become available earlier in those cells that receive a priming dose of interferon before becoming infected by the spreading infection. In some cases, the early availability of larger amounts of interferon may be sufficient to abort the infection.

Data comparable to some of the foregoing have been obtained independently by Friedman, who also showed that the enhancement phenomenon requires protein synthesis (*9*).

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References and Notes

1. P. DeSomer, A. Prinzie, P. Denys, Jr., E. Schonne, *Virology* **16**, 63 (1962); S. E. Grossberg and J. J. Holland, *J. Immunol.* **88**, 708 (1962).
2. H. B. Levy, *Virology* **22**, 575 (1964).
3. ———, D. Axelrod, S. Baron, *Proc. Soc. Exp. Biol. Med.* **118**, 384 (1965).
4. A. Isaacs and D. C. Burke, *Nature* **182**, 1073 (1958); R. Z. Lockart, Jr., *J. Bacteriol.* **85**, 556 (1963); J. Vilcek and B. Rada, *Acta Virol.* **6**, 9 (1962); L. A. Glasgow and K. Habel, *J. Exp. Med.* **117**, 149 (1963).
5. S. Baron, S. Barban, C. E. Buckler, *Science* **145**, 814 (1964).
6. C. E. Buckler, H. B. Levy, S. Baron, *ibid.* **152**, 80 (1966).
7. H. B. Levy, L. F. Snellbaker, S. Baron, *Proc. Soc. Exp. Biol. Med.*, in press.
8. S. Sigel, *Nonparametric Statistics for the Behavioral Sciences* (McGraw-Hill, New York, 1956), pp. 68–75. We thank Dr. D. Alling, of the NIAID, for his analysis of these data.
9. R. Friedman, *J. Immunol.*, in press.

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Human Visual Acuity Measured with Colored Test Objects

Abstract. *Visual acuity was measured with a grating test object in which alternating bars were matched in brightness but differed in wavelength. If the wavelength difference between adjacent bars was great enough, acuity scores were obtained which were as high as those obtained with test objects in which there was a large brightness difference between adjacent bars.*

Visual acuity is a measure of an observer's ability to perceive fine detail. Most experimental, and all clinical, tests of visual acuity use stimulus patterns in which there is a brightness contrast between the test object and the background from which it must be discriminated. Indeed, visual acuity is often treated as if it were a special case of brightness discrimination. This is not unrealistic since, in everyday life, brightness gradients are almost certainly the most important cues for visual discrimination. It has been reported that acuity is degraded when the test object and its background are equally bright but differ in hue (*1*); however, several recent studies (*2*) indicate that this may not be true when saturated stimuli are used. We have tested this proposition by measuring acuity with highly (but unequally) saturated monochromatic test objects which differ from their backgrounds in wavelength but not in brightness.

Foveal visual acuity was measured with a grating target which appeared to the observer as a series of equally wide bars filling a 1-degree-circular aperture centered in a 30-degree achromatic surround. Even-numbered bars were illuminated by one optical system, and odd bars by another similar system. Each system included filters and a grating monochromator, set for a nominal bandpass of 10 nm, so that the wavelength and intensity of the two sets of bars could be independently varied. The width of the bars could be changed optically to subtend visual angles between 0.5 and 2.0 minutes per bar, permitting measurement of acuity from 0.5 min^{-1} to 2.0 min^{-1} (20/40 to 20/10 in Snellen notation). The gratings were presented in Maxwellian view, with the observer's head position maintained by use of a forehead rest and dental impression block. Correcting optics and a 1.5-mm artificial pupil were used to reduce axial chromatic aberration. The following data were obtained from two emmetropic observers who had clinically normal color vision and whose photopic brightness matches resembled the photopic "standard observer."

Individual brightness-matching functions were obtained between 422 and 680 nm by step-by-step matching of stimuli which were separated by 5 nm. The luminance of the resulting stimuli could be approximately matched by a 7.5-millilambert extended source. These brightness matches were then used to equate all the acuity test objects and backgrounds. During a series of observations the wavelength and intensity of one set of bars remained fixed. These bars will be arbitrarily referred to as background. The other bars, which alternate with the background, were varied in wavelength and will be called the test objects.

