References and Notes

1. S. O. Gardner, *Br. Med. J.* **1**, 77 (1973); B. L. Padgett and D. L. Walker, *J. Infect. Dis.* **127**, 167 (1973).
2. B. L. Padgett, D. L. Walker, G. M. ZuRhein, R. J. Eckroade, B. H. Dessel, *Lancet* **1971-I**, 1257 (1971); O. Narayan, J. B. Penney, Jr., R. T. Johnson, R. M. Herndon, L. P. Weiner, *N. Engl. J. Med.* **289**, 1278 (1973); B. L. Padgett, D. L. Walker, G. M. ZuRhein, A. E. Hodach, S. M. Chou, *J. Infect. Dis.* **133**, 686 (1976).
3. S. D. Gardner, A. M. Field, D. V. Coleman, B. Hulme, *Lancet* **1971-I**, 1253 (1971); S. D. Gardner, in *Recent Advances in Clinical Virology*, A. P. Waterson, Ed. (Churchill Livingstone, London, 1977), pp. 93–115.
4. L. P. Weiner, R. M. Herndon, O. Narayan, R. T. Johnson, K. Shah, L. J. Rubinstein, T. J. Preziosi, F. K. Conley, *N. Engl. J. Med.* **286**, 385 (1972).
5. D. L. Walker, B. L. Padgett, G. M. ZuRhein, A. E. Albert, R. F. Marsh, *Science* **181**, 674 (1973); G. M. ZuRhein and J. Varakis, in *Proceedings of the Seventh International Congress on Neuropathology, Budapest, 1974*, St. Kornyey, St. Tariska, G. Gosztoni, Eds. (Excerpta Medica, Amsterdam, 1975), vol. 1, pp. 479; J. Varakis and G. M. ZuRhein, *Acta Neuropathol. (Berlin)* **35**, 243 (1976); J. N. Varakis, G. M. ZuRhein, B. L. Padgett, D. L. Walker, *J. Neuropathol. Exp. Neurol.* **35**, 314 (1976); G. M. ZuRhein and J. N. Varakis, in *Conference in Perinatal Carcinogenesis*, J. M. Rice, Ed. (National Cancer Institute Monograph, Bethesda, Md., in press).
6. J. Costa, C. Yee, T. S. Tralka, A. S. Rabson, *J. Natl. Cancer Inst.* **56**, 863 (1976); J. E. Greenlee, O. Narayan, R. T. Johnson, R. M. Herndon, *Lab. Invest.* **36**, 636 (1977); A. Corallini, G. Barbanti-Brodano, W. Bortoloni, I. Nenci, E. Cassai, M. Tampieri, M. Portolani, M. Borgatti, *ibid.* **59**, 1561 (1977).
7. L. E. Becker, O. Narayan, R. T. Johnson, *J. Can. Sci. Neurol.* **3**, 105 (1976).
8. J. E. Osborn, S. M. Robertson, B. L. Padgett, G. M. ZuRhein, D. L. Walker, B. Weisblum, *J. Virol.* **13**, 614 (1974).
9. W. F. Loeb, J. L. Cicmanec, M. Wickum, *Lab. Anim. Sci.* **26**, 1084 (1976).
10. B. L. Padgett and D. L. Walker, *J. Infect. Dis.* **127**, 467 (1973).
11. K. E. Astrom, E. L. Mancall, E. P. Richardson, Jr., *Brain* **81**, 93 (1958); G. M. ZuRhein, *Prog. Med. Virol.* **11**, 185 (1969).
12. P. Castaigne, P. Rondot, R. Escourolle, J. L. Ribadeau-Dumas, F. Cathala, J.-J. Hauw, *Rev. Neurol.* **130**, 379 (1974).
13. A. F. Weiss, R. Portmann, H. Fischer, J. Simon, K. D. Zang, *Proc. Natl. Acad. Sci. U.S.A.* **72**, 609 (1975).
14. R. A. Smith, D. A. Goldstein, W. J. Meinke, *Neurology* **27**, 343 (1977).
15. M. Fiori and G. Di Mayorca, *Proc. Natl. Acad. Sci. U.S.A.* **73**, 4662 (1976).
16. K. K. Takemoto and M. F. Mullarkey, *J. Virol.* **12**, 625 (1973); B. L. Padgett and D. L. Walker, *Prog. Med. Virol.* **22**, 1 (1976).
17. A. Corallini *et al.*, *Infect. Immun.* **13**, 1684 (1976); J. Costa, C. Yee, A. S. Rabson, *Lancet* **1977-II**, 709 (1977).
18. We thank B. Curfman, R. L. Brown, A. G. Krezlewicz, E. Ireland, and D. Metcalf for technical assistance and N. Witzel for manuscript preparation. This work was supported in part by grants AI-11217 (D.L.W. and B.L.P.) and NS-11129 (G.M.Z.) from the National Institute of Allergy and Infectious Diseases and the National Institute of Neurological and Communicative Disorders and Stroke.

