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11. Both eyes were refracted. Eighteen percent of the refractions revealed astigmatic anisometropia as defined by H. Blum, H. Peters, and J. Bettman [in *Vision Screening for Elementary Schools: The Orinda Study* (Univ. of California Press, Berkeley, 1959)]. Almost half of the cases of anisometropia showed a difference of one or more diopters of cylindrical power between the two eyes, the other half showed a difference of more than 30° in axis, and a few showed both.
12. Repeated refractive measures taken on the same day on 13 infants rarely deviated by more than ± 0.5 diopters.
13. Letters soliciting infants for testing were sent to new parents, who usually responded when the infants were between 2 and 5 months of age. Consequently, our sample of first refractions is largest in this age range.
14. In direct (with-the-rule) astigmatism, the meridian of greatest refractive power of the eye is within 30° of the vertical. In inverse (against-the-rule) astigmatism, the meridian of greatest refractive power of the eye is within 30° of the horizontal.
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16. The larger amounts of astigmatism are probably of corneal origin, although the lens could be a factor. Observation of the corneal reflections from the circle of a Placido disk often appeared elliptical, indicating some corneal astigmatism. We are currently performing keratoscopic measurements to determine the source of the cylindrical power.
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Infant Astigmatism Measured by Photorefraction

Abstract. *Photorefraction of a sample of 93 infants of ages 1 day to 12 months showed that 63 percent of the subjects had astigmatism of 0.75 diopter or greater, and 12 percent greater than 2 diopters. Seventy percent of these astigmatisms were in the horizontal-vertical meridians. By comparison, only 8 percent of a sample of 26 adults tested by the same method showed astigmatism (all 0.75 to 1 diopter). The high incidence of infant astigmatism has implications for critical periods in human visual development and for infant acuity.*

Photorefraction (*1*) is a photographic method for estimating the instantaneous refractive error of a subject's eyes, relative to the distance of the camera used. It requires no subjective report from subjects, nor their cooperation except in the brief fixation of a target, and so may be used with freely accommodating infants of all ages.

Figure 1 shows an example of the photographs on which measurements are made. The stars centered on each eye are produced by the retinal images of a point flash source centered in the camera lens and imaged on the film by a set of four cylindrical lens segments around the source. From the lengths of the star arms the defocus of each image in two orthogonal directions may be derived (*2*). The technique is therefore well suited for measuring astigmatic errors.

We now report a high incidence of astigmatism in an unselected sample of infants examined as part of an extensive photorefractive study of accommodative and refractive errors of infants from birth to 1 year of age (*3*). This finding is of interest because the first year of life is thought to be at least part of the critical period for human visual development (*4*), during which time the visual system may be vulnerable to deficient input; differences in image quality in different meridians have been suggested to have a developmental effect (*5*). If so, either infant astigmatism must result in meridional variations in acuity in later life, or neural plasticity must outlast the period of infant astigmatism (which we find to be at least 1 year).

The method used differed from the original method of photorefraction (*1*) in three ways. (i) An electronic flash rather than a tungsten light source was used. (ii) The photographs were taken on color transparency film (High Speed Ektachrome) rather than black-and-white film; this helped interpretation of the images in that the retinal reflexes were more readily distinguished from the background of the infant's face, and the white light from the retinal image of the source could be separated from the redder, more broadly distributed scattered light. (iii) The camera-to-subject distance was varied.

Infants in five age groups were studied: newborns (0 to 9 days), 1 month (4 to 7 weeks), 2 to 3 months, 6 to 8 months, and 9 to 12 months. Newborn infants from the postnatal wards of the (Cambridge, England) Maternity Hospital were tested when alert, usually shortly before or after feeding. The older groups were volunteered by their parents in response to recruiting leaflets distributed in well baby clinics in the Cambridge area. No infant in any group was more than 14 days premature.

Each infant was photorefracted while seated on the mother's or experimenter's knee at 150 and 75 cm from the camera. The estimates of astigmatism are principally based on photographs taken with the infant fixating at the camera distance. Between four and six photographs were taken at each of the two camera distances for each infant. This was achieved by using the photographer as the visual target; he or she attracted the infant's attention by calling, shaking brightly colored rattles, peekaboos, and other attention-seeking activity. The camera was operated when the infant was judged to be fixating the operator's face close to the camera. In this way the camera was always within 5° of the optical axis of the eyes at the moment of exposure, so off-axis errors of refraction (*6*) were avoided. Photographs were also taken with

Fig. 1. Photorefractive picture of infant with a 2.0-diopter astigmatism. The horizontal meridians of both eyes are relatively well focused while the vertical meridians are severely defocused.

