations of the pupil centre from the target position for successive fixations were the same in (a) and (b); in (c) no distortions of the positions of the reflections of the torch light within the marker lights were found. The derived positions of the centre of the pupil within the marker lights (from (a) and (b), above), and of the torch light's reflections (c) are shown in Figure 2.11. For one fixation position the torch light was held away from the fixation position to avoid obscuring the camera's field of view. The derived position of its reflection (arrowed in Fig. 2.11B) departs from regularity for this reason.

From these results it may be supposed that estimating the target position from the marker lights does not give rise to any further error, and that estimating the target position is not itself affected by the marker lights' distortion with peripheral fixations.

Testing sequence 7 Cowey (1963) reports this corneal reflection procedure to be relatively insensitive to head movements: "The position of the reflection relative to the outer and inner borders of the iris

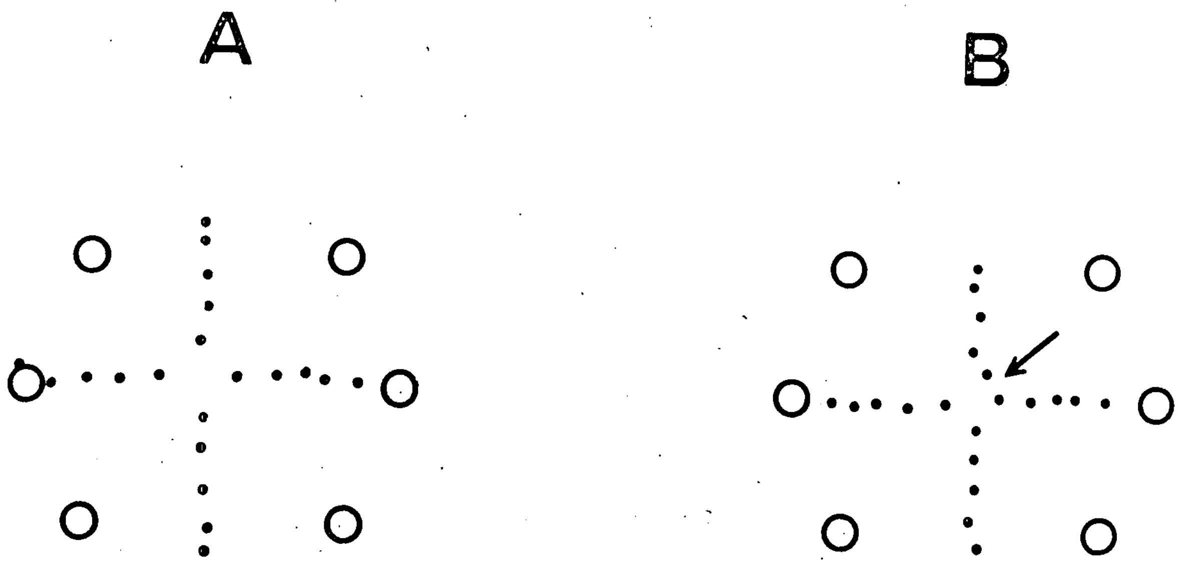

Figure 2.11 Fixation charts that constitute the raw data of testing sequence 6. In A are shown the derived positions of the pupil centre for successive fixations; in B the locations of the torch light are shown. If the two records are superimposed it can be seen that, as S fixates to the left, the pupil centre is displaced progressively to the left of the reflection of the torch light.

and to the centre of the pupil remains virtually unchanged if the eye maintains its fixation but the head moves, for instance, $\frac{1}{2}$in." (p85), and also (p86), "... all photographs for any single fixation point were essentially similar although the head had moved sideways up to $\frac{5}{8}$ in." In the experiments reported later in this thesis, both of the newborn's eyes were photographed simultaneously. When compared with photographing one eye alone this is equivalent to moving the right eye $\frac{3}{4}$ inches to right of midline, and the left eye $\frac{3}{4}$ inches to left of midline (assuming the field covered by the camera to be centred in the forehead).[4] These distances are larger than those tested by Cowey; additionally, if any further effects were to result, it would seem likely that they would be opposite in direction in the two eyes. Consequently, this final sequence with adults was formulated to test this possibility.[5]

One subject (DB) fixated 14 points, spaced regularly throughout the whole fixation area. Both eyes were (separately) recorded from under three conditions of viewing, (a) with the eye positioned $\frac{3}{4}$ inches to left of midline, (b) with the eye in a central position, and (c) with the eye $\frac{3}{4}$ inches to the right.

Results A small effect was found as a consequence of moving the eye $\frac{3}{4}$ inches from midline, equivalent to a change in the analysed fixation position of 1 to 2° visual angle. When the eye moved to the *left* the recorded position of the centre of the pupil shifted to the *right* of

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Footnote[4] This interpupillary distance of $1\frac{1}{2}$ inches is an average, for the newborn babies measured by the author. In the adult the equivalent distance is approximately $2\frac{1}{4}$ inches.

Footnote[5] This testing sequence was carried out after those on newborns reported in the next chapter. However, it seems reasonable to include it here rather than in its chronological order.

its previously recorded position, and vice versa. The effect is similar in both eyes and, within the limits of accuracy of the scoring procedure, appeared to be constant across the stimulus field. The "fixation maps" derived from the positions of the centre of the pupil are shown in Figure 2.12 for the left eye data. In this Figure the two horizontally located marker lights only are shown. If the fixation map for S fixating with his eye in a central position (B in Fig. 2.12) is placed over the map of S fixating the same points, but with his eye $\frac{3}{4}$ inches to left of midline (A in Fig. 2.12), with the marker lights' positions superimposed, it can be seen that the scored positions of the pupil centre are (in A) somewhat to the right of their positions in B. The opposite is found if B is placed over C in this Figure.

Thus, in the newborn baby, when both eyes are photographed the nature of this "binocular effect" will be to reduce the expected optical divergence of the eyes by a combined amount of approximately 3° visual angle.

CONCLUSION It is clear that there are often large discrepancies of the pupil centre from the fixation point, and that the assumption that the centre of the pupil coincides with the line of sight when using the technique cannot be made. It is evident that it is necessary to examine the technique in neonates, and the experiments reported in chapter 3 were carried out to do this.

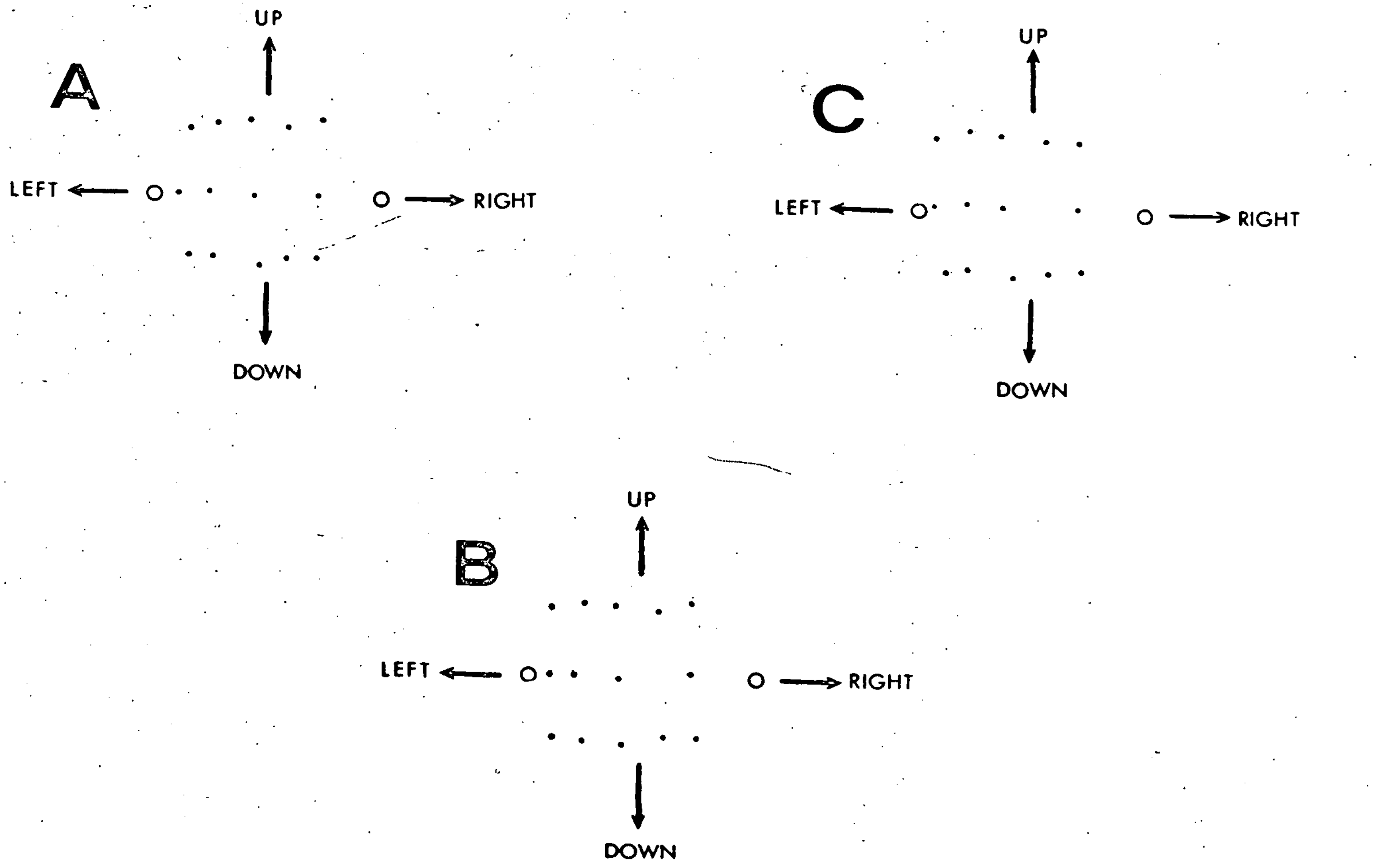

Figure 2.12 Scored positions of the pupil centre from testing sequence 7 for the left eye. In B, S was fixating with his eye in a central position, and in A and C with his eye $\frac{3}{4}$ inches to the left and $\frac{3}{4}$ inches to the right of centre, respectively.

CHAPTER 3

THE CORNEAL REFLECTION TECHNIQUE: EXPERIMENTATION WITH NEONATES

The experiments reported in this chapter were designed to investigate the corneal reflection technique with neonates. In all of these experiments the intention was to present a stimulus in known locations within the stimulus field, and to estimate the probable magnitudes of the angle alpha and of the off-axis parallax effects from the photographic records. It is not, of course, possible to instruct a newborn to fixate a particular stimulus, and it was therefore necessary to present a stimulus that the newborn would, from choice, fixate.

From the available literature it was not possible immediately to select a suitable stimulus that would capture the newborn's attention for some length of time. Consequently, in empirically arriving at a suitable stimulus several false starts were made (experiments 1 and 2). The stimulus that was eventually used, and was effective in eliciting looking behaviour, was a vertical, half-inch wide, array of lights. A vertical array was chosen because the subject could fixate any portion, up or down, of the stimulus, and the horizontal disparity between the centre of the pupil and the target's position within the marker lights could be scored. Vertical disparities of the pupil centre could not be derived directly from fixations of this type of stimulus, but could be estimated from the magnitudes of the horizontal disparities found.

Some of the experiments described (experiments 1 and 2 of this chapter; experiment 6 of chapter 6), were terminated before a large number of newborns had been used as subjects. However, when the experimental situation was changed before the results seemed to warrant it, it was either because the author felt that limitations in the design made unambiguous interpretation of the results impossible, or because a different stimulus seemed likely to produce better results. The variability of the subjects' responses was often a major cause of a stimulus change. Newborn babies do not make ideal experimental subjects: they cry, fuss, are sick, and in other ways indicate their lack of attention to the stimulus. However, if two or three apparently alert, wide awake, and quiet newborns failed to consistently look at a stimulus, even though their eye(s) were fixating around the area of the stimulus field that the stimulus was presented in, this appeared sufficient justification for changing the stimulus.

Apparatus The apparatus described in the previous chapter was modified for use with neonates. The underside of the stimulus screen was painted matt black, and stimuli were presented through holes in similarly painted stimulus panels which were separately placed as required over the 9½ inch diameter hole in the stimulus screen. A Kodak Wratten 88A filter was placed over a small hole in the centre of these panels to prevent the babies from seeing the camera lens. Sufficient infrared light passed through this filter to allow photographs of the eye to be taken. The aim was, so far as was compatible with photographic purposes, to present the stimuli against a uniform background.

The luminance of the bulb filaments of the marker lights, after the radiation had passed through the Kodak Wratten 87c and the Corning CS 7-69 filters, was 0.16 ft L., measured with an S.E.I. exposure photometer. Doris and Cooper (1966), suggested that brightness sensitivity undergoes rapid development in the first two months of life. They measured the optokinetic (following) responses of infants from 4 days to 69 days of age to a moving field of black and white stripes.

The brightness of the field was varied and the minimum intensity eliciting a response was considered the threshold. Variations in the intensity of the white stripes also involved variations in the relative intensity of white and black. The average (threshold) difference in intensity to which infants from 4 to 8 days responded was .086 apparent foot candles. This threshold measure decreased sharply from 4 to 20 days.

It does not seem possible to interpret these results in terms of the visibility of the marker lights to the neonates. However, there is no indication from the neonates so far tested that either the marker lights or the camera filter can be distinguished from the surrounding area. More specifically, even when the babies did not respond to the stimuli they did not appear to respond to any other feature of the situation.

Lighting for the stimuli was provided by two 60 watt strip lights, located behind and to the side of the head-restraining cot. These lights were connected in series.

Subjects Subjects for the experiments were newborn babies selected from those in the maternity ward of Dryburn Hospital, Durham. In this particular ward the babies remained in hospital, usually for a period of 10 days from birth. All babies were delivered without complications and were full-term at birth. When there were complications at delivery, or the babies were premature, they were housed in a different ward.

Initially the babies were seen between feeds. This, however, proved to be unsatisfactory as the large majority of potential subjects were asleep. Consequently, the babies used as subjects in all but the very early experiments were seen immediately after their midday feed. Many babies were seen who could not be used as subjects either because they cried, slept, or in other ways showed inattention to the stimulus.

Procedure Each baby was brought by his mother to the experimental room on the maternity ward of the hospital, and placed on his back in a head-restraining cot. Foam rubber clamps attached to the cot prevented gross side-to-side head movements. As a hygienic precaution a clean white towel was placed under each baby. A gauze patch was placed over one of the infant's eyes to ensure monocular conditions of viewing, and the infant was positioned under the apparatus, by means of markers placed on the cot and on the baseboard which supported the cot, so that the open eye was 10 inches below the centre of the stimulus panel and within the field of view of the camera. Curtains around the apparatus were drawn, to eliminate extraneous light, and an experimental session began when the stimulus was presented and the camera switched on.

The stimuli used are described in detail for each of the experiments.

Scoring and analysis A film frame was scorable if one or more of the marker lights was visible and if the centre of the pupil could be determined. Throughout the experiments described the data for each S in each stimulus position were analyzed separately, and were only scored if a preliminary check showed that there were at least 15 scorable frames. A frame in which only one marker light was visible was scored only if other frames within the same stimulus presentation allowed determination of the necessary image size.

For each scorable frame the position of the centre of the pupil relative to the marker lights' position was determined in the manner previously described for the adult data.

INITIAL TESTING SESSIONS When filming with adults' eyes, very good contrast between iris and pupil had been found. With the same conditions of photography, however, analysis of the developed film proved impossible because the centre of the pupil could not be determined with any accuracy.

The first 15 subjects were used for testing purposes only, to establish appropriate camera settings and illuminator levels. Several alterations to the photographic procedure were introduced. These included:

(a) the use of laterally placed illuminators. Previous investigators (i.e., Salapatek, 1968) have used lateral illumination to improve the contrast between iris and pupil, and

(b) developing to enhance contrast. Hershenson (1964) reported a developing process, supposedly to increase contrast. This requires developing for an additional 20 minutes in D19 with the active ingredients of the developer doubled. Film from the same subjects was cut into strips and separate strips developed either normally or using this method.

Neither of these alterations to the procedure produced satisfactory results: overdeveloping was found to produce film that was much grainier, but no more contrasty, than normal developing; as lateral illumination necessarily illuminates the eye(s) unevenly it produced more, rather than less, confusion.

Adequate contrast was later found when the diaphragm openings of the camera were varied: since neonates' eyes are smaller than adults' more light is needed to obtain a similar contrast.[1] All subsequent

Footnote[1] The contrast between the iris and the pupil in the film of neonates' eyes was, however, never quite as good as that found with adults. There are two reasons for this. Firstly, the lack of pigmentation in the newborn's iris. Secondly, it was possible to focus the camera for each adult S individually, by illuminating the eye with large amounts of visible light. This was not possible with neonates, and an average setting was used. Because of differences in the head size of different Ss, and the small depth of field of the camera (approximately $\frac{1}{2}$inch), the film records were often slightly out of focus.

photographs were taken with a diaphragm opening of f8, without the presence of lateral lights, and the film was developed normally. In Figure 3.1 are shown two photographs of newborns' eyes taken under these photographic conditions.

EXPERIMENT 1 The stimulus for this experiment was a small ($\frac{3}{8}$ inch diameter) light which either flashed on and off approximately once every half second, or remained on. The luminance of the stimulus light was approximately 25ftL. Wickelgren (1967) suggested that a small blinking light is successful in attracting newborns' attention. 4 subjects were used in the first stage of the experiment. With S in position below the stimulus screen the flashing light was presented, at various locations, through holes drilled in a stimulus panel, for a few seconds per location. It appeared from an analysis of the film records that in no case did the presence of the flashing light constrain the newborns' visual attention. Possibly the light was not placed in a particular location for a sufficiently long time for the subjects to localize it in space.

In the next stage of the experiment the stimulus panel was moved and the light was moved horizontally at the stimulus plane until the subject appeared to fixate it. The flashing light was then moved to a predetermined position and held there for 30 seconds while the camera recorded. 3 subjects were used.

For the final 2 subjects of the experiment, the non-flashing light was moved, as described above, until visual following movements appeared to be made. When it was felt that S was fixating, the light was held stationary, and the camera switched on. The light's exact location could later be determined from its reflection within the pupil.

Results The results were not analyzed in detail, for two main reasons:

Figure 3.1 Photographs of two newborns' eyes, taken under the conditions described (see text).

(1) On some frames the centre of the pupil was sufficiently close to its expected location within the marker lights to indicate fixation. On others it was not. Experimenter bias, it was felt, would influence the choice of frames to include in the analysis as indicating fixation.

(2) As it is apparently the case with a moving stimulus of this nature that quite a large movement of the stimulus may be necessary before correction of the slippage of the target from the fovea is made (see the review in Chapter 1), the subject, whilst appearing to fixate the light, might in fact be fixating a point, say, an inch away.

As it was not clear in this experiment how on-target fixations were to be distinguished from non-fixations, the experimental procedure was abandoned.

EXPERIMENT 2 A further 11 subjects were shown a series of $\frac{1}{2}$inch wide vertical strips, painted in white on the stimulus panels, located separately in different areas of the visual field. Each subject was shown a maximum of four lines, each stimulus being presented for approximately 30 seconds.

The results were very ambiguous, and no really clear-cut evidence of on-target fixation was found. A possible reason for this finding is that the white lines which, in the experimental situation each had a luminance of approximately 2 foot Lamberts, although clearly visible to an adult were too dim to be easily distinguished from the background by the newborn, whose brightness sensitivity is known to be reduced (Doris and Cooper, 1966). One positive finding that did emerge from this and the previous experiment was that, with the left eye open and the right occluded, the baby was most likely to fixate to the left of midline, and was most likely to look to the right when only the right eye was open. This is in agreement with Salapatek's (1968) finding that a newborn's eye fixates much more temporally when the other eye is covered than when it is not.

While it is possible that better results might have been obtained if the brightness level were increased, a different stimulus was used in the next experiment.

EXPERIMENT 3

Subjects Subjects for the experiment were 27 full-term babies from 43 to 261 hours old, median 117 hours. 28 other babies were seen but could not be used as subjects.

Stimulus The stimulus was an array of eight small, coloured lights, mounted on a strip of aluminium. The lights were grouped in two sets of four, those in each set being $\frac{11}{16}$ inches apart, with a central gap necessary for photographing through when the stimulus was presented centrally. The stimulus lights were presented through one of five vertical slits, each 6 x $\frac{1}{2}$ inches, in three stimulus panels. These panels were separately placed as required over the hole in the stimulus screen. On the first panel two of the slits were spaced $1\frac{5}{16}$ inches and $3\frac{1}{2}$ inches to the left of centre, and on the second panel identical slits were spaced the same distance to right of centre. The fifth vertical slit was cut in the centre of the third stimulus panel. The half-inch width of this slit did not obscure the camera's field of view.

The whole stimulus array covered an area slightly smaller than the 6 x $\frac{1}{2}$ inch slits in the stimulus panels. The luminance of each stimulus light was approximately 20 foot Lamberts, measured with an S.E.I. exposure photometer, a luminance that would appear to be acceptable to newborns (Hershenson, 1964).

Initially, these lights were blinking when presented to the subjects, being on for $\frac{1}{4}$ sec. and off for $\frac{1}{4}$ sec. (the "on-off" condition). The stimulus was later altered so that the lights could either blink or remain permanently on (the "on" condition). This modification was designed to reduce any habituation effects to the original stimulus, and during intra-subject stimulus presentations in later experimental sessions the "on-off" and "on" conditions were alternated.

Procedure The two 60 watt strip lights that had been used to illuminate the stimulus in the previous experiment were not used. Thus, when the curtains around the apparatus were drawn the only source of light (other than very small amounts of diffuse light that might have been present), was the stimulus.

The stimulus was shown to each baby in three positions, depending upon which eye was photographed. To maximize the possibility that S would look at the stimulus, the lights were shown in the central position and in the two positions to left of centre when the left eye was open, and centrally and in the two positions to the right when photographing the right eye. The stimulus was presented in each of the three positions for approximately 1 minute, the sequence of presentation being randomly determined for each S.

Data for the left eye were mostly collected initially. Although it was not expected that the disparities found would differ for the right eye, corroborative data were collected for the right eye, but using fewer subjects. If S fell asleep, or began to cry, the experimental session was discontinued.

Scoring and Analysis The film frames were initially scored as described earlier in this chapter. For each subject in each stimulus position there were potentially available approximately 60 scorable frames (in some cases, more). When the pupil centre had been found, relative to the marker lights' position, horizontal coordinates were obtained by dividing the stimulus field into 21 vertical $\frac{7}{8}$ inch wide areas. The number of fixations in each area was then determined for each stimulus position, these frequencies being converted to percentages to ensure that each S contributed equally to the results, All the film records whose data were used were re-scored, to provide evidence concerning intrascorer reliability.

Results 19 Ss contributed to the results for the left eye, and 8 Ss contributed to the results for the right eye. The percentage of fixations for each S in each stimulus position that fell within each area of the stimulus field is given in tables 3.1 through 3.6. The rows along from 1 and 2 (in the second column of these tables), give, respectively, the results obtained when the film records were first analyzed, and the results from the reanalysis. The total number of scored frames, both for the originally analyzed and the reanalyzed data, is given in the column on the extreme right of these tables, It may be noted that the number of frames deemed scorable usually differs for the original and reanalyzed data, a consequence of a number of frames that were not too clear. If the centre of the pupil had coincided with the line of sight the greatest percentage of fixations would have been found in the column(s) indicated by the single, thick line under the totals row.

The most common occurrence was for an individual S to fixate the stimulus when it was presented in one position, but not in the other positions. There are three main reasons for this finding: (1) S may have closed his eyes or started to cry during the experimental session; (2) if the baby's eye was not exactly centrally placed, a small head movement, of perhaps half an inch, took his eye out of camera shot, so that although he may have been fixating the stimulus, the results were not available for analysis; (3) the fixations of

TABLE 3.1

Percentage of fixations for each subject in each stimulus condition scored as being within 21 areas of the stimulus field, experiment 3

LEFT EYE Stimulus presented $3\frac{1}{2}$' to left of centre

Subject no.							LEFT		←	AREA FIXATED	→			RIGHT							Total no. of scored frames
		10	9	8	7	6	5	4	3	2	1	0	1	2	3	4	5	6	7	8	9	10	
55	2		18	21	25	21	4	4	7														28
	1	4	11	23	23	19	4	4	4	4				4									26
60	2		5	32	33	15	15																41
	1		15	29	27	22	7																41
63	2	12	12	30	23	12	11																43
	1	14	14	26	15	17	12						2										42
67	2	28	12	32	24	4																	25
	1	31	15	27	27																		26
80	2	9	13	31	20	9	6	4	4	3	1												47
	1	11	11	30	22	4	8	4	8		2												47
82	2		10	21	17	9	17	7	5	5	5	2	2										42
	1		4	23	14	9	14	14	8	5	4	5											43
87	2		14	9	28	22	12	9	3		3												35
	1		12	9	31	24	9	12			3												33
Totals	2	49	84	176	170	92	65	24	19	8	9	2	2										
	1	60	82	167	159	95	54	34	20	9	9	5	2	4									
Grand Total	2	700																					
	1	700																					

TABLE 3.2

Percentage of fixations for each subject in each stimulus condition scored as being within 21 areas of the stimulus field, experiment 3

LEFT EYE Stimulus presented 1$\frac{5}{16}$'' to left of centre

Subject no.		LEFT ←										AREA FIXATED →				RIGHT						Total no. of scored frames
		10	9	8	7	6	5	4	3	2	1	0	1	2	3	4	5	6	7	8	9	10	
47	2		3	6	8	5	8	36	14	17	3												36
	1		6	3	8		14	33	17	14	5												36
59	2				4	5	18	7	20	22	2	4	5	5	2	2			2	2			45
	1					10	15	12	23	23	4	3	7		3								39
60	2				6	14	33	28	8	8				3									36
	1					24	37	27	6	6													30
52	2				13	13	23	18	15	10	5				3								39
	1			4	9	14	23	18	27					5									22
55	2					6	17	36	19	17	5												18
	1					7	20	33	20	14	6												15
63	2			3	11	17	25	17	11	8	8												36
	1			5	3	20	34	7	21	5	5												39
73	2				6	17	18	29	21	6	3												34
	1				7	18	18	43	11	3													28
50	2				3	6	26	11	31	17		6											35
	1				4	7	15	15	41	18													27
76	2				3	3	19	36	25	8	6												36
	1				3	7	14	42	28	3	3												29
77	2				6		21	37	27	3	6												33
	1				5		33	38	24														21
Totals	2		3	9	60	86	208	255	191	116	38	10	5	8	5	2			2	2			
	1		6	12	39	107	223	268	218	86	23	3	7	5	3								
Grand Total	2	1000																					
	1	1000																					

TABLE 3.3

Percentage of fixations for each subject in each stimulus condition scored as being within 21 areas of the stimulus field, experiment 3

LEFT EYE Stimulus presented in the centre position within the marker lights

Subject no.								LEFT ←		AREA FIXATED		→			RIGHT							Total no. of scored frames
		10	9	8	7	6	5	4	3	2	1	0	1	2	3	4	5	6	7	8	9	10	
74	2					5			19	14	33	14	10	5									21
	1								13	27	40	13	7										15
76	2						8		20	32	20	12	4		4								25
	1						9		18	32	23	5	4	5	4								22
79	2								6	18	36	13	23	4									49
	1							2	2	17	41	12	21	5									42
81	2							2	8	25	42	15	7	1									113
	1							1	9	16	40	21	10	3									104
87	2				1		4	11	9	10	17	17	14	9	3	4			1				91
	1				1		3	9	9	13	16	19	15	6	4	4				1			89
91	2		2	6		2	10	14	14	27	23		2										49
	1		4	2	2	4	11	8	15	26	22	4	2										47
95	2							10	5	24	27	24	10										21
	1								11	25	36	17	11										18
Totals	2		2	6	1	7	22	37	81	150	198	95	70	19	7	4			1				
	1		4	2	3	4	23	20	77	156	218	91	70	19	8	4				1			
Grand Total	2	700																					
	1	700																					

TABLE 3.4

Percentage of fixations for each subject in each stimulus condition scored as being within 21 areas of the stimulus field, experiment 3

		RIGHT EYE			Stimulus presented in the centre position within the marker lights																		
							LEFT ←				AREA FIXATED →				RIGHT								
Subject no.		10	9	8	7	6	5	4	3	2	1	0	1	2	3	4	5	6	7	8	9	10	Total no. of scored frames
83	2						3		6	16	6	22	19	25	3								32
	1						3	3	3	13	12	20	22	21	3								37
85	2								4		4	17	46	17	4				4		4		24
	1										5	19	42	19	5				5	5			21
93	2						4	4	12	10	6	18	20	12	6	8							50
	1						2	6	8	14	4	19	19	10	12	6							49
Totals	2						7	4	22	26	16	57	85	54	13	8			4		4		
	1						5	9	11	27	21	58	83	50	20	6			5	5			
Grand	2	300																					
Total	1	300																					

TABLE 3.5

Percentage of fixations for each subject in each stimulus condition scored as being within 21 areas of the stimulus field, experiment 3

RIGHT EYE Stimulus presented 1$\frac{5}{16}$'' to right of centre

Subject no.		LEFT ←										AREA FIXATED →					RIGHT						Total no. of scored frames
		10	9	8	7	6	5	4	3	2	1	0	1	2	3	4	5	6	7	8	9	10	
41	2											12	20	15	24	24	3	2					40
	1										2	12	21	14	19	24	3	2	3				42
93	2							1	1		2	6	13	11	20	16	22	6	1	1			98
	1								3	1	3	3	13	15	16	13	22	7	3	1			102
94	2										2	4	4	11	18	13	20	11	4	7		6	54
	1										2	4	4	11	13	20	16	10	6	6	6	2	53
96	2														25	25	6	14	30				16
	1													7	20	33	7	13	13	7			15
Totals	2							1	1		4	22	37	37	87	78	51	33	35	8		6	
	1								3	1	7	19	38	47	68	90	48	32	25	14	6	2	
Grand Total	2	400																					
	1	400																					

TABLE 3.6

Percentage of fixations for each subject in each stimulus condition scored as being within 21 areas of the stimulus field, experiment 3

RIGHT EYE Stimulus presented $3\frac{1}{2}$'' to right of centre

		LEFT ⟵										AREA FIXATED			⟶	RIGHT							
Subject no.		10	9	8	7	6	5	4	3	2	1	0	1	2	3	4	5	6	7	8	9	10	Total no. of scored frames
88	2															7	3	14	38	31	4	3	29
	1															10	5	8	33	37	4	3	30
89	2												4	3		4	18	14	25	22	10		28
	1													7		7	21	7	29	22	7		28
93	2								2		3	5	5	10	2	5	15	17	18	13	5		40
	1								2	2	2	4	4	10	2	4	15	12	22	15	6		43
94	2															2	7	23	27	26	8	7	58
	1															2	8	19	31	27	9	4	55
96	2															3	6	16	41	22	9	3	32
	1															4	8	19	34	19	16		26
Totals	2								2		3	5	9	13	2	21	49	84	149	114	36	13	
	1								2	2	2	4	4	17	2	27	57	65	149	120	42	7	
Grand Total	2	500																					
	1	500																					

some Ss showed no definite grouping, and it was assumed that in this situation the stimulus was not available to S. An example of this form of fixation is shown in Figure 3.2. In A and B of this Figure each dot is the scored position of the pupil centre for a single film frame. The position of the stimulus is indicated by the vertical line. In part B of this Figure the tight grouping of fixations is a clear indication that this S is "captured" by the stimulus, and the data were used. In part A of the Figure the apparent fixations from a different S presented with the stimulus in the same central position are shown. In this instance the scored fixations are often widely displaced from the stimulus. It is possible, of course, that both of these Ss were looking at the stimulus and that the S whose fixation chart is shown in A was exhibiting a looser form of scan than the S shown in B. However, as the aim of the experiment was to extract information from Ss who were clearly looking at the stimulus (rather than, say, to investigate differences in patterns of scanning), the data from the S shown in part A of this Figure were not used in the analysis.

The first analyzed and the reanalyzed data were used to give a measure of intrascorer reliability. The number of fixations within each area of the stimulus field was ranked for the first and second analysis of the film records for ten of the individual sets of data, and Spearman rank order correlation coefficients (Siegel, 1956, p202) were calculated. These correlation coefficients ranged from .80 to .99, with a median of .90, and indicate that the number of fixations that were scored in the different areas of the stimulus field were very similar when the records were reanalyzed.

As a check that the reanalyzed data did not differ overall from those of the first analysis, correlations between the total percentages

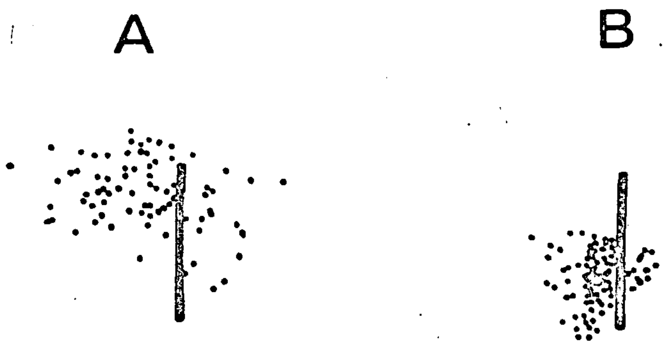

Figure 3.2 Distribution of 2 newborns' fixations when presented with the stimulus lights in the centre position between the marker lights. Data from S82 are shown in A, and from S81 in B. Both Ss viewed the stimulus with the left eye.

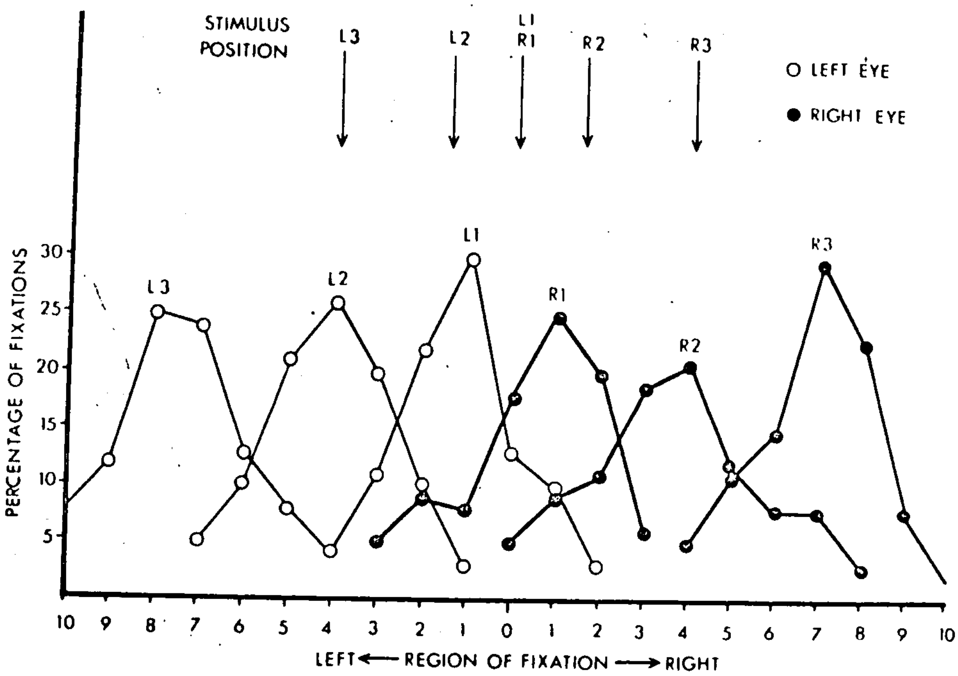

Figure 3.3 Frequency distributions of newborns' fixations in 21 regions of the visual field.

of fixations within the different areas of the stimulus field were calculated, for each of the six sets of data presented in tables 3.1 through 3.6. These correlation coefficients were from .92 to .98, with a median of .945.

8 Ss data are included in the results for more than one position. All of these Ss showed disparities similar to the "one-position" Ss who viewed the stimulus in these positions. All Ss whose fixation patterns demonstrated a definite preference for the stimulus showed consistent and similar disparities. Additionally, all Ss showed a fixation peak within 5° of the group mean. Consequently, all fixations on a particular target have been combined to give a distribution of fixation positions. Figure 3.3 plots these distributions for each target position, and is a graphical presentation of the data in tables 3.1 through 3.6. The numbered distributions L1, L2, L3 represent, respectively, the areas apparently fixated when the stimulus was presented centrally, and $1\frac{5}{16}$ inches and $3\frac{1}{2}$ inches to left of centre. The R1, R2 and R3 are the corresponding distributions for the right eye. The peak of the relevant distribution would have been immediately below the arrowed position of the stimulus if the centre of the pupil had coincided with the target positions. (Number of subjects in each condition: L3, N = 7; L2, N = 10; L1, N = 7; R1, N = 3; R2, N = 4; R3, N = 5).

In table 3.7 is given information about the ages at the time of experimenting, birth order, birth weight, and sex of the babies seen during the course of Experiment 3. Although 27 babies were used as subjects, and 28 babies were not, the relevant information concerning these variables was not always available. Where the data given in this table are not from the full complement, the number of babies who contributed to a given result is given in parentheses. A possible

TABLE 3.7

Information concerning the neonates seen during the course of Experiment 3

	AGES (HOURS FROM BIRTH)			BIRTH ORDER		BIRTH WEIGHT (lbs and ozs)			SEX	
	RANGE FROM	TO	MEDIAN AGE	FIRST BORN	OTHER	RANGE FROM	TO	MEDIAN WEIGHT	MALES	FEMALES
BABIES USED AS Ss N = 27	43	261	117	19 (N = 26)	7	6.1	9.5	7.6	18	9
BABIES NOT USED AS Ss N = 28	24	184 (N = 25)	115	18 (N = 24)	6	5.12 (N = 25)	10.5	6.15	13	15

difference between the subjects and those babies who were brought to the experimental room but whose data could not be used, is in their weights at birth. The median birth weight of the subjects was 7lbs 6 ozs, 7ozs heavier than the median birth weight (6lbs 15ozs) of the babies who were not used. A Mann-Whitney U test for independent samples (Siegel, 1956, p116) was carried out on the results, but an acceptable level of significance was not reached, (n_1 = no. of subjects = 27; n_2 = no. of babies not used = 25; U = 264, $p = .0885 > .05$).

APPARATUS CHANGE

Before experiment 3 had been completed the author became aware of Bower's (1971) suggestion that infants in a supine position are not fully awake. As a consequence new apparatus was built to allow eye fixation position to be recorded while the newborn baby is held in an upright position.

Figure 3.4 is a photograph of the new apparatus, and Figure 3.5 is a schematic drawing of the apparatus. Stimuli are positioned on black stimulus panels which are hung, as required, over the central hole, 9½ inches in diameter, cut in the black aluminium screen (B in Fig. 3.5). The stimulus panels are located 10 inches in front of the baby's eyes. The 16mm cine camera is mounted behind the aluminium screen, with the camera axis at a 90° angle to the screen. The optical bench allows the camera to be moved nearer or farther, as required, to photograph one or both eyes. During operation both camera and motor are covered by a soundproof box.