13 March 1978; revised 24 May 1978

Extreme Myopia Produced by Modest Change in Early Visual Experience

Abstract. *Chicks whose vision was restricted to the frontal visual field became extremely myopic (mean, −10 diopters; maximum, −24 diopters) and had eyes of increased axial length. Animals restricted to lateral field vision did not differ from normal animals. Monocular deprivation of form vision also produced myopia and eye enlargement and, in addition, produced increased anterior chamber depth.*

Myopia is an extremely prevalent human condition which, when severe, is associated with progressive retinal pathology leading to blindness (*1*). For many years environmental factors have been theorized to play a role in the development of myopia. One such hypothesis is that close visual attention leads to myopia. This relationship is weakly suggested by (i) the tendency of children to become more myopic from the age of six, when schoolwork starts (*2*); (ii) the high incidence of myopia in Eskimo schoolchildren whose parents were illiterate and tended to be hyperopes (*3*); and (iii) the tendency of men working in the close quarters of missile launch facilities to develop myopia related to their length of service (*4*). Young tested this close-work theory by keeping pig-tailed macaques seated in a monkey chair in an enclosed visual space for about a year; he reported that these animals developed a small amount of myopia (adults, 0.75-diopter change; young, 1.75-diopter change), which was retained for many months after their removal from the chair (*5*). In addition, cats raised in cages are about 2 diopters myopic compared with feral cats (*6*).

The amount of myopia found in all of these studies on environmental influences is very small. It is possible, therefore, that some of these myopias arise from an increased tonus of the muscles of accommodation, whereas the higher myopias found clinically have an anatomical origin. In part for this reason the hypothesis that there can be experiential influences on myopia has not fared well in comparison with the so-called biological theory that refractive errors are a genetic-embryological phenomenon (*7*).

We now report that restricting the vision of chicks to their frontal visual field produces extreme changes in ocular refraction (to a maximum of 24 diopters of myopia), which are not produced by restriction to the lateral visual field.

To restrict chicks to their frontal field of view, we developed lightweight, translucent, hemispherical occluders that fit over each eye and were glued to the skin with collodion (*8*). A trapezoidal notch cut in the front of the occluder permits the birds to have frontal vision (Fig. 1A). To restrict birds to lateral vision in one eye, an opaque vinyl cylinder 7 mm high was glued around the eye with collodion (Fig. 1B). Both types of occluders were put on at hatching and were exchanged for successively larger ones as the animals grew.

When the animals were 4 to 7 weeks old, their eyes were refracted by one of us (Trachtman), who is a retinoscopist familiar with refraction of the eyes of small animals. Measurements were made by streak retinoscopy in the horizontal meridian, 90° to the sagittal plane of the head, which is approximately 30° temporal to the optic axis. Neither the retinoscopist nor the person holding the animals knew to which group the animal belonged. We assessed the reliability of the measurements by twice determining the refractions on 19 animals ($r = .95$).

Postmortem measurements by means of an ocular micrometer in a dissecting microscope were made on formalin-perfused enucleated eyes from a sample including the animals refracted. The anterior chamber depth was approximated in this series of measurements and was also roughly estimated in living animals by a photographic technique (*9*).