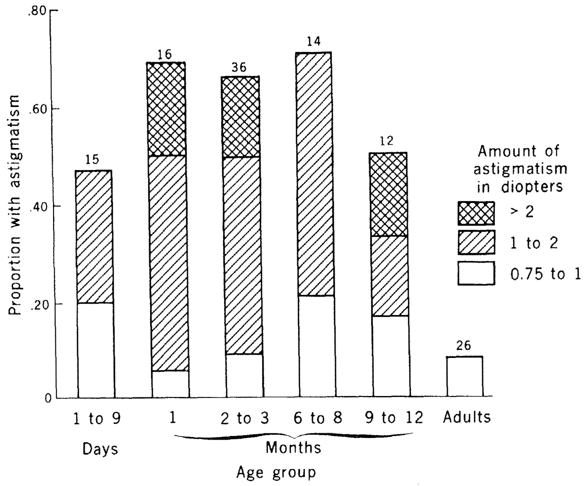

Fig. 2. Summary of astigmatisms found by photorefraction for various age groups. The mothers and laboratory personnel making up the adult group were unselected except for the exclusion of severe myopes.

fixation targets (rattles) at distances between the camera and the subject (five to ten photographs for each infant). In the data reported here, these have only been used to confirm the results of on-camera exposures, and only in cases where the target position and the infant's head posture as photographed indicated deviations of less than 5° from the optical axis. For each subject, some photographs were taken with the photorefractive attachment set to a horizontal-vertical orientation and some with it in an oblique orientation; this procedure allowed the components of astigmatism in each direction to be estimated.

The length of the star arms, together with the pupil diameter, gives the amount of defocus in one meridian but not its sign. A difference in these lengths in orthogonal directions in a particular photograph therefore allowed only an estimate of a lower limit of the astigmatism, since it was possible that the infant was accommodating so as to compromise between the foci for the two meridians (*7*). In some cases this potential ambiguity could be resolved by measurements on photographs taken with targets closer to the subject than the camera, since the accommodation, if compromised, would then bracket a distance other than the camera distance.

Each infant was also photographed with the use of a camera attachment consisting simply of a fiber-optic flash source centered in the camera lens. This source produced an image of the pupils flooded with light and thus allowed pupil diameter to be measured under the same lighting conditions as the photorefractive exposures. This measurement was necessary to infer dioptric defocus from the measured spread of the retinal image.

The lengths of the star arms were measured from the projected transparency in each case. A plot of this length against dioptric defocus was available for the range of pupil sizes, obtained by computer ray tracing (*2*).

The values used in constructing the histogram of the astigmatic errors found in each age group (Fig. 2) were the vector sums of minimum estimates of horizontal-vertical and oblique components of astigmatism. The proportions refer to the number of individual infants showing astigmatism of a particular magnitude. Of the 58 infants showing astigmatism of 0.75 diopter or greater, six met this criterion in one eye only, and an additional four showed a difference of more than 0.75 diopter in astigmatism between the two eyes.

The overall proportion of infants showing at least 0.75-diopter astigmatism in this sample was .6. An overall χ^2 test shows no significant difference between the incidence of astigmatism in the five infant age groups in a sample of this size. However, there is some suggestion in the data that astigmatism is commonest in the age range between 1 and 6 months, with a decline thereafter.

In the majority of cases (77 out of 110 eyes), the axes of the astigmatism were horizontal and vertical. Ten showed oblique astigmatism, and in 23 the axes were between the horizontal-vertical and oblique orientations.

Figure 2 also shows for comparison the incidence of astigmatism in a group of 26 adults measured according to the same procedure as for the infants. Fourteen of these adults were mothers of infants in the sample and 12 were members of the laboratory. Both groups were unselected apart from the exclusion of severe myopes (for whom the large refractive errors in both axes could have prevented comparison of the two). Two members of this group (8 percent) showed astigmatism between 0.75 and 1 diopter. This figure is comparable to data on the general incidence of astigmatism in the adult population (*8*).

It is clear that marked astigmatism is much more common in the first year of life. This result from photorefraction agrees with the high incidence of infant astigmatism found by near retinoscopy (*9*). Many individuals must lose their astigmatism between the age of 1 year and later childhood, but we do not yet have data to determine when this occurs. Nor do we know whether the source of infant astigmatism is an anisotropy of corneal growth or of the lens.

Early astigmatism has been proposed to lead, through selective neural development, to meridional amblyopia (*5*). Possibly the human visual system remains plastic beyond the period of high infant astigmatism, so that these astigmatisms do not have long-term consequences. Alternatively, infant astigmatisms with horizontal-vertical axes may provide a partial explanation of the poor acuity for oblique contours found in most adult subjects (*10*). Infants with these astigmatic axes may be able to bring either horizontal or vertical contours into sharp focus by suitable accommodation, but no position of accommodation will focus obliques sharply. However, a meridional difference in acuity has been found already present in nonastigmatic infants as young as 2 months (*11*).

Astigmatic errors of the size reported here are large enough to significantly affect the detection of spatial frequencies within the acuity range of infants 2 months and older (*12*). This effect can be demonstrated as a visual preference for a grating in the orientation in better focus at the viewing distance used (*3*). However, lower spatial frequencies, which will be little affected by the astigmatism, can provide much of the visual information infants may need to recognize forms, including human faces, at near distances.