Markers are fixed 10 inches from the stimulus panel so that the centre of the camera's field of view is the point of intersection of the two markers (C in Fig. 3.5). The baby is positioned between the padded ends of the markers so that the point of intersection is between

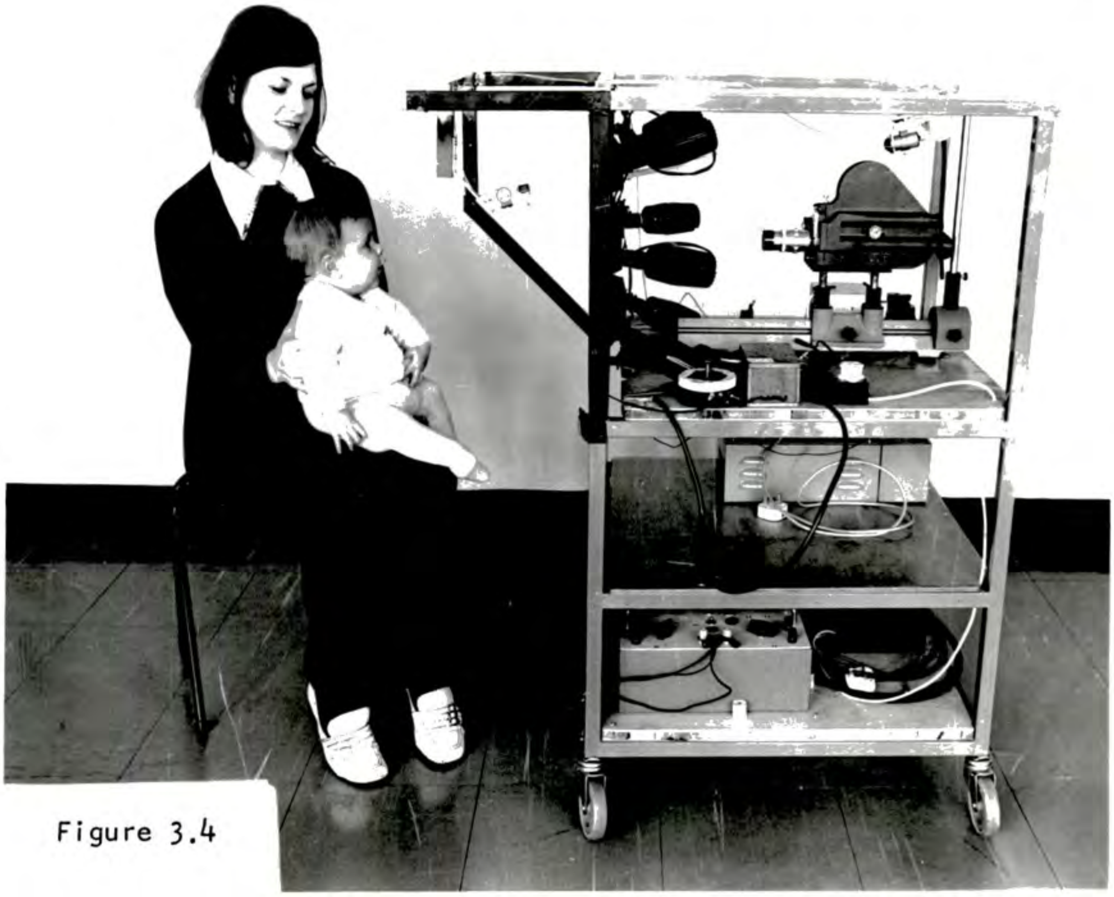

Figure 3.4

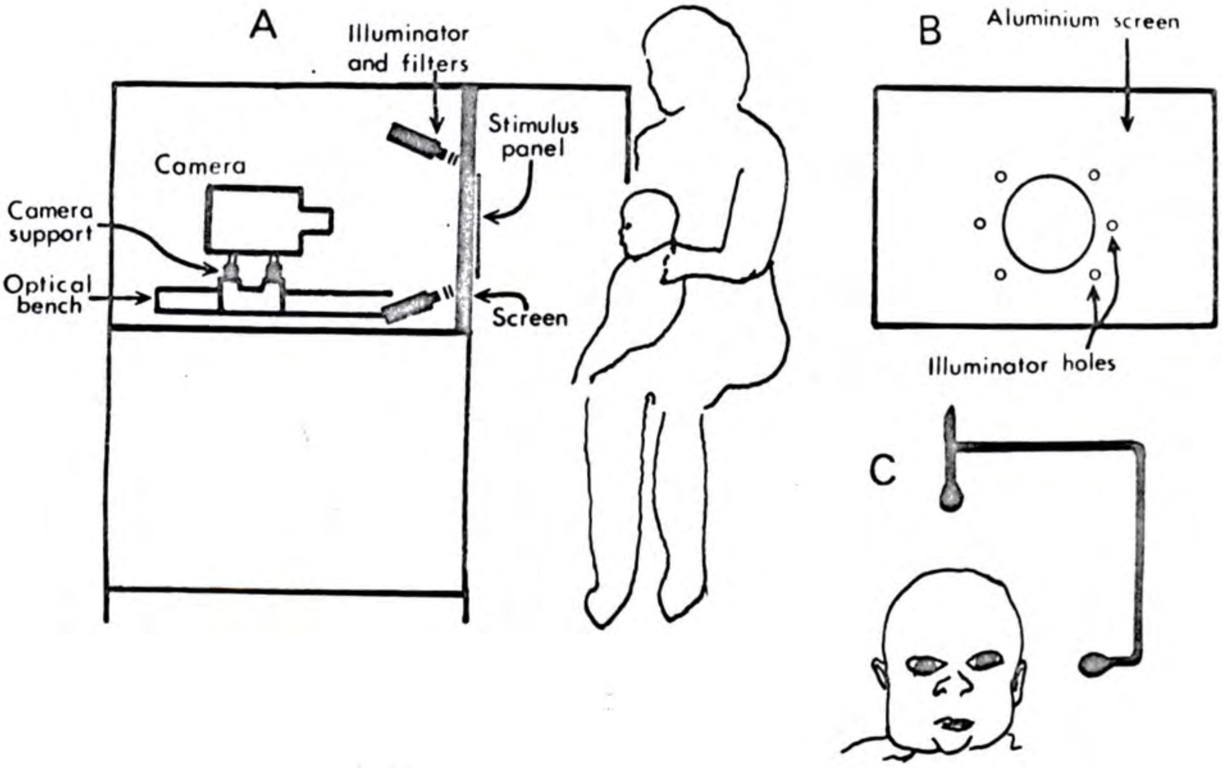

Figure 3.5

Figures 3.4 and 3.5 Photograph, and schematic drawing of the apparatus.

the two eyes (assuming both eyes are being photographed). Castors fitted to the apparatus allow it to be moved, as required, from one room to another.

Procedure The procedure is similar to that described earlier. The newborn babies are brought tightly swaddled, either by the mother or by the experimenter to the experimental room. There, the baby is wrapped in a towel (for hygienic purposes) and is held, seated upright on the E's knee, with his eyes in the centre of the two markers (C in Fig. 3.5). The central point between the two markers is 34 inches above the ground, a distance which allows E to hold the baby in the required position without strain. With practice it is possible for very precise positioning of the baby to be maintained, allowing the field of view of the camera to be very small: when both eyes are photographed the camera films an area which is $2\frac{1}{4}$ inches wide, a distance only slightly larger than the distance between the two outer canthi of the eyes. The baby can be supported in a supine position with one arm to allow E to switch the camera and change the stimulus.

As the author became more proficient in the use of this procedure several advantages over the previously used apparatus became apparent which markedly reduce the subject loss normally encountered. Firstly, records are no longer lost due to a head movement taking the baby's eye(s) out of the camera's field of view, such head movements being compensated for by E. This compensation does not produce any artefacts in the derived fixation position as head movements are not confounded with those eye movements that change the baby's fixation point. Similarly, tendencies to fixate outside of the stimulus area can be corrected by E who can turn the baby's head. Secondly, very few experimental sessions are now terminated as a result of the baby crying, fussing, or falling asleep - holding infants is known to have a soothing effect, in addition to promoting visual scanning (Korner, 1971, p615).

In experiment 3 data were collected from newborns looking at a central or an ipsilateral stimulus. A contralateral stimulus was not shown as earlier results had suggested that the newborn baby is most likely to fixate ipsilaterally when the non-fixating eye is occluded. With the new apparatus it was possible to obtain results from Ss looking contralaterally by holding them so that they were facing the stimulus.[2] Experiment 4 was carried out to obtain results from Ss looking at a contralateral stimulus.

EXPERIMENT 4

Subjects 23 newborn babies were seen. Of these 13 were used as subjects. 10 could not be used as subjects: in 5 cases there was an insufficient number of scorable frames (no film record was scored if a preliminary check showed that there were less than 15 scorable frames), and in 5 cases the scored records did not clearly indicate that the babies had been looking at the stimulus.

Stimulus and procedure The stimulus was the same array of 8 coloured lights that was used in experiment 3. The lights were presented through a 6 inches x ½ inch vertical slit in one of two stimulus panels that were hung over the 9½ inch hole in the aluminium screen. On one of these panels the slit was spaced 2 inches to the left of centre, and

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Footnote[2] "Contralateral looking" is defined in terms of fixations relative to the observer's position, and not in terms of the orientation of the baby's head. Thus, if the baby looks to the left of the centre of the stimulus panel with the right eye, he is "looking contralaterally" even though S may have turned to face the stimulus directly. The author found that, when babies fixate a stimulus they usually do turn their heads to face the stimulus. This finding is in accord with a report by Tronick and Clanton (1971, p 1485), who suggest that the infant, when visually attending to a stimulus, aligns the eyes and the head, a constraint being that the eyes must be centred in the head.

on the second panel was $3\frac{1}{2}$ inches to left of centre.

The procedure was similar to that described under experiment 3. An experimental session began when the stimulus was presented with the subject in position, and the camera was switched on. The switch for the camera motor was within easy reach of the seated E. Initially, it proved difficult to change the stimulus position (from 2 inches left of centre to $3\frac{1}{2}$ inches left of centre, or vice versa), for an individual subject, so that the first 13 babies seen (8 of whom contributed to the results) were shown the stimulus in only one position, for approximately two minutes.

The difficulty in changing the stimulus position was a consequence of the stimulus being mounted vertically with respect to the ground. The stimulus lights were screwed into position on the appropriate stimulus panel, and to change panels took several minutes. This difficulty was overcome when a third stimulus panel was constructed, with 6 inch x $\frac{1}{2}$inch vertical slits positioned 2 inches and $3\frac{1}{2}$ inches to left of centre. A strip of metal was fitted on the reverse of this panel and the stimulus lights, which rested on this metal strip, could be slid so that they appeared through the appropriate slit in the panel. 10 subjects, 5 of whom contributed to the results, were shown the stimulus in both positions.

To ensure that the lights, rather than any other aspects of the apparatus or surround, were the most obvious visual stimulus, curtains in the experimental room remained drawn throughout each experimental session.

In all cases the subject's left eye was occluded by a gauze patch, and each newborn was held facing the stimulus with the (open) right eye positioned in the centre of the markers on the apparatus (C in Fig. 3.5).

Scoring and results The scoring protocol was identical to that described under experiment 3. The percentage of fixations within each area of the stimulus field for each S in the two stimulus positions is given in tables 3.8 and 3.9. These tables are identical in construction to tables 3.1 through 3.6. The results are presented graphically in Figure 3.6, whose axes are the same as those of Figure 3.3.

Information about the ages, birth order, and birth weight of the babies seen during the course of this experiment is given in table 3.10. The only possible difference between those babies who were, and those babies who were not, used as subjects is in the birth weight. The median birth weight of the babies used as subjects was 8ozs greater than that of the babies whose results could not be used. As this finding is in the same direction as that of experiment 3 the data from both experiments were combined and a Mann-Whitney U-test carried out on the results. This again did not indicate a significant difference between the groups (n_1 = no. of babies used as subjects = 40; n_2 = no. of babies not used = 35; $U = 554$, $p = .061 > .05$).

Figure 3.7 is derived from the data in Figures 3.3 and 3.6. The points represent the average disparities found. The data for right and left eyes have been combined for the central and ipsilateral viewing conditions, and expected disparities are indicated by the broken lines. As is the case with adults, the disparities will be greatest as the right eye looks right and the left eye looks left. The axes of Figure 3.7 are equivalent to those of Figure 2.9.

CONCLUSION The central effect shown in Figures 3.3 and 3.7 is somewhat larger than that shown in the adult Ss (Figure 2.9A). The central displacement is approximately 1.5 inches which is equivalent to $8\frac{1}{2}^{\circ}$

TABLE 3.8

Percentage of fixations for each subject of experiment 4, scored as being within 21 areas of the stimulus field

RIGHT EYE Stimulus presented 2'' to left of centre

Subject no.		LEFT ←				AREA FIXATED		→		RIGHT		Total no. of scored frames
		6	5	4	3	2	1	0	1	2	3	4	
101	2		2	6	4	13	38	29	4	4			52
	1	1	3	6	3	17	32	34	2		1	1	71
104	2			1	5	38	40	9	5	2			120
	1			1	6	35	39	8	7	2	1	1	107
109	2			8	15	57	15	5					39
	1			12	21	54	11	2					38
110	2				4	16	25	31	16	8			51
	1				4	8	39	29	16	4			45
118	2			7	5	20	41	22	2		3		41
	1			4	7	20	43	20	3		3		30
119	2					20	54	17	5	2	2		46
	1				2	24	53	13	8				38
123	2				13	41	32	9	5				22
	1		15	7	7	38	22	7	4				27
Totals	2		2	22	46	205	245	122	37	16	5		
	1	1	18	30	50	196	239	113	40	6	5	2	
Grand	2	700											
Total	1	700											

TABLE 3.9

Percentage of fixations for each subject of experiment 4, scored as being within 21 areas of the stimulus field

RIGHT EYE Stimulus presented $3\frac{1}{2}$'' to left of centre													
		LEFT ⟵ AREA FIXATED ⟶ RIGHT											
Subject no.		8	7	6	5	4	3	2	1	0	1	2	Total no. of scored frames
106	2		13	21	32	14	19	1					58
	1		8	25	31	18	10	4	2	2			49
107	2	2	4	9	22	33	24	4			2		55
	1			10	23	30	19	10	2	4	2		55
108	2		1	10	28	37	15	4	1	4			79
	1		3	7	23	35	18	7	4	3			90
115	2			4		26	48	17	5				23
	1					47	40	13					15
116	2				28	35	10	10		10	7		29
	1				33	38	19	5	5				21
119	2					36	55	9					22
	1					33	39	22	6				18
121	2	4		6	6	36	34	8	6				54
	1	4	2		11	47	24	6	6				54
123	2	5	7	5	47	30	2	2	2				43
	1	5	9	11	41	25	5	2	2				44
Totals	2	11	25	55	163	247	207	55	14	14	9		
	1	9	22	53	162	273	174	69	27	9	2		
Grand	2	800											
Total	1	800											

TABLE 3.10

Information concerning the neonates seen during the course of Experiment 4

	AGES (HOURS FROM BIRTH)			BIRTH ORDER		BIRTH WEIGHT (lbs and ozs)			SEX	
	RANGE		MEDIAN AGE	FIRST BORN	OTHER	RANGE		MEDIAN WEIGHT	MALES	FEMALES
	FROM	TO				FROM	TO			
BABIES USED AS Ss N = 13	43	180	91	9	4	6.5	9.4	8.2	6	7
BABIES NOT USED AS Ss N = 10	39	192	93.5	8	2	6.1	8.5	7.10	5	5

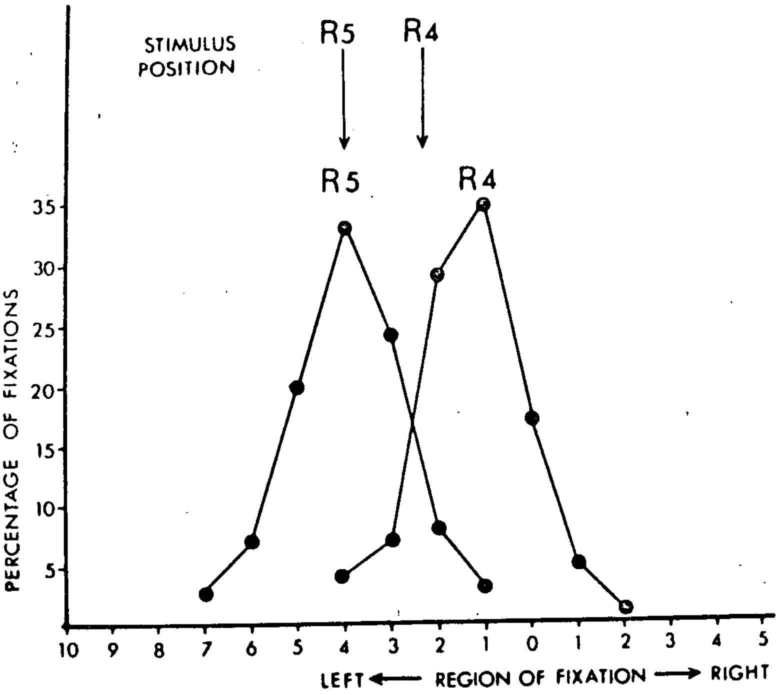

Figure 3.6 For explanation see text.

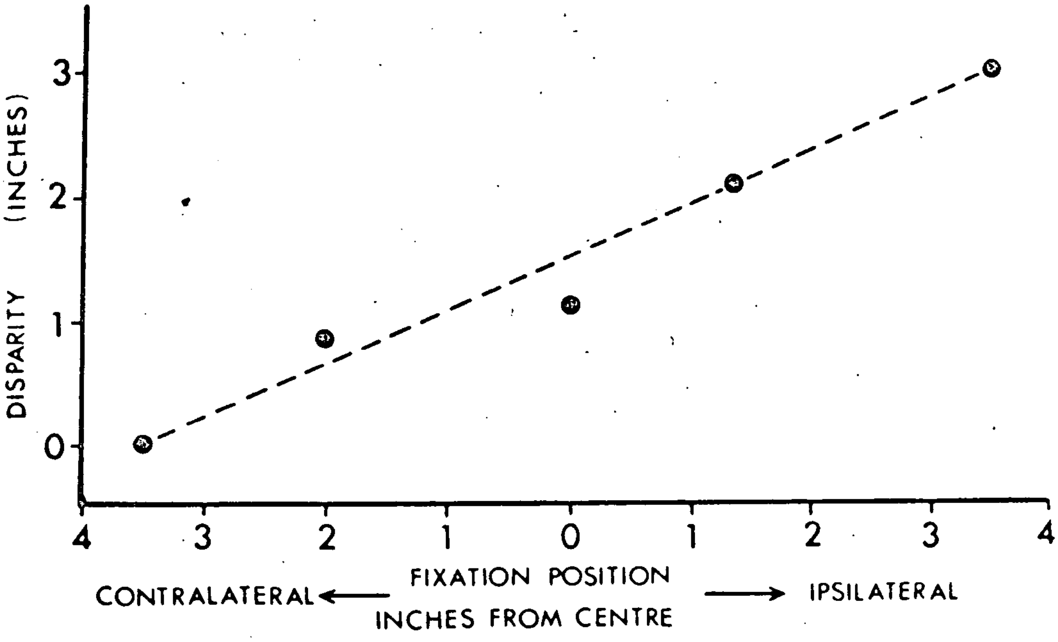

Figure 3.7 Observed displacement between the fixation position and the derived position of the pupil centre in neonates.

visual angle at the viewing distance (10 inches) used.[3] The off-axis effect is similar in form to that for the adult, but the magnitude of this effect is slightly larger. The disparites found of the scored position of the centre of the pupil from the fixation position can be explained by reference both to the anatomy of the eye and to the optics involved in this particular corneal reflection technique. A full consideration of these factors is given in the next chapter.

Footnote[3] It should, perhaps, be emphasized that this precise figure will not be applicable to all neonates. Because of the probabilistic nature of the data presented here it is not possible to accurately specify the intersubject variability in neonates. However, since the fixation peaks were all within 5° of the average in all conditions, it seems likely that a standard correction based on these data will be accurate to within ± 5° for most, if not all, neonate subjects.

CHAPTER 4

CAUSES OF THE DISPARITY OF THE PUPIL CENTRE FROM THE TARGET POSITION

The first use of the corneal reflection technique of eye position recording with neonates was by Salapatek and Kessen (1966), and the technique was developed from a method described for use with monkeys by Cowey (1963), and from a less precise method of recording visual preferences described by Fantz (1956). In Chapter 1 a more complete account of its development is given.

It is a particularly suitable method of recording from subjects whose heads cannot be rigidly restrained, as small head movements do not substantially affect its accuracy. Cowey (1963) discusses three other commonly used systems of finding the locus of fixation with human subjects: the "Dodge" corneal reflection method; electro-oculography; and the use of an attachment to the eye. Although these methods, when properly used, can give a much more precise measure of the locus of fixation than the present technique, they are unsuitable for use with newborn babies for two main reasons, (1) head movements need to be fairly rigidly restricted, and (2) the attachment of electrical hook-ups or other devices close to, or on the eyes is either impossible or would reduce a placid baby to an uncooperative one. Cowey (1963) gives fuller details concerning the unsuitability of these other methods for use with monkeys. The same arguments apply to newborn babies.

A simplifying assumption made by other researchers who have used the present recording method with neonates is that the centre of the pupil represents the line of sight. A fuller discussion of this is given in Chapter 1. However, the empirical data presented in the previous two chapters provide strong evidence that the portion of the stimulus that is being fixated is only rarely imaged in the pupil centre. This necessitates the application of various correction factors when measuring fixation positions by comparing the corneal reflection of the target to the pupil centre. These corrections can be taken directly from the empirical data presented and, in the case of adults for whom reliable figures are available, can be calculated from a knowledge of the eye's anatomy.

In this chapter detailed consideration will be given to the anatomical and optical causes of the described effects. Initially, the details will be given for the adult eye; later, the relevant details for the neonate eye will be presented, with particular emphasis on the differences between the adult eye and the eye at birth. Finally, the implications of these findings for previous research will be discussed.

CALCULATION OF THE PUPIL CENTRE DISPARITIES IN ADULTS

1. Positions of the visual and optical axes of the eye By observing that region of the target which is imaged in the centre of the pupil one is determining the eye's optic axis.[1] The optic axis is the axis of symmetry of the optical system and may be defined as "... the sagittal line passing through the centers of rotation of the refractive optical media of the eye, the cornea and the lens" (Polyak, 1968, p209). However, in the adult the fovea is known to lie some 5° temporal to the point of intersection of the optic axis with the retina (Bennett and Francis, 1962; Davson, 1950; Polyak, 1968). Thus, a centrally fixated point is actually viewed obliquely so far as the optic axis of the eye is concerned, and a line joining the fixated target to the fovea (the eye's visual axis, or the line of

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Footnote[1] Actually, the line through the centre of the pupil does not coincide with the optic axis: it is called the central pupillary axis, and in Fig. 4.1 the ∠DCE is called the ∠ kappa. For present purposes it is assumed that the ∠ alpha and the ∠ kappa are the same.

vision or gaze), will deviate from the optic axis by 5°[1A]. This effect is equal and opposite in the two eyes; when binocularly viewing an object the two eyes will deviate optically by approximately 10° in the adult. The effect is illustrated in Figure 4.1 for the left eye (part B of Fig. 4.1 is an enlargment of the relevant part of A). With the observer located behind the target position, the centre of the pupil (point D in Fig. 4.1B) will appear displaced to the left of the position of the corneal reflection of the target within the pupil (point E). The distance DE is calculated as follows: angle alpha (the angle DCE in the Figure) is the deviation of the optic axis from the visual axis; the distance AC is the radius of curvature of the cornea; DE lies along the plane of the entrance pupil (the entrance pupil is the image of the actual pupil formed by rays which have been refracted at the cornea, and seen by the observer). Figures for the adult eye are well established: alpha = 5°, AC = 7.8mm, AD = 2.8mm (figures derived from Bennett and Francis, 1962). Therefore, the distance DE = 5.0 tan 5 = 0.44mm. Thus, in the average adult, when the eye changes its fixation by 5° the centre of the pupil will appear to have moved through 0.44mm.

In addition to this effect, which necessitates a correction when the subject's fixation axis coincides with the observation axis, a number of other possible sources of error are present with off-axis fixation.

Footnote [1A] The visual axis passes through the double nodal point of the eye, this corresponding approximately to the centre of curvature of the cornea (Davson, 1950, p355). The fovea is also known to lie below the point of intersection of the optic axis with the retina. This effect is small - Bennett and Francis, 1962, give a figure of 1.5°, Polyak, 1968, one of 3.5° - and is of a similar direction in both eyes. In discussing the necessary corrections this effect has been ignored.

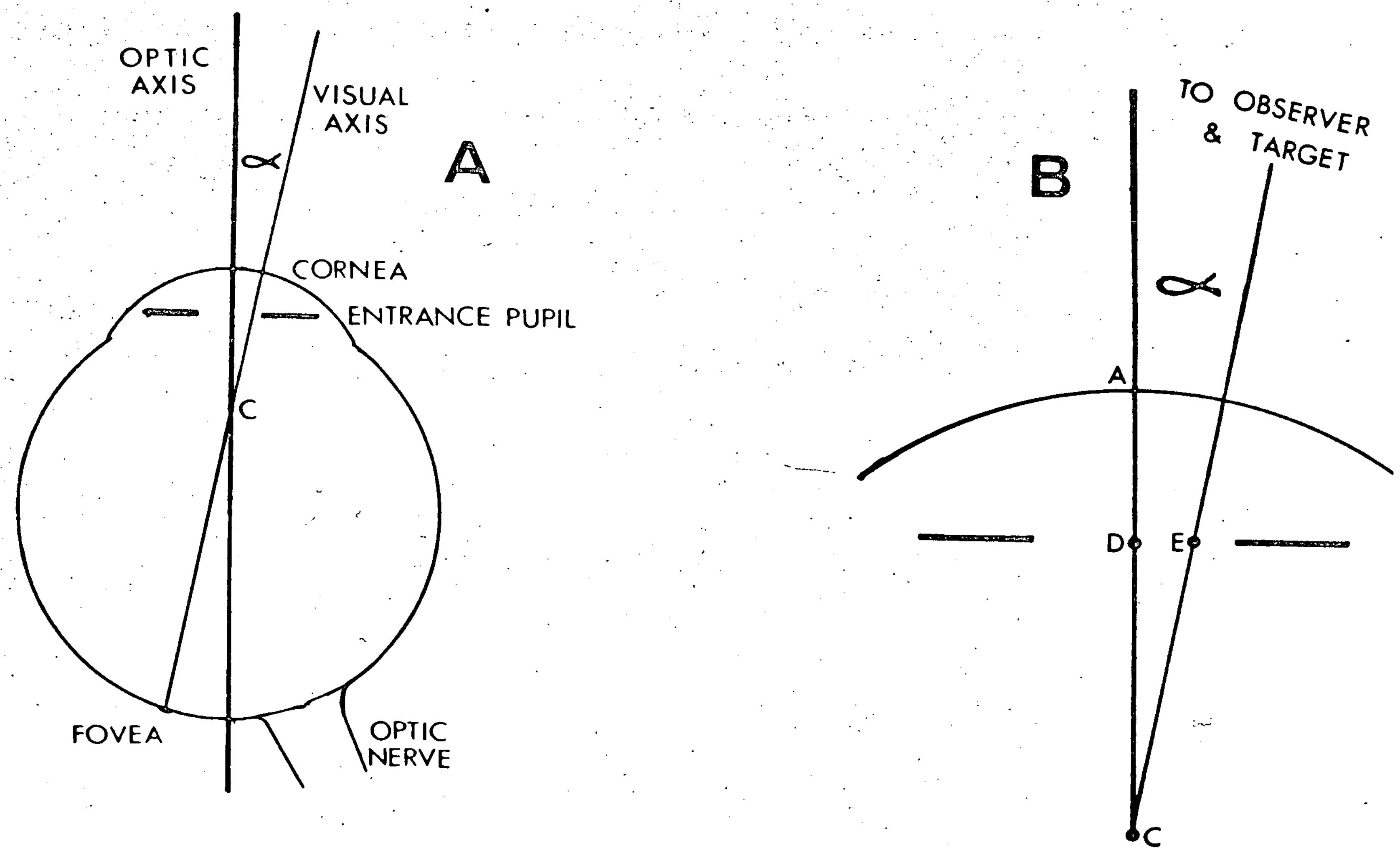

Figure 4.1 The angle alpha and measurement of the difference at the plane of the entrance pupil.

2. Projective Distortion A further effect, necessitating a second correction to the data, is found when the S's fixation point and the observer's location differ. This effect occurs because the position of the virtual image[2] of the corneal reflex does not coincide precisely in space with the entrance pupil, and thus a parallax shift occurs with oblique viewing.

Some slight problem arises here concerning the location of the entrance pupil. As mentioned in the previous section, the entrance pupil is the image of the actual pupil formed by rays which have been refracted at the cornea. It lies in front of, and is larger than the actual pupil, and its position is dependent upon the position of the real pupil. In the unaccommodated eye the pupil lies some 3.6mm posterior to the front surface of the cornea, and the apparent position of the pupil is 3.05mm from the cornea. When the eye accommodates for near vision the lens becomes more convex and the pupil (which is situated in the same plane as the front surface of the lens) is correspondingly displaced from this position towards the cornea. These changes are diagrammed in Figure 4.2. Using the Gullstrand schematic eye, the pupil in the eye focused for an object 11.6cm away is 3.2mm from the cornea, and the figure for the entrance pupil is 2.67mm[3]. The data presented in Chapter 2 are from adults accommodating (presumably) to stimuli at 10 inches. To simplify the calculations it is assumed here that the entrance pupil is, in this

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Footnote[2] The image formed by a convex mirror (i.e., the cornea), is defined as a virtual image because the reflected rays from the mirror appear to come from it (Davson, 1950, p329).

Footnote[3] Calculated from an equation given in Bennett and Francis, 1962, p106.

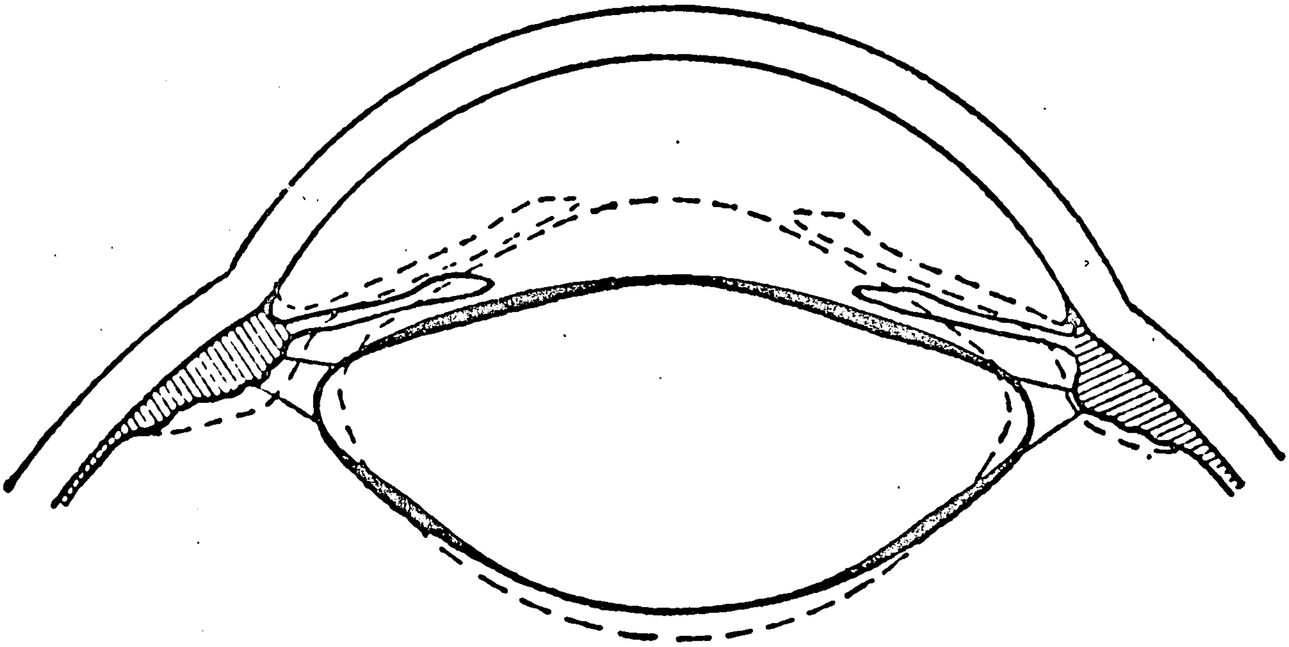

Figure 4.2 Changes in the position of the pupil during accommodation. Full lines indicate the unaccommodated eye, the dotted lines the changes caused by contraction of the ciliary muscle as the eye accommodates to near distances. (From Tansley, 1965, p72).

case, located 2.8mm from the anterior surface of the cornea.

The magnitude of the parallax shift may be calculated with reference to Figure 4.3 (part B of this Figure is an enlargement of the appropriate part of A). Here, the subject is assumed to be fixating a target (T) at infinity, and the observer views at angle θ away from the fixation axis. The observer will see the virtual image of the target which is located at the principal focus, F, but it is now observed along the axis OF and thus will be seen at point G relative to the entrance pupil. If the angle θ is small, it may be shown from the geometry of the figure that F lies 3.9mm behind the corneal surface and, as discussed above, the entrance pupil is located 2.8mm behind the corneal surface. When the angle θ is 20° the effect is given by the distance EG, which is EF tan θ .

Thus, the corneal reflection, previously located at point E in Figure 4.1, has moved through the distance EG (0.40mm) which is equivalent to an additional displacement of 4.6° visual angle. Considering both effects, in this example the reflection of the target is consequently 9.6° displaced from the centre of the pupil (if the observer had moved 20° to the right, instead of to the left, the corneal reflection would be displaced only 0.4° from the centre of the pupil.

3. Oblique aberration As mentioned in the previous section, if a parallel incident ray from a target at infinity is close to the optical axis the virtual image of the target is located at the principal focus, which is midway from the front surface of the cornea to its radius of curvature. However, as the angle between the observer and the fixated target becomes larger the position of the virtual image will approach the plane of the entrance pupil because of oblique aberration.

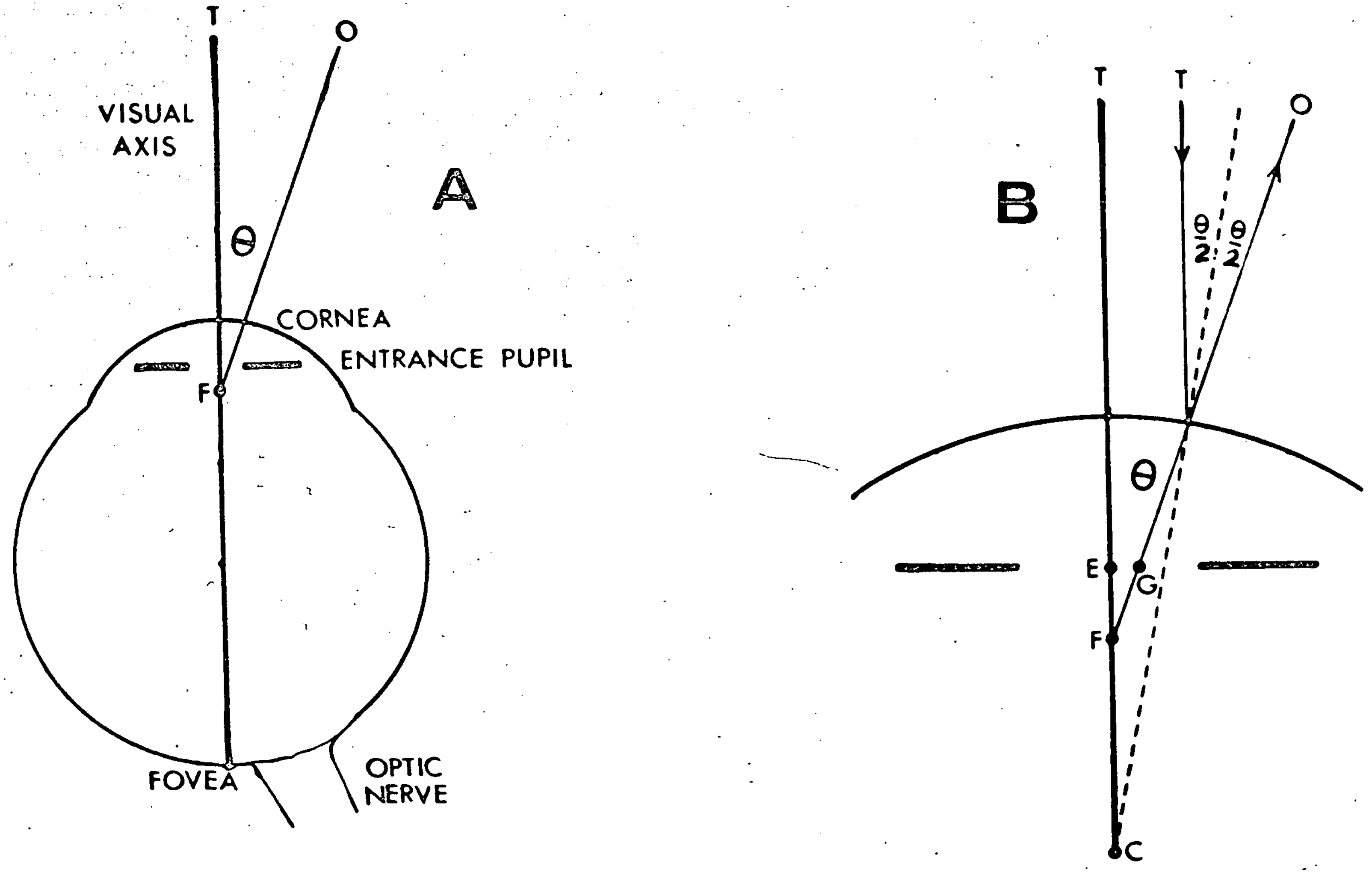

Figure 4.3 Measurement of the parallax effect due to oblique observation.

The geometry of the situation is shown in Figure 4.4. An extreme case of an observer located at right angles to the front surface of a convex mirror is used in this Figure to illustrate the shift in the virtual image, with extremely peripheral viewing, towards the front surface of the mirror. A typical oblique ray will follow the path TBO. Because of spherical aberration this path does not intersect the optical axis of the system at the principal focus, F, but at point F', which is the new location of the virtual image of the target. Oblique aberration will act to reduce the error calculated under projective distortion. When the observer is positioned 20^o from the subject's fixation position the location of the virtual image may be found as follows: the radius of curvature of the cornea (the distance BC, and also the distance AC, in Fig. 4.4) is R (7.8mm); the distance CF' is $\frac{1}{2}$ R sec 10 = 3.94mm. Thus, the virtual image is .04mm closer to the entrance pupil, and in this example the actual error resulting from projective distortion is 4.4^o, rather than 4.6^o as calculated in the previous section, which is an effect of only $.2^o$[4]. However, as the observer's angle increases, the virtual image will increasingly come to approach the entrance pupil (for example, when the angle is 30^o the virtual image, calculated in this manner, is .1mm anterior to the principal focus). This effect will, however, be compensated to some extent by a displacement in the same direction of the more distant edge

---

Footnote[4] The calculation of this effect was as follows. Since CF' = 3.94, the distance from the virtual image of the target to the entrance pupil is 1.06mm (i.e., .04mm less than the distance found by a direct calculation of projective distortion).

Thus, the distance EG, calculated under projective distortion with reference to Fig. 4.3, is EF' tan 20 = 1.06mm x .364 = .386mm. As a displacement of .44mm at the plane of the entrance pupil = 5^o, the displacement resulting from the combined effects of projective distortion and oblique aberration is $5 \times \frac{.386^o}{.44} = \underline{4.4}^o$.

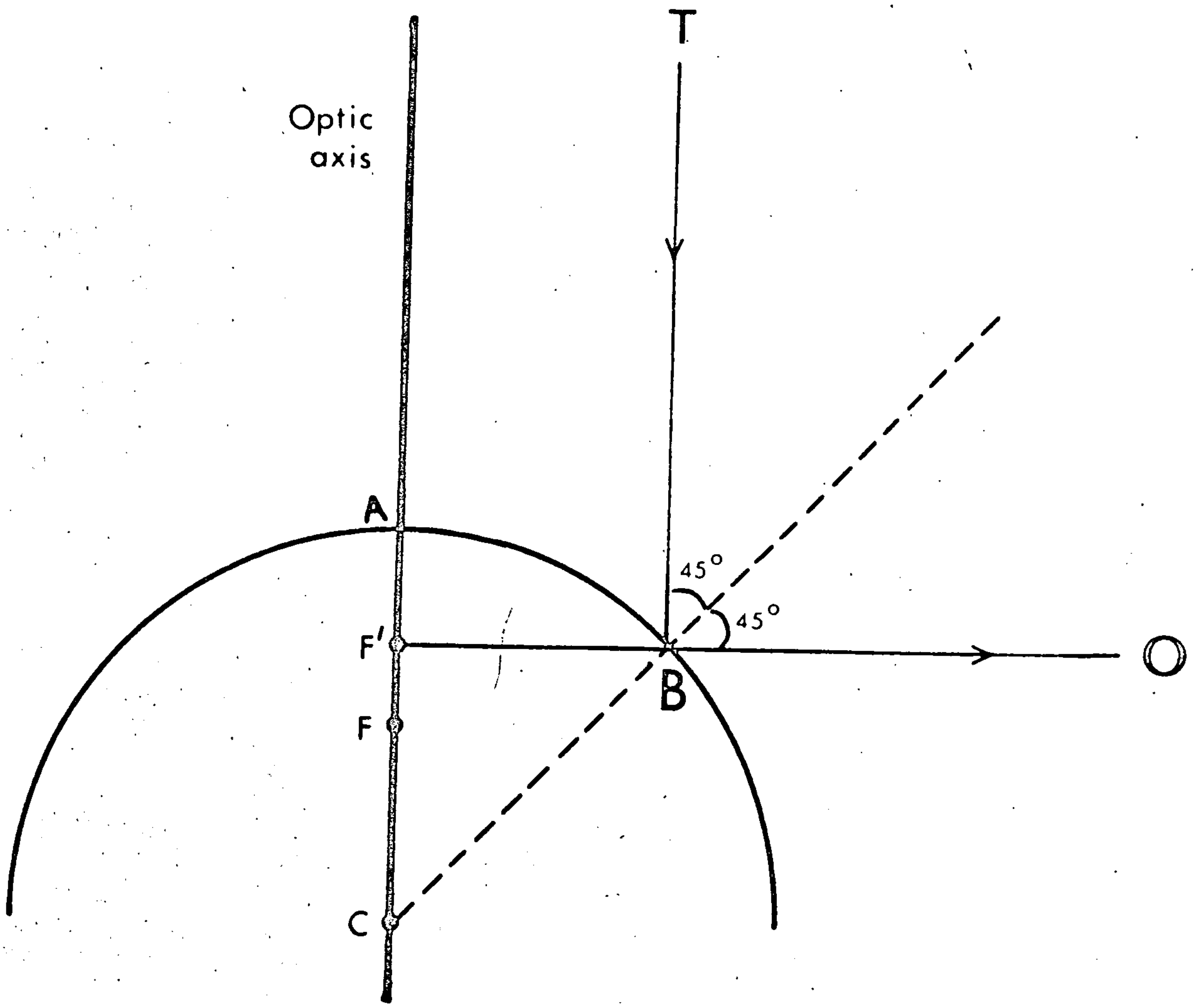

Figure 4.4 Diagram to illustrate the change in position of the virtual image due to oblique aberration.

of the pupil through oblique aberration.