The animals whose visual experience was confined to the frontal visual field were extremely myopic (mean, −10 diopters), unlike the lateral-field animals (mean, +1.9 diopters) (Mann-Whitney U test, $P < .001$), which did not differ from the normal animals (Fig. 2) (*10*). Similarly, the axial length of the eyes of the frontal-field animals was significantly greater than that of either the normals ($P < .01$) or the lateral-field animals ($P < .05$) (analysis of variance with Newman-Keuls test), which did not differ from each other (Fig. 3A).

It seems reasonable to suppose that the eyes of the frontal-field birds experienced more close vision than did the restricted eye of the lateral-field birds. In the frontal-field birds, vision was limited to the area around the beak, and the beak is a chick's only means of feeding and tactile exploring; in contrast, when the lateral-field birds approached an object, the eye with the occluder looked off to one side. There is evidence that in pigeons the frontal field is normally used for close vision and the lateral field for distant vision (*11*). The myopia is not analogous to a monocular visual deprivation effect, involving the animal's suppressing one eye in favor of the other,

0036-8075/78/0929-1249$00.50/0

since nearly all the eyes became myopic (Fig. 2).

To the best of our knowledge this is the first time that extreme myopia and increased axial length of the eye have been produced by alterations in the type of specific visual experience an animal has.

There is some evidence that nonspecific visual experience can cause myopia and changes in eye size. Wiesel and Raviola (*12*) and Sherman, Norton, and Casagrande (*13*) found that neonatal lid closure caused extreme myopia and increased axial length in two very different primates (macaque and tree shrew), although this result was not obtained by von Noorden and Crawford (*14*), who used a different, and perhaps less severe, surgical technique. We too have found myopia and eye enlargement in chicks whose lids were sealed (with collodion) at hatching (Fig. 3A). Since raising birds with the lids closed produces smaller lids, and since even the normal eye fits quite snugly in the orbit, we were concerned that a physical, rather than visual, restriction might be involved. Consequently, we raised birds with translucent occluders over one eye (Fig. 1C). These birds were also very myopic (mean, −12 diopters) (Fig. 2). Their eyes were significantly larger than those of normal and lateral-field animals (Newman-Keuls test, $P < .01$) and frontal-vision animals ($P < .01$) and were not significantly different from birds with closed lids (Fig. 3A). The possibility that gluing an occluder to the skin around the eye causes increased eye size is argued against by the normal eye size of the lateral-field animals.

There is a suggestion that the myopia produced by translucent occluders is different from the myopia in the frontal-field animals: the birds with translucent occluders developed substantially deeper anterior chambers (Fig. 3B). These birds are significantly different from all others except those with closed lids (Newman-Keuls test, $P < .05$), although there may be a small increase in anterior chamber depth in the frontal-field animals as well. This increase in anterior chamber depth also distinguishes these birds from birds with avian glaucoma syndrome, in which being raised in continuous light causes eye enlargement and a shallow anterior chamber, eventually leading to retinal degeneration and blindness (*15*).

The mechanism by which any of these myopias is produced is obscure. In the frontal-field animals, it seems that a larger proportion of the objects they see are close to them, compared to normal or

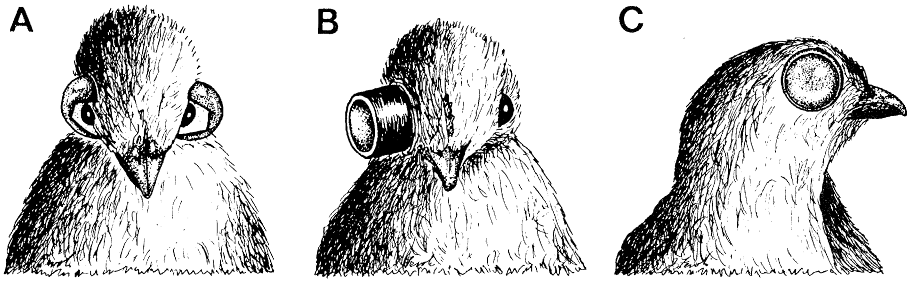

Fig. 1. Devices used to restrict visual fields to the frontal field (A) and the lateral field (B) and to prevent form vision (C).

