*THE SPECTRAL LUMINOSITY CURVES FOR A DICHROMATIC EYE AND A NORMAL EYE IN THE SAME PERSON**

By C. H. Graham and Yun Hsia

DEPARTMENT OF PSYCHOLOGY, COLUMBIA UNIVERSITY

Communicated November 6, 1957

We have recently had the opportunity to determine some visual functions of a unilaterally color-blind person, that is, one who demonstrates some form of color blindness in one eye and normal (trichromatic) vision in the other.

The fact that a condition of unilateral color blindness can exist has been known since 1879.[1] Cases of unilateral color blindness have been historically important, for it has been supposed that they could provide conclusive evidence on the chromatic perceptions of color-blind individuals. It is for this reason that most of the tests made upon them were concerned with comparisons between the colors seen in the normal and the color-blind eye. The evidence seems to show that in unilaterally color-blind subjects, any form of color deficit may be represented in the color-blind eye, e.g., dichromatism, anomalous trichromatism, or completely monochromatic vision. Judd[2] reports that thirty-seven cases of unilateral color blindness have been described in the literature. Because of inadequate procedure or background information, the data on only eight have proved of more than passing interest.

No case of unilateral color blindness so far reported has involved a color-blind eye whose discriminative functions are known in detail, and it is probable that in most of the cases reported the trichromatic eye has not met completely rigorous criteria of normality. We do not believe that these latter shortcomings apply in the case of our subject. We have made analyses of several of the visual functions exhibited by both the color-blind and the normal (trichromatic) eyes, and we are confident that the trichromatic eye of our subject does, in fact, meet the usual standards of normality.

A recent paper[3] by us has provided information on luminosity losses of dichromats. In that paper we pointed out the contradictory issues raised by the facts of luminosity losses in dichromats and the color-naming of unilaterally color-blind subjects. We have examined various visual functions of our unilaterally color-blind subject over a period of about three years, with considerable periods of interruption. (Since a later report on color mixture will show that, in her color-blind eye, she can match any spectral wave length by a mixture of 460 mμ and 650 mμ, we shall refer to her color blindness as a form of dichromatism.) The present paper reports the first of these studies, a description of this subject's luminosity curve for the normal and dichromatic eye. It is found that our subject, who gives typical dichromatic responses (of a predominantly deuteranopic type) on the screening tests, evidences a considerable degree of luminosity loss in the green and blue regions of the spectrum. In this respect her data are in accord with our recently published data on luminosity losses in protanopes and deuteranopes.[3]

Procedure.—The procedure used for observations with each eye of our unilaterally color-blind subject was similar to the one followed with the normal and color-blind subjects, as previously reported. Spectral lights, each of a narrow wave-

length band, were presented by means of our double monochromator. The duration of each flash, seen by the subject through an artificial pupil of 2.4 mm. in diameter, was 4 milliseconds. The diameter of the circular stimulus (which appeared within a dimly illuminated fixation ring, 2.5° in diameter) was 42 minutes. A correction of −2 diopters was required for the right eye and −4 for the left. (During the experiment the correction lenses were installed just behind the artificial pupil, on the side away from the subject.) The method of limits was used to determine threshold, and a 10-minute period of dark adaptation was given before each sequence of threshold determinations in a given experimental period. About four to six thresholds were obtainable in the usual experimental period of 1 hour.

Our subject took a considerable number of tests, including those given in the routine screening of subjects. The routine tests[4] involved (*a*) the reading of the Ishihara and Stilling plates, (*b*) the determination of the proportion of red and green required to match a yellow on the Hecht-Shlaer anomaloscope, and (*c*) the determination of the subject's neutral point made with a modified Helmholtz color-mixer.[5] In addition to the routine tests, the following were also employed: the Dvorine test (2d ed.), American Optical Company plates, Farnsworth Dichotomous D-15, and Farnsworth-Munsell 100-Hue tests.[4]

Dr. Gertrude Rand and Miss Catherine Rittler, of the laboratory of Ophthalmology, Columbia University College of Physicians and Surgeons, made additional examinations of our subject. They used the following tests for both the color-blind and the normal eye: the Hardy-Rand-Rittler pseudoisochromatic plates, the two Farnsworth tests, the American Optical Company plates, the Ishihara test, the Rabkin test, and the Boström-Engelberg test.[4] The Nagel anomaloscope[5] was used on both eyes. Dr. Rand and Miss Rittler concluded that, although our subject's right eye is normal by all the tests used, including the Nagel anomaloscope, her left eye does not fit a category of classical color defect. We deeply appreciate the co-operation of Dr. Rand and Miss Rittler. We are also indebted to Dr. R. L. Pfeiffer, of the Ophthalmological Institute, Columbia University College of Physicians and Surgeons, for the ophthalmological examination of our subject. He found no organic disease.