4. Asphericity of the cornea For oblique observation, as shown in Figures 4.3 and 4.4, a peripheral region of the cornea forms the reflecting surface. It is known that the radius of curvature of the cornea increases towards the periphery, and this will cause a displacement of the observed position. The degree of asphericity is known to be very small (Collignon-Brach, 1969); it has not, however, been possible to evaluate the magnitude of the effect for the present recording technique.

5. The effect of head movements The effect of head movements was empirically tested as described in Chapter 2 (testing sequence 7). Cowey has demonstrated (1963, pp85-86) that the position of a corneal reflection relative to the centre of the pupil remains virtually unchanged if the eye maintains its fixation but the head moves a small amount, provided that the source of reflection is reasonably far from the eye. This conclusion, however, only holds true when the plane of the stimulus coincides with the plane of the marker lights. In the present recording apparatus a head movement of $\frac{3}{4}$ inch from centre causes a small displacement of the scored position of the centre of the pupil amounting to between 1 and 2° visual angle. The cause of this effect is shown in Figure 4.5. The plane of the marker lights' filaments (LL) is some $4\frac{1}{2}$ inches behind the stimulus plane (SS). When the subject with his eye (E) in the central position fixates a point B at the centre of the stimulus plane an extrapolation of the fixation line shows that the subject will be scored also as fixating within the centre of the marker lights (point F), and no distortion will result. However, if the eye moves to the left of its previous position to E', and continues to fixate point B, the subject will appear to be fixating point F' at the plane of the marker lights (and

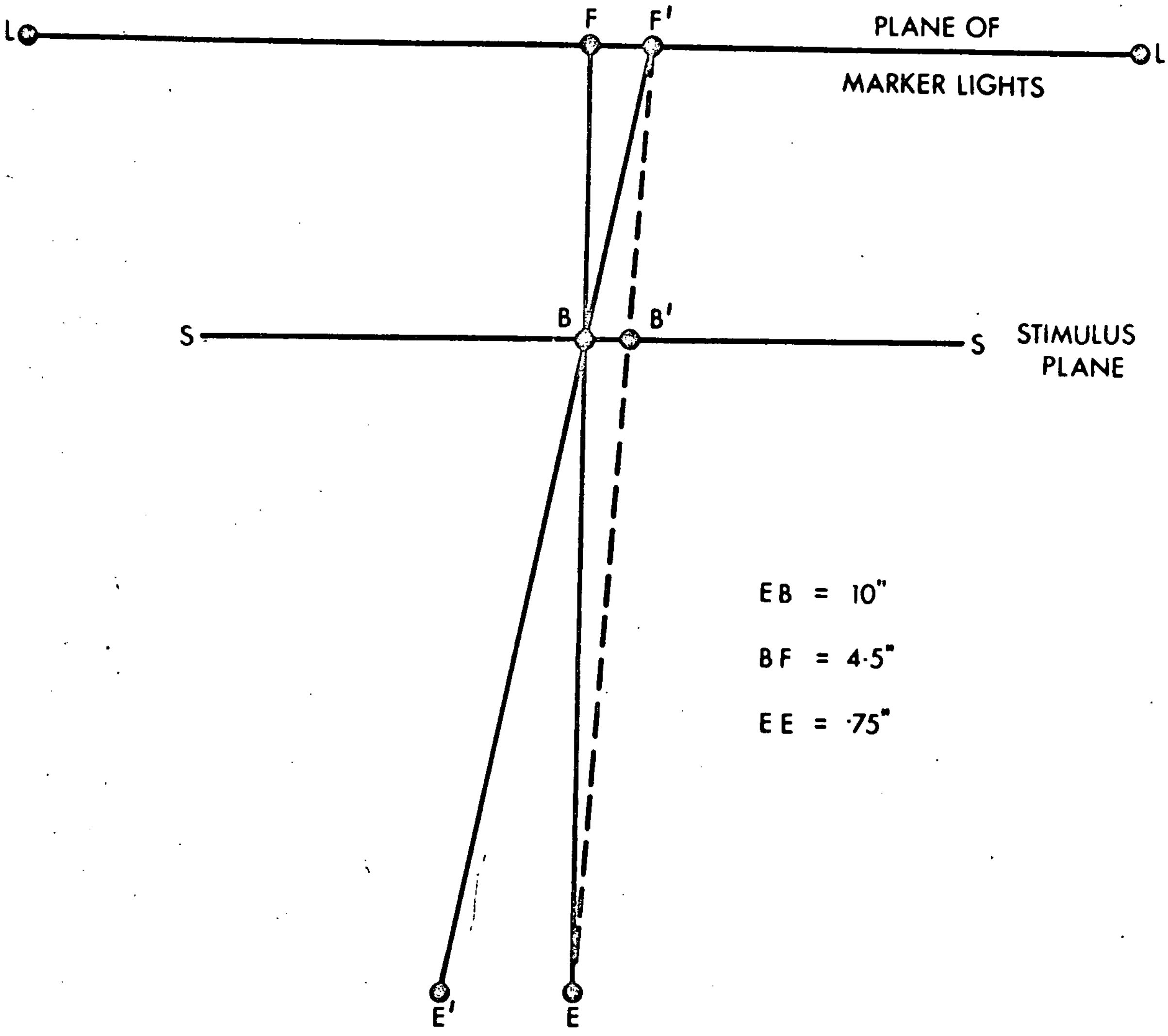

Figure 4.5 Diagram to illustrate the effect of head movements on the scored position of the pupil centre.

To find the angle BEB':

(1) Distance FF' = EE' x $\frac{BF}{EB}$ = .75 x $\frac{4.5}{10}$ = .3375"

(2) Therefore, tan angle BEB' = $\frac{.3375}{14.5}$ = .0233

(3) Thus, angle BEB' = 1.33°

hence to be fixating point B' at the stimulus plane). The magnitude of the resultant effect is found by determining the angular change in fixation position the eye at its original locus (E) would have had to make to fixate point B' at the stimulus plane - the angle BEB' which, when the eye moves $\frac{3}{4}$ inch from centre, is 1.33°. Thus, when both of the newborn's eyes are photographed simultaneously, inferring the stimulus position within the marker lights will be in error by this amount, the effect being equal and opposite for the two eyes. The magnitude of this effect has been calculated for a subject fixating a central region of the stimulus. The effect will, however, be of similar magnitude for fixations throughout the stimulus field.

CONCLUSION The results from the testing sequences with adults may now be examined in the light of these effects. The deviations found for central observation are satisfactorily explained by the inclination of the optic axis to the visual axis. With regard to the off-axis effects several factors can be seen to be at work. For fixation positions deviating an amount up to, say, 20° from the camera's (or observer's) position - the range within which the experimenter is usually most interested - the calculations described under projective distortion predict an error of position, in the direction found, of up to 5°.

As a direct illustration of the effects, in Figure 4.6 are shown two photographs taken of the same adult subject who was asked to fixate an unscreened light bulb. In part A of this Figure the photograph was taken from the right of the subject's fixation point. Note that the reflection of the light occupies the pupil centre of the right eye, but that the pupil centre of the left eye is displaced to the left. In part B of the Figure the photograph was taken from the left of the fixation point. Although the subject had not altered his locus of gaze

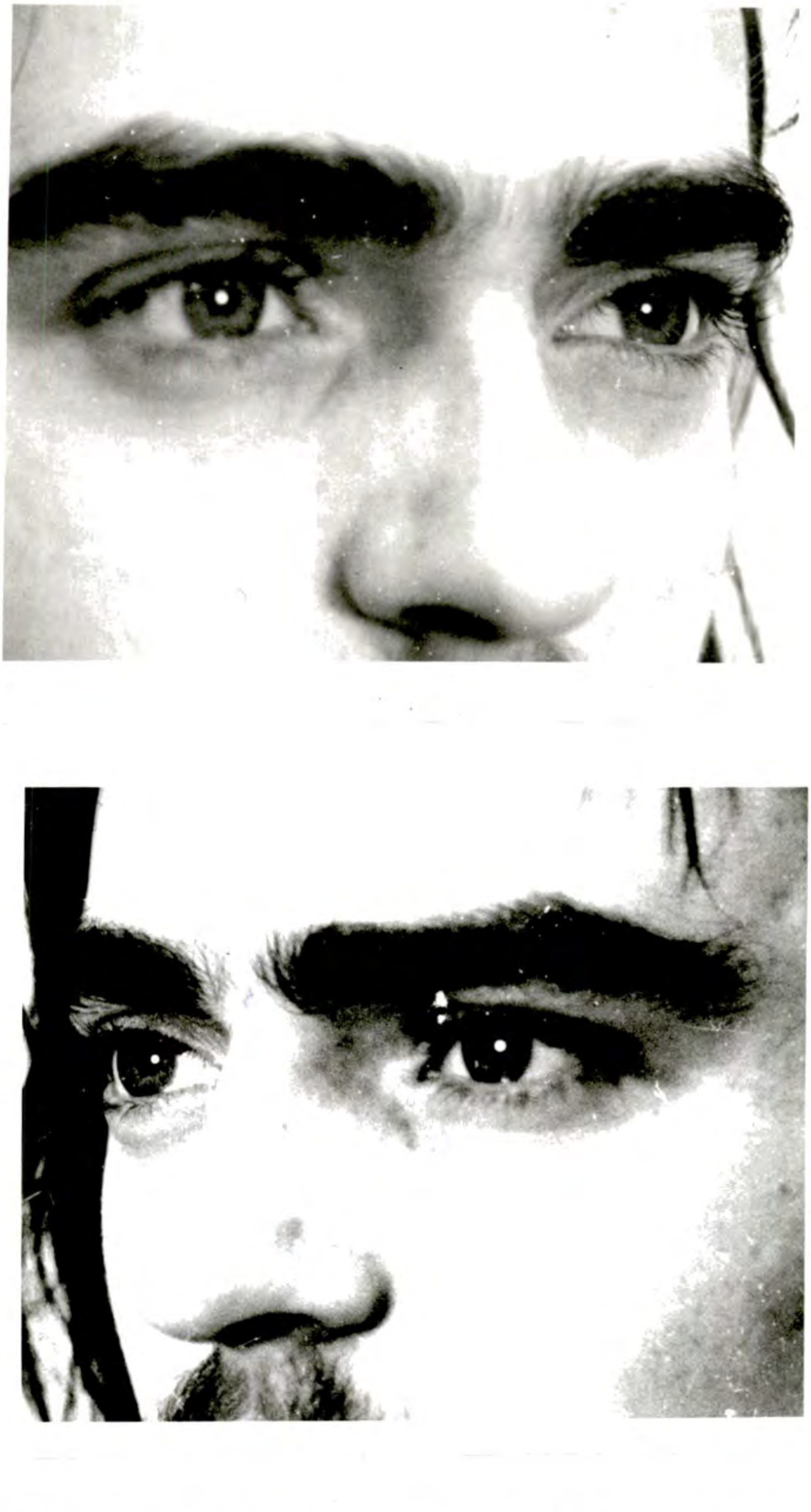

Figure 4.6 Photographs of an adult binocularly viewing an unscreened light bulb. In A (above), the photograph was taken from the right of S's fixation point, and in B (below), from the left. The corneal reflections of the target can clearly be seen.

the corneal reflections in the eyes can be seen to have shifted as a result of the shift in the observer's position. The reflection of the light is now displaced from the centre of the pupil of the right eye, and has moved to occupy (approximately) the pupil centre of the left eye.

With observation angles greater than 20° theoretical calculation of the expected deviation becomes suspect owing to the difficulty of quantifying the other causes of error described, none of which, however, have significant magnitude for the range in which we are interested. After eliminating the disparity resulting from the deviation between the optic and visual axes the empirically determined extent of the off-axis effect is shown in Figure 4.7 for adults (broken line) and neonates (filled line).[5] The expected magnitude of this effect in adults has been calculated, taking into account the effects of projective distortion and oblique aberration, for observation positions differing from the fixation position by 10° and 20°. These magnitudes are shown in Figure 4.7 (filled circles) and are very close to those observed.

The magnitudes of both the central effect and the off-axis effect, shown in Fig. 4.7, are larger in neonates than adults. Obvious differences exist between the adult and neonate eye, which may account for these larger effects. These differences are considered next.

Footnote[5]. This figure is derived from the data presented in Figs. 2.9A and 2.9B (Chapter 2), and Fig. 3.7 (Chapter 3).

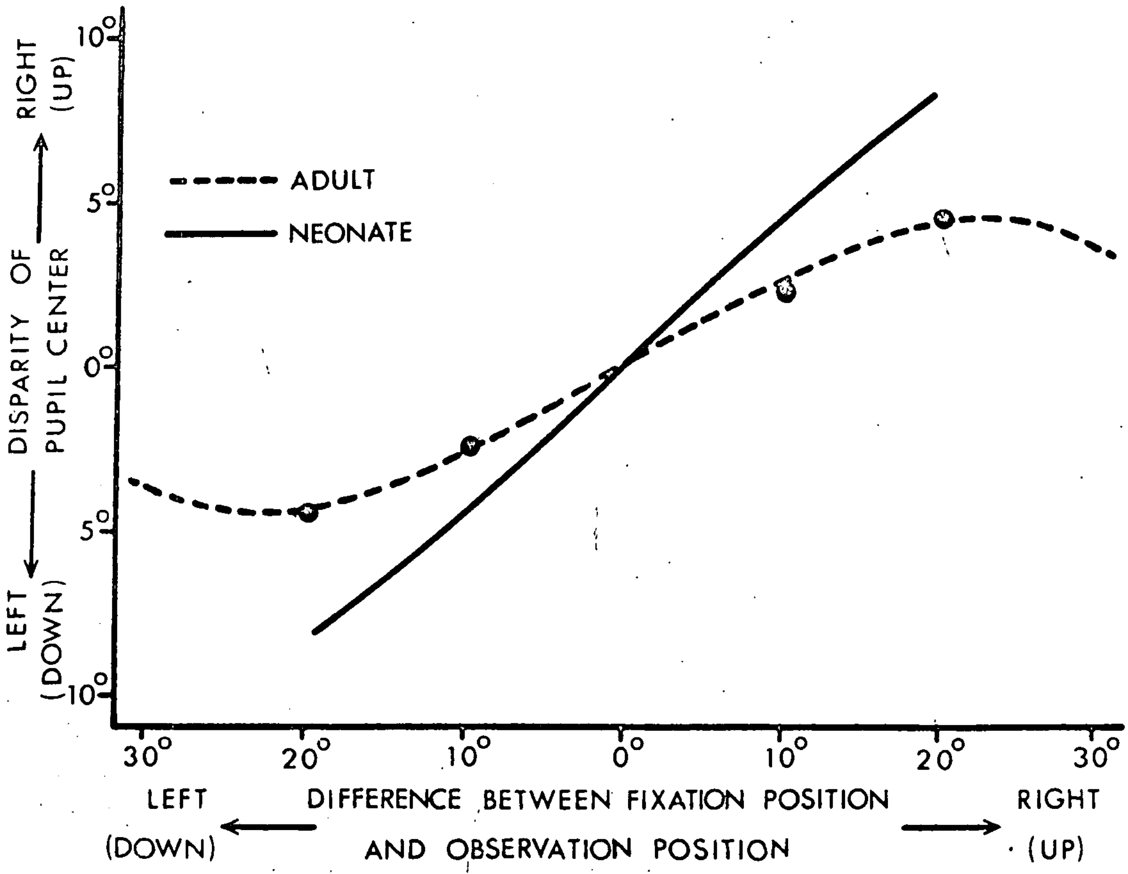

Figure 4.7 The magnitude of the parallax effect due to oblique observation, in adults and neonates.

CALCULATION OF THE PUPIL CENTRE DISPARITIES IN NEONATES

1. Positions of the visual axis and the optic axis The most recently available report concerning these variables is found in Mann (1964), who states that "... the line passing through the centre of the cornea and lens will at birth strike the retina at a point between the fovea and the disc ... as growth proceeds this inequality disappears and the optic axis is displaced laterally until it reaches the fovea" (p41). This indicates that a similar or slightly greater effect is present in neonates, and that the central disparity found of $8\frac{1}{2}^{\circ}$ fits well with the anatomical data, although it seems that Mann is unaware that the optic and visual axes do not normally coincide in the adult.

In view of the dispute over the findings (discussed in the next chapter) it is relevant to trace the source of Mann's information. The anatomical findings were first given by Merkel and Orr (1892). The following passages are taken from their report:

> There is another remarkable discovery, that is that the visual axis, i.e., the line which connects the top of the cornea with the fovea centralis, has a completely different position in the newborn than in the adult. If one superimposes the visual axes one can observe that the eye of the newborn is oriented obliquely when compared with the adult's in such a way that the lateral side of the frontal corneal surface does match pretty neatly with the corresponding surface of the adult's cornea, but the medial side comes to lie well anterior to that of the adult.
>
> To our surprise we found that the fovea centralis was located as far away from the optic nerve entrance in the newborn as in the adult, which means that there is no further growth between these two points later in life.
>
> In the further growth of the eye, therefore, the medial half of the eye will grow more, in proportion to the growth of the whole body, and the lateral side will have a retarded growth. This is natural since, as already

> discussed, in the newborn the area from the papilla to the macula is completely developed. The stronger growing nasal side pushes the cornea and its related parts during growth more and more lateralwards, so that eventually the crest comes to stand exactly over the fovea centralis, thus producing its definite position.
>
> On the 22nd day after birth the eye is virtually the same as the adult eye. (Merkel and Orr, 1892, from pp279, 291, 293 and 295: translated from the original German by Mrs. U. Delius).

These passages give essentially the same information as does Mann. Although various authors have subsequently restated their findings, either in whole or in part, (i.e., Keibel and Mall, 1912, p257, Wolff, 1961, p432, Ellerbrock, 1963, p84, and Mann, 1964), no other anatomical data (so far as the present author is aware), have been reported that are relevant to this issue.

Clearly, some points in this account by Merkel and Orr are in error. As discussed earlier the visual and optic axes do not coincide in the adult: from the research findings reported in this thesis the angular deviation of these two axes changes from $8\frac{1}{2}^{\circ}$ to 5° from the average newborn to the average adult eye, a decrease of only $3\frac{1}{2}^{\circ}$. In fact, Merkel and Orr's report that the axes coincide in the 22 day old infant was based on only one subject: because of individual differences, data from such a small sample cannot be reliably generalized.

It seems highly likely that this decrease in the angle alpha can be accounted for simply by the growth of the axial length of the eye with age. Figure 4.8 is a schematic diagram of a horizontal section through the adult and neonate eye to illustrate this. From birth to adult life the eye grows 3.25 times - a change in volume which parallels that of the brain, which grows 3.76 times. The body, on

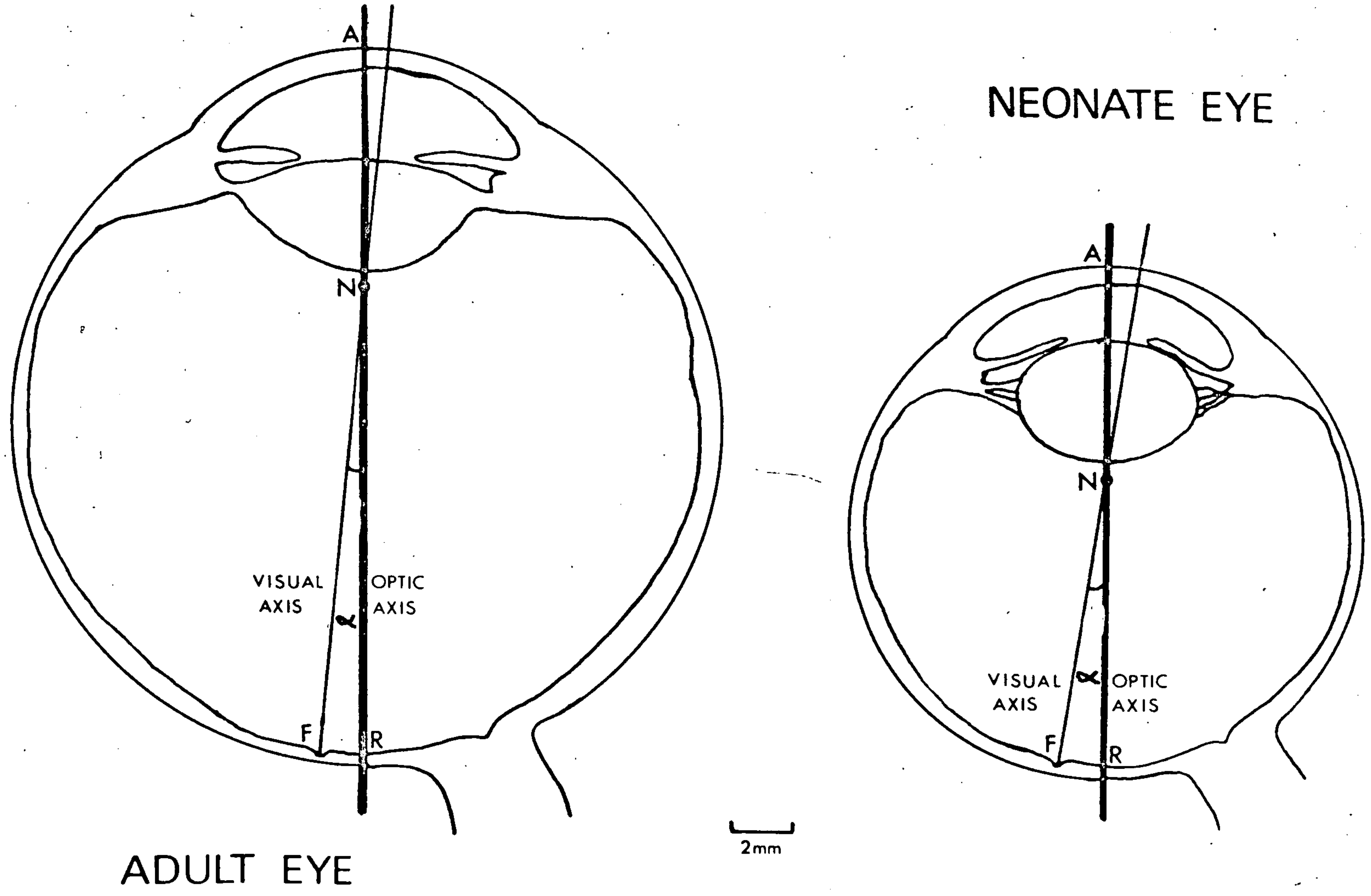

Figure 4.8 Schematic horizontal sections through the (left) eyes of the adult and neonate (to scale and magnified), to illustrate differences in gross size, in the shape of the lens, and in the depth of the anterior chamber. Primary sources: Larsen (1971A, 1971B, 1971C) and Bennett and Francis (1962).

the other hand, increases 21.36 times (Wolff, 1961, p432). The lens is rounder than in the adult, and on account of its anterior bulging the anterior chamber is shallow. The cornea is relatively large, its diameter (10mm) being only slightly less than that of the adult (11.6mm). The axial length of the eye (the distance ANR in Fig. 4.8) is approximately 24mm in the adult (Hirsch, 1963; Bennett and Francis, 1962), and is 17mm in the neonate (Hirsch, 1963; Larsen, 1971A, 1971B and 1971C). The radius of curvature of the cornea is 7.8mm in the adult; in the neonate it is 7.0mm (an average figure given by Luyckx, 1966). Thus, in Figure 4.8 the distances AN and NR are, respectively, 7.8mm and 16.2mm in the adult, and 7.0mm and 10mm in the neonate.[5A] In the adult the angle FNR (angle alpha) is 5°; this means that the distance from the point of intersection of the optic axis with the retina to the fovea (the distance FR) is, in the adult, 16.2 tan 5 = 1.42mm. If the distance FR were the same in neonates the equivalent angle alpha can be found by the following equation: tan alpha = $\frac{FR}{NR}$. Angle alpha would therefore be 8.1°. The close correspondence of this result with the angular deviation of the optic and visual axes found with neonates (8.5°) suggests that the larger angle alpha in newborns is not a surprise finding, but is predictable from the anatomical features of the eye. Furthermore, it strongly suggests that, not only is the distance from the disc to the macula the same in the newborn eye as in the adult, but that the distance from the point of intersection of the optic axis to the macula is the same also. This contradicts the suggestion that the optic axis is displaced laterally as growth proceeds, i.e., it would seem that the vertical growth of the eye is symmetrical around the optic axis.

Footnote[5A] These figures are approximate.

2. Projective Distortion The parallax effect previously described for the adult eye results from an interaction of the optics of this particular corneal reflection method with two anatomical variables: the radius of curvature of the cornea and the depth of the anterior chamber. As mentioned in the previous section, the radius of curvature of the cornea is large (7.0mm, which corresponds to a power of 47.5 diopters), and the anterior chamber is shallow compared with the adult eye. Larsen (1971A) gives a figure of 2.38mm (SD 0.12mm) for the anterior chamber depth in newborns. If Larsen's figure is correct the entrance pupil will be located 1.96mm behind the cornea.[6]

Using these figures a calculation of the parallax effect in newborns suggests that, when the observation axis is 20° inclined to the fixation axis, an additional displacement of 6.5° should result. This is slightly less than the 8° found (Fig. 4.7). It is likely that this small disparity of 1.5° between the expected and the observed effect is due to the state of accommodation of the neonates' eyes in the experiments reported in Chapter 3. As has been noted, accommodating to near distances decreases the radius of curvature of the anterior surface of the lens which reduces the depth of the anterior chamber and pushes the pupil (and hence the derived location of the entrance pupil) closer to the cornea. This acts to increase the extent of the parallax effect.

Larsen (1971A) was aware of the changes occurring as a result of accommodation, and was concerned with changes in the anterior chamber depth resulting from paralysis of accommodation. In order to study this more closely he measured the right eyes of three newborns, first

Footnote[6] The position of the entrance pupil is calculated using an equation given in Bennett and Francis, 1962, p106.

without, and then with, cycloplegia (paralysis of the accommodation system), and found no differences in the mean values for the depth of the anterior chamber. However, it is not known to what distance the newborns were accommodating when the measures without cycloplegia were taken, so these data seem equivocal with regard to the present problem. Larsen does in fact conclude that "the values must, however, be interpreted with caution, as the unrest appearing in this age group on repeated measurements may influence the results" (1971A, p258).

The scant available data on changes in newborn accommodation, discussed in Chapter 1, are somewhat equivocal. It does seem, however, that newborns are able to accommodate to near distances. In order for projective distortion to fully account for the parallax effects found, the entrance pupil would need to be approximately 1.3mm behind the front surface of the cornea. This would require the depth of the anterior chamber to be reduced to between 1.6 and 1.7mm. Certainly, there is no evidence to suggest that this reduction in depth could not take place when the newborn accommodates to near distances.

Of course, this slight discrepancy between the calculated and the found effects may be because the empirical data are in error in presenting the extent of the error; the individual differences found and the necessarily inferential method of determining the magnitude of the effect for each subject suggests that this could be the case. Whatever the explanation, the discrepancies are small enough for them not to grossly interfere with the accuracy of the analyzing procedure if a correction based on the empirical data is applied.

3. <u>Other Effects</u> The other causes of error discussed in the earlier

sections take effect only with fairly extreme peripheral fixations; they will not be considered here in detail as they are likely to be of similar magnitude in the neonate as in the adult eye. A possible exception concerns oblique aberration. With respect to the curvature of the cornea Duke-Elder (1963, p307) reports that "... in the newborn ... contrary to its condition in later years, it is more curved peripherally than centrally" (also reported in Wolff, 1961, p432). Thus, there is a possibility that the effect due to oblique aberration may be slightly more pronounced in the neonate.

The "binocular effect" considered earlier is a consequence of the recording apparatus, and will therefore be identical in neonates.

DISCUSSION

The greater magnitude of both the central and off-axis effects found in neonates is satisfactorily explained by the angular difference between the visual and optic axes of the eye, and by projective distortion. Consequently, it seems valid to conclude that the newborn babies from whom results were obtained were fixating the stimulus in all conditions with central (i.e., foveal) vision, and that the disparities found are a true indication of the effects in neonates. It is essential, therefore, because of the magnitude of the effects, to take account of these deviations when using this technique.

Those researchers who have used the method with newborn subjects do not appear to have considered the effects, although the non-correspondence of the visual and optic axes was referred to by Cowey and Weiskrantz (1963). It is felt that the existence of these disparities may account, at least in part, for instances of "off-contour" looking and nonconvergence reported by previous investigators. A review of these findings was presented in Chapter 1.

Salapatek and Kessen (1966, 1969) have reported instances of visual fixation by the newborn in which scanning was displaced from the actual stimulus figure by several degrees. Their explanation of this off-contour looking supposed that the unrecorded eye was directly fixating the target while the recorded eye moved conjugately with the unrecorded eye but had a line of sight displaced from target. The monocular conditions of viewing adhered to in the present experiments with neonates precludes a similar interpretation of the findings. Haith (1968; also reported in Kessen, Salapatek and Haith, 1972) also confined the neonate to monocular vision and found that, when a vertical edge was presented 3 inches left of centre, fixations were mostly within ± 1.5 inches of the edge; when the edge was presented 3 inches to the right, however, fixations peaked to the right of the contour. In this study the infant's right eye was always the one photographed. Kessen et al. (1972) offer two possible explanations for this off-edge viewing: "The tendency of infants to look to the right of the right edge and not to show a significant increase in right-edge crossing during experimental trials may depend on either of two factors. First, our measurement procedure may, for some unknown reason, have produced more right bias in the right visual field than in the left visual field. Such a bias would also, of course, limit our ability to detect actual edge crossings. Such an interpretation seems unlikely because calibrations in adults showed no such bias. The second possibility is that babies have difficulty in holding the eye in a fixed position on the temporal side. Haith (1967) reported that television records of newborn eye activity revealed that the eye often appeared to go out of control, into nystagmic jerks, during blank-field control trials and almost always on the temporal side" (Kessen et al., 1972, p19).

However, since the disparity of the centre of the pupil from the fixation point will be greatest when the right eye looks right (or when the left eye looks left), this study is in agreement with the present findings. The most plausible explanation of the effect would therefore seem to be their first one - that in both of their stimulus conditions the newborns were fixating the edge with central vision, but that their scoring procedure was at fault. Analysis of their second possible explanation will be left until the next chapter, where their more formally presented objections to these findings are discussed.

Consequently, it is suggested that evidence of off-contour looking may be an artefact resulting from inappropriate scoring procedures. If this applies to monocular and binocular viewing conditions the implication is that the neonate may be capable of convergence. Wickelgren (1967, 1969) photographed both of the baby's eyes and, using a method of analysis derived from the earlier scoring procedures, found that the neonate never converges, the two eyes looking various distances apart at the stimulus plane. It was invariably the case that the left eye looked further left than the right eye. She suggests that "... observer judgments based on one eye, particularly when both eyes are open, are unlikely to be a meaningful indication of newborn stimulus discrimination and preference" (1967, p84). This statement would not, of course, be appropriate if the neonate does show convergence. A possible reason for the newborn's apparent inability to converge might, she suggests, be related to the structure of the eyes. During embryonic development the eyes swing inward from the side of the head toward the front (Mann, 1964; Duke-Elder, 1963). The orbital axis makes an angle of 71° at birth; further growth reduces this to 68° in the adult. Wickelgren suggests that the further growth may be necessary before newborns can bring the eyes inward enough to converge consistently on a stimulus. (1967, p83). Two pieces of evidence argue against this. The first is that the larger angle alpha in newborns permits the eyes to be more optically divergent in newborns than in adults, whilst maintaining binocular fixation. The second is that, parallel with the change in the orbital axis, other growth processes alter the positions of the eyes: specifically, the eyes move farther apart, due to growth of the skull and an enlargement of the orbits, so that the interpupillary distance increases from 1½ inches in the newborn to 2¼ inches in the adult. As the eyes separate they also tend to diverge, since it increases the mechanical advantage of the lateral rectus muscle and lessens it for the medial rectus (Ellerbrock, 1963, p88; Wolff, 1961, p433).

On the basis of the present findings one would expect the pupil centres of the two eyes to be oriented some 17° apart if the neonate is converging. In table 4.1 are given the average optical divergence of the eyes in newborns reported by Wickelgren (1967, 1969), which range from 2.61 to 5.22 inches at the stimulus plane. These distances have been converted to angular deviations for the different stimulus conditions and for the eye-to-target distances used. These divergences are from 10.6° when the stimulus was striped vs. gray panels, to 25.3° when the stimulus was either a small stationary light or a moving sequence of 3 lights. Given that one may expect to find individual differences in the divergence of the visual and optical axes, none of these divergences reported by Wickelgren are so extreme that the conclusion that at least some of her subjects were converging is untenable.

Because these distortions are large, especially when the observed eye is fixating ipsilaterally, the less precise corneal reflection

TABLE 4.1

The average deviations of the pupil centres, in different stimulus conditions, of newborn Ss, reported in Wickelgren (1967 and 1969)

Stimulus	Eye-to-stimulus distance	Average deviation of pupil centres	Angular deviation of pupil centres
Striped vs. gray	14"	2.61"	10.6°
Red vs. gray (i.e., colour vs. brightness)	14"	5.22"	20.4°
Small centre light	14"	4.35"	17.3°
Stationary light and moving sequences of 3 lights	9.5"	4.5"	25.3°

method of observation first reported by Fantz (1956), and used by many investigators since then, will also be affected. In this method the standard criterion of fixation is the location of the image of the target over the pupil: it will therefore be subject to the same discrepancies of the pupil centre from the target. It is usually not possible to determine what biases the failure to take account of these effects has had on the reported findings from studies in this area: which eye is observed, and how long is spent looking at ipsilateral and contralateral targets are rarely specified. However, three specific examples from the available literature indicate that biases <u>are</u> likely to result with this technique.

Firstly, the optical divergence of the eyes that the present research suggests that one would expect to find if the infant is converging, has been used to substantiate the claim that the young infant is limited to monocular vision. Figure 1.1 in Chapter 1 is a photograph of a young infant presumed (by Fantz) to be fixating the stimulus with the right eye. It seems quite likely, though, that this infant was using well coordinated binocular fixation when viewing the target, and that the image of the stimulus was only centred in the right eye because the photograph was taken from the right of the subject. This photograph is therefore similar to part A of Figure 4.6. If a photograph, under identical circumstances, had been taken from the infant's left, the target reflection might well have been centred in the left eye and the conclusion would have been drawn that the <u>right</u> eye was the non-fixating eye. However, regardless of the implications for binocular fixation, if this interpretation is correct, this example serves to illustrate the point that, using Fantz's technique, unless the position of the observer, and the eye observed are controlled there will be instances where the infant is actually fixating the stimulus but is recorded as looking away.

The final two examples are, as it were, variations on this theme. Greenberg and Weizmann (1971) suggested that 8-week-old infants had difficulty focusing binocularly and, in this situation, observed the lead-eye, defined as "... the eye in which a pattern was reflected wholly within the pupil during the first few seconds of the first trial" (p237). Finally, McKenzie and Day (1972), who presented cubes of various sizes at different distances to their infant subjects, record that "... the infant was deemed to be fixating on the cube when the center of the corneal reflection of the cross.." (marked on the cube) "... was centered in the pupil as observed from a 7mm aperture in the side of the chamber in front of, and to the right of, the subject" (p1109). These two examples further illustrate that there is a likelihood of error if the expected deviations of the pupil centre from the fixation point are not taken into account, and if the parallax shift resulting from a change in the observer's position is not allowed for.

The further experiments reported in this thesis are all concerned to determine whether or not the neonate is able to converge, and to which kinds of stimuli. Initially, though, in the next brief chapter, objections to the reported findings will be discussed.

CHAPTER 5

OBJECTIONS TO THE REPORTED FINDINGS

When the research findings detailed in the previous three chapters were published (Slater and Findlay, 1972A), it was stressed that, because of the magnitude of the effects, a correction factor must be applied to data obtained when using this type of corneal photography.[1] However, Salapatek, Haith, Maurer and Kessen (1972), argue that our findings may be, to some extent, artifactual and, following their criticisms, concluded that "it remains inadvisable to apply such an average correction to individual cases..." (pp496-497). We feel this conclusion to be mistaken: their criticisms, and a more detailed answer to them than was possible in our reply to their paper (Slater and Findlay, 1972B), will be given here.

Salapatek et al. produce three main objections to our findings. These concern, (a) individual differences in the magnitudes of the effects, (b) the speculative nature of the anatomical information concerning the deviation of the visual and optic axes in the newborn, and (c) the possibility that the newborn babies used as subjects may, for at least some of the stimulus conditions, have been fixating with peripheral rather than foveal vision, or may have been fixating predominantly to one side of the stimulus.

It might be noted that their criticisms are often vague, and of a highly speculative nature, and are often unsupported by empirical

Footnote[1] In this paper we were unable completely to explain the effects observed when the fixation axis was inclined to the observation axis (pp354-356). A recheck of these calculations brought to light various errors, the chief of which was a confusion of exit and entrance pupils. Recalculation of these effects (presented in the previous chapter), shows that projective distortion and oblique aberration will satisfactorily account for the observations.

evidence. However, in order to present their objections as faithfully as possible, relevant sections of their note will be reproduced verbatim in consideration of each point.

a) The extent of individual differences Salapatek et al. firstly comment:

> Slater and Findlay are correct in saying this error is present, but it is present on the average, across adult subjects. They are incorrect in implying that we did not consider the effect. By 1966 we had conducted repeated calibrations on five adults, noticed the divergent error, and took it into account in calculating and reporting the average error (±4-5°) of our measure (Salapatek & Kessen, 1966). However, we did not and have not systematically corrected our plots of scanning by individual infants because of large individual differences in our adults' calibration data.
>
> Figure 1 shows this with three normal adults. We asked them to fixate known points (○) spaced at 3-in. intervals on a surface 10 in. distant. We then derived the same fixation points empirically (X, ▲, ▼, or □), by calculating the distance from the center of the pupil to the corneal reflection of whichever reference light (⊗, △⃝, ▽⃝, or □⃝) was closest. Subject 1 shows the large, progressive, ipsilaterally divergent error that Slater and Findlay report. But for subject 2 we obtained a much smaller error; and for subject 3 we obtained an error of relatively constant divergence across the entire field. In the face of such variability, we were reluctant to use or suggest using a general correction factor for individual plots of visual scanning (Haith, 1969; Salapatek, 1968, 1969; Salapatek & Kessen, 1966, 1972; Kessen, Salapatek & Haith, 1972).

(From pp495 and 497. Their Figure 1, p496, is reproduced here as Figure 5.1).