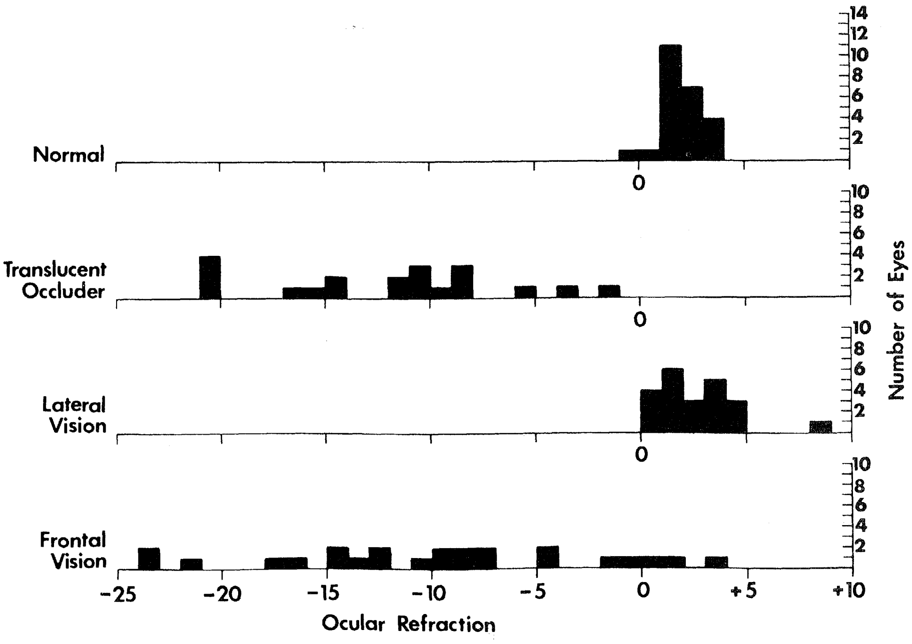

Fig. 2. Effect of different visual restrictions on ocular refraction. The values on the abscissa refer to the correction in diopters necessary for emmetropia. In the cases of the normal and frontal-field animals, both eyes are included; in the other groups only the treated eye is plotted.

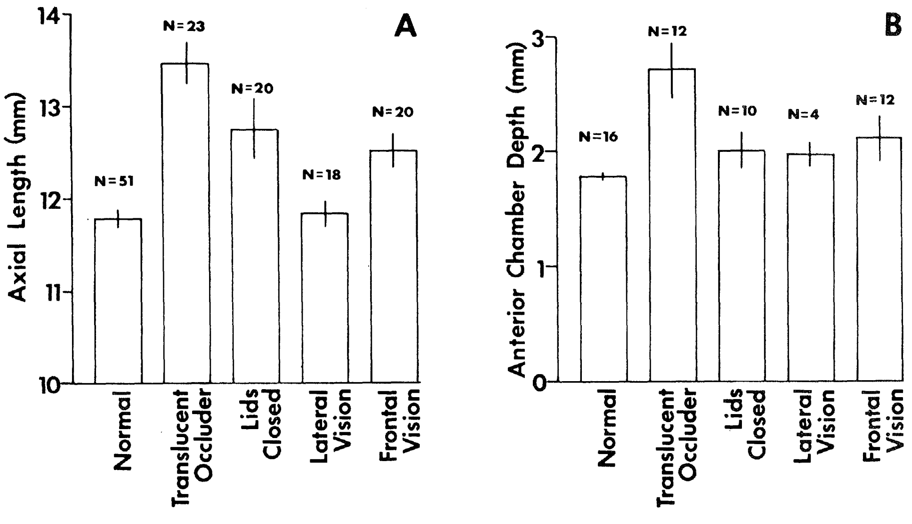

Fig. 3. Effect of different visual restrictions on morphological dimensions of the eye. Both eyes are plotted for normal and frontal-field animals; in all groups the untreated eyes did not appear to differ from the eyes of normal animals. The measurements in (B) were obtained by a photographic technique (*9*). This pattern of results was the same as that obtained from measurements on enucleated eyes. Ultrasound measurements of the distance from the cornea to the anterior surface of the lens on several live animals from the frontal-vision and translucent-occluder groups confirmed the effect. Preliminary results indicate that, despite the changes in axial length, removal of the occluders caused a gradual reduction in the degree of myopia; this may be analogous to emmetropization in humans, or it may reflect changes in the tonus of the muscles of accommodation.