Acuity thresholds were obtained by a modified method of adjustment (*3*). The grating was initially presented below threshold, and the observer increased the width of the bars until they were visible. The observer was required to detect the presence of the grating, but not to identify the hues of the bars. Figure 1 shows how acuity changes as a function of wavelength separation between test object and background. As expected, acuity is poor when only a small wavelength separation exists between adjacent bars. As wavelength separation is increased, acuity improves until it reaches a maximum of about 1.3 min^{-1}. This maximum is essentially the same as the observer's acuity measured with a conventional test grating made of adjacent black and white bars. An intentional brightness mismatch between adjacent colored bars improves acuity only when the wavelength separation between bars is small; once maximum acuity has been reached no further improvement can be effected by introducing either a small (0.1 log unit) brightness mismatch or by completely occluding one set of bars. We note parenthetically that examination of a number of these records did not reveal any consistent unusual effects when test object and background were illuminated with complementary wavelengths.

As a check on the method of adjustment acuity, thresholds were de-

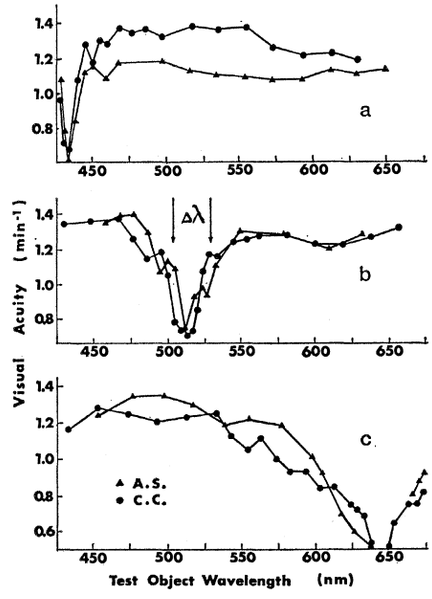

Fig. 1. Visual acuity measured with gratings in which adjacent bars are equally bright but differ in wavelength. In (*a*) the background bars were 430 nm; in (*b*), 520 nm; and in (*c*), 650 nm.

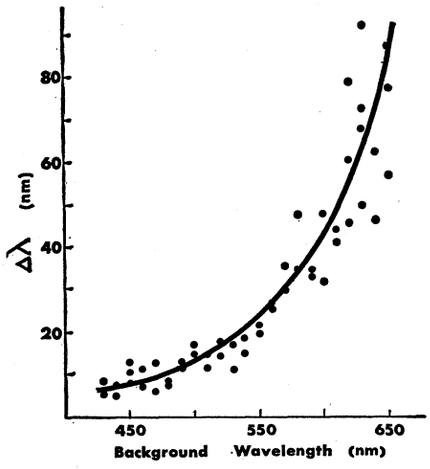

Fig. 2. Wavelength interval ($\Delta\lambda$) between those test-object wavelengths (above and below the background wavelength) which give a visual acuity of 1.0 min^{-1}. Line: least squares fit to log $\Delta\lambda$ plotted against background wavelength. Data points: session means for observer CC. Data from AS were similar, but showed a slightly narrower $\Delta\lambda$ interval at all wavelengths.

termined for a few wavelength pairs by the method of constant stimuli, in which the gratings were exposed for 0.5 second. The resulting acuity plotted against wavelength of the test object was almost identical to the same function determined by the method of adjustment. However, visual acuity was uniformly 0.2 min^{-1} higher when measured with the method of constant stimuli, which we attribute to the fact that a conventional 50 percent frequency-of-seeing threshold was used with the constant stimuli, whereas when the method of adjustment was used the grating had to be seen on each trial.

The effect of wavelength separation on acuity is not constant across the visible spectrum. Good acuity is attained with a small wavelength separation when both test object and background are illuminated with short wavelengths (Fig. 1*a*) while a wide wavelength separation is required to obtain the same acuity when adjacent bars are illuminated with long wavelengths (Fig. 1*c*). In order to describe the dependence of acuity on wavelength separation in a different part of the spectrum, the following measure was taken: functions similar to those in Fig. 1 were obtained by using backgrounds at 10-nm steps between 430 nm and 650 nm. The widths of these functions were measured at the point at which they cross an arbitrary criterion of 1.0 min^{-1} ($\Delta\lambda$ in Fig. 1*b*) and were plotted as a function of the background wavelength (Fig. 2). Contrary to our prior expectation this function does not closely resemble the normal wavelength discrimination function (*4*), particularly in that it does not rise in the short wavelength region. Log $\Delta\lambda$ increases linearly with background wavelength (mean product-moment correlation of 0.96) but we do not assign any physical meaning to this fact at present.