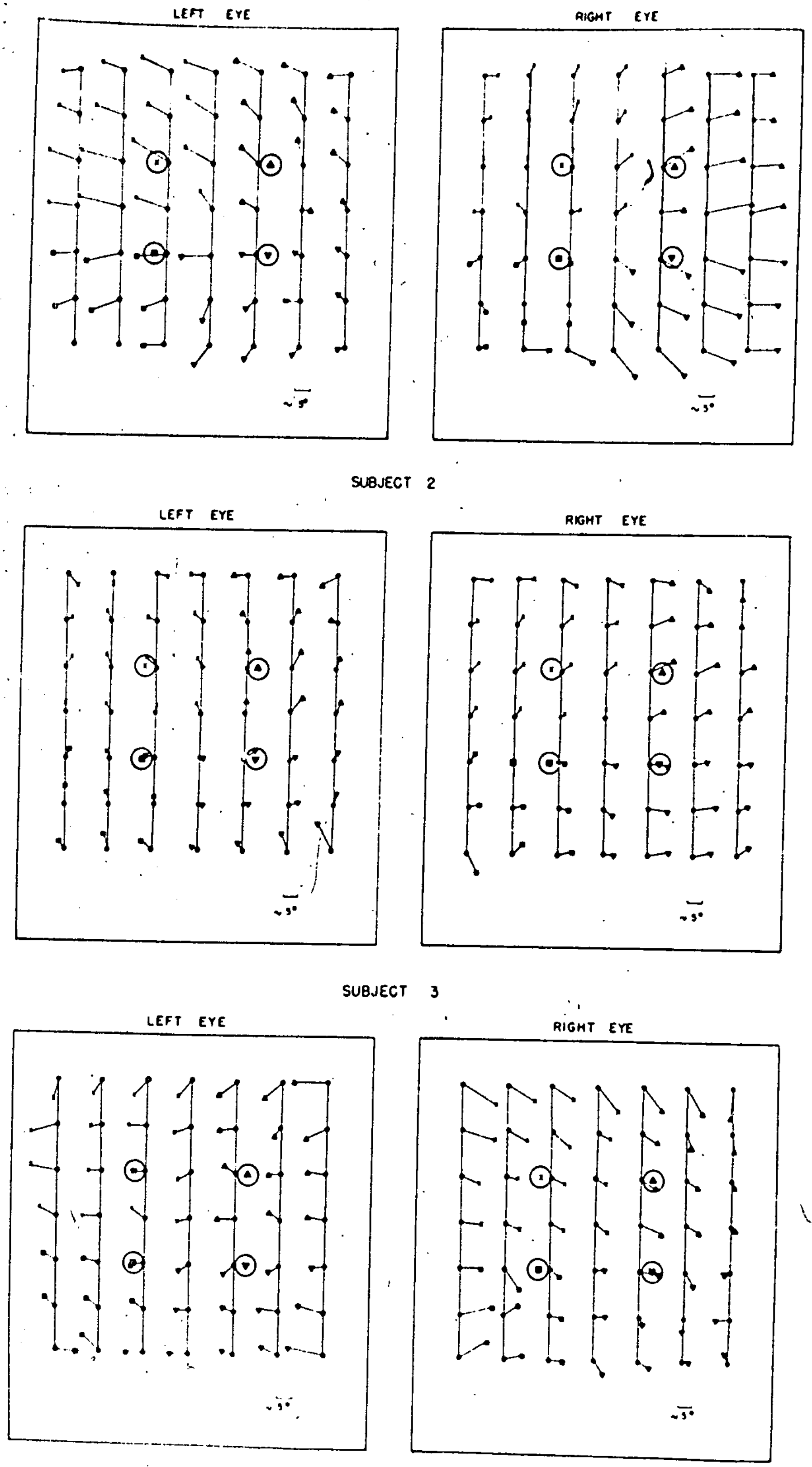

Figure 5.1 From Salapatek, Haith, Maurer and Kessen (1972). The straight lines connecting real fixation points to the scored position of the pupil centre allow the reader to note more easily the direction of error.

This variability is certainly present. In Figure 2.7B2 (Chapter 2), it can be seen that in subject 5 there is a virtual coincidence of the visual and optic axes, and subject 2, in Figure 2.8A1, shows very little off-axis effect. However, when the results were averaged for the adult Ss used, Figures 2.9A and 2.9B were derived (for horizontal and vertical disparities, respectively). A general correction factor based on Figures 2.9A and 2.9B would certainly lead to less overall error in locating the adults' line of sight than would taking the data "raw". The variability that exists may obscure detection of the effects but the presence of these systematic discrepancies seems beyond doubt. This conclusion is encouraged by the close correspondence between the empirical data and the relevant anatomical and optical data (Chapter 4).

A major difference between the calibration data they present in their Figure 1, and the data presented in Chapter 2, concerns the location of the points the adult subjects were asked to fixate. The calibration data of Chapter 2 were mostly derived from subjects' fixations of a grid of points, spaced $\frac{7}{8}$ inch apart, and within 4.4 inches of midline. It is possible (from testing sequence 4), that the effects do not increase substantially for fixations of more extremely placed targets. Their fixation points were spaced at 3 inch intervals along the stimulus plane. Thus, as they were predominantly working outside the range used by the present author, they may have missed some of the effects.[2]

Footnote[2] Calibration data were not collected for extremely placed targets as it was not intended to present stimuli to newborns more than 4" from midline.

Nevertheless, many of the scored positions of the pupil centre, shown in their Figure 1, are clearly displaced much more than 5^o from the target position, and their statement that their method of scoring measures "ocular orientation to within approximately $\pm 5^o$ of visual angle" (Salapatek and Kessen, 1966, p155), is not justified by their own calibration data.

However, they do agree that these effects are present, <u>on average</u>. This being the case, it would seem to be both logical and reasonable to apply an average correction to the data.

b) <u>The visual and optic axes in the newborn baby</u>

> In the second part of their paper Slater and Findlay deal with the error of measurement using corneal reflection with infants. They speculate that it should be greater than in adults, largely because of data cited by Mann (1969, pp40,41) indicating greater discrepancy between the optical and visual axis in infants than in adults. But these data were extracted from dead newborns only. There are no data from live infants, nor are there data dealing with postnatal changes, or variability among infants.
>
> Slater and Findlay attempted to verify their speculations by examining the distribution of fixations around lights placed in different parts of the visual field. And indeed, they concluded that the average error in estimating fixation points is greater in newborns than in adults.

We find that the deviation of the visual axis from the optic axis is greater in newborn babies (approximately $8\frac{1}{2}^o$) than in adults (approximately 4-5^o). Salapatek et al. refer to this as "speculation" based largely on data cited by Mann (1964, p41). In fact, this is a somewhat distorted interpretation of our original presentation. If the neonates are fixating foveally (see below), then the procedure detailed in Chapter 3 provides an objective measure of this deviation. Salapatek et al. contend that Mann's report is unreliable as the newborn babies used were, of necessity, dead. There seems no obvious reason why this fact should systematically bias the anatomical findings as they seem to imply. Indeed, Staflova (1971), in a histologic study of embryonic and newborn eyes, gives reasons for supposing that such measurements on the eye are more reliable than on other organs: "In comparison to other organs, the development of the eye is very stable and is subject to very few individual variations. The eyes ... are intact in about 80 per cent of cases of spontaneous or induced abortion, due to the fact that the sclera serves as a protective barrier for the entire globe from early embryonic stages" (p126). In fact, the larger deviation found of the visual and optic axes of the newborn eye, when compared with the adult eye, can be accounted for by the shorter axial length of the eye at birth.[3]

c) <u>Central and peripheral vision in the newborn: other possible sources of bias</u> Their further criticisms of the findings from newborn babies are based on the possibilities that there may have been bias in the subject loss encountered; that the babies might not have been fixating foveally; and that monocular fixation might differ from binocular fixation.

> However, certain methodological cautions must be made before their conclusion can be accepted.
>
> First, they assumed that the infants looked at the array of lights and did so no matter where the lights were in the visual field. Yet most of the babies in Expt 2 (there is no information on Expt 3) seemed to look

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Footnote[3] Discussed in Chapter 4.

> at the lights in only one-third of their locations; and, as they noted, babies are less likely to look at a contralateral target than an ipsilateral one. Thus, infants' ability and/or desire to look at stimuli may vary systematically with their location in the visual field; part of what Slater and Findlay measured may have been the local accuracy of infants' fixations.
>
> Second, they assumed that newborns fixate with macular vision. However, the macula is relatively undeveloped at birth, so it may not always be used for direct inspection - and its use, in fact, might even vary systematically with the position of the stimulus in the visual field. Thus, some of the "error" Slater and Findlay found may be the result of fixation with the peripheral retina and not a problem of the technique.
>
> But most important, they assumed that infants fixate monocularly in the same way they fixate binocularly. Yet, a comparison of the fixations of a single eye under control conditions (blank, homogeneous field) in a binocular (Salapatek et al., 1966) versus a monocular (Salapatek, 1968) study shows that a newborn's eye fixates much more temporally when the other eye is covered than when it is not. Thus, Slater and Findlay may have measured a divergence which is to some extent unique to monocular fixation, and not just the optical error in the measurement technique.

They correctly point out that the babies used as subjects did not all look at the stimulus lights in all positions. The reasons for this have already been given (Chapter 3), and the author considers subject loss to be an inevitable consequence of this sort of research using newborn babies as subjects. The loss of subjects, for various reasons, in their own studies testifies to this;[4] more importantly,

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Footnote[4] In the studies reported by Salapatek and Kessen (1966), Wickelgren (1967, 1969), and Kessen, Salapatek and Haith (1972), 100 babies in all were used as subjects, and 162 were seen but could not be used.

there is no reason to suppose that the subject loss reported in Chapter 3 was related in any way to the position of the array of lights in the babies' visual field, as they seem to suggest.

There is the interesting suggestion that neonates fixate at times with the peripheral retina rather than foveally. There is no convincing experimental evidence (of which the author is aware) in support of this. One relevant piece of evidence is from Bower (1970), who suggests that infants may fixate along the optic axis (which he places 10° nasally away from the fovea)[5]. Fixation along the optic axis would permit isomorphic retinal registration of distal variables such as straightness. Straight lines projected along the optical axis are retinally straight, and would remain straight during scanning, whereas this is not true of straight lines projected away from the optic axis. At the time of this speculation, though, Bower was unaware that the fovea is also displaced temporally from the optic axis in the adult eye. The results presented in Chapter 3 for the central viewing condition do suggest, however, that newborn babies fixate along the visual axis.

There are, at present, few data available from which an assessment can be made of the relative contributions to infant vision of peripheral and central areas of the retina. Tronick (1972), suggested that the newborn's effective field of view is cone-shaped, peripheral stimuli less than 15° from the line of sight being responded to by a shift in gaze to the peripheral object, and fixation of it. (This study was considered in more detail in Chapter 1). Wickelgren (1967), presented a small blinking light in a central position above her supine newborn Ss, both prior to and between presentation of the experimental stimuli" ... in order to bring S's

Footnote[5] The source of Bower's information concerning the disparity between the visual and optic axes is not given in his paper.

orientation back to midline" (p77). Additionally, Salapatek (1969), discussing the selection of features and figures by newborns, suggested that localization of the feature selected for viewing occurs for most subjects within a few seconds of presentation of the stimulus, and often involves an eye movement across some portion of the figure during the approach to the selected feature. This suggests that "... the newborn is capable of some pattern discrimination in the peripheral visual field, which determines the particular pattern feature that is approached" (p6).

All of these studies indicate that the peripheral retina is functional in directing the newborn's attention to stimuli, which are then brought to the fovea for more direct inspection.[6] The corneal reflection technique itself assumes foveal fixation and if this does not occur the results from studies making use of this technique are liable to be invalid. Salapatek and Kessen (1966), referring to instances of "off-contour" fixations, argue that it is plausible to suspect that "...occasionally the unphotographed eye was on target, and the photographed eye slightly misaligned" (p184). If their criticisms of the findings reported earlier in this thesis are justified, it would be equally plausible to suspect that the

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Footnote[6] When Wickelgren (1969), analyzed newborn's fixations to a single small blinking light, presented in a central position, she reported that the gaze of each S's two eyes typically straddled the light. She suggested that "... since the newborn infant has both eyes open, and since his eyes usually do not converge, peripheral stimuli, which send a similar directional message to both eyes, may well be stronger for him than are central stimuli" (p481). However, as she did not take into account the deviation between the visual and the optic axes, these findings, and the conclusions she draws, are of dubious value, and cannot be taken as indicating fixation by the peripheral retina.

photographed eye was on target, but that S was maintaining a well-directed fixation with a peripheral portion of the retina.[7]

A further point concerns differences in newborns' fixations when both eyes are open and when the baby is confined to monocular conditions of viewing. The author has found that, with one eye covered, the fellow eye is most likely to fixate ipsilaterally (Chapter 3). In recognition of this, stimuli were presented, in experiment 3 of Chapter 3, in central and ipsilateral positions only. The intention here was to present the stimulus in that region where the baby was most likely, by chance, to be looking, and the only assumption made was that it would be increasing the probabilities of getting results.

It is a well-established finding that the newborn fixates more temporally (i.e., ipsilaterally) under monocular, when compared with binocular, conditions of viewing (Salapatek and Kessen, 1966, p165; Salapatek, 1968, p250). In this context it is relevant to include Kessen, Salapatek, and Haith's (1972) possible explanation for their finding that the centre of the pupil was displaced markedly to the right when a vertical edge was presented to newborns 3 inches to the right (discussed in Chapter 4: the right eye was always the one photographed, with the left eye occluded). They suggest that babies may have difficulty, (especially when confined to monocular vision), in holding the eye in a fixed position on the temporal side. All these findings, however, are from control trials in which the neonate was

Footnote[7] In scotopic vision, of course, objects are best seen when viewed peripherally. At the illumination levels found on a dark night the fovea is less sensitive than more peripheral regions of the retina. In this case, maximum sensitivity occurs in a region of 5 to 15° to each side of the fovea (Davson, 1950, p103; Pirenne, 1967, p57). The luminance levels (20ft L) used in experiments 3 and 4 of Chapter 3 would seem to be well within the range of photopic vision.

shown a blank field - i.e., a homogeneous black or white field. Haith (1968), did, in fact, suggest that "... visual input, especially vertically oriented input, stabilizes the position of the eye" (p8: the "loss of control" that he mentions was only found during blank-screen periods). Additionally, when one eye is covered by a gauze pad, the field of view of the open eye does extend more in an ipsilateral direction, so it does not really seem surprising that newborn babies should "fixate" more temporally in these conditions. The changes in eye position that occur when no stimulus is present may be active "searching" movements, or may be, in some sense, random movements of the eye. As, by definition, little visual information results from these movements they cannot be said to be fixations in the same sense that looks directed at a target are. That is, there is no evidence to suggest that the location of a newborn's fixations, or his pattern of scanning, differs for monocular and binocular viewing conditions, when actively viewing a stimulus.

There is also no evidence to suggest that a newborn presented with an ipsilateral stimulus might tend to look more to one side of it than the other. A difficulty is found here in the definition of ipsilaterally and contralaterally presented stimuli (a similar problem is considered in Chapter 3, footnote[1]). Although, relative to the camera's central placement, stimuli are presented a constant distance to left or right at the stimulus plane, this does not mean that the angular deviation of the stimuli from the neonate's midline can be specified: however carefully babies are positioned within the apparatus, some will have their heads to one side. Thus, if there were some form of bias resulting from the angular deviation of the stimulus from the baby's midline, the consistency of the findings reported in Chapter 3 would probably not have occurred.

However, the most valid, and least speculative, reply to the criticisms of Salapatek et al. results from a consideration of the causes of the disparities found. The disparities found for neonates are in the same direction as those found in adults, and the anatomical and optical variables considered in the previous chapter satisfactorily explain the differences in magnitude, and warrant the conclusion that the babies in all the stimulus positions used in experiments 3 and 4 of Chapter 3 were looking with foveal vision.

The concluding statement of Salapatek et al. (pp496-497) is: "But, though the evidence does suggest a correction be applied to averaged results, it remains inadvisable to apply such an average correction to individual cases until some objective measure of optical-visual axis discrepancy for individual infants is discovered." On logical and statistical grounds, this conclusion is not justified. Because of the magnitude of the effects, and since the fixation peaks of the neonates used as subjects were all within $\pm 5^{\circ}$ of the average, there will be less overall error in placing the line of sight for each subject if a correction based on the average magnitudes is applied.

Finally, it has not been suggested that the conclusions of Salapatek et al. regarding the selection of pattern features by the newborn are in error; it is though, interesting to note that "these effects become stronger for some infants when a correction factor such as Slater and Findlay suggest, is applied" (p496). Data concerning the question of infant convergence and fusion are presented in the next chapters of this thesis.

CHAPTER 6

BINOCULAR FIXATION IN THE NEWBORN: RESPONSES TO STIMULI AT DIFFERENT DISTANCES

The available literature concerning the newborn's ability to converge was considered in Chapter 1. The prevailing opinion is that, at birth fixation is monocular, binocular fixation first appearing at the end of the second month of life. However, most previous researchers who have been concerned with this variable have been unaware that the optic and visual axes of the eye do not coincide, and have erroneously assumed that optical divergence of the two eyes means that they are also visually divergent.

The experiments described in this, and the following chapter, were designed to investigate the neonate's ability to converge.[1] If the neonate is able to converge, this ability will manifest itself in four ways. These are:

(1) The two eyes will be optically divergent, on average, by some 17°.

(2) Each eye will be scored as being on-target when a correction factor is introduced for the expected deviations of the pupil centre from the target.

(3) The two eyes will be optically more divergent when fixating more distant targets, (i.e., when binocularly viewing a target at infinity the visual axes of the eyes are parallel).

(4) Subjects will converge to any stimulus that attracts their (visual) attention.

Footnote[1] As used in this chapter, the terms "convergence", "bifoveal fixation", and "binocular fixation" are synonyms.

The results from experiments in which the first three of these was investigated, are given in this chapter, and in all the experiments stimuli at different distances were presented. Initially, alterations to the apparatus, and changes to the scoring procedure, will be described.

Apparatus and photography The Crouzet motor fitted to the camera was changed, and in all the experiments reported in this, and the following chapter, the camera, when in operation, recorded at a speed of two frames per second. The camera was moved back along the optical bench fitted to the apparatus, so that its field of view ($2\frac{1}{4}$ in x 2 in) encompassed both of each subject's eyes. The exposure time ($\frac{1}{8}$ sec) and diaphragm setting (f8) were not changed. Other details concerning the apparatus and general procedure are given in Chapter 3. Modifications to the apparatus to allow the stimuli to be presented, and the stimuli used, will be detailed for each experiment.

Scoring and analysis A film frame was scorable if both eyes of each subject were visible and the pupil centre of each eye could be determined relative to the marker lights' position. No subject's record was scored if a preliminary check indicated that there were fewer than 14 scorable frames. Figure 6.1 illustrates the scoring procedure. The photograph is of a neonate's eyes (S10 of Expt. 8), taken when the stimulus presented was a vertical array of lights, positioned two inches to the right of centre. Each scorable frame was projected, in the usual way, onto a scaled-down copy of a print showing the relative positions of marker lights (B in Fig. 6.1), and the positions of the pupil centres, for both eyes, were marked. Sheets were prepared, each with 40 identical print copies on them, and a different "template" was used in scoring the separate frames.

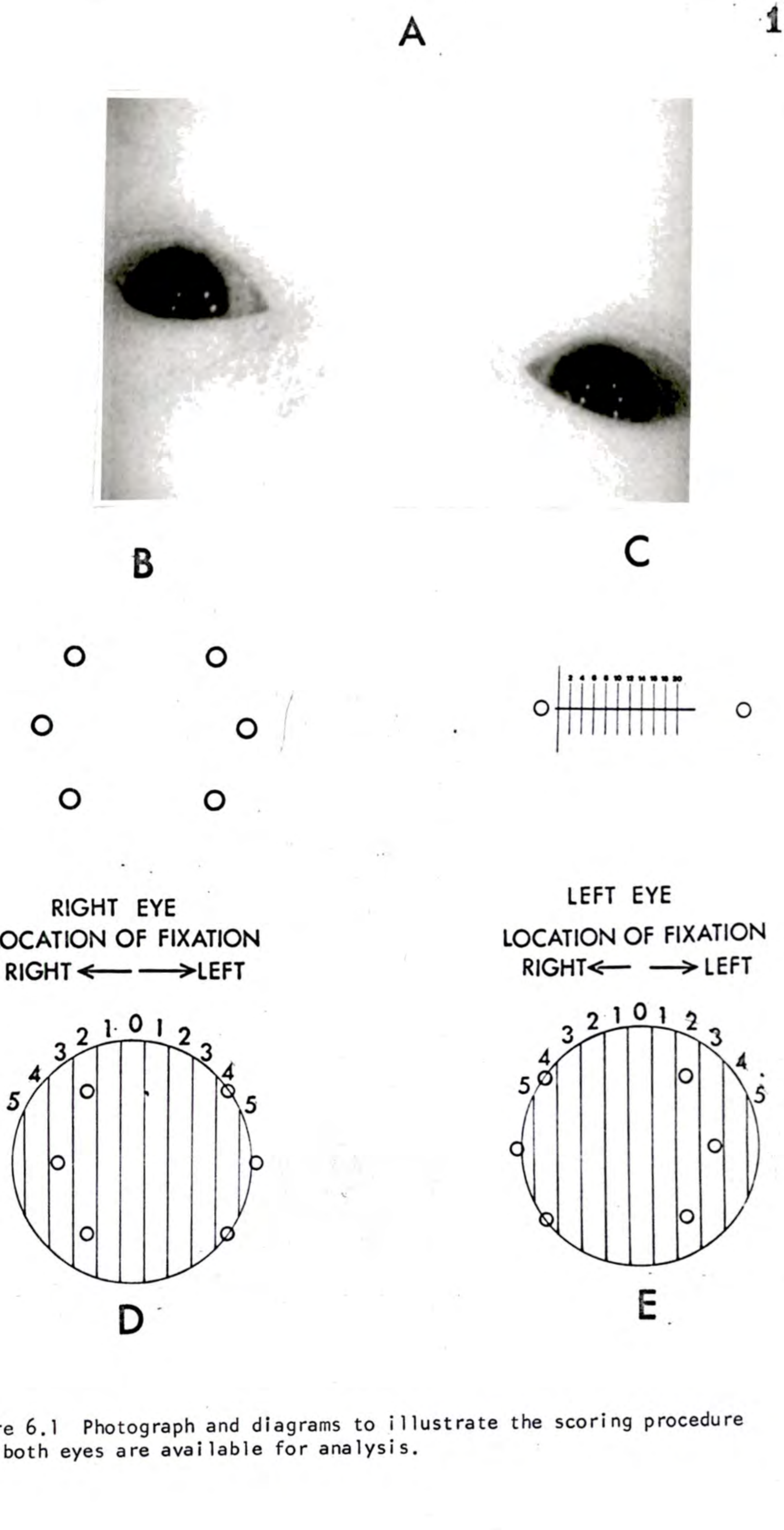

Figure 6.1 Photograph and diagrams to illustrate the scoring procedure when both eyes are available for analysis.

These scored positions of the pupil centres constitute the raw data for each S in each stimulus condition. The optical divergence of the two pupil centres was then found for each of the scored print copies. If the optical divergence of each eye is $8\frac{1}{2}^{\circ}$, the scored separation of the pupil centres would be 3 inches at the level of the stimulus plane (10 inches from the S's eyes). A diagram was constructed, showing the distances apart the derived positions of the pupil centres would be for optical divergences ranging from 0 to 20°, and also showing the separation (12 inches) of the two horizontal marker lights. This was photographed, and film transparencies were prepared, reduced to the same size as the print copies. A transparency (C in Fig. 6.1), was fitted to the scored position of the pupil centres, and their optical divergence read off.[2]

The area of the stimulus field fixated by each eye was also found. To do this, diagrams were prepared in which a correction for the expected displacements of the pupil centre from the target position was introduced. For the purposes of this analysis the stimulus field was divided into 1 inch vertical areas, up to a 5 inch radius from the centre position within the marker lights. Photographic transparencies of these diagrams were prepared, such that the positions of the marker lights on them exactly fitted those on the print copies. These transparencies, for right and left eye disparities, (D and E, respectively, in Fig. 6.1), were separately placed over each scored print copy, and the area fixated was found for each eye. The average disparities were used in preparing these transparencies

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Footnote[2] The marker lights present on these transparencies were needed in their preparation, i.e., the distance between the horizontal marker lights is the same for the transparencies and the print copies. They were not used in the analysis itself.

(derived from expts. 3 and 4, and from Fig. 3.7). Thus, if the eyes were optically divergent by 17°, and S was looking with both eyes at a point 3 inches to the right of centre, it can be seen from D and E of Figure 6.1 that the pupil centre of the right eye would be approximately vertically aligned with the right horizontal illuminator, and the pupil centre of the left eye would be somewhat to the left of this marker light. For the film frame from which the photograph, (A in Fig. 6.1), was taken, the S was scored as looking two inches to the right with both eyes, and the optical divergence of each eye was 11°.

It was often the case that great ocular activity was displayed by a particular subject, and the reflections of the marker lights on the film frames were visible as streaks. Isolated scorable frames amongst such activity did not, it was felt, indicate attention to the stimulus, and for this reason frames were not scored if there were not two or more consecutive frames for analysis. A frame was not scored if both eyes were looking more than 5 inches from centre.

Further treatment of the results is described for each experiment.

EXPERIMENT 5

Subjects Subjects for the experiment were 16 newborn babies, 6 females and 10 males, 11 of whom were first born. Their ages at the time of experimenting ranged from 57 to 190 hours, median 114.5 hours; and their birth weights ranged from 5lb 15oz to 9lb, median 7lb 9oz.

Data collected from a further 12 babies could not be used as there were not 14 scorable frames in any stimulus condition. An initial difficulty in focusing the camera was the major cause of this subject loss, and data on these babies are not given here.

Stimuli and procedure Three stimuli were presented, at eye-to-target distances of 5 inches, 10 inches, and 20 inches. The 10 inch stimulus was the array of coloured lights used in experiments 3 and 4. This stimulus was mounted on one of three stimulus panels to enable it to be presented in one of three positions: 2 inches to left of centre, centre, and 2 inches to right of centre.

The same array of lights was also the stimulus for the 20 inch viewing condition. In this condition the lights were mounted laterally with respect to the S's eyes. A black shield around the side of the lights prevented S from seeing them with peripheral vision. A small (5in x 4in) front-surfaced mirror was mounted above the small central hole in a stimulus panel, and angled so that, with S in position, the stimulus lights could be seen in the mirror at a reflected distance of 20 inches.

The stimulus at the smallest viewing distance was a single, white light, $\frac{1}{2}$inch in diameter. When required, this light was swung into position, and was 5 inches from S's eyes, and 1 inch above the centre of the camera's field of view. When presented to the subjects, all thestimuli were either blinking, being on for $\frac{1}{4}$ sec and off for $\frac{1}{4}$ sec (the "on-off" condition), or remained on (the "on" condition), and during intra-subject stimulus presentations the "on-off" and "on" conditions were alternated.

The three stimuli were separately presented, in a predetermined order for each S, for approximately 1 minute each. For the 10 inch stimulus the positions to right and left of centre were alternated between Ss, and the central position was introduced during later experimental sessions. Also included in the experiment was a control trial, i.e., a trial in which a black stimulus panel only was presented. The luminance of each stimulus light was constant at approximately 20ft L.

Thus, the ideal situation was for each S to view stimuli at the three different distances, and also the blank stimulus panel. After a few experimental trials, however, certain problems became apparent. Firstly, Ss became noticeably more active when no stimulus was available, and photographic records were difficult to obtain. Secondly, difficulties were found in presenting the stimulus at 20 inches: the stimulus panel on which the mirror was mounted was bulky, and a long time was taken to change to this stimulus condition. Also, possibly because of an incorrect placing of the infrared filter in the centre of this stimulus panel, the developed film records from this condition seemed overexposed and could not be scored.

Consequently, the control trial, and the 20 inch condition were only included in the first few experimental trials, and results were only obtained from Ss presented with the stimuli at the 5 and 10 inch distances.

Throughout each experimental session two experimenters were present. E_1 (the author) held the babies in position, and E_2 (Mr. Bruce White) was responsible for switching the camera and changing the stimuli.

Discussion In this experiment the retinal image size of the stimuli at the different distances was different. It might properly be considered a pilot experiment for the experiments reported later in this chapter (expts. 7 and 8). However, it is appropriate to consider here the changes in the optical divergence of the eyes one would expect to find if the neonate were to converge to stimuli at 5, 10 and 20 inches.

The procedure adopted for scoring the results was designed to give maximum accuracy at a viewing distance of 10 inches. If the newborn binocularly fixates a stimulus at this distance, in this apparatus, the optical divergence scored for each eye will be approximately 8.5° (there will, of course, be some intersubject variability)[3]. If the neonate then changes the convergence angle of the eyes to bifoveally fixate stimuli at 5 inches and 20 inches, the changes in optical divergence can be found from a calculation based on Figure 6.2. In this Figure the left eye is considered and is located at E', which is 0.75 inches to the left of centre (E). A, B, and C of this Figure indicate the positions of targets that are, respectively, 5, 10 and 20 inches from the midpoint between the baby's eyes. The S fixating target B will have a line of sight along the line E'B. To view targets at 5 inches and 20 inches the line of sight changes, to view along the lines E'A and E'C, respectively. Thus, the expected changes in the scored position of the eye are the angles BE'A and BE'C. These angles are, respectively, 4.2° and 2.15°[4]. Thus, if S changes binocular fixation from a target at 10 inches to one at 5 inches, the optical divergence of each eye will be <u>reduced</u> by 4.2°; when he changes fixation position from 10 inches

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[3] Footnote In testing sequence 7 of Chapter 2 a "binocular effect" was found, a consequence of displacing each eye from centre. From a consideration of the cause of the effect (Chapter 4), it is evident that the scored optical divergence will tend to <u>underestimate</u> the actual divergence by an amount of 1.3° visual angle, for each eye. Because of the small magnitude of this effect, a correction for it has not been introduced. It will, however, be considered later (Chapter 8).

[4] Footnote The calculation of these angles was as follows:

(1) To find $\angle$BE'A. EA = 5"; E'E = .75". Thus, tan$\angle$E'AE = .75/5 = .15. Therefore, $\angle$E'AE = 8.5° and $\angle$E'AB = 171.5°: EB = 10"; E'E = .75". Thus, tan $\angle$E'BE = .75/10 = .075. Therefore, $\angle$E'BE = 4.3°. Consequently, $\angle$BE'A = 180 - (171.5 + 4.3)° = <u>4.2°</u>.

(2) To find $\angle$BE'C. $\angle$EBC = 175.7° (since $\angle$E'BE = 4.3°). tan $\angle$E'CE = .75/20 = .0375. Therefore, $\angle$E'CE = 2.15°. Consequently, $\angle$BE'C = 180 - (175.7 + 2.15)° = <u>2.15°</u>.

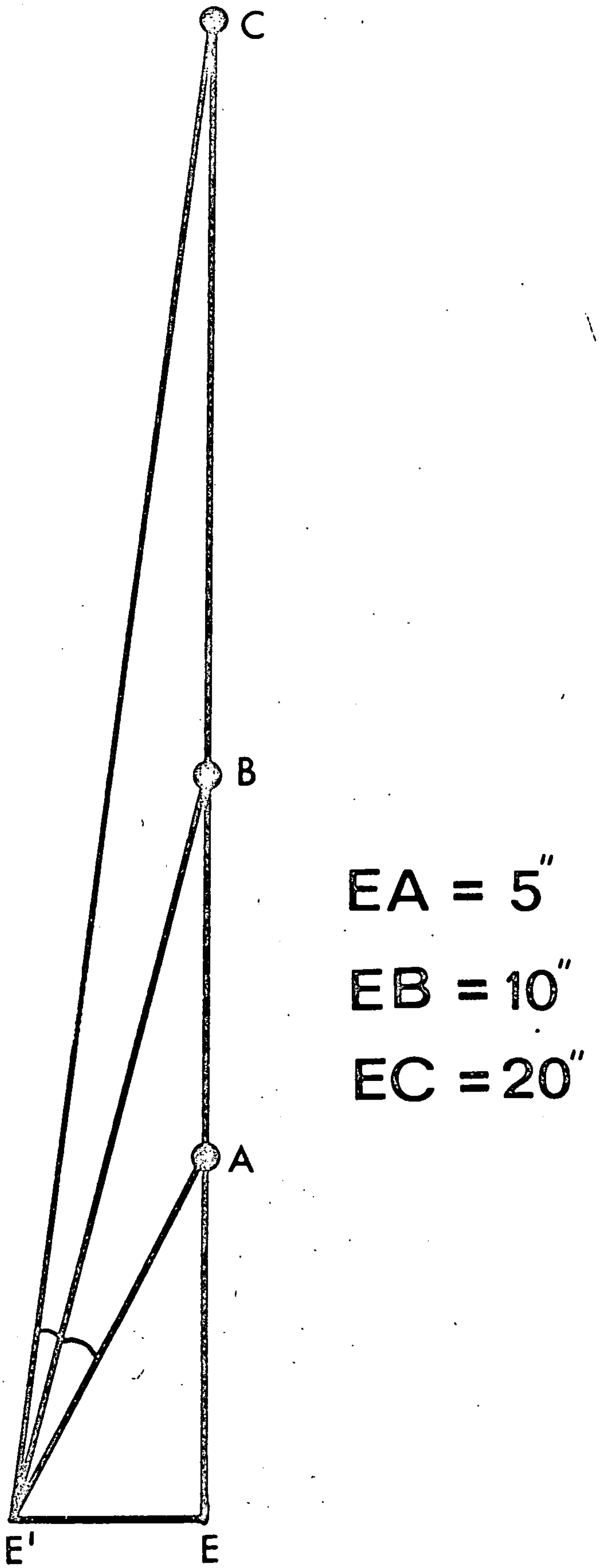

Figure 6.2 Diagram (not to scale) to illustrate the changes in the scored divergence of the eyes for binocular fixation of stimuli at 5, 10 and 20 inches.

to 20 inches the optical divergence of each eye will <u>increase</u> by 2.15°.

A complication, however, results from the method of scoring this optical divergence, which will affect the magnitudes found. The nature of the off-axis parallax effect (i.e., "projective distortion") is such that, when a subject changes fixation by an amount of, say 1 inch, the derived position of the pupil centre within the marker lights indicates a greater change, (from Figure 3.7 it can be seen that when the neonate fixates from centre to a point $3\frac{1}{2}$ inches from centre, the pupil centre will appear to have moved through $3\frac{1}{2} + 1\frac{1}{2}$ inches = 5 inches). Although a correction for the parallax effect is included in the present scoring system for deriving the actual location of the newborn's fixations (D and E of Fig. 6.1), the scoring of the optical divergence of the eyes (C in Fig. 6.1), is not calibrated for changes in optical divergence resulting from viewing stimuli at different distances, and will <u>overestimate</u> these changes by 0.43° for every 1° of change.

Consequently, when S changes binocular fixation from 10 to 5 inches the optical divergence of each eye will be scored as decreasing by $4.2 + (4.2 \times 0.43)^{\circ} = \underline{6^{\circ}}$. When the change is from 10 to 20 inches, the scored optical divergence of the eyes will increase by $2.15 + (2.15 \times 0.43)^{\circ} = \underline{3.1^{\circ}}$.

<u>Results</u> 6 of the 16 babies from whom results were obtained in this experiment contributed to the results for both the 5 and 10 inch viewing distances. 7 Ss gave results for the 10 inch distance only, and the remaining 3 Ss gave results for the 5 inch distance.

<u>The stimulus at 10 inches</u> Results for the 13 babies who viewed the stimulus at the 10 inch distance are given in table 6.1. In column A the stimulus condition is shown, (R in this column indicates that the stimulus was presented 2 inches to the right of centre; L and

TABLE 6.1

The areas of the stimulus field fixated, and the optical divergence of the eyes, for Ss presented with the 10 inch stimulus, experiment 5

A	B	C	D	E														F	G
STIMULUS	SUBJECT	NO. OF SCORED FRAMES	EYE	LEFT ← AREA FIXATED → RIGHT (INCHES)														AVERAGE AREA FIXATED	AVERAGE OPTIC AXIS DIVERGENCE (DEGREES)
				6	5	4	3	2	1	0	1	2	3	4	5	6	7		
on-off R	2	32	R				1		1	8	17	3	2					0.78	17.5
			L	1			2	14	10	2	2	1						-1.44	

C indicate the stimulus positions to the left of centre, and centre). In column B the subject number is shown, and in column C, the number of frames scored per subject. The eye scored, right and left, is shown in column D, and the number of fixations scored within each 1 inch area of the stimulus field is given in the appropriate rows of the area designated by E, for each eye of each S. The figures in these columns have been arranged such that fixations on-target (i.e., scored as fixating the target directly, or being within $\frac{1}{4}$ inch to either side of the $\frac{1}{2}$inch wide stimulus), are in area 0. Thus, fixations scored as being on-target, regardless of whether S viewed the stimulus in the centre position, or to right or left of centre, are placed in area 0. Column F gives the average area fixated, in inches from the exact centre of the stimulus, for right and left eyes; positive values indicate that the average location of the eye was to the right of this point, and negative values indicate a displacement to the left. Column G gives the average optical divergence of each eye, for each S (to obtain the optical divergence of both eyes the values given in this column are simply doubled).

From the totals of this table it can be seen that the right eye was on-target in 223 of the 477 frames scored, or 47% of the time. The left eye was on target 41% of the time. Both eyes were looking within $\pm 1\frac{1}{4}$ inches of the stimulus (i.e., within $\pm 1\frac{1}{2}$"of the exact centre of the stimulus), in over 80% of the scored frames (84% for the right eye, and 82% for the left eye).

On average the subjects' right eyes were located 0.29 inches to the right of the exact centre of the stimulus, and the left eyes were located 0.05 inches to the right of the stimulus centre. The average optical divergence of each eye was 9.22°, a figure that is close to the average divergence of 8.5° expected if the Ss were binocularly fixating the stimulus at this distance.

The results from two of the Ss call for special comment. For S2 the average optical divergence of each eye was 17.5°, perhaps larger than one would expect if this S had been converging. The right eye was scored as being, on average, 0.78 inches to the right of the centre of the stimulus, and the left eye was 1.44 inches to the left of the stimulus centre. Thus, for this S, it is possible that strabismus was present and that the eyes were straddling the stimulus, as it were. However, it seems equally plausible to suppose that this S was converging, and that the angle alpha was large. It is not possible to decide which of these possibilities is correct. Both eyes of S18 were, on average, fixating an area some distance to the right of the stimulus. For this subject it is not, for this reason, appropriate to draw any conclusions about binocular fixation.[5]

The results for the other 11 Ss provide convincing evidence of binocular fixation of this stimulus.

The stimulus at 5 inches The average divergence of the optic axis of the eye for each S from whom results were obtained at the 5 inch viewing distance are given in table 6.2. The average deviation was 9.83°, clearly far larger than one would have expected to find if these Ss had been fixating the stimulus bifoveally. For 6 of these Ss results are also available for the 10 inch stimulus, and the optic axis divergence in this condition is shown for these Ss in the appropriate column of the table. The final column of this table

Footnote[5] If S2 and S18 are excluded from the analysis, the average location of both the left and right eyes of the remaining 11 Ss would be 0.05 inches to the right of the centre of the stimulus, and the average optical divergence is 8.21° for each eye.

TABLE 6.2

Average scored optical divergence of the eyes (in degrees) for Ss presented with the 5 inch stimulus, experiment 5

SUBJECT	5"	10"	DIFFERENCE
1	10.0	-	-
8	11.32	8.3	-3.02
9	6.88	5.79	-1.09
13	13.63	-	-
18	5.05	12.08	7.03
19	4.07	6.09	2.02
24	8.69	7.07	-1.62
25	14.0	-	-
27	14.79	4.65	-10.14
AVERAGES	9.83°	7.33°	-1.14°

shows the difference in scored optic axis deviation for these Ss, between conditions. In four cases there was a greater divergence of the eyes in the 5 inch condition.

From the scored records from the Ss in the 5 inch condition, there is no obvious indication that any S fixates the stimulus in any consistent manner, either monocularly or binocularly. As the stimulus used was smaller in area than the 10 inch stimulus, a direct comparison of the results from the two conditions is not possible. As results are available from an experiment (expt. 8), in which stimulus variables other than distance were equated, the negative results from the 5 inch condition in this experiment will not be considered in any further detail.

Conjugate eye movements That the neonate has the ability to move the eyes in a coordinated, yoked fashion, is well known (see Chapter 1). However, a measure was taken of conjugate movements of the eyes in the stimulus conditions used in this experiment, for the first thirteen Ss from whom results were obtained (both in the 5 and 10 inch conditions). For the scorable frames each eye was scored as looking within a 1 inch vertical area of the stimulus field (using the photographic transparencies described earlier, i.e., D and E of Fig. 6.1), and where successive frames were available for analysis, the movement of the eyes (if any) from their previous position was noted. Thus, if both eyes moved either to the left or to the right, a conjugate movement was scored, and if one eye moved to the left and the other to the right, a non-conjugate movement was scored.[6]

[6] Footnote Those instances in which one eye moved, and the other apparently did not, could not be counted as non-conjugate shifts because of the scoring procedure. If, for example, the right eye had been scored as looking to the extreme right within the centre area, and the left eye as looking to the left within this area, and the eyes then moved conjugately to fixate half an inch to the left of the /continued

139 eye movements were scored. Of these 130 were conjugate shifts, 66 to the left, and 64 to the right. The remaining 9 were non-conjugate movements. 4 of these were instances in which the eyes moved outwards (i.e., the left eye shifted to the left, and the right eye to the right); the other 5 were movements inward.

The small number of eye movements recorded in this manner is possibly a consequence of the subjects' attention to the stimulus. In keeping with other reports (i.e., Stechler and Latz, 1966, p524), the author found that attentive behaviour was often accompanied by a marked reduction of motor activity, and the maintenance, often for the duration of a stimulus presentation, of a fixed posture. This "vigilance-like" state is often manifest in the film records: thus, for S19, viewing the 10 inch stimulus, 25 successive frames, representing some $12\frac{1}{2}$ seconds' viewing time, were scored in which very little movement of either eye was apparent.

Nevertheless, these results show that, in this situation the neonates' eyes move conjugately much more often than they do non-conjugately.

