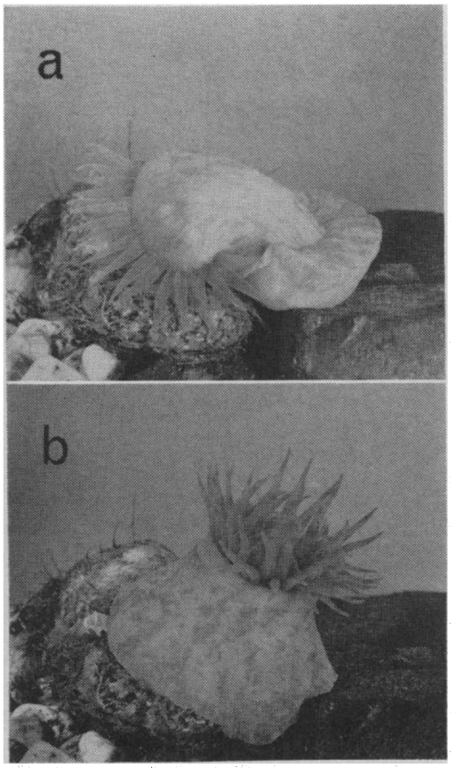


Fig. 1. (*a*) Response of *Stomphia coccinea* to *Modiolus modiolus*. The tentacles and oral disc are directed toward the shell; the pedal disc has expanded and is making contact with shell. (*b*) *Stomphia* sliding across shell toward final position on top. Time between *a* and *b*, 12 minutes.

ing flat stones, a living *Modiolus*, and an ample area of glass between. The animals were arranged lying on the glass so that the tentacles of six *Stomphia* and the pedal discs of six others were touching shells; the remaining six were touching stones. One hour later, 11 of the 12 animals touching shells had settled on shells. Of the rest, five had settled on the glass and two were still unattached.

When *Stomphia* comes out of its "post-swimming torpor" (*2*), it usually settles quickly on any available surface by attaching its basal disc little by little to that surface. *Stomphia* in contact with shells behaved differently. Some bent over shells with tentacles and oral disc extended outwards like an umbrella. Others leaned on shells with a few tentacles in contact. This tentacular-oral activity was followed by remarkable movements of the basal region. Sometimes it was extended horizontally as a huge plate which was turned toward the shell. In other instances, it swelled up into a hemisphere which was pushed towards the shell. These were slow flowing movements, just quick enough to be visible. The events beginning with the tentacle response and ending with the movement of the basal disc to the shell took only about 1 to 2 minutes. Figure 1 shows stages in this behavior pattern.

In a number of experiments the following observations were made.

1) If even a small area of the basal disc made contact with the shell, it adhered quickly and spread itself on the shell. When this happened, the oral-tentacular contact ceased and the column, which had been bent into a right angle, became straight again. If the basal disc failed to make contact with the shell in the first movement, it resumed its normal shape and position, but after a pause, during which the anemone's tentacles moved farther across the shell, the performance was repeated not once but several times if necessary.

2) *Stomphia* which had settled on other surfaces up to about 3 hours earlier transferred readily to *Modiolus* shells. With tentacles and oral disc on the shell, the basal disc was released from its attachment on the other surface and moved over to the shell. Sometimes this involved a long (up to 1 hour) process of advancing and retreating before the gap between the other surface and the shell was successfully bridged. Animals which had been settled on other surfaces more than 3 hours showed no tendency to transfer to shells.

3) This behavior was not specific to shells of *Modiolus* but was evoked by shells of other bivalve molluscs, for example, *Pecten*. An empty shell evoked the same response.

Films at ordinary and time-lapse speeds emphasize the purposive features of this behavior pattern. The muscular and hydrodynamic mechanisms involved and the nervous coordination are difficult to comprehend. Remembering that *Stomphia* is also able to swim in response to other specific stimuli, and recalling the behavior pattern of the sea anemone *Calliactis* in relation to hermit crabs (*5*), one realizes that the behavior of these so-called simple animals can be surprisingly complex.