Even if the brightness of the test object and background are matched in the external stimulus, brightness gradients will exist on the retina as a result of diffraction caused by the system exit pupil. We do not believe that these retinal brightness gradients are the effective cues for discrimination in this situation, however. The $\Delta\lambda$ function (Fig. 2) rises more sharply than one would predict from a diffraction explanation. Also, retinal brightness contrast produced by diffraction will generally be less when the test object and background are equally bright than when either is black. If acuity were mediated by brightness contrast alone, it should be improved by increasing contrast. However, occluding one set of bars completely does not improve acuity once good acuity has been obtained by means of wavelength separation between test object and background. We therefore believe that good acuity is possible without significant brightness contrast on the retina.

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References and Notes

1. E. Brücke, *Sitzungsber. Akad. Wiss. (Wien)* Kl. 3, **80**, 18 (1879); S. Exner, *Arch. Ges. Physiol.* **73**, 117 (1898); S. Liebmann, *Psychol. Forsch.* **9**, 300 (1927).
2. Eastman Kodak Co., *Influence of Color Contrast on Visual Acuity* (National Defense Research Committee, Cambridge, Mass., 1944. Contract OEMsr-1070, OSRD No. 4541); M. N. Crook, J. A. Hanson, R. E. Shor, R. P. Winterberg, *The Discrimination of Simulated Colored Radar Scope Targets* (Tufts University, Institute for Applied Experimental Psychology, Medford, Mass., 1959); H. P. Bishop, *Factors in Acuity with Chromatic Test Objects* (Tufts University, Institute for Applied Experimental Psychology, Medford, Mass., 1961).
3. S. Schlaer, *J. Gen. Physiol.* **21**, 165 (1937).
4. W. D. Wright and F. H. G. Pitt, *Proc. Phys. Soc. (London)* **46**, 459 (1934); M. H. Siegal, *J. Opt. Soc. Amer.* **54**, 827 (1964).
5. Supported by U.S. Army Medical Research and Development Command, contract DA-49-193-MD-2666. We thank Dr. J. A. Whittenburg for encouragement and suggestions, Dr. R. H. Peckham for technical advice and Dr. H. N. Bernstein for performing ophthalmological examinations.

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Specialized Receptive Fields of the Cat's Retina

Abstract. *Three new types of receptive field have been found in the cat's retina. The responses of these fields to flashing lights and moving objects suggest that the manner in which they code visual information may be quite different from that of the center-surround fields described in previous studies. These "specialized" fields were all found in the area centralis. A definite functional difference, corresponding to the known anatomical difference, between this region and the rest of the retina, is suggested.*

Since Kuffler (*1*) first described the concentric center-surround organization of the receptive fields of ganglion cells of the cat's retina, subsequent studies of these fields (*2–4*) have revealed only this form of organization, with one exception noted by Rodieck and Stone (*5*). However, Stone (*6*) has shown that the cells in the area centralis are much smaller than those in the peripheral retina, which raises the question whether the receptive fields of cells in this area also have the concentric center-surround arrangement. We have now made special effort to examine the receptive fields of units in the area centralis, recorded using varnished tungsten microelectrodes. The receptive fields were plotted on tangent screens placed at distances up to 5 m from the cat's eye. The location of these units in the area centralis (defined as the area of retina in which ganglion cell density exceeds 3000 cells per square millimeter) was checked histologically on whole mounts of the retina (*4*). The other techniques used were identical with those described by Rodieck and Stone (*4, 5*) except that, for some animals, decerebration was replaced by nitrous oxide anesthesia (70 percent N_2O_2 and 30 percent O_2) (*7*) and paralysis of the extraocular muscles and immobilization of the eyes were maintained by a continuous infusion of Flaxedil and Curare (*7*) (12.5 and 2.5 mg/hr, respectively).

It proved very difficult to isolate