<u>Conclusions</u> From this experiment it is possible to draw conclusions about the accuracy of the corrections introduced into the scoring procedure to allow for the expected displacement of the pupil centre from the target position, and also about binocular fixation in the

/continued/ previous fixation position, the left eye would have crossed the centre area and would be scored within the area 1in to the left, whilst the right eye would still be scored as fixating within the centre area, albeit this time to the left of this area. No instances were found of one eye apparently shifting fixation position through 2in and the other eye not moving.

It is, of course, possible that many eye movements, conjugate or otherwise, were missed completely. If the eyes changed fixation by, say, $\frac{1}{4}$ in, they could have been scored as fixating within the same 1in stimulus area. To divide the stimulus field into smaller than 1in areas, however, would introduce the risk of scoring eye movements that had not, in fact, occurred, because of imprecisions in the method of scoring.

newborn.

In the 10 inch condition, regardless of whether the stimulus was blinking or not, or was in the centre position, or to the left or right of centre, the subjects' fixations with both eyes were mostly scored within ± $1\frac{1}{2}$ inches of the centre of the stimulus. Thus, in most cases, both eyes of the subjects were on-target, and the pupil centres were displaced from the target position by the amounts predicted from the experiments in which monocular conditions of viewing only were allowed (experiments 3 and 4). Since the average divergence of the optic axis (9.22°), was also close to that expected (8.5°), it is a necessary conclusion that the babies in this experiment (with the possible exceptions of Ss 2 and 18), were fixating the stimulus bifoveally.

In the 5inch stimulus condition there was no evidence of binocular fixation. However, as there was also no evidence that the babies were fixating the stimulus, the results are ambiguous in this context. The high degree of conjugate eye movements found (94%) agrees with previous findings concerning this variable.

EXPERIMENT 6 This experiment was designed to test for convergence movements of the eyes to an approaching and retreating stimulus. A conclusion resulting from experiments 3 and 4 (Chapter 2), from the theoretical considerations of Chapter 4, and from experiment 5, is that newborn babies can and do fixate with the fovea and, when the stimulus is a vertical array of lights presented at a distance of 10 inches, will do so consistently, in both monocular and binocular viewing conditions. If the neonate binocularly fixates an object, perhaps at 30 inches, and this object is moved closer, the image of the object will, unless appropriate vergence movements of the eyes are made, fall on non-corresponding regions of the retinae and thus will, in the absence of any special provision to the contrary, be seen double.

Stimulus The stimulus was a single, white light, 1 inch in diameter and flashing at an on-off rate of 4 times per second. The light was connected to a pulley system, and could be moved from 30 inches from the midpoint between S's eyes to 6 inches from this midpoint. When 10 inches away, the light was $2\frac{1}{2}$ inches above the centre of the stimulus field. The pulley was slanted so that the light was along a direct line of sight from the centre of S's eyes. Figure 6.3 is a schematic diagram of the arrangement. Microswitches located at the limits of the stimulus light's travel stopped the movement of the stimulus, and reactivation of the small Crouzet motor, connected to the pulley string, caused it to reverse its direction of travel. To move from 30 inches to 6 inches (or the reverse), took 8 seconds. The pulley system passed through the $9\frac{1}{2}$ inch diameter hole in the aluminium stimulus screen, and a black stimulus panel was placed in position, 10 inches from the S's eyes, to prevent S from seeing the camera. The top portion of this stimulus panel was removed so that movement of the light was not prevented. Other portions of the apparatus that were visible through the hole in the stimulus panel were either painted black, or covered with a black cloth, the intention being to make the light the only obvious visual stimulus. When the stimulus was 6 inches from the S's eyes, part of it could be seen at the top of each developed film frame. This acted as a marker, and enabled the film to be scored with respect to the distance of the stimulus from the S's eyes.

Procedure and subjects With S in position, the camera was switched on, and the stimulus activated. The stimulus was started at either

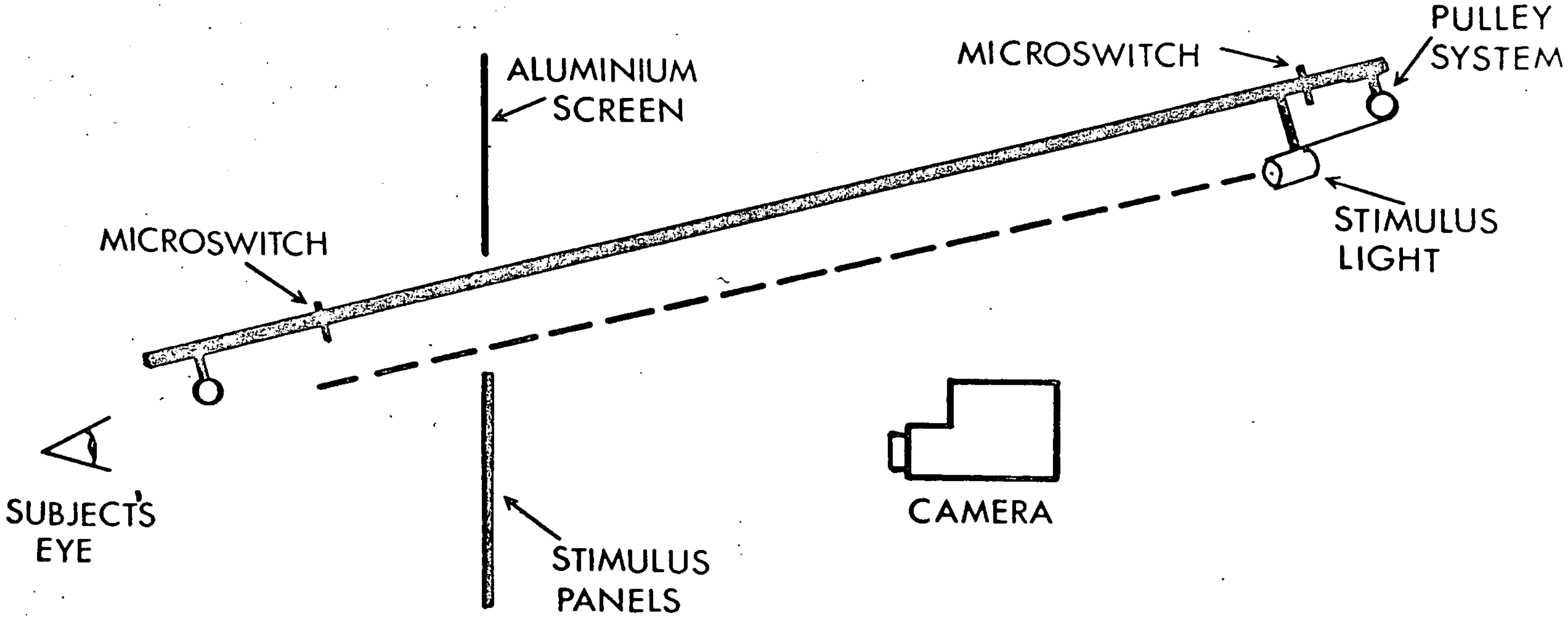

Figure 6.3 Schematic illustration of the stimulus arrangement, experiment 6.

the 6 inch or 30 inch distance, and the first direction of travel was alternated between Ss. The stimulus, having reached its 30 inch or 6 inch distance from S, stopped, and remained there for 4 seconds, and its direction of travel was then reversed. The light was moved back and forth, in this manner, until either 3 minutes had passed, or S terminated the session by crying or fussing.

Six babies were seen.

Results When six babies had been used as Ss the experiment was terminated because of the poor results. Of the six babies, only two appeared to fixate the stimulus consistently. For these 2 Ss the optical divergence of the eyes was calculated from the film obtained when the stimulus was stationary, both at its 6 inch and 30 inch distances. For neither S was there any apparent change in convergence angle. For the first S, the scored optical divergence of each eye was 2.65° and 3.11° for the 6 inch and 30 inch distances, respectively. The scored divergence of each of the second S's eyes was 6.91° and 6.22°. None of the six Ss showed any apparent indication of appropriate vergence movements to the approaching or retreating stimulus during its travel.

On certain trials it was noticed that the S sometimes moved his head backwards when the stimulus light approached. Detailed records were not made of the frequency of this phenomenon.

Discussion An experiment that is similar in form to the present one was reported by Ling (1942). In her experiment supine babies were presented with a black disk, 2 inches in diameter. The disk was moved from 36 inches to 3 inches from the bridge of the S's nose. Its speed of movement (2 in. per sec) was similar to the speed of the stimulus light used in the present experiment (3in per sec), but the movement of the disk was suspended at the first sign that the infant's regard was diverted, and continued only when the S renewed his fixation.

She used a longitudinal design, and infants in an age range from 7 minutes to 24 weeks were seen.

Despite these differences in experimental design it is of interest to compare Ling's findings with the few results from the present study, and to consider some of her remarks.and conclusions in the light of more recent research.

Like the present author, she found that no newborn baby made appropriate convergence movements to the approaching and retreating object. She also reported that, as the stimulus disk reached its nearest point of approach, the head sometimes moved backward (pp251 and 253). This form of response, which is seen about 2 weeks of age, she described thus: "... a number of infants are repeatedly seen tensing the trunk, stiffening the neck, and pressing the body, including the head, down hard against the mattress... as if they were attempting to increase the distance between the disk and their eyes" (p255). Additionally, as the disk approached, especially during the last foot of its descent, sucking movements, activity of the tongue, and swallowing or "chewing" movements were often observed, (p251), which Ling interpreted as perhaps meaning food to the infant, or the development of an association "... between the stimulus disk and such biologically significant things as food, warmth, and social intercourse with another individual" (p270, footnote). That this interpretation, although seemingly appropriate, is erroneous, is suggested by more recent research.

Bowper, Broughton, and Moore (1970), found that the near approach of a foam rubber object caused violent upset to infants aged 6 to 20 days. In its full form the response consisted of three components: (1) eyes open wide; (2) the head goes back; (3) both hands come up between object and face. Since Ling found all three of these components to the near approach of her stimulus disk, it seems curious that Bower (1971), found that infants in their second week of life, more than 40 of them, "did not even blink", when they were placed on their backs and objects of a wide variety of sizes, and a wide variety of speeds, were moved, either noisily or silently, towards them. Aronson and Rosenbloom (1971), demonstrated that infants from 30 to 55 days, (a younger age group was not tested), coordinate vision and sound to the extent that great distress results if the mother's voice appears to come from 90° to left or right of her seen position. A response that accompanied this distress was the appearance of "mouthing of the tongue." This would seem to be a similar type of response to the mouth movements reported by Ling during the last foot of the stimulus disk's approach. It therefore seems likely that the infants in Ling's study, and to some extent in the present experiment, were responding to the disk's approach with <u>distress</u> rather than pleasure.

Ling reported the absence of binocular fixation and convergence movements until the end of the second month of life, (range 1 week, 4 days to 20 weeks, 6 days, median 7 weeks, 2 days). When convergence movements first occur they are carried out by a series of small globus jerks: "As the stimulus disk approaches, no immediate adaptive ocular movements are observed. Then a succession of spasmodic movements of the pupils toward each other alternate with relatively long intervals of ocular inactivity... As the infant grows, the process of convergence in response to the approaching stimulus disk becomes smoother and smoother until it occurs, in all appearances, as a continuous process..." (1942, p245).

Since convergence movements of the eyes to approaching and retreating objects are intimately associated with changes in accommodation, it is perhaps not surprising that these movements are not easily observed in the newborn. When the adult changes gaze from a far to a near object, the lines of sight of the two eyes converge to maintain a single image, the lens of each eye increases its refractive power, and the pupils become smaller, bringing the near object sharply into focus (Alpern, Lowenstein and Loewenfeld, 1962; Alpern, 1969). There is little available literature on visual accommodation in human infants (see Chapter 1), but it would seem likely, from the work of Haynes, White and Held (1965), that the newborn has only a limited accommodative capacity. It would also seem likely that the development of visual accommodation is influenced, to some extent, by experiential variables. Greenberg, Uzgiris and Hunt (1968), got the parents of 10 infants to hang "stabile" patterns within the infants' view, beginning when they were 5 weeks of age. These infants blinked in response to the drop of a bull's eye target at younger average ages than did 10 infants whose mothers hung nothing over their infants' cribs during the course of the experiment. This result, they suggest, is "... presumably based upon the hastening in the development of visual accommodation through the exercise of looking" (p172). It seems probable, also, that practice may influence the development of vergence movements.

The apparent inability of the newborn to make appropriate vergence movements, both in the present experiment, and in Ling's experiment, does not, of course, imply the lack of binocular fixation of other stimuli. To maintain binocular fixation in the present experiment, fairly rapid inward and outward movements of the eyes would have had to be made. When the neonate is presented with a simple stimulus at a fixed distance, however, there are fewer demands on the oculomotor system. The foveas of both eyes may "zone in", as it were, on such a stimulus, whether independently or otherwise, perhaps by a process of trial and error. A change in convergence angle as the stimulus changes in distance from the eyes may result from trial and error corrections for the resulting diplopia.

There are two other possible reasons why vergence movements were not observed in the present experiment: (1) there may have been rapid habituation of the vergence reflex - habituation of vergence movements was found by Hughes (1972) to occur in the cat; (2) the stimulus at the near distance (6 inches from S's midline), may have been too close for the neonate to accommodate to it.

As it appeared unlikely that vergence movements to an approaching or retreating object would be made by newborns in the present experiment, and to avoid causing possible distress to the subjects, no further observations were made.

EXPERIMENT 7 In experiment 5 it did not prove possible to obtain results from newborns fixating a stimulus both at 10 inches and 20 inches. This experiment was designed to collect results in just this situation.

Subjects 25 babies were seen. Of these, 15 were used as subjects, 8 females and 7 males, 13 of whom were first born. Their ages ranged from 22 to 186 hours, median 155, and their birth weights ranged from 6lb 14oz to 9lb 1oz, median 7lb 8oz.

10 babies could not be used as subjects. In 9 cases there was an insufficient number of scorable frames: in 3 of these cases the film was out of focus; in 2 others the babies were apparently asleep during the experimental session. For the remaining baby the film record revealed extreme ocular activity, and the S gave no indication of looking within the stimulus area.

Stimuli The stimulus at 10 inches was similar to the array of lights used previously at this distance. Each of 8 stimulus bulbs was covered by a white perspex lens, $\frac{1}{2}$ inch in diameter, and the lights, equally spaced, covered an area $5\frac{1}{2}$ x $\frac{1}{2}$inch. The stimulus was mounted on one of two stimulus panels, and could be presented either 2 inches to the left of centre, or 2 inches to the right of centre.

The stimulus at 20 inches was the same retinal image size (to S), as the 10 inch stimulus. Eight stimulus bulbs, (slightly larger than those used in the 10 inch stimulus), were covered by 1 inch diameter white perspex lenses. The equally spaced lights covered an area 11 x 1 inch. This stimulus was mounted on one of two pieces of large black cardboard, and each piece was positioned immediately in front of the camera lens, so that the stimulus lights, which were vertically placed either 4 inches to the left, or 4 inches to the right of centre, were 20 inches (± 1 inch) from S's eyes.

The two sets of lights were separately run from two labpacks, and the luminance of each stimulus light was 20 ft. L. (measured with an S.E.I. exposure photometer). At this level of illumination all the lights appeared yellowish in colour, rather than white, but to an adult at the babies' viewing position they seemed identical both in brightness and colour. Although the 20 inch stimulus was presented 4 inches from centre, and the 10 inch stimulus 2 inches from centre, both were the same angular deviation from the midpoint between S's eyes. Throughout each experimental session the experimental room was fairly dark, and all non-relevant parts of the apparatus were blacked-out. The stimulus lights, when presented, were permanently on.

<ins>Procedure</ins> With S in position either the 10 inch or the 20 inch stimulus was shown for approximately 30 seconds. The stimulus presented first was alternated between Ss. The stimulus at the next distance

was then shown for the same period of time, and this procedure was repeated. Thus, most of the Ss were shown each stimulus twice. 3 Ss were shown the 20 inch stimulus once again before the experimental session terminated, and for 3 Ss (Ss 1, 4 and 7), who began fussing during the second stimulus trial, the procedure could not be completed. For these 3 Ss results are available at one stimulus distance only. For the remaining Ss results from the trials at 10 inches were analyzed together, as were the results for the 20 inch trials.

For the first 6 Ss from whom results were obtained in both stimulus conditions, the 10 inch stimulus was shown 2 inches to the left of centre, and the 20 inch stimulus, 4 inches to the right. To balance the experimental design the remaining 6 Ss were shown the 10 inch stimulus to the right, and the 20 inch stimulus to the left.

Scoring The scoring procedure was detailed above. In the 20 inch condition the lines of sight of each eye, (if the S is viewing the stimulus bifoveally), will pass slightly to the left and right of the centre of the area 2 inches (either to the right or left), from centre at the 10 inch distance. Thus, scoring of the data from the 20 inch stimulus, presented 4 inches to the left of centre, was carried out as if S had been presented a stimulus at 10 inches, 2 inches to the left, (or to the right, when the 20 inch stimulus was to the right).

Results

Average location of the eyes The average location of each of the Ss' eyes, in each stimulus condition, is shown in table 6.3. If the eyes were scored on-target the average location of each eye would have been 2 inches from centre in all stimulus conditions. All figures are given in inches' displacement, and a value of less than 2.0

TABLE 6.3

Average location of fixations, in inches, for both stimulus conditions, experiment 7

10'' Stimulus					20'' Stimulus		
Subject	LE	RE	Scored frames		LE	RE	Scored frames
1	-	-	-		1.7	3.1	(39)
2	2.0	1.1	(25)		1.3	1.6	(44)
3	1.8	2.1	(49)		1.5	2.7	(30)
4	2.2	2.2	(39)		-	-	-
5	2.4	2.3	(25)		1.8	1.9	(59)
6	2.1	2.0	(17)		1.4	1.8	(34)
7	1.8	2.7	(35)		-	-	-
8	1.4	1.8	(17)		1.9	2.7	(52)
9	2.6	1.5	(49)		2.6	2.2	(37)
10	2.1	2.2	(39)		1.6	2.3	(33)
11	2.2	0.9	(52)		1.4	1.7	(81)
12	2.1	2.8	(53)		1.4	2.8	(32)
13	1.9	2.3	(19)		2.6	3.1	(14)
14	2.0	1.7	(26)		1.5	2.2	(21)
15	2.6	1.5	(40)		2.3	1.8	(37)
Totals			(485)				(513)
Averages (N=14)	2.09	1.94		(N=13)	1.77	2.30	

indicates that the eye scored was, on average, scored as fixating to the left of the centre of the stimulus. Values greater than 2.0 are scored fixations to the right. Only in 3 cases, (the right eye of S11 in the 10 inch stimulus condition, and the right eyes of Ss 1 and 13 in the 20 inch condition), do the scored fixations peak slightly more than 1 inch from the centre of the stimulus.

On average, in the 10 inch condition, the left eyes were scored as being 0.09 inches to the right, and the right eyes 0.06 inches to the left, of the centre of the stimulus. In the 20 inch condition the left eyes were scored as being 0.23 inches to the left, and the right eyes 0.30 inches to the right. The number of scored frames, for each S in each stimulus condition, is given in parentheses in the appropriate columns. The left eyes in the 10 inch condition were on-target (i.e., scored as being within $\frac{1}{2}$ inch from the centre of the $\frac{1}{2}$ inch wide stimulus), 58% of the time (279 of the 485 scored frames), and the right eyes were on-target 42% of the time (202 frames). In the 20 inch condition, the left eyes were on-target 44% of the time (228 of the 513 scored frames), and the right eyes were on-target 38% of the time (197 frames).

These results indicate that the Ss were looking at the stimulus with both eyes, at both of the distances used. The local accuracy of the infants' fixations is clear from the fixation records shown in Figure 6.4. Here, each dot shows the derived position of the centre of the pupil within the marker lights for each S from whom results were obtained in both stimulus conditions. The fixation records are shown for the right eyes only. For convenience the marker lights are not shown in this Figure; however, the vertical lines show the position of the stimulus within the marker lights. For the Ss whose fixation records are shown in columns A and B the 10 inch

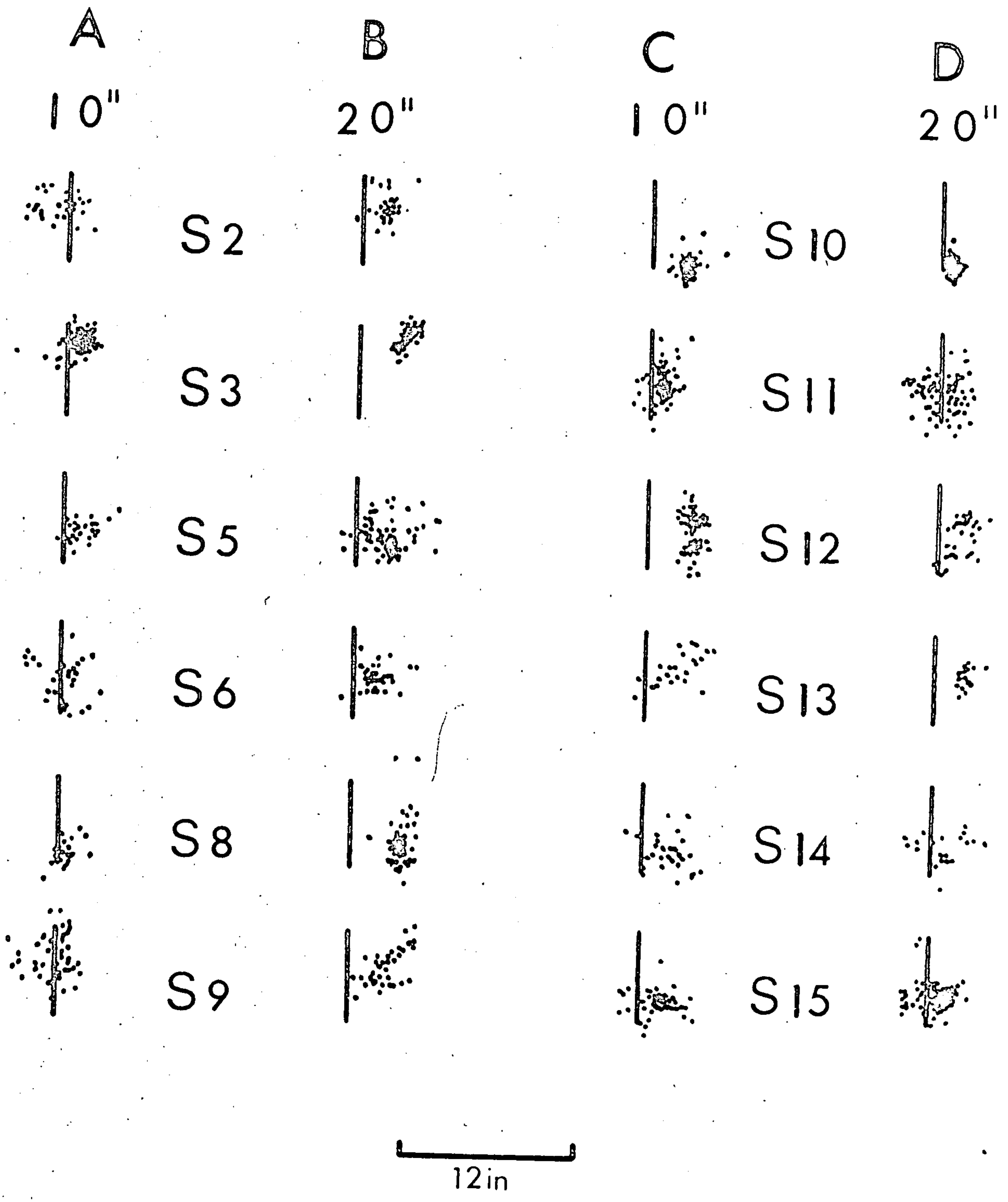

Figure 6.4 Visual fixation records of subjects viewing two arrays of lights, at 10 inches and 20 inches, experiment 7. Right eye only.

stimulus was presented to the left of centre, and the 20 inch stimulus to the right. For Ss 10 through 15 (columns C and D), the 10 inch stimulus was to the right, and the 20 inch stimulus to the left.

From Figure 3.7 it can be seen that fixations of the right eye on a target 2 inches to the left of centre should be scored as being slightly to the right (an average amount of 0.64 inches), of the target; fixations on a target 2 inches to the right of centre should be displaced an average amount of 2.36 inches to the right of the inferred position of the target. It is, in fact, apparent in Figure 6.4 that the scored pupil centre positions in columns B and C are, on average, farther to the right of the stimulus than those in columns A and D. (This expected displacement was taken into account in presenting the average location of fixations in table 6.3).[7]

Divergence of the optic axis The average scored divergence of the optic axis of each eye in each stimulus condition, for those Ss from whom results were obtained in both conditions, is shown in table 6.4.

When the experiment had been completed, seven Ss' film records were completely rescored, independently of the original analysis, and the optic axis divergence was calculated again. The figures for the reanalyzed data are given in parentheses. In each case, this divergence was within 1° of its originally scored value.

The differences in magnitude of the scored optic axis divergence between the 10 inch and 20 inch stimulus conditions, for the individual Ss, are shown in the last column of this table. All differences are positive, and the average increase (2.6°), is close to the increase

Footnote[7] The optic divergence of each eye of those Ss who viewed the stimulus at one distance only is as follows: S1 (20 inch condition), 14.4°; S4, 8.8°, and S7, 11.6° (10 inch condition).

TABLE 6.4

Scored divergence of the optic axis (in degrees)
for both stimulus conditions, experiment 7

Subject	10" Stimulus Average Divergence	SD	RA	20" Stimulus Average Divergence	SD	RA	Difference
2	5.52	3.23	-	9.27	2.20	-	3.75
3	8.78	2.54	(9.54)	13.20	1.79	(12.59)	4.42
5	7.92	1.96	(7.27)	9.42	2.35	(9.51)	1.50
6	7.65	2.67	(7.38)	9.59	1.54	(10.18)	1.94
8	10.24	2.44	(9.64)	11.96	1.61	(11.72)	1.72
9	3.88	3.35	-	6.49	1.45	-	2.61
10	8.82	1.82	(9.70)	11.58	1.48	(12.17)	2.76
11	2.77	2.06	-	5.46	2.76	-	2.69
12	11.51	1.61	-	14.12	1.76	-	2.61
13	9.47	1.61	(10.00)	10.57	1.45	(11.18)	1.10
14	7.54	2.06	(7.50)	11.52	1.89	(11.11)	3.98
15	3.90	2.68	-	6.00	3.57	-	2.10
Averages (N=12)	7.33°			(N=12) 9.93°			2.60°

expected (3.1°), if these Ss were viewing both stimuli bifoveally. To confirm this finding, Mann-Whitney U-tests were carried out on the optic axis data for each of these Ss, between conditions. The increase in optic axis divergence for S13 was significant at the .05 level (1-tailed); all other comparisons were significant at $p < .01$.

The data presented indicate that the neonate can, and does, binocularly fixate stimuli at two different distances, and will increase the convergence angle of the eyes by an appropriate amount to fixate the far stimulus. However, the optical divergence of the eyes did not remain constant for the scored fixations of the individual Ss at a particular distance, i.e., there was some fluctuation around the mean values scored. As an indication of this variance the standard deviation of the scored optic axis divergence, for each S in each condition, is given in table 6.4. None of these standard deviations is especially large. Scoring errors, it is believed, are the source of some, but not all, of this variance. The scoring of the optical divergence will also tend to increase the variance - i.e., when S changes the divergence of the optic axes by 2° per eye the scored change will be $2 + (2 \times 0.43)^\circ = 2.86^\circ$. It seems likely that, when the neonate is fixating binocularly, his poorer acuity (no doubt a consequence of the relatively underdeveloped macula area), allows for some divergence and under-convergence of the eyes before diplopia sets in and is corrected for. Thus, some slight independent "wavering" of the eyes around the mean convergence angle does not imply the lack of a unified binocular image, or poor neuromuscular control of the eyes (although these possibilities still remain).

The results from this experiment clearly indicate that the neonates were fixating the stimuli bifoveally. In the next experiment neonates' ability and/or desire to converge to stimuli at different distances was further investigated.

EXPERIMENT 8 In this experiment results were taken from newborns presented with stimuli at 5 inches and at 10 inches. The experiment is, essentially, a partial replication of experiment 5, but with the stimuli equated for luminance and retinal image size.

Subjects 19 babies were seen. Of these, 11 were used as subjects, 4 females and 7 males, 9 of whom were first born. Their ages ranged from 18 to 193 hours, median 163, and their birth weights ranged from 5lb 11oz to 8lb 14oz, median 7lb 2 oz.

8 babies could not be used as Ss: in 3 cases there was an insufficient number of scorable frames (14) in both stimulus conditions; in 5 cases the records revealed extreme ocular activity, and the Ss gave no indication of looking within the stimulus area, (one of these Ss was sick during the experimental session).

Stimuli The stimulus at 10 inches was the array of lights used in experiment 7. This stimulus was always presented 2 inches to the right of centre.

The stimulus presented at the 5 inch viewing distance was a vertical array of 8 small bulbs. A strip of white paper was painted matt black, with the exception of an area, $2\frac{3}{4} \times \frac{1}{4}$ inches, which was positioned in front of the bulbs, and through which the light from the bulbs was visible. The rest of the piece of paper was bent back and glued to the sides of the bulbs. This stimulus was attached to the vertical portion of a T-shaped piece of perspex, which was painted matt black. The horizontal component of this piece of perspex was rested on the upper part of the apparatus when the stimulus was presented, so that the stimulus was 5 inches from the midpoint between

S's eyes, and in a central position. When the 5 inch stimulus was shown, the stimulus panel containing the 10 inch stimulus was moved, and a plain, black panel substituted.

That the 5 inch stimulus was in the correct position was indicated by a vertical strip in the centre of each developed film frame. Thus, each S had to be accurately held in position so that the eyes were visible to either side of this blank area.

<u>Procedure and scoring</u> The procedure was similar to that described in experiment 6. The stimulus shown first (either at 5 inches, or at 10 inches), was alternated between Ss and, when conditions allowed, each stimulus was presented twice to each S, alternately, for approximately 30 seconds each presentation. In 3 cases the first-presented stimulus was shown a third time, and in 2 cases the experimental session was terminated by S after three stimulus presentations.

No S's film record was scored unless there was a sufficient number of scorable frames in both the 5 inch and 10 inch stimulus conditions. Thus, for all the 11 Ss used, a comparison of fixations between the two conditions is possible. For each S, the results at a particular stimulus distance were scored together.

The method of scoring adopted for the results from the 10 inch condition was the same as that described earlier. For the results from the 5 inch condition the average location of each eye was derived in a slightly different manner. Since this stimulus was 5 inches away from the midpoint between S's eyes, when fixating the stimulus the left eye would be apparently looking $\frac{3}{4}$ inches to the right of centre, at the 10 inch scoring distance, and the line of sight of the right eye would pass through a point $\frac{3}{4}$ inches to the left of centre. To allow for this, the vertical 1 inch areas on the photographic transparencies (D and E of Fig. 6.1), which were used to derive the area apparently fixated for each scored frame, were displaced through $\frac{3}{4}$ inch in the appropriate (and opposite) directions for each eye.

Results

Average location of the eyes The average location of the Ss' eyes, in both stimulus conditions, is given in table 6.5, which, in presenting the data for the 10 inch condition, is similar to table 6.3 of experiment 7. Only in two cases (the left and right eyes of S6, starred in the table), do the fixations peak more than 1 inch (i.e., more than 5.7°), from the centre of the stimulus. On average, in the 10 inch condition, the left eyes were scored as being 0.01 inches to the left of the exact centre of the stimulus, and the right eyes were scored as being 0.2 inches to the right of the stimulus centre. The results for this condition are similar to those of experiments 5 and 7, and are a further indication that newborn babies will consistently converge to this stimulus at this distance.

For the stimulus presented at a distance of 5 inches, however, this is not the case. If the Ss had been fixating the stimulus bifoveally the average scored location for each eye would be 0 inches. Negative values for the left and right eyes in the columns showing the 5 inch data, indicate that the eye was scored as looking to the left by that amount of inches at a 10 inch distance (positive values in these columns indicate scored fixations to the right of the centre of the stimulus).[8]

[8] Footnote The nature of the scoring means that, for the 5 inch data, a value given in this table indicates fixations to the right or left of the stimulus, by that amount of inches at a 10 inch eye-to-target distance. A scored displacement of 1 inch to the left means that the S's eye was, in fact, fixating on average, $\frac{1}{2}$ inch to the left at the 5 inch distance, but was the same angular deviation from target as a scored displacement of 1 inch to the left in the 10 inch condition.

To permit a more direct comparison of the results from the two conditions, the values for the 5 inch condition have not been halved.

TABLE 6.5

Average location of fixations, in inches, for both
stimulus conditions, experiment 8

	5" Stimulus			10" Stimulus		
Subject	LE	RE	Scored frames	LE	RE	Scored frames
1	0.59	0.41	(32)	2.9	2.07	(30)
2	-0.33	1.44*	(27)	1.95	2.24	(38)
3	-3.2*	-0.13	(15)	2.21	2.24	(33)
4	-0.67	0.69	(51)	2.65	2.1	(40)
5	-1.02*	1.02*	(66)	1.25	2.1	(59)
6	-2.87*	1.33*	(39)	0.95*	3.05*	(39)
7	-1.53*	0.37	(19)	2.05	1.34	(59)
8	-1.04*	1.32*	(28)	1.69	2.46	(26)
9	-2.29*	0.64	(66)	1.96	2.23	(26)
10	-2.23*	0.18	(60)	2.1	2.65	(69)
11	-0.34	1.14*	(35)	2.15	1.73	(33)
Totals			(438)			(452)
Average	-1.36	0.76		1.99	2.20	

In 12 cases (starred in the table), the line of sight of the eye concerned was displaced, on average, by more than 1 inch from the stimulus at the 10 inch scoring distance (displacement of greater than 5.7°). For 8 of the 11 Ss in the 5 inch condition at least one eye was scored as being on-target, but in only 2 cases (Ss 1 and 4), were both of the Ss' eyes so scored. The average displacements scored were 1.36 inches to the left, and 0.76 inches to the right, for the left and right eyes, respectively.

The left eyes in the 10 inch condition were on-target 57% of the time (259 of 459 scored frames), and the right eyes were on-target 44% of the time (199 frames). In the 5 inch condition, the left eyes were scored on-target 21% of the time (90 of 438 scored frames), and the right eyes were on-target 34% of the time (148 frames). Clearly, there are many fewer instances of on-target fixations to the 5 inch stimulus. To confirm this finding, Wilcoxon matched-pairs signed-ranks tests (Siegel, 1956, p75), were carried out, separately on the left eye and the right eye data. To arrive at a value of T for the left eye data, the percentage of on-target fixations for each S was found for the left eyes in both conditions and, for each S, the difference between these two values was found. For each of the 11 Ss there was a greater percentage of on-target fixations in the 10 inch condition, ($T = 0$; $N = 11$; p, 2-tailed, $< .01$). For the right eyes, 4 Ss (Ss 1, 3, 6 and 10), had a greater percentage of on-target fixations in the 5 inch condition, and an acceptable level of significance was not reached ($T = 18$; $N = 11$; p, 2-tailed $> .05$).

A further Wilcoxon test was carried out on the overall data. Thus, the left eye and the right eye data were combined and the total percentage of on-target fixations was found for each S in both conditions. Only in one case (S1), were both eyes on-target a greater percentage of the time to the 5 inch stimulus, and the results indicate that, overall, there were less on-target fixations to the stimulus at the near distance ($T = 2$; $N = 11$; p, 2-tailed $< .01$).

These date are evidence that the newborns did not fixate the stimulus at the 5 inch distance in the same way that they fixated the 10 inch stimulus.

Fixation records The fixation records, derived from the scored film, are shown in Figure 6.5. This Figure is similar to Figure 6.4 in that the derived positions of the pupil centres are shown relative to the stimulus position within the marker lights. As the neonates were fixating binocularly the 10 inch stimulus, data for the right eye only are shown for this condition. For the 5 inch data the positions of the pupil centre are shown for both the left and the right eyes for each S. The vertical line in each part of this Figure shows the position of the stimulus: for the 5 inch records the stimulus position is $\frac{3}{4}$ inches to the left of centre for the right eye data, and $\frac{3}{4}$ inches to the right of centre for the left eye data.

It can be seen that the pupil centres of the right eyes for the 10 inch stimulus condition are displaced, on average, some distance to the right of the stimulus position - the displacements expected, and taken into account in deriving the average location of fixations for each S.

The data for the 5 inch condition are more difficult to interpret. If the neonates were fixating predominantly with monocular vision, there would be a clustering of fixations some 1.2 inches to the right of the stimulus (for the right eye data), if the right eye were the viewing eye, or 1.2 inches to the left of the stimulus, for the left eye data, if the left eye were the viewing eye. Some of the records show clear evidence of monocular fixation. Ss 3, 9 and 10 show a

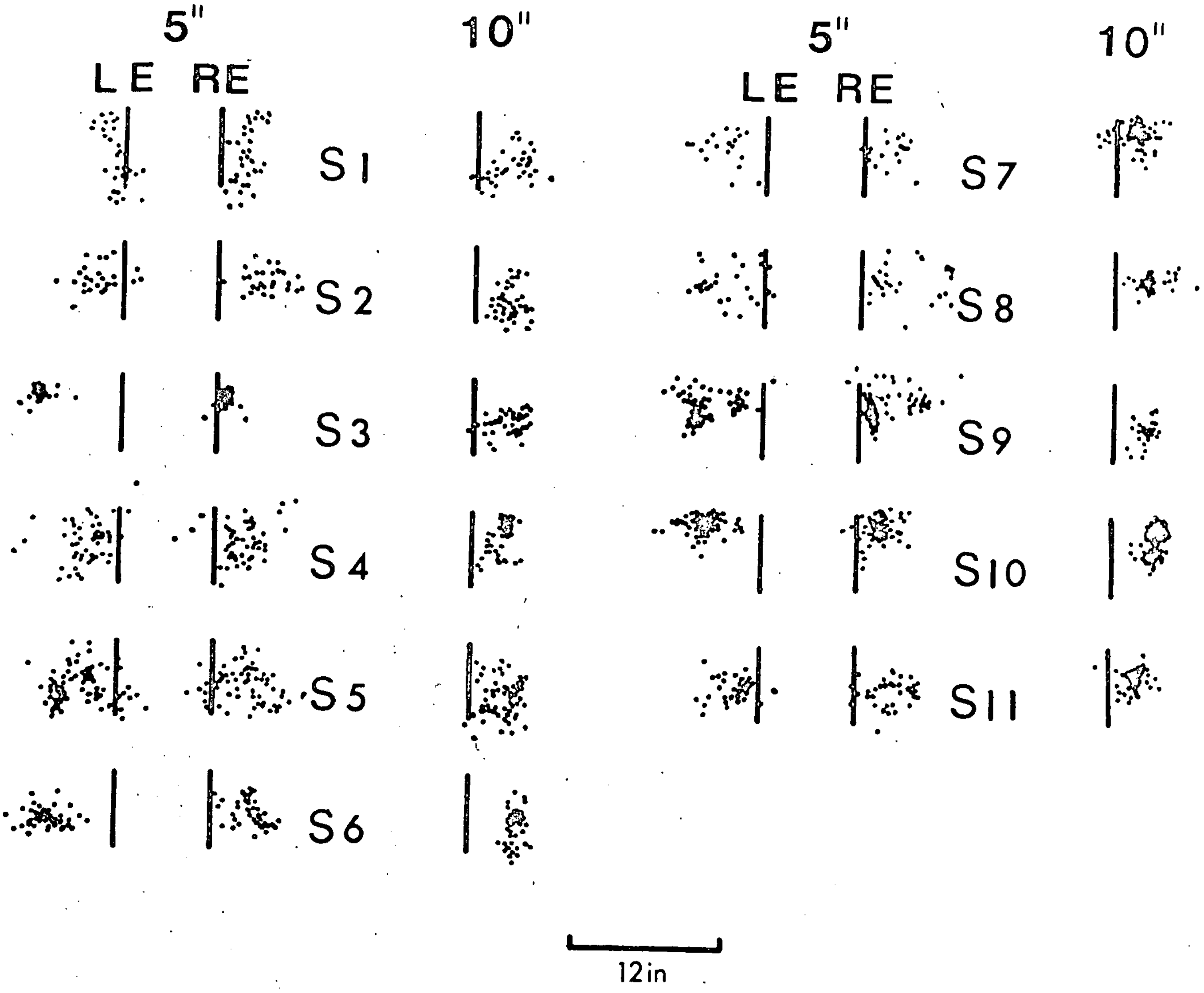

Figure 6.5 Visual fixation records of subjects viewing arrays of lights, at 5 inches and 10 inches, experiment 8. The scored records for both eyes are shown for the 5 inch condition. For the 10 inch condition, only the records for the right eye are shown.

tight grouping of fixations to the right of the target with the right eye, and it seems probable that these Ss were fixating the stimulus with this eye. Fixation records that are similar in form to those from the right eyes are evident for the left eyes of these Ss, but are displaced considerably to the left of the stimulus. For S7, the right eye was scored, on average, .037 inches to the right of the centre of the stimulus, an indication that this S, also, may have been fixating monocularly with the right eye. The fixation records, and the average scored location of the eyes, of Ss 2 and 11, allow of the possibility that these Ss were also fixating the stimulus monocularly, this time with the left eye.