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took into account the probe size both as a light source and a vignetting object. Where vignetting introduced an uncertainty about the amount of astigmatism present, a minimum estimate was taken. The maximum amount of astigmatism which can be present but not measurable due to vignetting is approximately 0.25 diopter at a distance from the camera of 1.5 m, and 0.5 diopter at 0.7 m.
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Productivity of Ospreys in Connecticut–Long Island Increases as DDE Residues Decline

Abstract. *Nesting success of ospreys (*Pandion haliaetus*) breeding in the Connecticut–Long Island area has increased since 1973 and is now approaching the levels recorded prior to the 1950's. Simultaneously, DDE and dieldrin residues have declined in unhatched eggs. Levels of polychorinated biphenyls have shown no changes over the period 1969 to 1976. The increase in productivity is attributed primarily to lower levels of DDE contamination. Detrimental effects in the past on ospreys in the Connecticut River estuary are attributed to local contamination with dieldrin.*

Ospreys (*Pandion haliaetus*) breeding in Connecticut and eastern Long Island (hereafter C-LI) declined rapidly in numbers in the late 1950's and throughout the 1960's, in association with abnormally low reproductive success (*1–4*). Earlier, between 1938 and 1942, Wilcox (*5*) had banded an average of 1.71 young per active nest (annual range 1.38 to 2.21) among a total of 100 nests on Gardiners Island, Long Island. In the early and mid-1960's, productivity fell to 0.07 to 0.4 young per active nest on Gardiners Island, in the Connecticut River estuary, and at Orient Point (*1, 3*). The productivity of these ospreys has since increased from about 0.5 fledged young per pair in 1969 to 1973 to 1.2 fledged young in 1976–77 (Fig. 1), approaching the range observed in 1938 to 1942. We now report that this increasse in reproductive success has coincided with a decrease in residues of DDE and dieldrin (*6*), and we provide further evidence for the conclusion that low reproductive success of ospreys is associated with residues of DDE in their eggs (*2, 4, 7–9*).

The major cause of low productivity of C-LI ospreys in the 1960's was failure of eggs to hatch, rather than failure of adults to breed (*1, 2*). Exchanges of eggs in 1968, 1969, and 1973 between nests in C-LI and Maryland, where hatching rates were substantially higher, showed that the factor (or factors) responsible for hatching failure were intrinsic to the egg and did not include abnormal parental behavior or human disturbance (*4, 10*).

Eggs from Connecticut that were used in transplant experiments or were collected unhatched in the period 1967 to 1970 had shells 15 to 20 percent thinner than the mean for eggs collected in the eastern United States prior to 1947 (*4, 7*). This degree of eggshell thinning approximates the critical level associated with hatching failure in other species (*7*). Shell thinning of osprey eggs, as in other species (*11, 12*), has been associated primarily with residues of DDE (*8*). Other chemical pollutants, however, including PCB's (*6*), dieldrin (*4, 8*), smaller quantities of other organochlorine compounds, and chemicals as yet unidentified (*13*), have been detected in osprey eggs from C-LI. The cause of the low productivity could not therefore be associated with certainty with any particular pollutant or with shell thinning per se.

We collected unhatched (*14*) osprey eggs from representative nests in C-LI between 1969 and 1976. Organochlorine and mercury residues were measured as described (*15*). Geometric mean concentrations of DDE declined fivefold between 1969 and 1976 and approximately threefold since 1973 (Fig. 1). This decline followed the decline in uses of DDT in the northeastern United States during the 1960's and the virtual cessation of DDT use in North America since 1972 (*12*). In spite of restrictions on uses of PCB's (*16*), their levels in osprey eggs have shown no significant changes between 1969 and 1976 (Fig. 1). Dieldrin has also declined significantly in the same period: geometric means, parts per million (ppm), dry weight, were 1.04, 1.05, 1.25, 0.95, and 0.78 in 1969 to 1973, and 0.25 in 1976 (sample sizes are the same as those shown in Fig. 1). This decline coincides with the cessation of use of aldrin (*6*) and dieldrin since 1974.

Table 1. Associations of osprey productivity with shell thickness and pollutant levels in sample eggs.

Miscellaneous	Young produced per active nest			Probability of difference	
	None	One	Two*	Analysis of variance	Kruskal-Wallis
Number of nests	41	14	13		
Mean shell thickness (μm)	411	436	442	.051	.054
Pollutant levels in unhatched eggs†					
DDE	113	59.6	29.1	$<10^{-8}$	$<10^{-9}$
PCB	144	130	83.8	0.027	0.025
Dieldrin	0.89	1.05	0.43	0.005	0.021
Mercury‡	0.25	0.18	0.22	0.621	0.728

*Includes one nest in which three young were raised. †Geometric means, parts per million, dry weight. There were significant associations between several of the pollutant variables. The correlation coefficient r between ln DDE and ln PCB was .531 ($P < .0001$); r between ln DDE and ln dieldrin was .432 ($P < .001$). Eggshell thickness was related to ln DDE by the regression equation: thickness = 501 − 18.2 (ln DDE), $F = 8.2$, $P < .01$. ‡N = 35, 10, 7, respectively.

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