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## Visual Accommodation in Human Infants

Abstract. *By the technique of dynamic retinoscopy, we found that the alert newborn infant can focus his eye on targets only at a particular distance (median, 19 centimeters). Images of targets nearer or farther away are proportionately blurred. However, during the first few postnatal months the range of flexible accommodation increases and approximates adult performance by the 4th month.*

Increasing interest in the vision of newborn infants is demonstrated by the growing amount of research on their acuity, form discrimination, preferences, and other visually controlled behaviors (*1*). In all such studies the focus of the retinal image limits the fineness of discrimination. Moreover, changes in focus may be confounded with other conditions that determine responses to visible objects. Nevertheless, in practically all research on infant vision, focal length has been an uncontrolled variable. Whereas accommodation of the lens in the eye of the young adult automatically focuses the retinal image for target distances ranging from 10 cm to optical infinity, we cannot assume comparable behavior in very young infants. The fragmentary data that are available suggest limited accommodative capacity, at best, in the newborn human (*2, 3*). Even if an infant's eyes are oriented toward a target, his optical system may be focused for any distance along his line of sight. The blurring of the retinal image that results from inadequate focusing may interact significantly with the effects of experimental variables. We now report the first data known to us on the course of acquisition of accommodative ability in human infants.

Changes in accommodation are largely accomplished by involuntary contraction or relaxation of the ciliary muscle which in turn changes the shape of the crystalline lens. Retinoscopic studies performed with the ciliary muscle immobilized by atropine (cycloplegia) have suggested that the normal infant is hyperopic (farsighted) for all target distances (*2*). On the other hand, Elschnig found a significant difference between responses measured during cycloplegia as opposed to nondrugged conditions in 2-day-old infants (*3*). He concluded that the newborn infant is capable of some degree of accommodation. Aside from these reports we know of no others on dynamic accommodative behavior in human infants.

Dynamic retinoscopy is a technique for measuring accommodative responses without immobilizing the lenticular system (*4*). A sharply focused streak or spot of light is projected into the subject's eye through the pupillary opening. Modifications in the reflected image are used as an index of the refractive state of the eye. These modifications are quantitatively assessed by means of lenses of known power. Refraction is measured while the subject fixates nearby objects and also while he tracks an object moving toward and away from his eye. Although this technique has been employed with considerable success with adults it has been less useful with children because it requires a cooperative subject. Children of 1 or 2 years of age can rarely be induced to attend persistently to a prescribed target. Fortunately, we have found that infants between 2 and 5 months of age make good subjects for this task. Unlike older children, they will stare at appropriate targets steadily enough to allow measurement. In fact, by occasionally moving the target one can often induce the young infant to maintain fixation for several minutes. This type of performance is not at all unusual in infants during the first half year of life. Both McGraw and Ling have cited several instances of comparable "stimulus-bound" behavior in such subjects (*5*).

A white cardboard shield, 11.4 by 13.3 cm, was mounted on a Reid streak retinoscope to shield the major portion of the examiner's head from the infant's view. A 0.95-cm hole was cut in the center to allow the beam of the retinoscope to shine into the subject's eyes. Centered around this aperture a red annulus with an outside diameter of 3.8 cm was painted. Black marks and dots were inked into this red area in a random manner to increase the complexity of the stimulus.

The study was performed at a state institution on 22 normal infants ranging in age from 6 days to 4 months. Their time at the institution varied as a consequence of several factors, including adoption. Consequently, some subjects were available for examination only once, whereas others were tested repeatedly for several months. On the average, each subject was tested five times. Sample size for the 4 months varied from 7 to 13 (Fig. 1). The children were examined in a supine position under standardized conditions. One examiner did the retinoscopy while the other measured the distance between the retinoscope target and the eye of the infant. To assure "on axis" retinoscopy (*4*) both examiners had to agree that the child appeared to be fixating within the 3.2-cm target area before an observation was acceptable.