The scored fixation records for Ss 4, 5, 6 and 8, do not appear to indicate that these Ss were "captured" by the stimulus. For the remaining S (S1), there is a possibility of binocular fixation of the target.

Divergence of the optic axes The average divergence of the optic axis of each eye, in each stimulus condition, and the standard deviation of the scored divergence, are shown in table 6.6, which is similar in construction to table 6.4. The average divergence in the 10 inch condition was 9.33°, which again is clear evidence of binocular fixation of the stimulus at this distance. A possible exception is S6, for whom the average scored divergence was 17.01° for each eye. Like S2 of experiment 5, it is possible that this S's eyes were fixating to either side of the stimulus, or that the S was fixating binocularly, and that the angle alpha is large.

If bifoveal fixation had been present to the 5 inch stimulus, the scored optic axis divergence should have been 6.0° less to the 5 inch stimulus than to the 10 inch stimulus. In fact, in all but two cases (Ss1 and 5), the scored divergence was greater in the 5 inch

TABLE 6.6

Scored divergence of the optic axis (in degrees), for both stimulus conditions, experiment 8

	5" Stimulus		10" Stimulus		
Subject	Average Divergence	SD	Average Divergence	SD	Difference
1	2.19	3.47	5.43	1.61	3.24
2	10.44	1.15	9.61	1.60	-0.83
3	15.27	1.91	8.79	1.87	-6.48
4	8.53	1.27	6.48	1.36	-2.05
5	10.65	2.22	12.00	1.62	1.35
6	20.38	5.08*	17.01	2.56	-3.37
7	10.68	1.34	5.22	3.53	-5.46
8	13.14	2.69	11.58	3.01	-1.56
9	14.27	1.40	9.50	2.69	-4.77
10	13.02	2.37	10.71	1.67	-2.31
11	8.88	4.17*	6.33	2.17	-2.55
Averages	11.59°		9.33°		-2.25°

condition. To find whether the changes in optic axis divergence are significantly different between conditions, Mann-Whitney U-tests were carried out for each S, the procedure being identical to that described for experiment 7. All 11 comparisons gave significant values of U (for Ss 2, 5 and 8 the associated probabilities, 2-tailed, $< .05$. For all other comparisons, p, 2-tailed, $< .01$), a further indication that the subjects did not fixate the 5 inch stimulus the same way they did the stimulus at 10 inches. The two largest standard deviations of the scored optical divergence (starred in table 6.6) are from two Ss (Ss 6 and 11) viewing the 5 inch stimulus - a further indication that these two Ss were not fixating this stimulus binocularly.

Discussion It is known that infants will spend more time looking at stimuli at some distances rather than others. McKenzie and Day (1972) found a linear decrease in the fixation times of infants aged from 6 to 20 weeks as the eye-to-object distance increased from 30 to 90cm. White, Castle and Held (1964), also reported that infants under $1\frac{1}{2}$ months rarely look at a stimulus closer than 7 inches, a finding they attribute to the infant's inability to accommodate to stimuli at this distance. Compatible with this latter suggestion, Ling (1942), found that, when convergence movements to an approaching object first occurred, (at the end of the second month), and "... when the disk comes within a close range (3-4 inches), not infrequently strabismus sets in - an overcompensation in accommodation for near vision. The infant will then blink violently to free himself from this apparently highly uncomfortable state" (p245).

An alternative explanation for the lack of bifoveal fixation of near stimuli is that neonates are unable to bring the eyes inward enough to converge consistently (Wickelgren, 1967). However, evidence from experiment 9, in the next chapter, suggests that newborns are well able to converge their eyes, often appearing extremely "cross-eyed".

Thus, it would seem most probable that the absence of convergence to the 5 inch stimulus, found in this experiment, is a consequence of an inability to accommodate.

Only in one instance (S1), was it likely that the subject was fixating the nearer stimulus bifoveally, although the difference in the scored optic axis divergence between conditions (3.24^{o}), is only about half that expected (6.0^{o}). Three possible (albeit somewhat speculative) explanations suggest themselves for the failure to find the full difference in this S: (1) accommodative blur of the near stimulus could prevent accurate alignment of the target on the foveas of the eyes; (2) since the eyes are physically more convergent to the near stimulus, slippage of the target might be in a divergent direction only. If slippage of the target from the foveas is caused by an equal number of convergent and divergent eye movements in the 10 inch condition, the scored averages would be closer together than expected; (3) if the S was working near the limits of his accommodative ability, fatigue may occasionally set in, accompanied by slight divergence of the eyes. The frequencies of the scored optic axis divergence, for this S in the two conditions, are shown in Figure 6.6. It can be seen that, in the 10 inch condition the frequency distribution approximates normality. The skewed nature of the frequency distribution in the 5 inch condition suggests that, of the three alternatives above, (2) and (3) are the most plausible.

The experimental results of experiments 5, 7 and 8 show that the neonate is well able to fixate binocularly, given a simple stimulus at a reasonable distance from the eyes. In an attempt to extend the generality of this finding, stimulus variables other than distance were varied in the experiments reported in the next chapter.

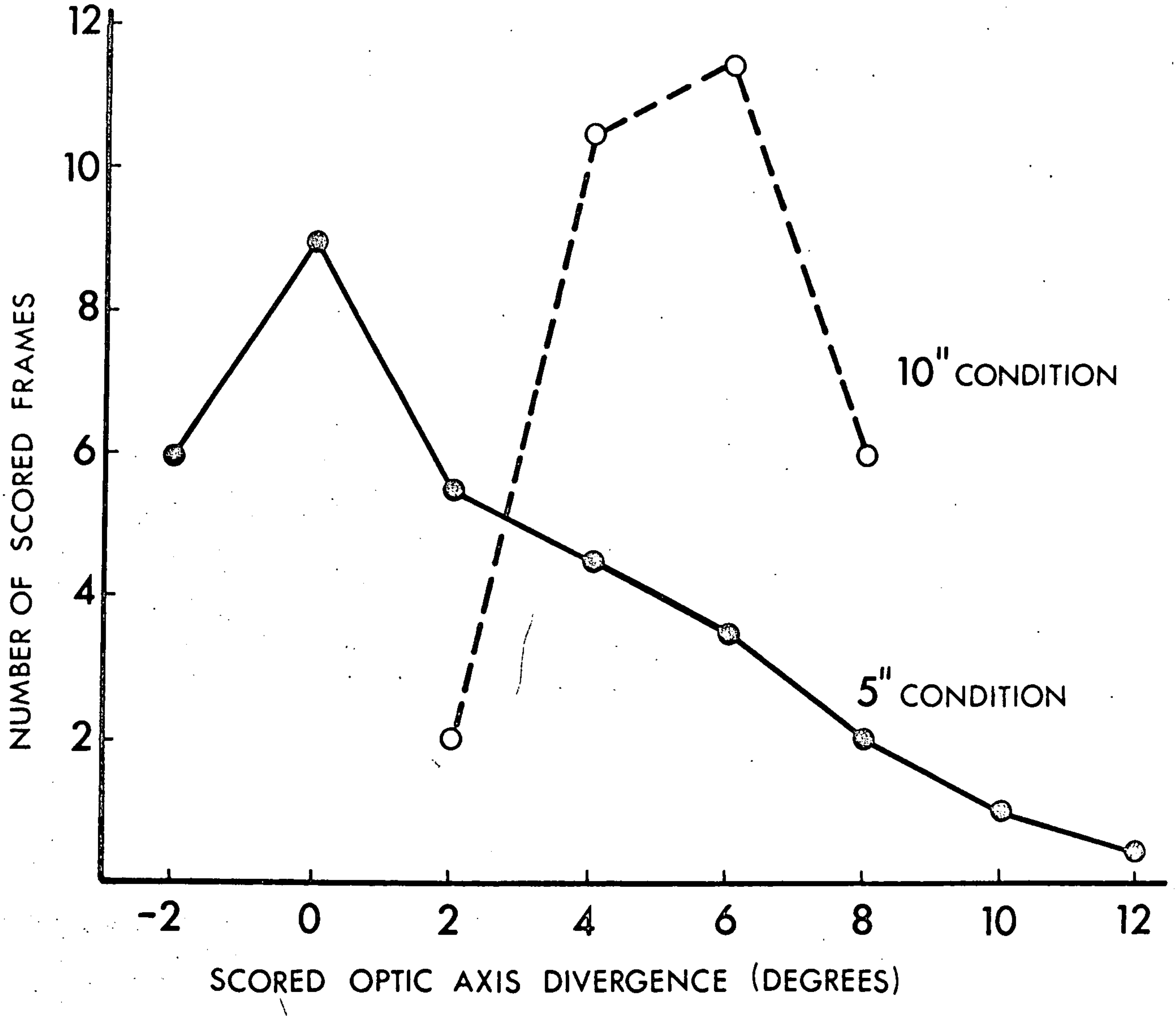

Figure 6.6 Frequency distributions of the scored optic axis divergence for S1 of experiment 8.

CHAPTER 7

BINOCULAR FIXATION IN THE NEWBORN: RESPONSES TO DIFFERENT STIMULI

In the experiments reported in the previous chapter it was shown that the newborn baby will binocularly fixate a simple stimulus (a vertical array of lights), when this stimulus is presented at distances of 10 inches and 20 inches from the eyes (with the retinal image size and luminance of the stimulus held constant). Thus, three of the four criteria for consistent binocular fixation by the newborn are satisfactorily met.[1] It may, therefore, be assumed that the newborn has the basic requirements for binocular vision.

The fourth requirement is that newborns will converge to any stimulus that attracts their visual attention, so long as the stimulus is presented a reasonable distance from the eye (i.e., presumably farther than approximately 7 inches).

In two of the experiments reported in this chapter (experiments 9 and 11), stimulus variables were manipulated whilst the stimuli were presented a constant distance (10 inches) from the eyes. When experiment 9 had been completed it was possible to investigate binocular fixation in a baby who had been a subject in that experiment. This baby was seen three more times, when aged 4, 5 and 6 weeks. The results from this infant are described under experiment 10.

Footnote[1] These criteria, or "demands", were outlined in the introduction to chapter 6. They are (1) the two eyes are optically divergent by some 17° on average, (2) each eye is on-target when the expected divergence of the pupil centre from the target position is allowed for, and (3) the eyes will be scored as being more optically divergent when fixating more distant targets.

The apparatus, procedure, and scoring of the film are, with minor variations that will be described for the separate experiments, similar to those detailed previously.

EXPERIMENT 9

Subjects Subjects for the experiment were 8 newborns. Details are not available for subject 1: the other 7 babies were 3 females and 4 males, 5 of whom were first born. The ages of these Ss at the time of experimenting ranged from 26 to 188 hours, median 68 hours, and their birth weights ranged from 5lb 12oz to 8lb 13oz, median 7lb 8oz.

Data collected from 3 other babies could not be used as there were not 14 scorable frames in any stimulus condition.

Stimuli Two stimuli were presented, at a 10 inch (± 1 inch) viewing distance. The first stimulus was a large equilateral triangle, painted non-glossy white on a black stimulus panel. The thickness of each side of the triangle was 1 inch; each outer contour of the triangle, from corner to corner, was $7\frac{7}{8}$ inches, and the inner contours measured $4\frac{1}{4}$ inches.

The second stimulus was a filled white semi-circle. The left-hand portion of a black, 5 inch diameter stimulus panel was painted a non-glossy white, and a vertical edge was presented 1 inch to the left of the centre of the stimulus screen, (this stimulus is hereafter referred to as the "vertical edge" or "edge" stimulus). The physical characteristics of both stimuli can be seen in Figure 7.2.

Diffuse lighting from the windows in the experimental room provided the illumination for the stimuli. The luminance of the white areas of the stimuli, measured several times in these conditions, was 25ft. L.

These stimuli were chosen because similar stimuli have received extensive theoretical and experimental treatment (Hebb, 1949; Salapatek and Kessen, 1966; Nelson, 1969; Salapatek, 1968; Haith, 1968; Kessen, Salapatek and Haith, 1972), and it was felt that they were likely to attract the newborns' visual attention.

Procedure The stimulus presented first was alternated between the 11 newborns seen (8 of whom were used as Ss). Each stimulus was presented for approximately 1 minute while the camera recorded at a speed of two frames per second. 3 of the Ss were shown the triangle first, and 5 the edge stimulus.

Results

Divergence of the optic axes Results were obtained for both stimuli from all of the Ss. The average scored divergence of the optic axis of each S's eye, in each stimulus condition, is shown in table 7.1. The standard deviation of the scored divergence is also shown.

The differences in magnitude of the average scored divergence between the two stimulus conditions are shown in the last column of this table. If these Ss had been viewing both stimuli bifoveally the values given in this column would be small. In four cases (Ss 1, 2, 4 and 5, starred in the table), the scored optic axis divergence was sufficiently large that it is not possible to conclude that these Ss consistently fixated both stimuli binocularly. In four instances the variability of the scored divergence was large (starred in the table: Ss 1 and 5 to the triangle; S4 to both stimuli); in these records the eyes did not maintain a relatively constant magnitude of optical divergence.

The distributions of the scored optic axis divergence are shown for all Ss in Figure 7.1. From this Figure it can be seen that some of the Ss (S1 to the triangle, S4 to both stimuli, and S5 to the triangle), had many instances in which the eyes were *optically*

TABLE 7.1

Scored divergence of the optic axis (in degrees), for both stimulus conditions, experiment 9

	EDGE		TRIANGLE		
Subject	Average Divergence	SD	Average Divergence	SD	Difference
1	7.74	3.02	-0.40	7.20*	8.14*
2	18.15	1.49	13.20	2.18	4.95*
3	10.93	1.69	12.32	1.29	-1.39
4	4.83	5.11*	-1.64	6.70*	6.47*
5	16.38	2.09	12.92	7.51*	3.46*
6	10.85	2.93	11.68	2.93	-0.83
7	9.34	2.72	7.90	2.38	1.44
8	9.68	2.47	9.48	3.59	0.20
Averages	10.99°		8.18°		2.81°

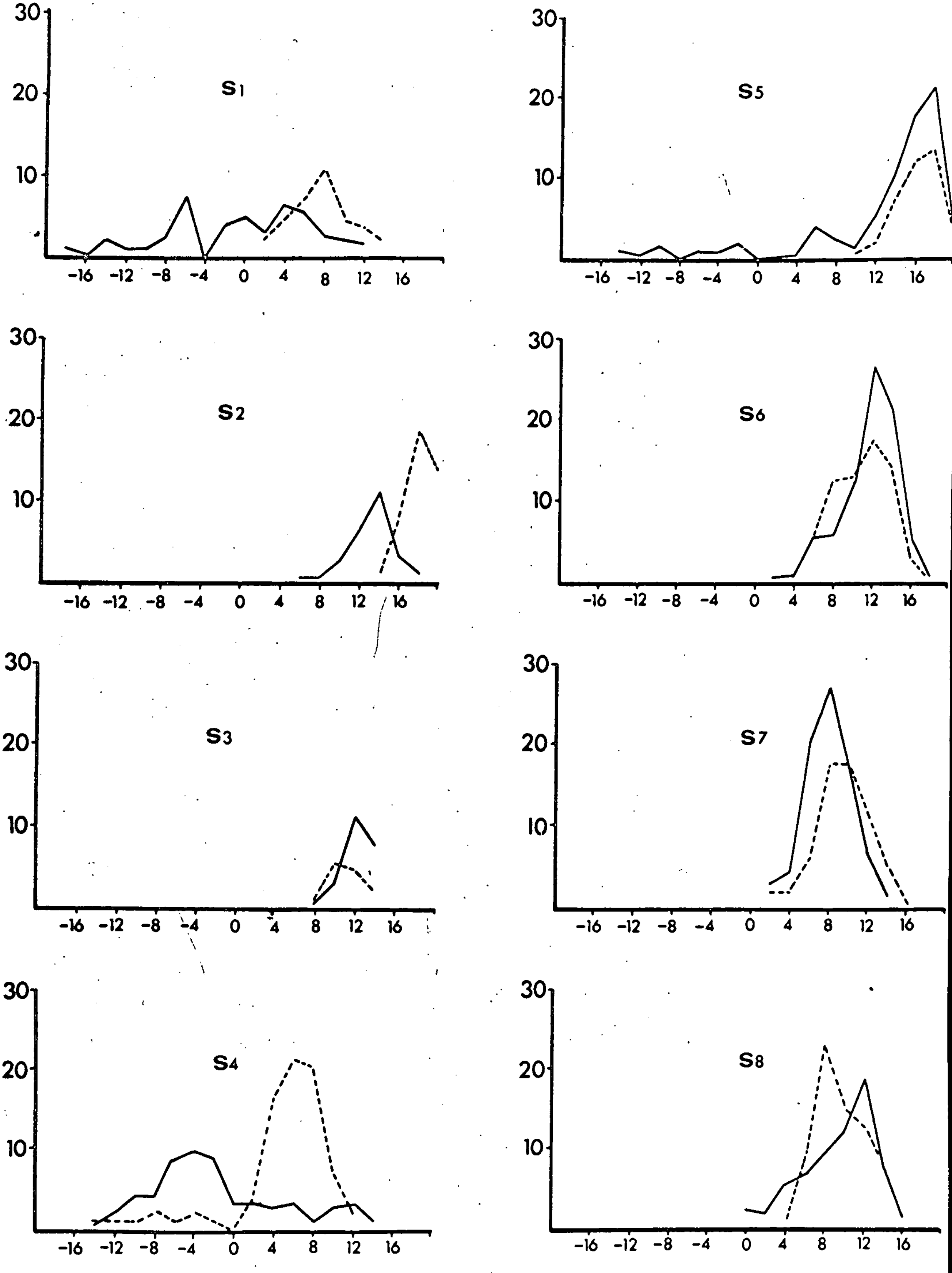

Figure 7.1 Distributions of the scored optic axis divergence for all subjects, experiment 9. Broken lines show the distributions for the edge stimulus, and filled lines show the distributions for the triangle. The abscissa of each graph gives the scored divergence (in degrees). The vertical axis gives the number of scored frames.

"cross-eyed", i.e., scored divergences of less than 0°. This would seem to refute Wickelgren's (1967) suggestion that newborns cannot consistently converge the eyes. Pupil diameter was measured from a sample of the film records from these Ss. The diameter of the pupil usually fell within a range of from 3.4mm to 4.7mm, but there was no obvious relationship between pupil diameter and the magnitude of the scored divergence of the optic axes.

Fixation records The fixation records, derived from the scored film, are shown in Figure 7.2. In the fixation records of Figures 6.4 and 6.5 the derived positions of the pupil centres were shown relative to the stimulus position within the marker lights. For convenience, the records shown in Figure 7.2 have been constructed differently: the stimuli have been positioned (using the average disparities found in experiments 3 and 4 of Chapter 3) so that on-target fixations by S should coincide with the area of the stimulus fixated.

Because of the variability encountered the implications of these data are considered separately for each S.

Subjects 3, 6, 7 and 8 The small differences in the scored optic axis divergence between conditions (from -1.39° to 1.44°, table 7.1), suggests that these Ss were fixating both stimuli bifoveally. This suggestion is further borne out by the overlap of the distributions of the scored optical divergence, and the definite peaks of this variable, shown for each S in Figure 7.1. The fixation records (Figure 7.2) for Ss 6, 7 and 8 show a clear grouping around the contours of the "edge" stimulus and to a corner of the triangle. Although this might also have been the case for S3, the small number of scored fixations (14 from the record for the edge stimulus, and 22 for the triangle) does not permit a firm conclusion to be drawn.

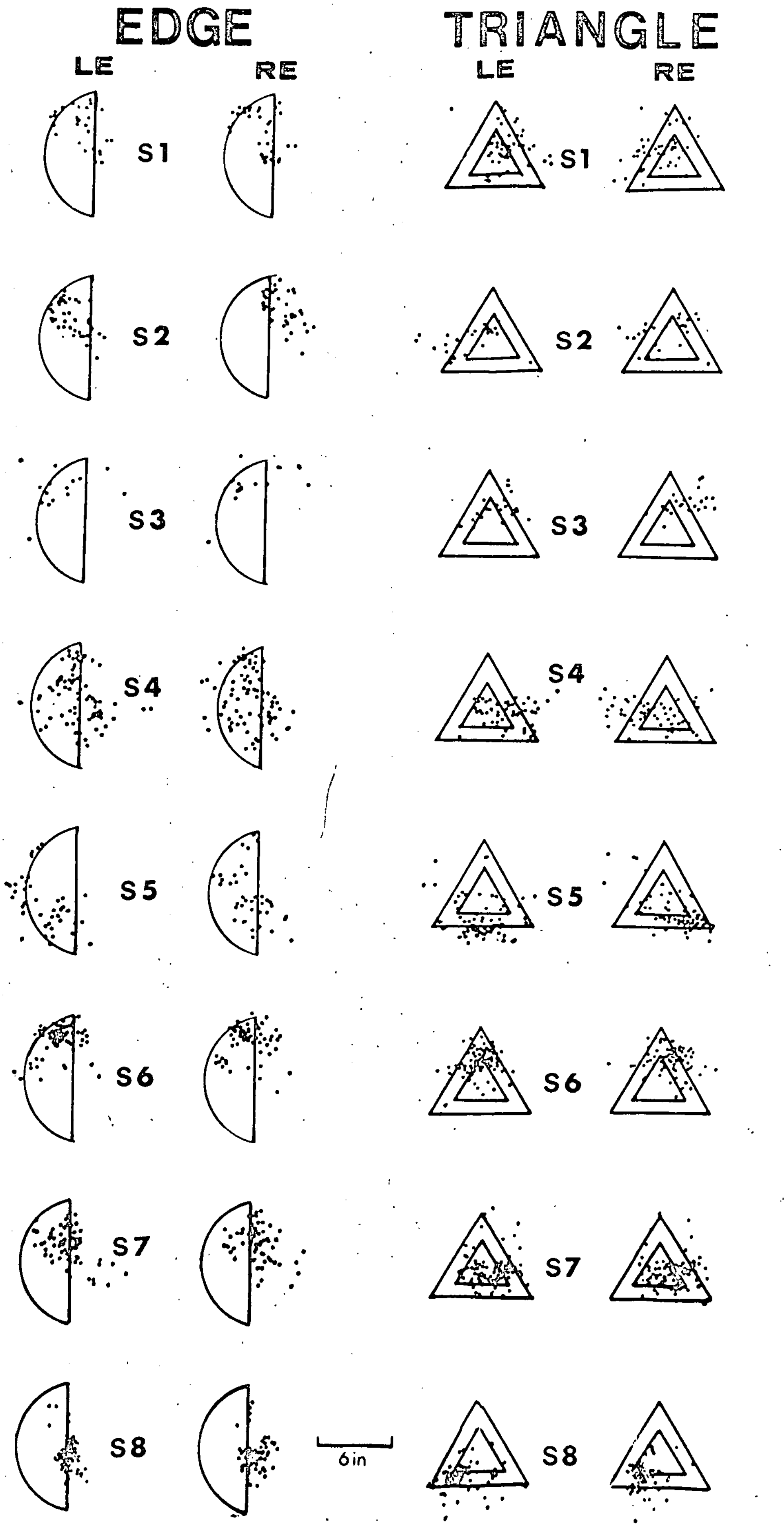

Figure 7.2 Visual fixation records of subjects viewing an edge stimulus, and a triangle (both eyes), experiment 9.

Subject 5 It is likely that this S converges, at least for some of the time. The scored optic axis divergence (Figure 7.1) shows a considerable overlap of the distributions obtained to the two stimuli, around 16 and 17° visual angle, although the negative skew of the distribution for the triangle reduces the average divergence in this condition, and adds to its variability. From the fixation records obtained (Figure 7.2) it is possible that this S predominantly fixated around the contours of the edge stimulus, and towards the bottom right hand corner of the triangle.

Subjects 1 and 4 The scored optic axis divergence for these Ss was very variable: the larger the variance of this scored divergence, the smaller is the indication that the eyes were consistently converging to the stimuli. It is possible that S1 was binocularly fixating the edge (most fixations by this S, shown in Figure 7.2, are near the contour), but the wide variability in the other conditions (i.e., S1 to the triangle, and S4 to both stimuli), shows that there was no consistent convergence. The fixation records for these conditions (Figure 7.2), do not show a definite grouping.

Subject 2 Although the variability of the scored optic axis divergence is small for this S in both stimulus conditions (SD = 1.49° for the edge stimulus, and 2.18° for the triangle), the large difference in the averages of this divergence between conditions (4.95°) is an indication that this S also did not fixate the stimuli bifoveally. As this S was the subject for experiment 10, further comments will be made when the results from that experiment are discussed.

Discussion Unlike the results from experiments 7 and 8 (Chapter 6), the results from this experiment do not permit a unanimous interpretation. Whilst some Ss converge to both stimuli, others clearly do not. It is certainly the case that large variability in the scored optical divergence of the two eyes is an indication of a lack of binocular fixation.

A possible reason for the ambiguous nature of the results from this experiment concerns the author's ability to hold the Ss in position. By the time this experiment was carried out the author had become sufficiently adept that it was possible to obtain records from all Ss who did not either engage in such extreme ocular activity that the film records were unscorable, or closed their eyes during the experimental session (results were unobtainable from only 3 of the 11 babies seen). It might be that this introduces a further variable to an already variable subject population (i.e., it might be, as it were, that one can point a newborn's eyes in the direction of the stimulus, but one cannot make him look).

The few positive findings from this experiment are in agreement with Salapatek and Kessen's (1966) finding that newborns will fixate a corner of a large triangle, and Haith's (1968) finding that vertical contours are attractive.

In the face of such variability the author was reluctant to carry out more quantitative analyses of the data, and no further results were taken.

<u>EXPERIMENT 10</u> When experiment 9 had been completed a longitudinal study was carried out on one baby who had given results in that experiment (Subject 2).[2] This baby was seen on four separate occasions: the first when she was a subject in experiment 9 (26 hours old); additionally, she was seen when 3 weeks, 6 days, 4 weeks, 6 days, and

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Footnote[2] Thanks are due to Mrs. Mary Pearson, whose daughter Anna was the subject in this experiment.

6 weeks of age.

On the first occasion, she was shown the triangle and the edge stimulus described under the previous experiment. On the three subsequent occasions she was shown these two stimuli, the vertical array of lights at 10 inches that had been used as a stimulus in experiments 7 and 8, and the array of lights at a 5 inch distance that was used in experiment 8.

Results

Divergence of the optic axes The scored divergence of the optic axis, and the standard deviations, are given in table 7.2. Where results were not available from a particular stimulus presentation, no entry is made in the table.

On the fourth experimental session (when S was 6 weeks old), the scored divergence was, to the stimuli presented at an eye-to-stimulus distance of 10 inches, an average of 10.40°, and all three averages are within 0.32° of this value (columns B, C and D of table 7.2). The standard deviations of the distributions of the scored divergence, for this session, were very small, being a maximum of 1.02°. The data from this session are evidence for binocular fixation of the stimuli by this 6 week-old S. In this final experimental session S was also reliably converging to the stimulus presented at a viewing distance of 5 inches: the scored optic axis divergence was 3.94°, which is 6.46° less than that to the stimuli at 10 inches.[3]

The results from the records obtained when S was presented the stimulus at 5 inches call for special comment. For the second

Footnote[3] The expected reduction in the scored divergence for an S binocularly fixating a stimulus at 5 inches is 6.0° (Chapter 6).

TABLE 7.2

Scored divergence of the optic axis (in degrees) for the four stimulus conditions (A, B, C & D), and the four experimental sessions (1, 2, 3 & 4) of experiment 10.

		A 5" Stimulus		B Array of lights		C Triangle		D Edge		
Exptl. session	Age (Weeks & Days)	Average Divergence	SD	Average Divergence	SD	Average Divergence	SD	Average Divergence	SD	Maximum difference between stimulus conditions B, C & D
1	0,1	-	-	-	-	13.20	2.18	18.15	1.49	4.95
2	3,6	14.59	2.43	10.96*	3.54	-	-	10.68*	1.92	0.28
3	4,6	2.75	7.45	-	-	-3.61	7.05	-	-	-
4	6,0	3.94*	0.59	10.46*	0.78	10.08*	1.02	10.66*	0.95	0.58

experimental session (when S was 3 weeks, 6 days old), the scored divergence of the pupil centres was an average of 14.59°, showing that S was not fixating the stimulus bifoveally. The fixation record of this session (Figure 7.3) indicates that S was viewing the stimulus monocularly, with the left eye. For the third experimental session the average scored divergence was 2.75°. However, although this divergence is approximately that required to indicate binocular fixation, the large variability, and the failure to consistently fixate the stimulus (Figure 7.3), preclude this interpretation of the results. The range of the scored optic axis divergence to the 5 inch stimulus for the third experimental session is shown in Figure 7.4. In this Figure the range for the final experimental session is also shown. It can clearly be seen that the well-defined peak found in the distribution of the results from the fourth session is not present in the results from the third session.

Pupil Diameter It was mentioned in the last chapter that, when an adult changes fixation from a far to a near object the eyes converge, the anterior surface of each lens bulges forward to accommodate to the near object, and the pupils become smaller (to counteract the spherical aberration that would otherwise be present), bringing the object sharply into focus. These changes occur together, and would seem to be the result of a common, muscular innervation (Alpern, Lowenstein and Loewenfeld, 1962, p213). During experimental session 3 (when S was 4 weeks, 6 days old), the pupil centres of the eyes were often scored as being markedly under-convergent (i.e., "cross-eyed"). From a sample of the film records it was clear that, to the triangle stimulus presented during this session, the smallest pupil diameters were found during some of these under-converged occasions. When the optic axes were scored as being parallel (a value of 0°), or

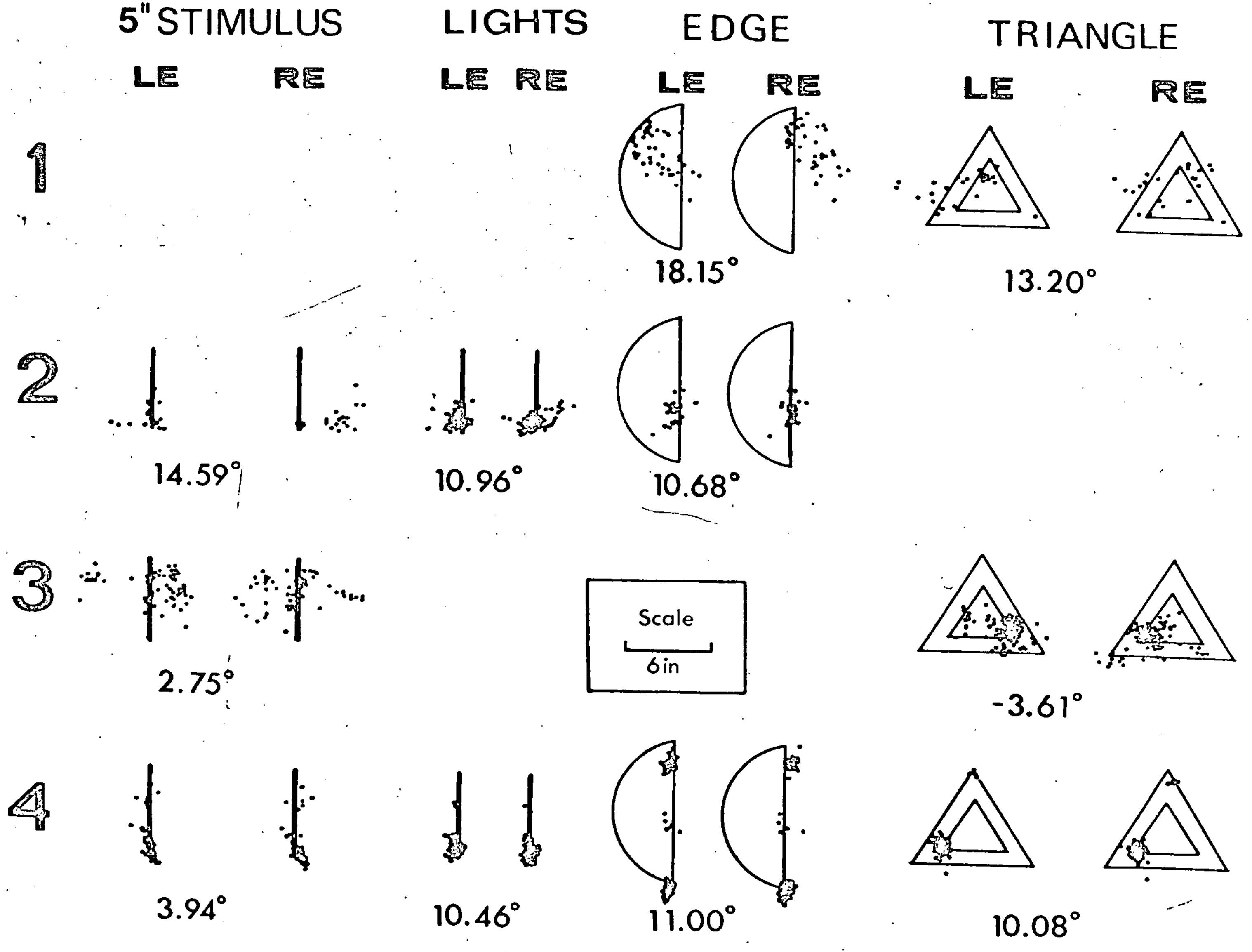

Figure 7.3 Visual fixation records of one subject (Anna Pearson), experiment 10.

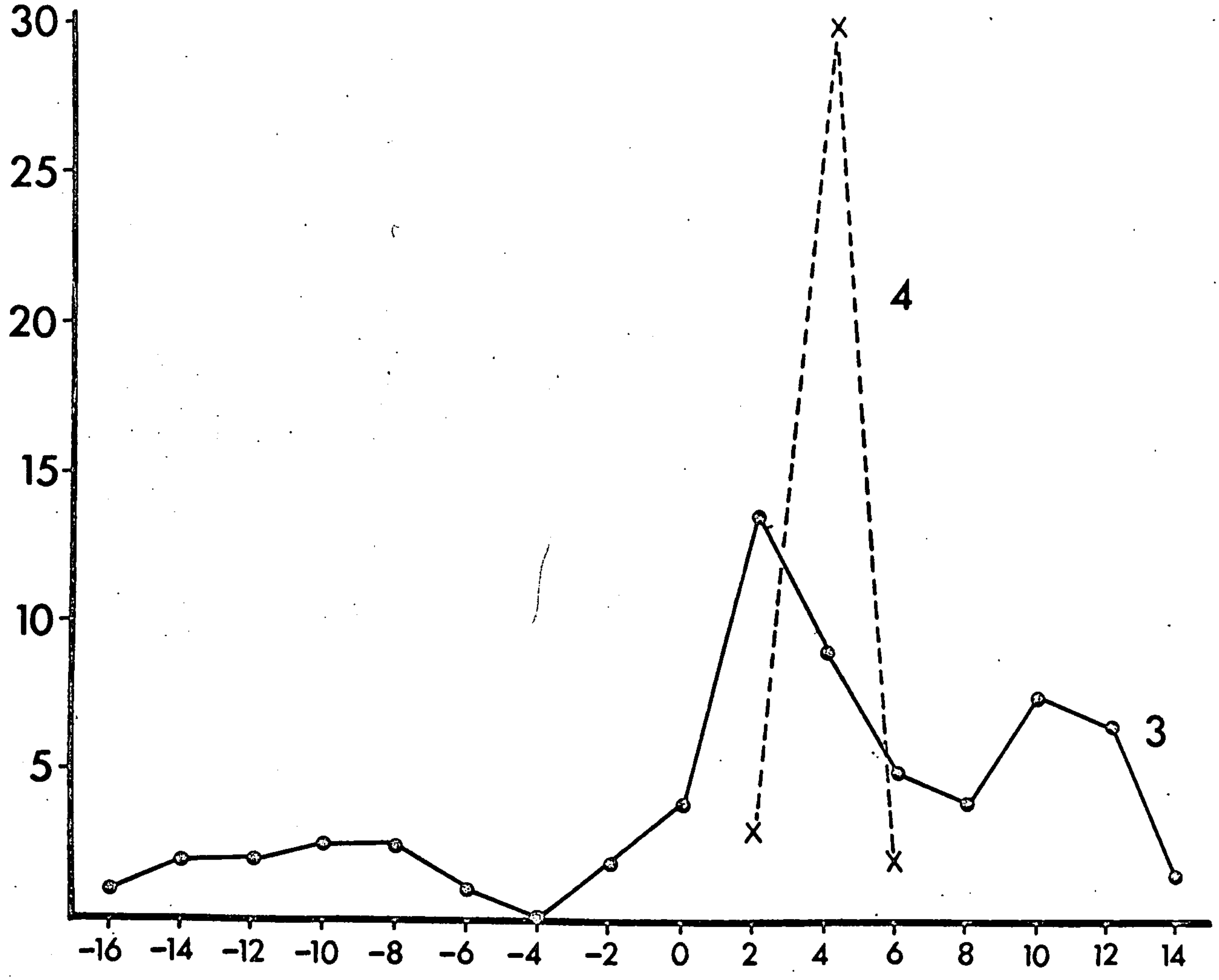

Figure 7.4 Distributions of the scored optic axis divergence for the 5 inch stimulus, sessions 3 and 4, experiment 10. The axes are the same as those of Figure 7.1.

divergent, the pupil diameter ranged from 4.7 to 4.9mm. When the optic axes had a scored value of less than 0^{o}, the pupil diameter ranged from 3.2 to 4.7mm. The same result was found from a sample of the records to the 5 inch stimulus. Thus, for this S at 4 weeks, 6 days of age, there appeared the presence of the pupil constriction reflex.

For the fourth experimental session (when S was 6 weeks old), pupil diameter was measured from a sample of the film records, (a) when S was converging to the 5 inch stimulus, and (b) when S was converging to the array of lights presented at a 10 inch viewing distance. Since the stimuli were equated for luminance and retinal image size, differences in pupil diameter are not to be explained by these variables. To the array of lights the pupil diameter was an average of 5.06mm (14 scored frames); to the 5 inch stimulus the pupil diameter was an average of 4.5mm (15 scored frames). A Mann-Whitney U-test was carried out on these data, and a significant value of U was obtained ($U = 12.5$, p, one-tailed, $< .01$). Thus, the changes in pupil diameter that one would expect to accompany convergence to a near object were found for this 6 week old S.

Fixation records The fixation records of the derived positions of the pupil centre are shown in Figure 7.3. The positions of the stimuli are again arranged so that fixations on-target would coincide with the portion of the stimulus fixated. The average scored divergence of the pupil centres is shown under the records for each presentation.

For the fourth experimental session the fixations are on-target to a marked extent, with groupings around the contour of the edge stimulus, the left hand corner of the triangle, and the bottom of the 10 inch array of lights. During the second experimental session it is clear that S was also converging to those stimuli presented at a viewing distance of 10 inches from which results were taken.

Clearly, the fixations of this S during the first experimental session (row 1 of Figure 7.3), when S was 26 hours old, were much more variable than those obtained when S was binocularly fixating the stimuli during later sessions. During the third session S appeared to fixate the right hand corner of the triangle with the left eye, and the left hand corner of the triangle with the right eye. This pattern of fixations is unique to the present experiment: it is most likely coincidental, because of the large variability in the scored divergence (SD = 7.05°).

Conclusions This longitudinal study does not provide unambiguous results concerning the development of binocular fixation. Three conclusions emerge, however:

(1) When S's eyes fluctuated markedly around the mean optic axis divergence (edge stimulus and triangle for session 1; 5 inch stimulus for session 2; 5 inch stimulus and triangle for session 3), there was no evidence (from the other variables recorded) for binocular fixation;

(2) When binocular fixation was clearly present (array of lights at 10 inches and edge for session 2, and all stimuli for session 4), the mean of the scored optic axis divergence was similar (with a range from 10.08° to 11.00°), and its variability was small;

(3) There was not an orderly progression in the development of binocular fixation.

The last conclusion is limited by the small sample size: fluctuations in S's state probably influenced these results.

However, the results from sessions 2 and 4 do provide clear evidence that, in this S, the angle alpha is large (approximately 10.40°), and empirically refute Merkel and Orr's (1892) suggestion that the visual and optic axes of the eye coincide in the three-week-old infant.

EXPERIMENT 11 Because of the variability encountered in experiment 9, a stimulus similar to the vertical array of lights used in experiments 3, 4, 5, 7 and 8 was presented in the present experiment, together with other stimuli. It is known, from these earlier experiments, that most newborns will readily fixate this stimulus with the foveas of both eyes, and it was hoped that fixations of this stimulus would allow determination of the angle alpha for each individual S in the present experiment, and that this could be used to give some indication of what was happening during those instances when Ss did not binocularly fixate the other stimuli.