lateral-field animals. We can speculate that this would cause their eyes to accommodate more and that accommodation might conceivably lead to changes in eye growth. Others have made similar speculations (*16*). Another possibility is that near objects cause increased convergence of the eyes. We have shown by recording eye movements that frontal-field birds make more divergent and convergent saccades than do normal birds, whereas lateral-field birds make fewer (*17*). One could imagine that increased convergence might affect ocular growth. Alternatively, retinal location may be an important variable. If the absence of objects in the lateral visual field either causes extreme accommodation or otherwise has a particular effect on eye growth, it would account for the similar degree of myopia in the frontal-field animals and in those monocularly deprived of form vision.

In normal animals, each of the dimensions of the eye that affect refraction shows substantial interindividual variation (*7*). If, at least in birds, myopia is caused by increased accommodation for close vision, this etiology could be a clue to a developmental feedback mechanism that normally assures that the eye grow toward correct refraction. Thus an animal that starts out somewhat hyperopic would tend to accommodate more than a normal animal, which might cause a pattern of ocular growth that would tend to decrease the hyperopia.

The effects of different visual experiences on neuronal connectivity in the brain are well established. Our results suggest that the morphology of the eye is influenced not only by the absence of visual experience but also by the nature of the specific visual experiences.

JOSH WALLMAN
JOSEPH TURKEL
Department of Biology,
City College of City University
of New York, New York 10031
JOSEPH TRACHTMAN
Mount Sinai School of Medicine of
City University of New York

References and Notes

1. S. Duke-Elder, *Diseases of the Eye* (Churchill, London, 1970).
2. E. V. L. Brown, *Arch. Ophthalmol.* **28**, 845 (1942); F. A. Young, R. J. Beattie, F. S. Newby, M. T. Swindal, *Am. J. Optom. Arch. Am. Acad. Optom.* **31**, 192 (1954).
3. F. A. Young, G. A. Leary, W. R. Baldwin, D. C. West, R. A. Box, E. Harris, C. Johnson, *Am. J. Optom. Arch. Am. Acad. Optom.* **23**, 676 (1969).
4. M. A. Greene, *J. Am. Optom. Assoc.* **41**, 1012 (1970).
5. F. A. Young, *Am. J. Ophthalmol.* **52**, 799 (1961); *Am. J. Optom. Arch. Am. Acad. Optom.* **38**, 545 (1963); *Invest. Ophthalmol.* **2**, 571 (1963).
6. L. Rose, U. Yinon, M. Belkin, *Vision Res.* **14**, 1029 (1974); M. Belkin, U. Yinon, L. Rose, I. Reisert, *Doc. Ophthalmol.* **42**, 433 (1977).
7. A. Sorsby, in *Clinical Ophthalmology*, T. D. Duane, Ed. (Harper & Row, New York, 1976), vol. 1, chap. 34.
8. J. Wallman, C. Ledoux, M. B. Friedman, *Behav. Res. Methods Instrum.* **10**, 401 (1978).
9. The eyes of deeply anesthetized birds were photographed from above, oriented so that the optical axes were nearly horizontal. The pupil, which appeared in the photographs as a narrow ellipse, was superimposed on one of a set of standard ellipses, and the distance along the short axis of the ellipse from the center of the pupil to the corneal surface was measured. By knowing the ellipse shape that fit the pupil, we could calculate a trigonometric correction for the slight tilt of the eye. Although this technique ignores the distortion caused by viewing the pupil through the peripheral cornea, this error probably does not affect the relative differences between the experimental groups both because the peripheral corneal curvature was approximately the same in all groups and because the results obtained were similar to those obtained with other measurement techniques (Fig. 3).
10. The apparent slight hyperopia of the normal animals is probably in part a systematic error of retinoscopy of small eyes [M. Glickstein and M. Millodot, *Science* **168**, 605 (1970)]. Pigeons, however, are somewhat hyperopic in their lateral visual fields (*11*), where these measurements were made.
11. M. Millodot and P. Blough, *Vision Res.* **11**, 1019 (1971), P. W. Nye, *ibid.* **13**, 559 (1973).
12. T. N. Wiesel and E. Raviola, *Nature (London)* **266**, 66 (1977).
13. S. M. Sherman, T. T. Norton, V. A. Casagrande, *Brain Res.* **124**, 154 (1977).
14. G. K. von Noorden and M. L. J. Crawford, *Nature (London)* **272**, 53 (1978).
15. J. K. Lauber, J. E. Boyd, T. A. S. Boyd, *Exp. Eye Res.* **9**, 181 (1970); J. K. Lauber and J. McGinnis, *Vision Res.* **6**, 619 (1966); M. E. Smith, B. Becker, S. Podos, *Invest. Ophthalmol.* **8**, 213 (1969). A related effect, involving eye enlargement and myopia, occurs in chickens raised under diurnal, low-intensity blue light [A. B. Bercovitz, P. C. Harrison, G. A. Leary, *Vision Res.* **12**, 1253 (1972); P.C. Harrison, A. B. Bercovitz, G. A. Leary, *Int. J. Biometeorol.* **12**, 351 (1968).
16. F. A. Young, *Am. J. Optom. Arch. Am. Acad. Optom.* **42**, 439 (1965).
17. J. Wallman, in preparation.
18. We thank C. Ledoux for assistance in all phases of the work, L. Blumenstein for help with the anatomical measurements; Dr. E. Giglio and the New York State College of Optometry for assistance with the ultrasound measurements, and D. Pratt for statistical assistance. Figure 1 was drawn by J. Fevoli. Supported by a City University of New York faculty research award program grant and a NIH biomedical sciences subgrant. J. Turkel was a National Eye Institute postdoctoral fellow.