The examination procedure was as follows. To capture the infant's attention, the retinoscope and attached target were moved back and forth horizontally at approximately 2.5 cm/sec across the infant's line of sight. The examiner did not place his eye to the retinoscope until after pursuit fixations were obtained from at least one eye. (Infants less than 1 month of age did not exhibit sustained fixations on the target. With these subjects the examiner simply placed the retinoscope at several points along the line of gaze). Retinoscopic measurements were taken whenever possible within each of four ranges of distance: (i) 8 to 15 cm; (ii) 15 to 25 cm; (iii) 25 to 51 cm; and (iv) 51 to 100 cm. The typical sequence of testing was (iii)-(ii)-(i)-(iv). The accommodative response was measured by briefly introducing lenses of known power in front of the fixating eye. By moving the retinoscope in depth, thereby inducing accommodative tracking, we then determined the range of distance over which each infant could maintain accommodation on the target within 0.5 diopter. In subjects who had developed convergence responses prior to testing, each eye was observed alternately. For each distance the average response was recorded. Since the examiner's eye was not placed exactly at the plane of the target the data were corrected for the resultant error, as described previously (*4*). Repeated measurements were taken routinely on many of the infants. They rarely varied more than 0.5 diopter. Whenever an infant had been examined more than once in a particular month, measurements taken at replicated distances were averaged.

The corrected and averaged data for the multiple-distance retinoscopy taken during each of the 4 months were plotted for each infant. The best-fitting straight line was then drawn for each subject (see Fig. 1). Each line typically represents six points compiled from these separate examinations. The extent of the lines indicates the range of distance over which data were actually collected. The lines do not always extend over the full range, since subjects often turned away from the target when it was presented nearer than 10 cm or farther than 38 cm

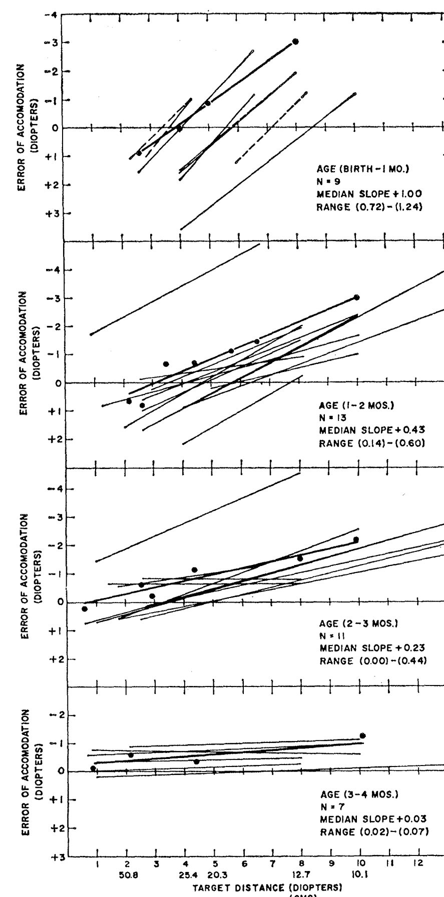


Fig. 1. Four stages in the development of accommodation in the first 4 months of life. The heavy lines fitted to the filled circles illustrate both the progress of a typical infant and also the closeness of fit of the lines to the plotted points. During the first month, the data that were estimated are represented by dashed lines. Plus values indicate myopic performance. Minus values indicate deviations in the hyperopic direction.

from the eye. A slope value was calculated for each subject at each test age. Median slope values and their ranges were then calculated from the group data for each month starting at birth and ending at 4 months of age. The group performance for each month is shown in Fig. 1.