Subjects Subjects for the experiment were 15 newborns, 7 females and 8 males, 9 of whom were first born. Their ages at the time of experimenting ranged from 42 to 210 hours, median 146, and their birth weights ranged from 6lb to 8lb 8oz, median 7lb 1oz.

A further 7 babies were seen, but could not be used as Ss. In 3 cases the camera was badly focused and the photographic records could not be scored. In a further 3 cases the experimental session was terminated during or after presentation of the first stimulus, because the baby cried, fussed, or fell asleep. The film from one newborn was not scored as most of the apparent fixations were well outside the stimulus area.

Stimuli It had not been possible to control exactly the level of illumination of the white areas of the stimuli presented in experiment 9. In order to provide a uniform level of illumination of all parts of the stimuli, and to allow a number of different stimuli to be separately presented, a light diffuser was constructed for use in the present experiment.

Ten small bulbs were mounted (evenly spaced) on a circular (10 inches in diameter) piece of aluminium, which had a two inch square hole cut out of its centre. A piece of crumpled aluminium foil was glued to the aluminium, its purpose being to diffuse the light that it reflected from the bulbs. A similarly-shaped piece of semi-translucent, white perspex was mounted approximately 1½ inches above the front surface of the bulbs. When the bulbs were switched on the front surface of the perspex appeared evenly illuminated throughout its entire area. An infrared filter was glued to the central hole in the perspex. When the light diffuser was screwed into position on the apparatus, it covered the 9½ inch diameter hole in the stimulus screen, and the camera photographed through the infrared filter in the perspex. To ensure that this central filter did not reflect or transmit light from the bulbs, either into the camera lens, or to the subjects' eyes, a two inch square piece of tubing was slotted between the central holes in the aluminium bulb mounting and the white perspex. The inside of this tubing was painted matt black. The voltage of the bulbs was adjusted until the luminance of the front surface of the perspex was 20 ft. L.

When this light diffuser was fitted to the apparatus it was possible to present a stimulus to the subject at a distance of 10 inches from the eyes, and with a constant luminance, throughout an area 9½ inches in diameter (with the exception of the 2 inch square central area, which appearedblack), by covering unneeded areas of the front surface of the perspex (the surface seen by S). To present the stimuli, aluminium stimulus panels (painted black), were hung over the perspex, with the stimulus shape removed.

Three stimuli were presented in this experiment. The first was a vertical strip, 6 inches x ½ inch, and presented two inches to the left of centre. The second stimulus was an outline equilateral triangle and an outline square, presented together. The length of each outer contour of the triangle was three inches, and of the square was two and a half inches. The sides of each of the figures were half-an-inch wide. For the first 8 Ss the triangle was presented to the left of centre, and the square was to the right. The centres of these figures were three inches from the centre of the stimulus panel. For the last 7 Ss the stimulus panel was reversed so that the square was to the left. The third stimulus was an arrangement of four open squares, of two inches side. The arrangement of these squares can be seen in Figure 7.5.

These stimuli were chosen for their known, or supposed, ability to attract newborns' visual attention. Evidence reviewed in Chapter 1 suggests that an array of squares, of two inches side, at a viewing distance of 10 inches, will be fixated more frequently than other stimulus arrangements. A triangle and square, similar in size to the present ones, were used by Salapatek (1968), in an extensive study with 72 newborn subjects.

Procedure To increase the probabilities of obtaining results to the vertical strip, this stimulus was always presented first. As an additional precaution, during eight of the experimental sessions this stimulus was also shown after presentation of the other two stimuli. If results were available from the first presentation, however, this final trial was not scored. The order of presentation of the other two stimuli was alternated between Ss, and all three stimuli were presented for approximately 1 minute.

Results Results were obtained from all but one of the Ss for all three stimuli. This S (S3) began fussing during presentation of the triangle-and-square stimulus: results were obtained from this

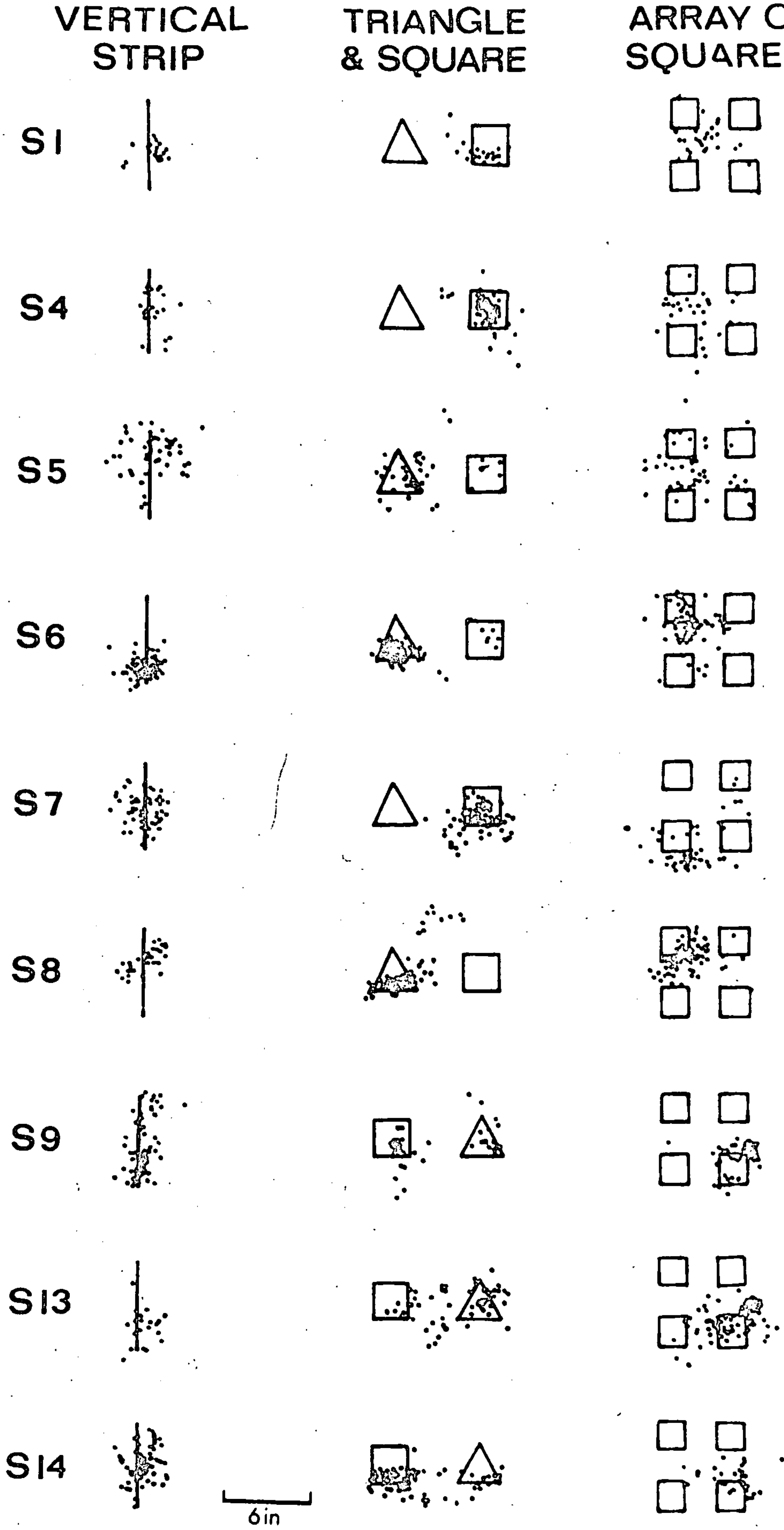

Figure 7.5 Visual fixation records of those subjects from experiment 11 who are presumed to be binocularly fixating all the stimulus figures. Right eye only.

presentation, but the array of squares was not shown this S.

Divergence of the optic axes The average scored divergence of the optic axis of each S's eye in the three stimulus conditions is given in table 7.3, together with the standard deviations of the scored divergence. The largest difference in the average scored divergence between any two of the three stimulus conditions is shown in the last column of this table, for each S. A large value in this column is an indication that S was not consistently bifoveally fixating all the stimuli. In six cases (Ss 2, 3, 10, 11, 12 and 15, starred in the table), the maximum difference scored was sufficiently large to indicate that this was the case. The results are considered separately for each S.

Pupil diameter It was again the case that some Ss' eyes were scored as being optically under-convergent. A comparison of pupil diameter between instances of under- and over-convergence did not reveal any obvious difference between the conditions, although the smallest pupil diameters seemed associated with instances of under-convergence. Thus, for S15, viewing the triangle-and-square stimulus, a range of pupil diameter from 4.7 to 5.4mm was found when the eyes were optically over-convergent, and a range from 3.19 to 4.7mm was found when the eyes were under-convergent. In the adult, the pupil diameter continues to decrease beyond the near point of accommodation. (Alpern, 1962, p213). It seems possible that the changes in pupil diameter associated with vergence movements are present in newborns, but that the present recording technique is unable to detect them - i.e., if changing from over- to under-converging is accompanied (in neonates), by a decrease in pupil diameter, but the pupil dilates again shortly thereafter, the rate of filming (2 frames per second) may be too slow to pick up these changes.

TABLE 7.3

Scored divergence of the optic axis (in degrees), for the three stimulus conditions of experiment 11

	Vertical Strip		Triangle and Square		Squares		
Subject	Average Divergence	SD	Average Divergence	SD	Average Divergence	SD	Maximum Difference Between Conditions
1	6.47	1.95	6.25	1.94	7.08	2.59	0.83
2	7.35	1.64	0.81*	6.70	-3.63*	9.67	10.98*
3	15.97	1.71	11.35*	7.10	-	-	4.62*
4	7.21	1.64	7.65	1.27	7.70	1.40	0.49
5	12.47	1.86	12.48	2.65	12.36	2.04	0.12
6	7.16	2.93	7.92	1.61	7.92	1.90	0.76
7	6.06	1.79	5.49	2.31	5.63	1.76	0.57
8	11.69	1.00	10.42	3.90	12.14	1.39	1.72
9	10.36	2.07	11.96	1.73	11.19	1.67	1.60
10	17.28*	1.58	12.81*	4.61	13.90*	2.54	4.47*
11	14.91*	2.42	17.29*	2.10	17.30*	1.89	2.39*
12	21.29*	1.50	14.75*	4.22	14.89*	4.60	6.54*
13	12.27	1.32	11.79	2.36	11.05	3.12	1.22
14	11.24	1.76	10.93	3.13	11.45	1.41	0.52
15	7.52	2.29	4.78*	9.38	7.36	2.70	2.74*
Averages	11.28° (N = 15)		9.78° (N = 15)		9.74° (N = 14)		2.64° (N = 15)

Subjects 1, 4, 5, 6, 7, 8, 9, 13 and 14

For these Ss the maximum difference in the scored optic axis divergence was small, less than 2° in each case.[4] The fixation records for these Ss are shown in Figure 7.5, for the right eye only. To the vertical strip, the eyes were fixating, on average, 0.26 inches to the right of its centre with the right eye, and 0.02 inches to the left with the left eye: in each case the average scored location of each eye was within 1 inch of the centre of the stimulus. To the second stimulus (the triangle-and-square), it is apparent from Figure 7.5 that these Ss tended to look at one, rather than both, of the figures, with a grouping of fixations around the contours of the chosen figure.

To the third stimulus (the array of squares), the fixations are more difficult to interpret. Six of the Ss (Ss 6, 7, 8, 9, 13 and 14) fixated around the contours of one of the squares: the other three Ss (Ss 1, 4 and 5) fixated mostly within the stimulus arrangement. This raises problems concerning the nature of the stimulus presented to the Ss. If Ss fixated within this arrangement, they may well have been viewing a black cross against a well-illuminated background.

However, the purpose of this experiment was to investigate binocular fixation of these stimuli, rather than to investigate the functional characteristics of the stimuli. It would seem a necessary

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Footnote[4] A precise criterion of what is, and what is not, binocular fixation of all stimuli is not possible. However, if the optic axis divergence scored between conditions is very similar, and if the variability of this divergence is also small for each stimulus presentation, this seems a convincing demonstration of convergence. For every one of these 9 Ss the average divergence scored for each stimulus presentation was within 1° of its overall average.

conclusion that all of these 9 Ss were binocularly fixating all of these stimuli.

Subjects 2, 3 and 15 For these three Ss the maximum difference in the scored optic axis divergence between conditions was large (10.98°, 4.62° and 2.74°). The distributions of this variable, for each stimulus presentation, are shown in Figure 7.6, for these Ss. In all cases there is a definite peak of the distributions, but to some presentations (the triangle-and-square, and the array of squares for S2; the triangle-and-square for Ss 3 and 15), the distribution is negatively skewed, which accounts for the smaller average divergence of the eyes, and the large variability, in these conditions (table 7.3). In the other stimulus conditions (the vertical strip for all three Ss, and the array of squares for S15), the scored divergence has a small range, and it seems probable that in these cases the Ss were maintaining a well-directed bifoveal fixation of the stimuli: each eye's fixation position was scored as being, on average, within 1 inch of the centre of the vertical strip.

Because the distributions for each S (Figure 7.6) peak in approximately the same place for all the conditions from which results were taken, it would seem possible that these Ss were converging some of the time in the more doubtful conditions, even though the range of the distributions is large. For this reason, the fixation records for these Ss (Figure 7.7) have been divided (for the doubtful conditions), to separately show those occasions when the optic axis divergence suggested that S was converging, and those when S did not seem to be converging. This division was made in the following manner, described for S2: the average scored optical divergence of each eye was 7.35° when S was (presumably) binocularly fixating the vertical strip; the eyes' fixation positions for those occasions when the

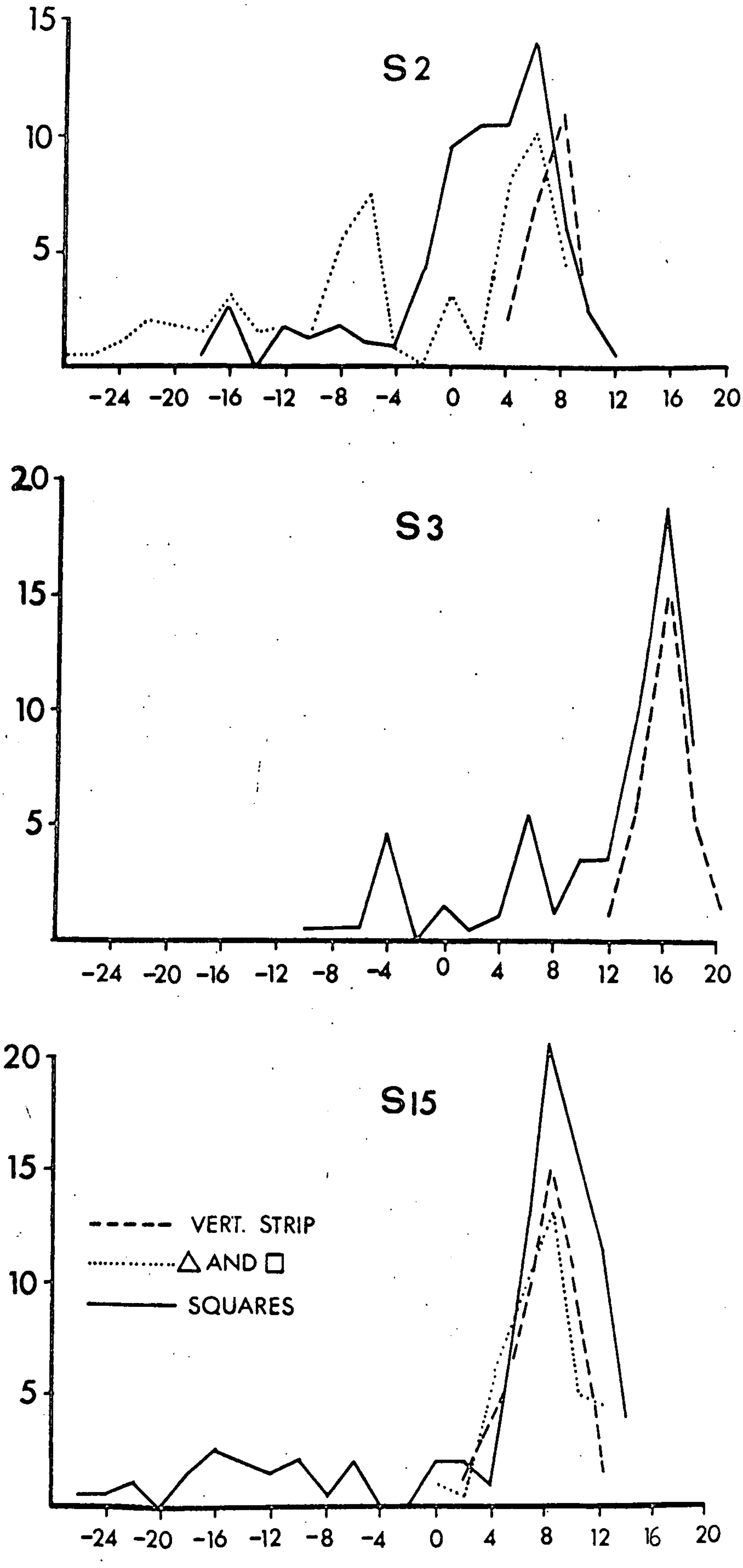

Figure 7.6 Distributions of the scored optic axis divergence for subjects 2, 3 and 15, experiment 11. The axes of each graph are the same as those of Figures 7.1 and 7.4.

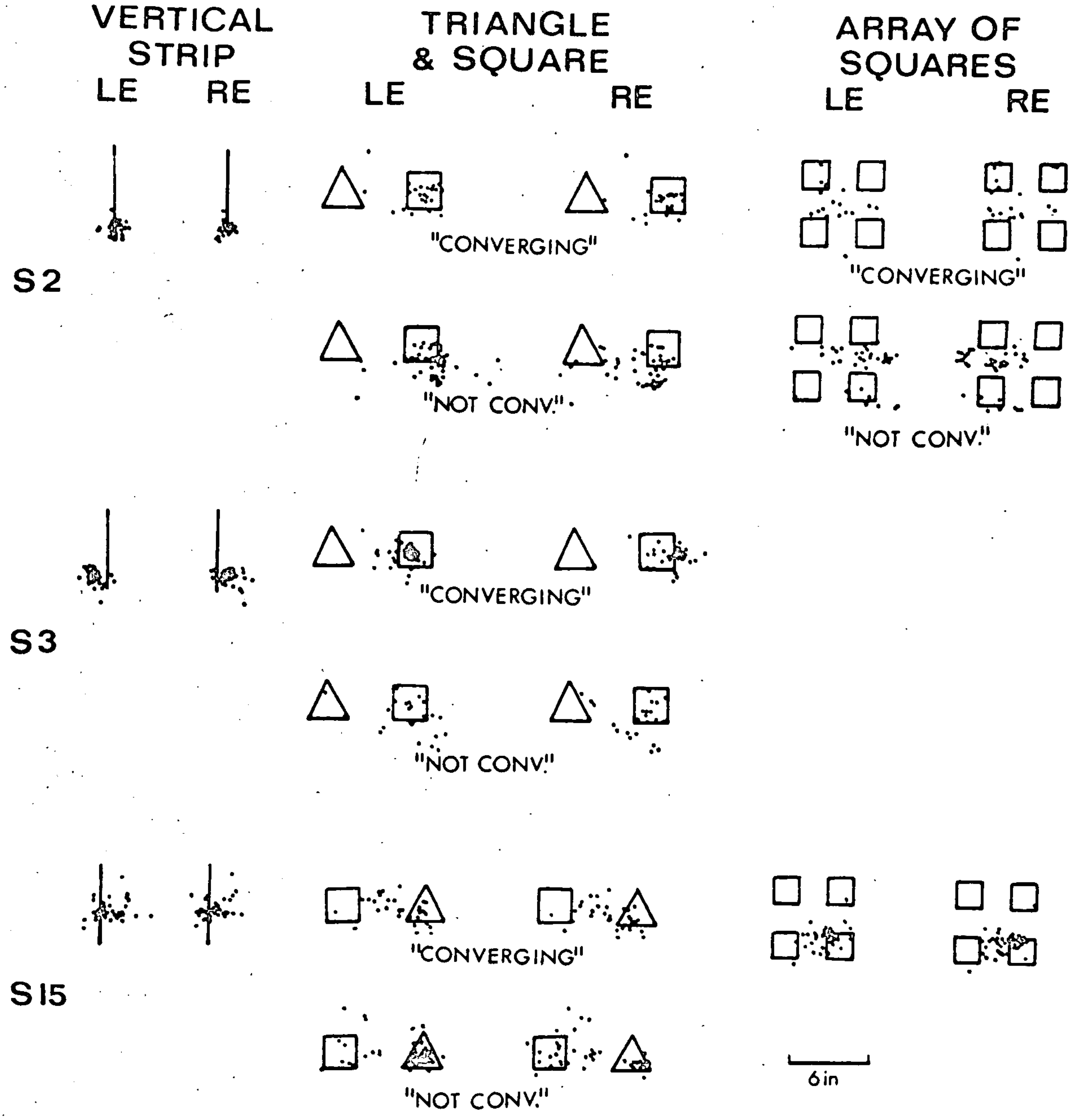

Figure 7.7 Visual fixation records of subjects 2, 3 and 15, experiment 11. For further explanation, see text.

divergence was 7 ± 2° in the other stimulus conditions are shown in Figure 7.7 as "converging", and the derived fixations when the divergence was outside this range are shown as "not converging." Similar separations are shown in this Figure for Ss 3 and 15.

When S2 was "converging" to the triangle-and-square, the square was primarily selected for viewing, and more fixations were on-target (those scored as being on or within the contours of the figures) than when S2 was "not converging." The number of on-target fixations was 16 out of a total of 23, and 17 out of 23, for the right and left eyes, respectively, when S2 was "converging", and were 19 out of a total of 51, and 18 out of 51 for the right and left eyes when S2 was "not converging." X^2 tests (Siegel, 1956) were carried out on these frequencies, for the left eye and right eye data separately. These comparisons indicate that there were more on-target fixations when S was presumed to be converging (X^2, right eye = 6.58, p, two-tailed, < .02; X^2, left eye = 9.42, p, two-tailed, < .01).

A visual inspection of the fixation records for the array of squares does not suggest any obvious differences in the location of fixations between conditions for this S, and statistical comparisons of the data were not made.

The fixation records for S4 for the triangle-and-square show that, when S4 was presumed to be converging, there was a tighter grouping of fixations than when S was judged to be not converging. However, X^2 tests carried out on the number of on-target fixations did not indicate a significant difference in the location of fixations between the two conditions.

Similar analyses were carried out on the data for S15 in the triangle-and-square condition. The X^2 test carried out on the results from the left eye gave a significant value (X^2 = 8.39, p, two-tailed,

< .01). For this eye, 15 out of a total of 34 fixations were on-target when S was "converging"; when S was "not converging" 35 out of 46 fixations were on-target. Thus, the results indicate that the left eye of this S was fixating on-target a greater number of times when S was judged to be not converging than when S was judged to be converging, a finding that is opposite in direction to the results from S2 in this experiment. It is possible that S15 was maintaining monocular fixation of the triangle in the "not converging" condition.

Clearly, there is no guarantee that the criterion adopted for separating instances of convergence was actually successful. Although these Ss were probably fixating the vertical strip binocularly (and S15 was fixating the array of squares binocularly), the results in the other stimulus conditions are ambiguous in interpretation. It would appear to be the case that, when newborn babies do not converge to a stimulus, there is no single alternative mode of fixation adopted. A similar conclusion was reached when Ss' apparent fixations to a stimulus presented at a 5 inch viewing distance were considered (experiment 8).

Subjects 10, 11 and 12 The fixation records for these Ss, for both eyes in all stimulus conditions, are shown in Figure 7.8. The distributions of the scored optic axis divergence are shown in Figure 7.9.

The left eye of S10 was scored as being, on average, 0.22 inches to the left of the centre of the vertical strip stimulus. The right eye, on the other hand, was an average of 1.88 inches to the right of the stimulus centre - good evidence that this S was monocularly viewing the stimulus. The small variability of the scored divergence (SD = 1.58°) suggests that the right eye was moving conjugately with

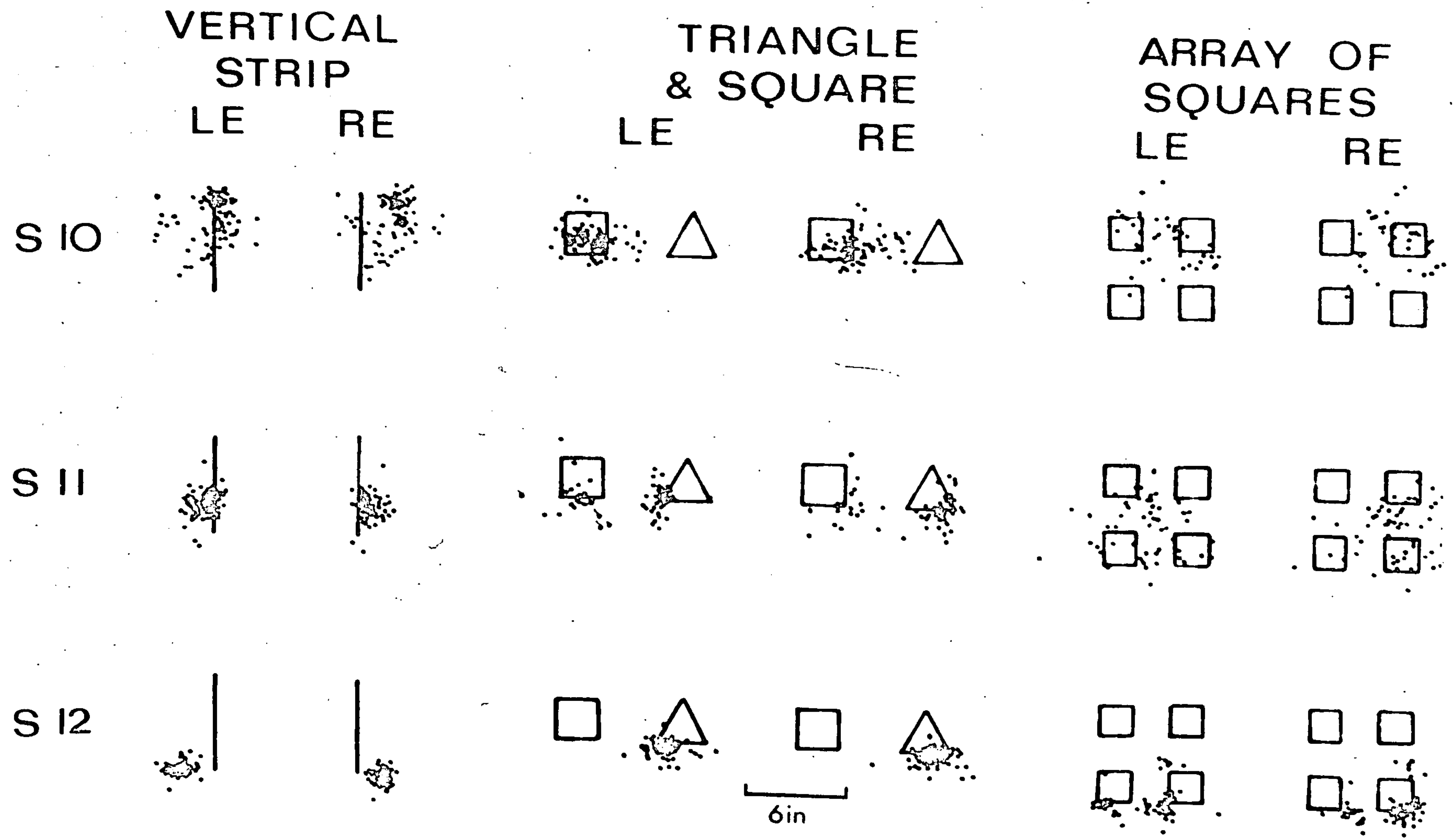

Figure 7.8 Visual fixation records of subjects 10, 11 and 12, experiment 11.

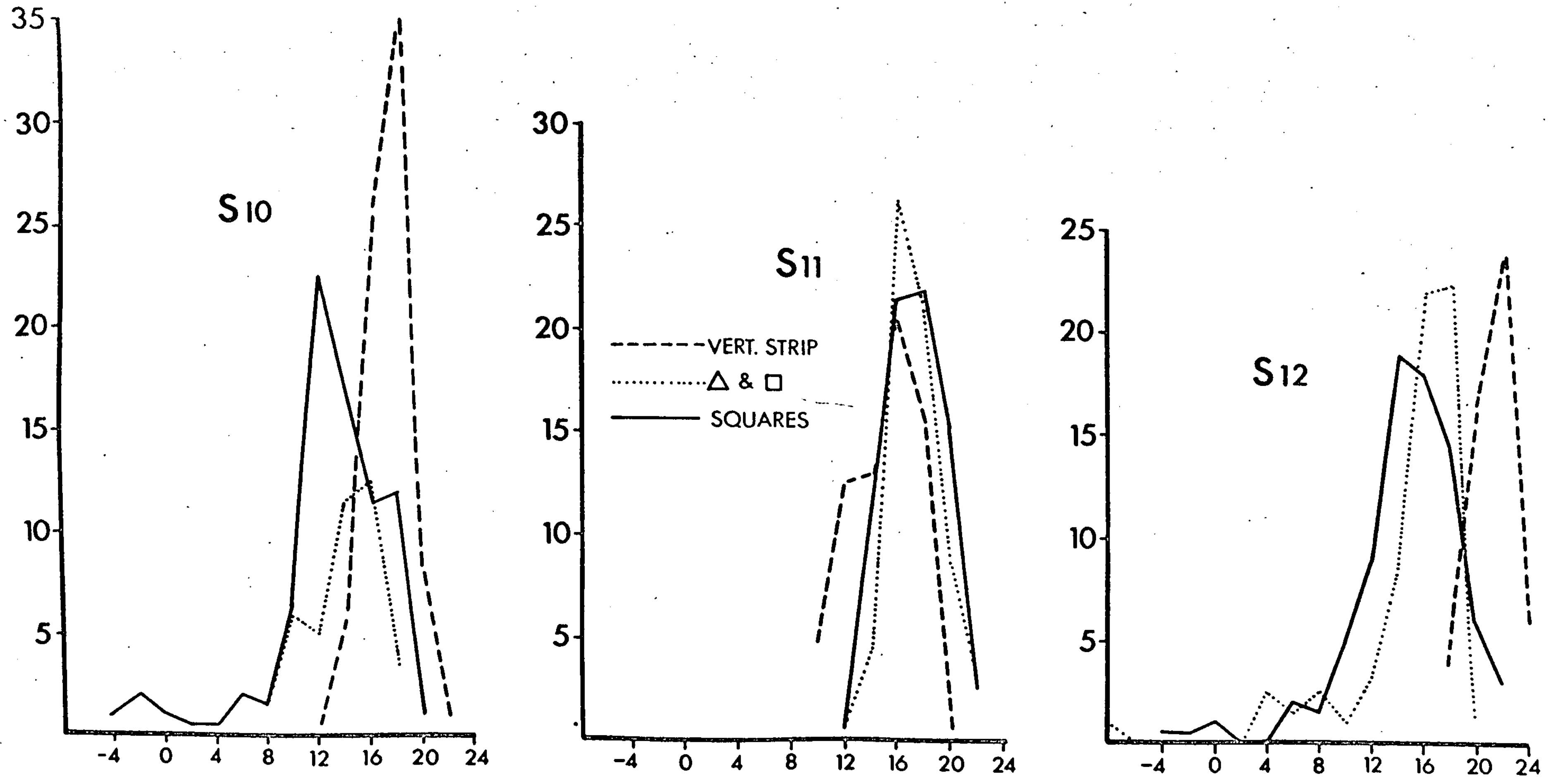

Figure 7.9 Distributions of the scored optic axis divergence for subjects 10, 11 and 12, experiment 11. The axes of each graph are the same as those of Figures 7.1, 7.4 and 7.6.

the on-target left eye. This S could have been fixating the other stimuli bifoveally, in which case the angle alpha would have a magnitude of 13 - 14°.

Both eyes of S11 were scored as being, on average, within 1 inch of the centre of the half-inch wide vertical strip. Although the average divergence (14.91°) is somewhat less than in the other two stimulus conditions (17.29° and 17.30°, table 7.3), this S could have been fixating all three stimuli binocularly, a tentative conclusion strengthened by the marked overlap in the distributions shown for this S in Figure 7.9.

A similar assertion cannot be made for S12. The very large optical separation of each eye when S was shown the vertical strip (a scored value of 21.29°), and the large variability of this divergence in the other conditions (given in table 7.3, and graphically presented in Figure 7.9), suggest that this S did not consistently converge to any of the stimuli. The fixation records for the vertical strip stimulus are of interest. The left eye was scored as fixating 1.84 inches (on average) to the left of the stimulus centre, and the right eye was scored as fixating 1.28 inches to the right. The tight grouping of fixations (Figure 7.8), for this stimulus, suggests that this is a genuine instance of the eyes "straddling" the stimulus, as it were. It can be seen from Figure 7.9 that there is little overlap of the distributions for the vertical strip results and those for the other stimulus conditions.

<u>Ocular responses to the different stimuli</u> In the foregoing discussions of the results from this experiment the presence or absence of binocular fixation of the stimuli was primarily considered, for the individual subjects. Mention will now be made of the ocular responses to the different stimuli.

The results obtained from Ss fixating the vertical strip can be interpreted with little ambiguity. It is clear that the majority of Ss fixated this stimulus bifoveally (the exceptions are Ss 10 and 12, and possibly S11).

The subjects also consistently fixated the triangle-and-square. One of the two figures was usually selected for prolonged inspection, but there was no overall indication that one figure was preferred to the other. As a measure of on-contour looking, the number of on-target fixations was counted for each S. 11 of the 15 Ss had more fixations on-target than off-target (the exceptions are Ss 2, 11, 12, and 13: neither of these Ss' eyes was on-target more than 50% of the time). If the area of on-target fixations is extended to include all fixations within 1 inch of the outer contours of the stimulus figures, all Ss were on-target in over 50% of the scored frames, with both eyes.

The reverse holds true for the array of squares. For every subject there were <u>more</u> fixations, for each eye, <u>off-target</u> than on-target, On-target fixations were defined as those scored as falling within, or on the contours of, any of the stimulus squares. It does not seem likely that the level of luminance of the squares (20ft. L) was aversive, as a higher level of luminance (35.6 apparent foot candles) was found by Hershenson (1964) to attract newborns' visual attention. As was mentioned previously, it is possible that some Ss were seeing a black cross against a well-lit surround.

<u>DISCUSSION</u> The results from the experiments reported in this chapter are considerably more varied than those from experiments 7 and 8. Nevertheless, it is possible to draw some definite conclusions from these results. It is clear that many of the babies used as subjects

in experiments 9 and 11 were converging to all the stimuli presented (at least four, and possibly five, of the eight subjects in experiment 9, and at least nine, and possibly more, of the fifteen subjects in experiment 11). This is evidenced by the close correspondence of the within-S magnitudes of the scored optic axis divergence between stimulus conditions, by the small range and variability of the scored divergence, and by the fact that the average divergence for each of these Ss (a measure of the magnitude of the angle alpha) is close to the 8.5^{o} (average) expected.

Because of the variability normally encountered with newborn subjects, these findings show that most newborn babies have good coordination between the two eyes, and possess the ability to binocularly fixate an appropriately presented stimulus. It is therefore suggested that binocular fixation by the newborn is not limited to a highly specific form of visual stimulus.

Nevertheless, it is equally clear that many of the newborn subjects were <u>not</u> consistently fixating the stimuli binocularly. It was mentioned earlier that when a newborn is not converging, the fixation records obtained are not systematically different (in any consistent manner) from those records obtained when newborns are clearly converging (this applies both within and between Ss). Because of such variability, the method of presenting the experimental results in this chapter has been graphical, tabular, and descriptive, rather than statistical.

In many respects, therefore, the results presented in this chapter leave many questions unanswered. Further discussion of the implications of these findings is given in the next, and final, chapter of this thesis.

CHAPTER 8

SUMMARY AND CONCLUSIONS

1. INTRODUCTION In this final chapter a brief summary will first be given of the previous chapters. In the next section some conclusions resulting from the research will be detailed; consideration of the possible differences between binocular fixation and binocular vision will be given, and the magnitude of the angle alpha in neonates, together with its range and variability, (derived from the experiments in chapters 6 and 7), will be discussed. In the fourth section some further implications of the findings from the research reported in this thesis, and related findings, will be given, and in the final section, some suggestions for further research directly within the research area covered by this thesis made.

2. SUMMARY In Chapter 1 mention was made of research that is directly relevant to the research presented in the other chapters of this thesis. Factors influencing the newborn baby's ability and/or desire to look at stimuli were discussed: these include the infant's state and orientation, the size of the stimulus, and the distance at which it is presented.

The limited data on accommodation and visual acuity suggest that the newborn is equipped with sufficient resolving power to be responsive to stimuli within at least some range of distance.

There is considerable evidence that the newborn is well able to move his eyes in a conjugate fashion. It would seem to be equally clear that the neonate does not possess the ability to fixate binocularly. However, most previous researchers have been unaware that the optic and visual axes of the eye do not coincide, and have assumed that optical divergence of the two eyes means that they are also visually divergent.

In the final section of the first chapter the development of the corneal reflection technique was described (i.e., Salapatek and Kessen, 1966). These researchers, and later users of the technique, have assumed that their method of scoring the film records is accurate in placing the newborns' line of sight to within a few degrees of visual angle. The research reported in subsequent chapters of the thesis shows that this is not the case.

In Chapter 2 the results from seven testing sequences (with adult Ss) were given. Each of these sequences was carried out to determine the accuracy of the corneal reflection technique, and in most of them the subjects fixated a series of points at a 10 inch viewing distance.

When individually derived "fixation maps" are available, the technique is accurate in placing the line of sight in subsequent fixations to within $3\frac{1}{2}^{\circ}$ (and probably better). However, it was clear that the centre of the pupil does not always represent the line of sight. Two effects were found. When an (adult) S fixates the centre point within the stimulus area the pupil centre is seen horizontally displaced by some 4° visual angle from the corneal reflex of the target: this effect is equal in magnitude, and opposite in direction, in the two eyes. When S fixates away from midline a parallax effect is found, which seems to stabilize with more peripheral fixations. This effect means that the pupil centre will be displaced most from the corneal reflection of the stimulus as the right eye fixates to the right, and the left eye fixates to the left.

The experiments reported in Chapter 3 were designed to investigate the corneal reflection technique with neonates. In experiments 3 and 4 a vertical array of lights was presented to newborns in various positions within the stimulus field. The results from these two experiments indicate that both of the major effects found in adults (the central effect and the off-axis effect), are found also in neonates, and have a greater magnitude.

In Chapter 4 consideration was given to the anatomical and optical variables involved in this particular technique, to explain the disparities of the pupil centre from the reflection of the fixated target.

The central effect is satisfactorily explained by the inclination of the visual axis to the optic axis in the eye (the angle alpha). The off-axis parallax effect ("projective distortion") occurs because the spatial location of the virtual image of the corneal reflection of a target does not coincide with the position of the entrance pupil: relevant anatomical variables are the radius of curvature of the cornea, and the depth of the anterior chamber. The latter variable is affected by the eye's state of accommodation.

The expected and observed magnitudes of both effects are in close agreement for both the adult and the neonate data: the differences in the magnitudes of the effects can be accounted for by differences in the size and shape of the adult and newborn eyes.

In Chapter 5 objections to the foregoing research findings were discussed. Salapatek, Haith, Maurer and Kessen (1972), argue that these findings may be artifactual, and suggested that an average correction should not be applied to individual cases. The most valid, and least speculative reply to their criticisms is that the anatomical and optical variables satisfactorily account for the observed findings: it is, therefore, necessary to apply corrections to individual cases.

In Chapter 6 experiments were reported in which the newborns' ability to fixate binocularly was investigated. In all of these experiments, both of the Ss' eyes were photographed, and stimuli at different distances were presented.

Arrays of lights, equated for luminance and retinal image size, were presented at distances of 10 and 20 inches in experiment 7. The newborns from whom results were taken fixated both stimuli bifoveally, and the scored optical divergence of the eyes increased as Ss fixated the stimulus at the farther distance.

In experiments 5 and 8 stimuli were presented at distances of 5 and 10 inches from the eyes. To the 10 inch stimulus (an array of lights), it was apparent that most, if not all, of the newborn subjects were fixating bifoveally. The same was not the case for the stimulus presented at 5 inches (a single, small light in experiment 5, and an array of lights in experiment 8): some Ss fixated the stimulus monocularly, whilst others did not appear to fixate it at all. This result was accounted for by the newborn's inability to accommodate to stimuli at this near distance.

In two of the experiments reported in Chapter 7 (experiments 9 and 11), stimulus variables other than distance were manipulated, to see whether or not newborn Ss will converge to a variety of stimuli that attract their visual attention. Experiment 10 was a longitudinal study, carried out on one baby who had been a subject in experiment 9.