24 February 1978; revised 27 June 1978

Ethology of Sleep Studied with Time-Lapse Photography: Postural Immobility and Sleep-Cycle Phase in Humans

Abstract. *Human sleep is characterized by episodes of immobility punctuated by major postural shifts. The organization of this motor activity was shown with a combination of photographic and electroencephalographic recording to be periodic and related to the electroencephalographic sleep cycle. The amount of immobility as measured photographically was positively related to subjective estimates of the goodness of sleep.*

Since the discovery of the mammalian sleep cycle, it has been known that major body movements occur predominantly before and after the periodically recurrent episodes of desynchronization of the electroencephalogram (EEG) and rapid eye movements (REM) (*1*). Direct observation, photography, and videotape analysis have shown that many of these phase-locked movements are postural shifts (*2*). Implications of this finding are (i) that the longest periods of postural immobility are associated with the non-REM (NREM) phase of the cycle and (ii) that inactivation of the motor apparatus is a phase-locked event. It follows that postural immobility, easily detectable in time-lapse photographic data, could by itself provide a simple quantitative read-out of the state of the brain oscillator controlling the REM-NREM sleep cycle. In addition, the total duration of immobility so measured might be correlated with objective or subjective estimates of sleep duration and thus serve as a simple but valid measure of sleep quantity or quality. If so, time-lapse photography might be a means of conducting field studies of sleep behavior that could be related to the findings of the sleep laboratory. Here we report the results of our first efforts to explore this possibility.

Observation of 50 individuals sleeping at home and being photographed at 15-minute intervals revealed epochs of apparent postural immobility lasting from 45 to 75 minutes and recurring with a periodicity of 75 to 120 minutes (*3*). We wished to determine the relationship of these epochs to the EEG sleep cycle and to verify the apparent absence of movement in the photographs by continuously monitoring muscle activity on the polygraph. The sleep of each of six subjects (three male and three female, between the ages of 20 and 30) was therefore recorded in the sleep laboratory for four consecutive nights with an electroencephalograph (Grass model 6). A camera (Zeiss Contarex) was mounted on the ceiling over the bed and connected to an electronic timer. The camera was housed in a Lucite box lined with polystyrene foam for sound attenuation. Black-and-white pictures (35mm) of the subject were taken automatically every 15 minutes throughout the night; a time ex-

0036-8075/78/0929-1251$00.50/0