Perfect adjustment to changing target distance would be represented by a slope of 0.00, whereas the complete absence of accommodative change would be indicated by a value of + 1.00. Prior to 1 month of age, the infant's accommodative response did not adjust to changes in target distances. The system appeared to be locked at one focal distance whose median value for the group was 19 cm. This is indicated by a slope value for the group of + 1.00. Occasionally, infants of this age did not remain alert long enough to allow complete calibration of their responses. In these few instances, the magnitude of error was estimated (see Fig. 1). Flexibility of response began at about the middle of the 2nd month and performance comparable to that of the normal adult was attained by the 4th month, as shown by a median slope value of 0.03.

For infants less than 1 month of age it might be assumed that the accommodative system is incapable of any change whatever. We therefore tested 11 sleeping infants, opening their lids in order to take readings. In every case, the lenticular system was relaxed and measured on the average 5 diopters less than when the infant was awake and alert.

During the 2nd month of infancy, the accommodative system began to respond adaptively to change in target distance. By 3 months of age, the median magnitude of hyperopia for targets at 20 cm was 0.75 diopter, a degree of accuracy comparable to the emmetropic (normal) adult. By the time the infants began to look at their own hands and make swiping motions at nearby objects (*6*) their eyes were able to focus sharply on such targets.

Knowledge of the developmental state of the accommodative system is a prerequisite for measuring the limits of visual discrimination in infants, because resolution is limited by the sharpness of the retinal image. Although accurate accommodation is a first step in achieving clear vision, there is not a simple relation between the capacity to focus an image on the retina and the ability to see clearly (visual acuity). Even when the image is optically focused on the retina, visual acuity in the infant is unlikely to be equivalent to that of the adult until the visual receptor mechanisms and neural pathways are sufficiently mature. The results of this study provide a basis for the design of studies of the vision of human infants.

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## Adaptation to Prismatically Rotated Visual Fields

Abstract. *The aftereffects of viewing a tilted field of lines differ from the effects of viewing a tilted field of objects. The difference is attributed to the fact that unlike isolated lines, objects have specifiable normal orientations.*

Viewing a field of tilted lines results in a change in the apparent orientation of a field of vertical lines subsequently viewed. Gibson (*1*) showed that the magnitude and direction of this aftereffect is contingent upon the angle of tilt of the inspection lines. When the lines are tilted less than 45° from true vertical, the position of apparent vertical shifts in the direction of tilt of the lines. When the lines are tilted more than 45°, the position of apparent vertical shifts counter to the direction of tilt of the lines. Gibson attributes this change in direction to a change in the axis toward which the tilted lines adapt. When the lines are tilted less than 45° from vertical, adaptation is toward the vertical axis; when more than 45° from vertical, adaptation is toward the horizontal axis. The general rule is that tilted lines adapt toward the axis to which they are closest (*2*).

If the inspection field is composed of tilted objects rather than lines, a different condition prevails. Unlike isolated lines, objects may have "normal" orientations toward one or the other axis (trees and walls are "normally" vertical; streets and floors "normally" horizontal). For our purposes, we consider visual stimuli to be "objects" by virtue of these specifiable orientations or past histories of experienced positions.

This distinction gains significance in the light of a second group of experiments in which the visual world is reversed, displaced, or tilted by means of prisms worn over the eye (*3*). After such prisms are worn, the initially displaced or tilted scene appears more normal. If, for example, tilting prisms are worn, the position of apparent vertical shifts in the direction of tilt of the prism. These studies, then, are similar to those of Gibson's in that for small angles of tilt (the only angles tested), similar directional aftereffects are obtained. They differ from Gibson's in the following ways. In the prism studies, aftereffects are much larger and require, according to some (*4*), active movement of the subject in order to be established. As noted above, they also differ in the kind of visual field used.

In view of these considerations we attempted to determine systematically, with but one method of presenting a tilted field (optically rather than directly), the role of the following: (i) type of inspection field (lines or objects); (ii) degree of inspection tilt (15° or 75° clockwise from vertical); (iii) activity during inspection (walking or sitting). For our object field we chose the corridors and classrooms of a school building. To generate the line field, we mounted luminescent strips of cardboard vertically in an otherwise dark