In experiment 9 a large, white triangle and an "edge" stimulus were separately presented. Three stimuli were presented in experiment 11. Each was of a constant luminance (20 ft. L.). The first was a vertical strip, 6 x ½ inch; the second was a small triangle and square, presented together; the third was an array of squares, each of 2 inches wide.

A general conclusion resulting from these experiments is that most, if not all, normal newborn babies are able to fixate an appropriately presented stimulus bifoveally, and that binocular fixation is not, therefore, limited to a highly specific form of stimulation.

3. <u>CONCLUSIONS</u> It is clearly demonstrated that the centre of the pupil does not represent the line of sight. Those researchers who fail to apply appropriate correction factors to the data they collect when using the present, or similar, corneal reflection techniques, in which an image of the stimulus is seen (or inferred) on the eye (i.e., Fantz, 1956, 1961: Bagshaw, Mackworth and Pribram, 1970; Mackworth, 1968; Mackworth and Otto, 1970), will be in error in reporting their findings. Some further implications of the present, and related, findings, will be mentioned in the next section. The accuracy of the correction factors applied by the present author to the neonatal data is discussed below.

A. <u>Binocular fixation and binocular vision</u> Most newborn babies will binocularly fixate a stimulus presented a suitable distance from the eye. Whether the newborn also has binocular vision remains to be seen. In addition to requiring accurate simultaneous monocular fixation by both eyes, binocular vision is further characterized by, (a) a sensory correspondence system organized about the foveas as centre, (b) similarity of the final ocular images (cortical) from each eye, and (c) sensory unification of the two ocular images, so that a single image is seen (Morgan, 1963). Alternatives to binocular vision, whilst permitting binocular fixation, might be, (i) the input from one eye only is "processed", that from the other being suppressed, (ii) the visual input from both eyes is alternately processed, and (iii) the input from both eyes is simultaneously processed, but separately. There does, however, seem to be no reason why the newborn baby should not have binocular vision.

There would appear to be good reasons why binocular fixation should be established as the dominant mode of fixation as early as possible in life. Hubel and Wiesel (1963, 1968), have described cells in the striate cortex of the cat and monkey that are selectively responsive to highly specific retinal stimulation. The area of the retina to which a particular cell is responsive is known as its retinal receptive field. These cells are also found in the visually inexperienced kitten, and approximately 80% of them are binocularly driven. There is reason for supposing that cells of a similar nature are to be found within the human visual system (i.e., Blakemore, Muncey and Ridley, 1971; Weisstein, 1969). If, in the kitten, the normal development of binocular vision is interrupted (by monocular visual deprivation of one eye from the time of normal eye opening, by alternately depriving each eye, so that at no time are both eyes open, or by artificially creating a squint), the proportion of cells driven binocularly falls dramatically from its previous level of 80% to levels of 9% and 20%. There may be severe behavioural defects if the kitten, after the experimental deprivation, is only allowed the use of the deprived eye: recovery effects may be very limited. There are also critical periods, early in the kitten's life, during which the experimental visual deprivation will be most pronounced (Dews and Wiesel, 1970; Hubel and Wiesel, 1965, 1970; Wiesel and Hubel, 1963, 1965A, 1965B).

If similar effects were to be present in humans then a monocular start to life would be a distinct disadvantage.

B. Observed alternatives to binocular fixation It is apparent that, in some of the experiments described in this thesis, a few babies do not converge to some or all of the presented stimuli. One or more of several alternative modes of fixation are then adopted:

(a) Monocular fixation This form of fixation is common when the stimulus is presented close to the eyes (experiment 8). Here, the on-target eye maintains fixation of the stimulus, whilst the fellow eye is divergent from, but conjugate with, the viewing eye. Very few clear instances of monocular fixation are seen when the stimulus is presented at 10 inches (S10 of experiment 11 obviously monocularly fixated a stimulus at 10 inches).

(b) "Straddling" the stimulus This form of fixation is where the S's left eye looks to the left of the stimulus, and the right eye looks to the right. When the scored optic axis divergence is large it is often not possible to say whether this form of fixation has been adopted, or whether it is simply the case that the angle alpha is large. Since this form of fixation is uncommon, one suspects the latter for S2 of experiment 5, and S6 of experiment 8 (scored optic axis divergences of 17.5° and 17.01°, respectively). The only clear instance of "straddling" is by S12 of experiment 11, to the vertical strip stimulus.

(c) "Variable" This mode of fixation does not, perhaps, constitute "fixation" at all. When this apparent mode of fixation is shown the two eyes do not work closely together in a conjugate fashion; the scored divergence of the optic axis (at the level of the stimulus plane) is very variable, and S engages in fairly extensive ocular activity; the derived fixations do not bear any clear relationship to the contours of the stimulus figure. Examples of this form of "fixation" are Ss 1 and 4 of experiment 9.

C. Binocular fixation in all (normal) newborns? The simple view, supported to some extent by the experiments presented in this thesis, would be that the (normal) newborn is well equipped to fixate binocularly, and will manifest this ability when a suitable stimulus is shown: when S does not fixate binocularly, this is because his attention is elsewhere - i.e., he may be fussing, crying, eliminating, hiccoughing, or undergoing a change of state.

An attempt was made, throughout the reported experiments, to monitor the S's state, and to note instances in which S may not have been attending to the stimulus. For some of those Ss who did not consistently converge it was noted that S had been, for example, fussing, during the experimental session. But the records for some other Ss, from whom good results were obtained, were similarly annotated. There were other instances where S appeared attentive throughout the session, but the film records indicated marked ocular activity. There was, that is, no obvious relationship between the author's subjective impression of each S and the film records. For this reason, this variable has not been discussed under the separate experiments: the variability inherent in this subject population has already been mentioned. Because no obvious relationship was found, this does not, of course, mean that there isn't one - it would, indeed, be surprising if there were not a relationship between S's state and his ability and/or desire to view visual stimuli. However, during each experimental session the author was busy with changing stimuli, switching the camera, holding the baby, and so forth, and careful monitoring of the S's state, and related variables, was not possible.

D. The angle alpha, and the accuracy of the correction factors In experiments 5 to 11, both of the newborns' eyes were photographed. From those Ss who gave clear evidence of binocular fixation it is possible to obtain a fairly direct estimate of the angle alpha, and also to specify the accuracy of the correction factors introduced for scoring the film records (detailed in Chapter 6). For the 50 Ss who clearly converged in these experiments the average magnitude of the angle alpha was 8.63°, and the standard deviation was 2.84°[1]. The angle alpha, for individual Ss, ranged from 2.77° to 15.97°. Only two of the scored values differ from the average value by more than 5°. The distribution of the scored values is shown in Figure 8.1. The average value (8.63°) is very close to that value (8.5°) used in the corrections. However, a "binocular effect" was found in testing sequence 7 of Chapter 2. A discussion of the cause of the effect (Chapter 4) suggests that, in experiments 5 to 11, the scored value of the angle alpha will underestimate its actual value by some 1.3°. Thus, the angle alpha in newborns could be somewhat higher (about 10°) than the values given here. Nevertheless, given that there is some intersubject variability, an average correction using a value of 8.5° will be accurate in placing the line of sight to within 5° visual angle for the large majority of babies.

Two of the subjects seen (S2 of experiment 5, and S6 of experiment 8), were considered "doubtful" convergers, because of the magnitude of the scored divergence of the optic axis (17.5° and 17.01°, respectively). If these Ss are included in the calculation of the average angle alpha, this average becomes 8.96°, with a standard deviation of 3.25°.

Since the scored magnitude of the off-axis parallax effect is influenced by the magnitude of the angle alpha, it does not seem possible to arrive at an independent measure of the accuracy of the corrections introduced for the displacements of the pupil centre from the target position with off-axis viewing. Nevertheless, in experiments

Footnote[1] For those 4 Ss who converged to the triangle and edge stimuli of experiment 9, the average scored divergence was used in arriving at these figures: for most of the other Ss the scored divergence for S viewing the array of lights, or the vertical strip, presented at a viewing distance of 10 inches, was used.

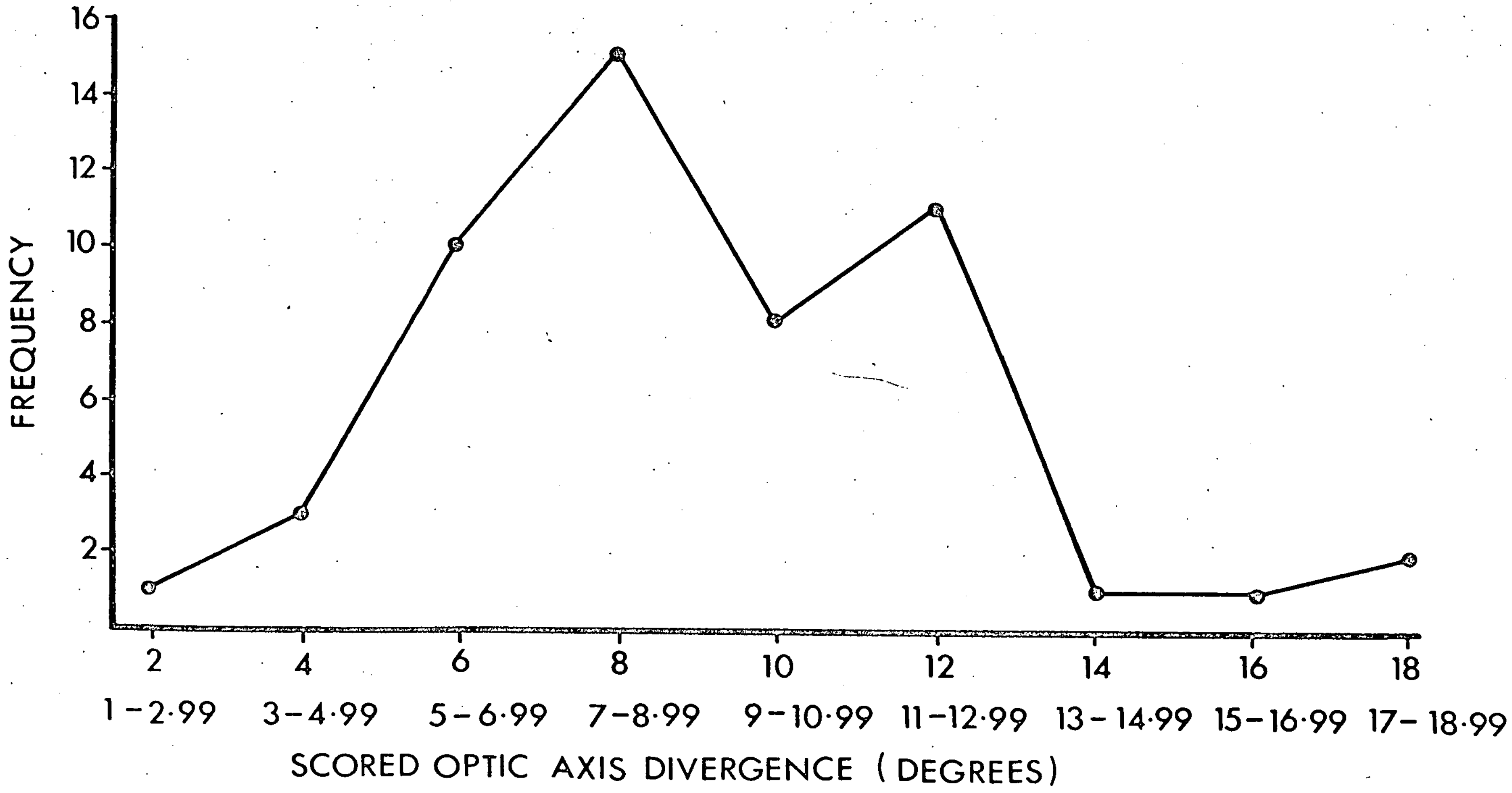

Figure 8.1 Distribution of the scored optic axis divergence (a measure of the variability of the angle alpha) for those Ss who converged (see text). The "doubtful convergers" - S2 of experiment 5, and S6 of experiment 8 - are included in this distribution.

5, 7, 8, 10 and 11 a half-inch wide vertical array of lights, or strip of light, was used as one of the stimuli, with a viewing distance of 10 inches: this stimulus was shown in various locations in the stimulus field. The fact that most of the Ss' fixations of this target were scored (with the off-axis correction included) as being, on average, very close to the centre of the stimulus, with neither the right eye nor the left eye being more "on-target", suggests that the off-axis effect found in experiments 3 and 4 is a true indication of the magnitude of this effect.

It may, therefore, be restated that there are large discrepancies of the pupil centre from the inferred target location. Further, it is apparent that the effects described under experiments 3 and 4 were from neonates fixating foveally, and the discrepancies found are a reliable representation of the discrepancies to be expected by future users of this technique with neonates.

4. <u>IMPLICATIONS FOR PREVIOUS RESEARCH</u> The implications of the present findings have been discussed at length throughout this thesis (especially Chapters 1 to 5), and the author's intention in the present section is to raise some points that have not been discussed earlier. Additionally, related findings will be described, that have direct relevance to research into newborns' vision.

A. <u>Brightness sensitivity</u> Doris and Cooper (1966) measured the OKN (following) response, in newborns and older infants, to a moving field of black and white stripes.[2] The luminance of the field was varied, and the minimum intensity eliciting the following response was considered the threshold. They reported that "brightness sensitivity undergoes rapid development in the first two months of life" (p31).

Footnote[2] This experiment was also described in Chapter 3.

However, their striped pattern was presented very close to the eyes: "The infant's eyes were approximately four inches from the screen when threshold estimations were made. A child was started with his eyes at approximately six inches from the screen, but when a response was not obtained at a particular level of brightness this distance was reduced to 4 inches" (p32).

The results from experiment 8 (Chapter 6 of this thesis), and the available data on the newborn's accommodative ability (Haynes, White and Held, 1965; White, 1971), are a clear indication that newborns cannot focus on stimuli closer than approximately 7½ inches, and when stimuli are presented at very near distances they will either not look at them, or will fixate monocularly. The newborn's apparent reluctance to fixate stimuli at near distances may not, in fact, grossly interfere with the elicitation of the (reflex) OKN response. But it is probable that what Doris and Cooper were measuring was nothing more than the development of accommodative ability, and their conclusions concerning the development of brightness sensitivity are probably erroneous.

This again raises the question of the visibility of the marker lights to newborns (the bulb filaments of the illuminators were visible to the adult as a dull red glow: wavelengths above 800nm, and below 1000nm, were transmitted through the two filters placed in front of each illuminator). Griffin, Hubbard and Wald (1947) measured the sensitivity of the adult human eye to infrared radiation. At 800nm, the fovea is less sensitive by a factor of 3.9×10^{-6} than at its maximum sensitivity (to green light at a wavelength of 555nm). At 1000nm, the fovea is less sensitive by a factor of 2.2×10^{-10} than at its maximum. Since spectral sensitivity curves are not yet available for newborns, it is not possible to decide whether the marker lights can be seen by them. However, as was stated earlier (Chapter 3), none of the subjects used in the present experiments appeared to respond to these lights.

B. Visual acuity At least three studies have been carried out to determine visual acuity in newborns. All three of these studies have provided different estimates of the neonate's acuity.[3] These differences can be accounted for by factors that are well known to affect visual acuity, namely, accommodative blur and luminance.

Using the OKN following response, Gorman, Cogan and Gellis (1957), reported that the newborn's acuity is at least the equivalent of 20/670 (Snellen notation), although there was usually no response to a 20/222 stimulus. However, Dayton, Jones, Aiu, Rawson, Steele and Rose (1964), found a positive OKN response to targets with a Snellen notation of 20/150, a separation that the data of Gorman et al. would suggest is well beyond the resolving power of the newborn. These differences are simply explained by the eye-to-target distances used in the two studies: Gorman et al. presented their moving striped patterns at a viewing distance of 6 inches, a distance that would reduce the newborn's acuity because of accommodative blur; Dayton et al. presented their stimuli at 14.5 ± 1 inch. Gorman et al. do not give the luminance of their striped patterns; in the study by Dayton et al., the illumination of the targets was approximately 25 foot candles.

Fantz, Ordy and Udelf (1962) measured visual acuity using both the "visual preference method" and the OKN response. With the visual preference method it was found that infants under 1 month responded to striped patterns with a Snellen equivalent of 20/800. The illumination

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Footnote[3] These experiments were also discussed in Chapter 1.

of the stimuli was about 4 foot candles, and infants up to six months of age were also tested. In experiment 3 of their study, they repeated the experiment with infants from 7 to 29 weeks of age (a younger age range was not tested), with a higher level of illumination of the stimuli (about 12 foot candles), and at each age range the threshold for pattern was lower.

C. <u>Other artifacts and failures to report</u> Nelson (1968), reported an experiment in which infants from 6 to 19 weeks of age were presented repetitions of a left to right row sequence of six lights. Each light was on for $\frac{2}{3}$ sec, with no pause between extinction of one light and onset of the next in the sequence. The lights were spaced two inches apart, and the whole stimulus array covered an area $\frac{5}{8}$ x 12$\frac{1}{4}$ inches. The centre of the stimulus array was some 11 inches above each S's right eye (the right eye only was recorded from). The method of recording eye position changes was the same as that reported by Salapatek and Kessen (1966), although video-tape, rather than photographic, records were taken. The investigation was an attempt to observe changes in visual responses with successive presentations of the light sequence. The criterion of a "hit" (i.e., whether the infant was fixating the light that was on at a given moment), was "...whether or not the pupil of the infant's eye centered on the corneal reflection of the stimulus light" (1968, p197). It is clear, from the results presented in this thesis, that as the right eye progressively fixates to the right the disparities of the pupil centre from the corneal reflection of the target fixated will systematically increase, and this must have been the case in Nelson's study. However, no mention of this source of error is to be found in his article.

McKenzie and Day (1972; this experiment was also mentioned in Chapters 1 and 4), reported that infants' looking time bears a linear relationship to the distance at which the stimulus is presented from the eyes. They used Fantz's (1956) visual preference method of recording fixations, and observed the subjects through a peephole in front of, and to the right of, the subjects. They do not specify which of the subjects' eyes they observed, but it must have been the right eye: researchers who attempted to replicate their important finding would be unable to do so if they were to observe the left eye.[4]

Conclusions The experiments mentioned in this section are evidence, (a) that artifacts will continually recur if users of the corneal reflection technique with infants fail to apply corrections to their data for the disparities of the pupil centre from the reflection of the stimulus, and (b) that some previously reported (and currently accepted) research findings are in error because the appropriate optical problems have not been considered.[5] While there is much yet to be learnt about the functioning of the newborn eye, sufficient appears to be known at the present time that future experimenters in this area can avoid the worst hazards that have befallen early investigators.

5. SUGGESTIONS FOR FURTHER RESEARCH Research into infant vision, like its subjects, is in its infancy. For that reason it would be possible to give a list of experiments that one would like to see carried out into early visual function (for example, such basic functions as

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Footnote[4] These remarks, and those in the preceding paragraph, are not intended as a criticism of the findings of Nelson (1968), or of McKenzie and Day (1972).

Footnote[5] This last remark is not intended as a criticism of those experiments discussed under "brightness sensitivity" and "visual acuity" in this section: when these experiments were carried out the paper by Haynes, White and Held (1965), on accommodation in infants, had not been published.

brightness discrimination, visual acuity, spectral sensitivity, colour vision, form perception). For the present purposes, however, a few suggestions will be made that are directly relevant to the research covered in this thesis.

Certain limitations of the recording technique used by the author are apparent. The present corneal reflection technique is ideal for recording eye position, and eye movements, in newborn babies. However, recording at a rate of two frames per second means that some changes of fixation are missed, and it is not possible to obtain a clear idea of what is happening during those times when the newborn makes many eye movements in a short period of time. For two reasons, continuous recording was not used:

(i) The cost of film, and processing, when recording at two frames per second, is small. Continuous recording (i.e., at a rate of 16 frames per second) would make the cost prohibitive, however. Additionally, at a speed of 16 frames per second each roll of film (125 feet) would last for 5 minutes - a length of time that the camera would normally be "on" for a single subject. Thus, with continuous recording it would be possible to see only one baby, or two at the most, during a visit to the hospital.

(ii) To analyze the data in full, for a single S in a single stimulus condition, takes several hours. The author was reluctant to increase the analyzing time by a factor of 8.

The obvious answer to this problem is videotape recording. It is possible to obtain closed circuit television cameras fitted with infrared-sensitive tubes. Such a system was described by Haith (1969). The use of CCTV reduces the problems described: the videotape, since it can be used many times, is inexpensive; from viewing the recordings it would be possible to select those few seconds required for analyzing.

With this method of recording it would be possible to specify what is happening during those instances when the eyes apparently go "out of control" (i.e., when marked ocular activity is present).

It is not yet known whether neonates will also binocularly fixate a moving stimulus. Conjugate movement of the eyes would appear to be the rule when neonates make appropriate visual following movements, but it may be that when the (reflex) OKN pursuit is elicited the (presumably) more voluntary bifoveal fixation breaks down. What actually happens remains to be seen.

At times, it is clear, newborns' eyes are not bifoveally directed. Longitudinal studies will probably be necessary before one can specify the individual differences in the development of consistent binocular fixation. Thus, corrections for the angle alpha, and for the off-axis parallax effect, could be applied to the early records, on an individual basis, from later records during which the S was seen to be converging.

One further advantage of CCTV recording is that it is possible to see, in a monitor, what the baby is doing with his eyes <u>at the time</u> of the experiment (with photography, of course, the results can only be seen when the film has been developed). This opens up many interesting experimental possibilities: for example, stimuli could be presented in that area of the stimulus field that the baby is known to be looking at.

The failure to record continuously has not, though, affected the results presented in this thesis. It has previously been mentioned that, when a newborn looks at a stimulus, his fixations are characteristically within a small area, and from the best records obtained many lengths of film were available in which each frame could be scored. The contribution to research into infant vision of the results presented in this thesis is twofold. Firstly, it has been demonstrated that those researchers are mistaken who have followed Fantz (1956) in assuming that the centre of the pupil represents the line of sight, and that the corneal reflection method in which the target is imaged in the eye requires the application of certain correction factors. This conclusion is supported by experimental results, and by theoretical considerations. Secondly, the results from experiments 5 through 11 are the first demonstration that the newborn baby has the ability to fixate an appropriately presented stimulus binocularly.

BIBLIOGRAPHY

ALPERN, M. Vision. In M. Alpern, M. Lawrence & D. Wolsk, Sensory Processes. Brooks/Cole Publishing Company: California, 1969.

ALPERN, M., LOWENSTEIN, O., & LOEWENFELD, I.E. Accommodation and the pupil. In H. Davson (Ed.), The Eye. Vol. 3. New York: Academic Press, 1962.

AMES, E.W., & SILFEN, C.K. Methodological issues in the study of age differences in infants' attention to stimuli varying in movement and complexity, 1965. Reported in M. Hershenson, Development of the perception of form. Psychological Bulletin, 1967, 67, 326-336.

ARONSON, E., & ROSENBLOOM, S. Space perception in early infancy: perception within a common auditory - visual space. Science, 1971, 172, 1161-1163.

ASHTON, R. The state variable in neonatal research: a review. Merrill-Palmer Quarterly of Behavior and Development, 1973, 19, 3-20.

BAGSHAW, M.H., MACKWORTH, N.H., & PRIBRAM, K.H. Method for recording and analyzing visual fixations in the unrestrained monkey. Perceptual and Motor Skills, 1970, 31, 219-222.

BARTEN, S., BIRNS, B., & RONCH, J. Individual differences in the visual pursuit behavior of neonates. Child Development, 1971, 42, 313-319.

BARTLETT, N.R. Thresholds as dependent on some energy relations and characteristics of the subject. In C.H. Graham (Ed.), Vision and Visual Perception. John Wiley & Sons, Inc., 1965.

BENNETT, A.G. & FRANCIS, J.L. Reflexion at plane and spherical surfaces, and, The eye as an optical system. In H. Davson (Ed.), The Eye. Vol. 4. Academic Press: New York and London, 1962.

BELL, R.Q. Some factors to be controlled in studies of the behavior of newborns. Biology of the Neonate, 1963, 5, 200-214.

BLAKEMORE, C., MUNCEY, J.P.J., & RIDLEY, R.M. Perceptual fading of a stabilized cortical image. Nature, 1971, 233, 204-205.

BOND, E.K. Perception of form by the human infant. Psychological Bulletin, 1972, 77, 225-245.

BOWER, T.G.R. The visual world of infants. Scientific American, 1966, 215, 80-92.

BOWER, T.G.R. Morphogenetic problems in space perception. In F. A. Young & D.B. Lindsley (Eds.), Early Experience and Visual Information Processing in Perceptual and Reading Disorders. National Academy of Science: Washington, D.C., 1970.

BOWER, T.G.R. The object in the world of the infant. Scientific American, 1971, 225, 30-38.

BOWER, T.G.R., BROUGHTON, J.M., & MOORE, M.K. Infant responses to approaching objects: An indicator of response to distal variables. Perception and Psychophysics, 1970, 9, 193-196.

BRAZELTON, T.B., SCHOLL, M.L., & ROBEY, J.S. Visual responses in the newborn. Pediatrics, 1966, 37, 284-290.

BRENNAN, W.M., AMES, E.W., & MOORE, R.W. Age differences in infants' attention to patterns of different complexities. Science, 1966, 151, 354-356.

COLLIGNON-BRACH, J. Etude de la biometrie de la cornee au Moyen d'une technique photographique. Ophthalmologica, 1969, 159, 442-459.

COWEY, A. The basis of a method of perimetry with monkeys. Quarterly Journal of Experimental Psychology, 1963, 15, 81-90.

COWEY, A. & WEISKRANTZ, L. A perimetric study of visual field defects in monkeys. Quarterly Journal of Experimental Psychology, 1963, 15, 91-115.

DAVSON, H. The Physiology of the Eye. London: J. & A. Churchill,Ltd., 1950.

DAYTON, G.O. (Jr.), & JONES, M.H. Analysis of characteristics of fixation reflex in infants by use of D.C. electro-oculography. Neurology, 1964, 14, 1152-1156.

DAYTON, G.O. (Jr.), JONES, M.H., AIU, P., RAWSON, R.A., STEELE, B., & ROSE, M. Developmental study of coordinated eye movements in the human infant. 1. Visual acuity in the newborn human: a study based on induced optokinetic nystagmus recorded by electro-oculography. Archives of Ophthalmology, 1964, 71, 865-870.

DAYTON, G.O. (Jr.), JONES, M.H. STEELE, B., & ROSE, M. Developmental study of coordinated eye movements in the human infant. II. An electro-oculographic study of the fixation reflex in the newborn. Archives of Ophthalmology, 1964, 71, 871-875.

DEWS, P.B., & WIESEL, T.N. Consequences of monocular deprivation on visual behaviour in kittens, Journal of Physiology, 1970, 206, 437-455.

DORIS, J. & COOPER, L. Brightness discrimination in infancy. Journal of Experimental Child Psychology, 1966, 3, 31-39.

DUKE-ELDER, S. (Ed.), System of Ophthalmology. Vol. III. Normal and abnormal development. Part 1. Embryology. London: Henry Kimpton, 1963.

ELLERBROCK, V.J. Developmental, congenital, and hereditary anomalies of the eye. In M.J. Hirsch, & R.E. Wick (Eds.), Vision of Children. An Optometric Symposium. Chilton Books: Philadelphia and New York, 1963.

FANTZ, R.L. A method for studying early visual development. Perceptual and Motor Skills, 1956, 6, 13-15.

FANTZ, R.L. Pattern vision in young infants. The Psychological Record, 1958, _8_, 43-47.

FANTZ, R.L. The origin of form perception. Scientific American, 1961, _204_, 66-72.

FANTZ, R.L. Pattern vision in newborn infants. Science, 1963, _140_, 296-297.

FANTZ, R.L., ORDY, J.M., & UDELF, M.S. Maturation of pattern vision in infants during the first six months. Journal of Comparative and Physiological Psychology, 1962, _55_, 907-917.

GESELL, A. Infant vision. Scientific American, 1950, _182_, 20-22.

GIACOMAN, S.L. Hunger and motor restraint on arousal and visual attention in the infant. Child Development, 1971, _42_, 605-614.

GORMAN, J.J., COGAN, D.G., & GELLIS, S.S. An apparatus for grading the visual acuity of infants on the basis of opticokinetic nystagmus. Pediatrics, 1957, _19_, 1088-1092.

GREENBERG, D.J., & O'DONNELL, W.J. Infancy and the optimal level of stimulation. Child Development, 1972, _43_, 639-645.

GREENBERG, D., UZGIRIS, I.C., & HUNT, J.McV. Hastening the development of the blink response with looking. Journal of Genetic Psychology, 1968, _113_, 167-176.

GREENBERG, D.J., & WEIZMANN, F. The measurement of visual attention in infants: a comparison of two methodologies. Journal of Experimental Child Psychology, 1971, _11_, 234-243.

GREENMAN, G.W. Visual behavior of newborn babies. In A.J. Solnit, & S.A. Provence (Eds.), Modern Perspectives in Child Development. New York: International University Press, 1963.

GRIFFIN, D.R., HUBBARD, R., & WALD, G. The sensitivity of the human eye to infra-red radiation. Journal of the Optical Society of America, 1947, _37_, 546-554.

HAITH, M.M. Visual scanning in infants. Paper read at Regional Society for Research in Child Development meetings, Clark University, March 28, 1968.

HAITH, M.M. Infrared television recording and measurement of ocular behavior in the human infant. American Psychologist, 1969, 24, 279-283.

HARTER, M.R., & SUITT, C.D. Visually-evoked cortical responses and pattern vision in the infant: a longitudinal study. Psychonomic Science, 1970, 18, 235-237.

HAYNES, H., WHITE, B.L., & HELD, R. Visual accommodation in human infants. Science, 1965, 148, 528-530.

HEBB, D.O. The Organization of Behavior. New York: Wiley, 1949.

HERSHENSON, M. Visual discrimination in the human newborn. Journal of Comparative and Physiological Psychology, 1964, 58, 270-276.

HERSHENSON, M. Form perception in the human newborn. Paper read at the Second Annual Symposium, Center for Visual Science, University of Rochester, June, 1965.

HERSHENSON, M. Development of the perception of form. Psychological Bulletin, 1967, 67, 326-336.

HERSHENSON, M., KESSEN, W., & MUNSINGER, H. Pattern perception in the human newborn: a close look at some positive and some negative results. In J.C. Mott-Smith, W. Wathen-Dunn, H. Blum, & P. Lieberman (Eds.), Symposium on Models for the Perception of Speech and Visual Form. M.I.T. Press, 1967.

HIRSCH, M.J. The refraction of children. In M.J. Hirsch & R.E. Wick (Eds.), Vision of Children. An Optometric Survey. Chilton Books: Philadelphia and New York, 1963.

HOROWITZ, F.D., PADEN, L., BHANA, K., & SELF, P. An infant-control procedure for studying infant visual fixations. Developmental Psychology, 1972, 7, 90.

HOROWITZ, F.D., PADEN, L., BHANA, K., AITCHISON, R., & SELF, P. Developmental changes in infant visual fixation to differing complexity levels among cross-sectionally and longitudinally studied infants. Developmental Psychology, 1972, 7, 88-89.

HUBEL, D.H., & WIESEL, T.N. Receptive fields of cells in striate cortex of very young, visually inexperienced kittens. Journal of Neurophysiology, 1963, 26, 994-1002.

HUBEL, D.H., & WIESEL, T.N. Binocular interaction in striate cortex of kittens reared with artificial squint. Journal of Neurophysiology, 1965, 28, 1041-1059.

HUBEL, D.H., & WIESEL, T.N. Receptive fields and functional architecture of monkey striate cortex. Journal of Physiology, 1968, 195, 215-243.

HUBEL, D.H., & WIESEL, T.N. The period of susceptibility to the physiological effects of unilateral eye closure in kittens. Journal of Physiology, 1970, 206, 419-436.

HUGHES, A. Vergence in the cat. Vision Research, 1972, 12, 1961-1994.

KAGAN, J. Attention and psychological change in the young child. Science, 1970, 170, 826-832.

KARMEL, B.Z. The effect of age, complexity, and amount of contour on pattern preferences in human infants. Journal of Experimental Child Psychology, 1969, 7, 339-354.

KARMEL, B.Z., WHITE, C.T., CLEAVES, W.T., & STEINSIEK, K.J. A technique to investigate averaged evoked potential correlates of pattern perception in human infants. Paper presented at meeting of the Eastern Psychological Association, Atlantic City, April, 1970. Cited in E. Bond, 1972.

KEIBEL, F., & MALL, F.P. (Eds.) Manual of Human Embryology. Philadelphia & London: J.B. Lippincott Company, 1912.

KESSEN, W. Sucking and looking: two organized congenital patterns of behavior in the human newborn. In H.W. Stevenson, E.H. Hess, & H.L. Rheingold (Eds.), Early Behavior: Comparative and Developmental Approaches. New York: Wiley, 1967.

KESSEN, W., SALAPATEK, P., & HAITH, M.M. The visual response of the human newborn to linear contour. Journal of Experimental Child Psychology, 1972, 13, 9-20.

KIFF, R.D., & LEPARD, C. Visual response of premature infants. Archives of Ophthalmology, 1966, 75, 631-633.

KORNER, A.F. Individual differences at birth: implications for early experience and later development. American Journal of Orthopsychiatry, 1971, 41, 608-619.

LARSEN, J.S. The sagittal growth of the eye. I. Ultrasonic measurement of the depth of the anterior chamber from birth to puberty. Acta Ophthalmologica, 1971A, 49, 239-262.

LARSEN, J.S. The sagittal growth of the eye. II. Ultrasonic measurement of the axial diameter of the lens and the anterior segment from birth to puberty. Acta Ophthalmologica, 1971B, 49, 427-440.

LARSEN, J.S. The sagittal growth of the eye. III. Ultrasonic measurement of the posterior segment (axial length of the vitreous) from birth to puberty. Acta Ophthalmologica, 1971C, 49, 441-453.

LEROY, B., LEROY, D., & LEROY, J. Examen oculaire systématique du nouveau - né. Revue Francaise de Gynecologie et d'Obstetrique, 1971, 66, 397-406.

LEWIS, M., KAGAN, J., & KALAFAT, J. Patterns of fixation in the young infant. Child Development, 1966, 37, 331-341.

LING, BING-CHUNG. A genetic study of sustained visual fixation and associated behavior in the human infant from birth to six months. Journal of Genetic Psychology, 1942, 61, 227-277.

LIT, A. Visual acuity. Annual Review of Psychology, 1968, 19, 27-54.

LUYCKX, J. Mesure des composantes optiques de l'oeil du nouveau-né par échographie ultrasonique. Archives Ophthalmologie (Paris), 1966, 26, 159-170.

MACKWORTH, N.H. The wide-angle reflection eye camera for visual choice and pupil size. Perception and Psychophysics, 1968, 3, 32-34.

MACKWORTH, N.H. & OTTO, D.A. Habituation of the visual orienting response in young children. Perception and Psychophysics, 1970, 7, 173-178.

MANN, IDA. The Development of the Human Eye. London: British Medical Association, 1964.

McGINNIS, J.M. Eye movements and optic nystagmus in early infancy. Genetic Psychology Monographs, 1930, 8, 321-430.

McKENZIE, B., & DAY, R.H. Object distance as a determinant of visual fixation in early infancy. Science, 1972, 178, 1108-1110.

MERKEL, FR., & ORR, A.W. Das auge des neugeborenen an einem schematischen durchschnitt erläutern. Anatomische Hefte, 1892, 271-296.

MIRANDA, S.B. Visual abilities and pattern preferences of premature infants and full-term neonates. Journal of Experimental Child Psychology, 1970, 10, 189-205.

MIRANDA, S.B., & FANTZ, R.L. Distribution of visual attention by newborn infants among patterns varying in size and number of details. Proceedings of the Annual Convention of the American Psychological Association, 1971, 6, 181-182.

MORGAN, M.W. Anomalies of binocular vision. In M.J. Hirsch & R.E. Wick (Eds.), Vision of Children. An Optometric Symposium. Chilton Books: Philadelphia and New York, 1963.

NELSON, K.E. Organization of visual-tracking responses in human infants. Journal of Experimental Child Psychology, 1968, 6, 194-201.

NELSON, K. Visual scanning by human newborns: responses to complete triangles, to sides only, and to corners only. Proceedings of the 77th Annual Convention of the A.P.A., 1969.

PIRENNE, M.H. Vision and the Eye. Science Paperbacks and Chapman and Hall, Ltd., 1967.

POLYAK, S. The Vertebrate Visual System. The University of Chicago Press, 1968.

REINECKE, R.D., & COGAN, D.G. Standardization of objective visual acuity measures: opticokinetic nystagmus vs. Snellen acuity. A.M.A. Archives of Ophthalmology, 1958, 60, 418-421.

SAAYMAN, G., AMES, A.W., & MOFFETT, A. Response to novelty as an indicator of visual discrimination in the human infant. Journal of Experimental Child Psychology, 1964, 1, 189-198.

SALAPATEK, P. Visual scanning of geometric figures by the human newborn. Journal of Comparative and Physiological Psychology, 1968, 66, 247-258.

SALAPATEK, P. The visual investigation of geometric pattern by the one and two month old infant. Paper presented at meetings of the American Association for the Advancement of Science, Boston, Massachusetts, December 26-31, 1969.

SALAPATEK, P., HAITH, M.M., MAURER, DAPHNE, & KESSEN, W. Error in the corneal-reflection technique: A note on Slater and Findlay. Journal of Experimental Child Psychology, 1972, 14, 493-497.

SALAPATEK, P., & KESSEN, W. Visual scanning of triangles by the human newborn. Journal of Experimental Child Psychology, 1966, 3, 155-167.

SALAPATEK, P., & KESSEN, W. Prolonged investigation of a plane geometric triangle by the human newborn. Paper presented at meetings of the Society for Research in Child Development, Santa Monica, California, April, 1969.

SALAPATEK, P.H., & KESSEN, W. Prolonged investigation of a plane geometric triangle by the human newborn. Journal of Experimental Child Psychology, 1973, 15, 22-29.

SIEGEL, S. Nonparametric Statistics for the Behavioral Sciences. McGraw-Hill Book Company, Inc., 1956.

SLATER, A.M., & FINDLAY, J.M. The measurement of fixation position in the newborn baby. Journal of Experimental Child Psychology, 1972A, 14, 349-364.

SLATER, A.M., & FINDLAY, J.M. The corneal-reflection technique: A reply to Salapatek, Haith, Maurer, and Kessen. Journal of Experimental Child Psychology, 1972B, 14, 497-499.

STAFLOVA, J. Relation of the size of the eye to the age and length in human ontogenesis. American Journal of Obstetrics and Gynecology, 1971, 110, 126-128.

STECHLER, G., & LATZ, E. Some observations on attention and arousal in the human infant. Journal of the American Academy of Child Psychiatry, 1966, 5, 517-525.

STIRNIMANN, F. Uber das farbenempfinden neugeborener. Annales Pediatrici, 1944, 163, 1-25. Cited in R.L. Fantz, 1961, and E. Bond, 1972.

TANSLEY, K. Vision in Vertebrates. Chapman and Hall, Ltd., 1965.

TRONICK, E. Stimulus control and the growth of the infant's effective visual field. Perception and Psychophysics, 1972, 11, 373-376.

TRONICK, E., & CLANTON, C. Infant looking patterns. Vision Research, 1971, 11, 1479-1486.

WEISSTEIN, N. What the frog's eye tells the human brain: single cell analyzers in the human visual system. Psychological Bulletin, 1969, 72, 157-176.

WHITE, B.L. Human Infants, Experience and Psychological Development. Prentice-Hall, Inc., 1971.

WHITE, B.L., CASTLE, P., & HELD, R. Observations on the development of visually-directed reaching. Child Development, 1964, 35, 349-364.

WICKELGREN, L.W. Convergence in the human newborn. Journal of Experimental Child Psychology, 1967, 5, 74-85.

WICKELGREN, L.W. The ocular response of human newborns to intermittent visual movement. Journal of Experimental Child Psychology, 1969, 8, 469-482.

WIESEL, T.N., & HUBEL, D.H. Single-cell responses in striate cortex of kittens deprived of vision in one eye. Journal of Neurophysiology, 1963, 26, 1003-1017.

WIESEL, T.N., & HUBEL, D.H. Comparison of the effects of unilateral and bilateral eye closure on cortical unit responses in kittens. Journal of Neurophysiology, 1965A, 28, 1029-1040.

WIESEL, T.N., & HUBEL, D.H. Extent of recovery from the effects of visual deprivation in kittens. Journal of Neurophysiology, 1965B, 28, 1060-1072.

WOLFF, E. Anatomy of the Eye and Orbit. 5th Edition, revised by R.J. Last. London: H.K. Lewis & Co., Ltd., 1961.

WOLFF, P.H. Observations on newborn infants. Psychosomatic Medicine, 1959, 21, 110-118.

WOLFF, P.H. The development of attention in young infants. Annals of the New York Academy of Science, 1965, 118, 815-830.