The Luminosity Curve.—The luminosity curves of our subject are given in Figure 1. The figure shows that in the red end of the spectrum both eyes of our subject have about the same degree of sensitivity. The curves for the two eyes differ in absolute luminosity values in the blue and green regions of the spectrum.[6] The luminosity of the normal eye in those regions is comparable to the luminosity given by normal subjects, but the luminosity of the color-blind eye shows considerable loss as contrasted with the normal eye. The data for the color-blind eye look like the data for a deuteranope, although it might be said that the luminosity loss occurs at wave lengths probably unusually far into the orange. In any case, the subject shows a considerable degree of luminosity loss in the green and blue for her color-blind eye.

Discussion.—Our unilaterally dichromatic subject exhibits a considerable degree of luminosity loss in the color-blind eye, particularly in the orange to blue region of the spectrum. In this respect she shows an effect comparable to that shown by five of six deuteranopes that we have tested.[3]

No claim is made, despite the comparability of our subject's data to those found

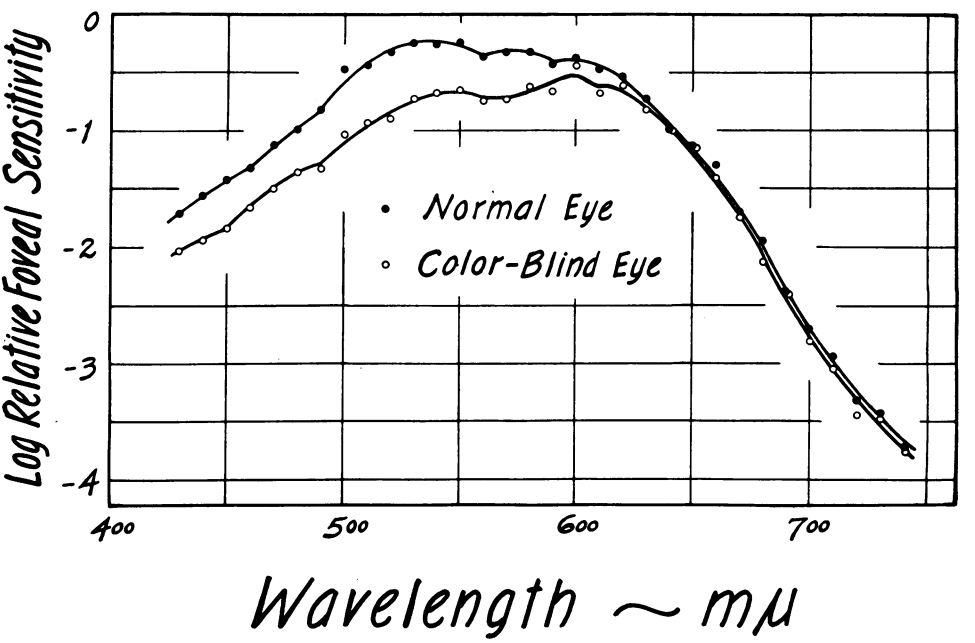

FIG. 1.—Log foveal sensitivity values for threshold in the trichromatic and color-blind eye of a unilaterally color-blind subject.

earlier with deuteranopes,[3] that she is, in fact, a simple deuteranope. Later reports will show, as did the diagnostic testing of Dr. Rand and Miss Rittler, that our subject may not be typically deuteranopic. For example, her hue discrimination is better than that of the usual deuteranope in the short-wave region of the spectrum.

Summary.—We have determined the respective luminosity curves of the two eyes of a unilaterally color-blind person. The subject's right eye is normal, and her dichromatic eye, except for a few details, is most directly classifiable as deuteranopic. Her color-blind eye shows a loss of luminosity as contrasted with her normal eye in the spectral range from about 625 mμ to 430 mμ. The loss that she exhibits is greater than comparable ones shown by five out of six deuteranopes in a previous report.[3]

* This work was supported by a contract between the Office of Naval Research and Columbia University and by a grant-in-aid from the Higgins Fund of Columbia University. Reproduction in whole or in part is permitted for any purpose of the United States government. An abstract of some of the present research has appeared earlier (see C. H. Graham and Yun Hsia, *Science*, **120**, 780, 1954). We wish here to express our deep appreciation to our subject (A. H. C.) for the many hours of observation that she devoted to our work.

[1] The four following references are the earliest, the second, third, and fourth being concerned with the famous case of Hermann Goldenberg, the nature of whose color blindness still remains in controversy: O. Becker, *Graefe's Arch. Ophthalmol.*, **25**, 205–212, 1879; A. Von Hippel, *Graefe's Arch. Ophthalmol.*, **26**, 176–186, 1880; F. Holmgren, *Proc. Roy. Soc. London*, **31**, 302–306, 1881; A. Von Hippel, *Graefe's Arch. Ophthalmol.*, **27**, 47–55, 1881.

[2] For a history and analysis of the problem see D. B. Judd, *J. Research Nat. Bur. Standards*, **41**, 247–271, 1948. The latest research on unilateral color blindness reported by Judd is that of Louise L. Sloan and Lorraine Wollach, *J. Opt. Soc. Amer.*, **43**, 890–894, 1953.

[3] Y. Hsia and C. H. Graham, these PROCEEDINGS, **43**, 1011, 1957.

[4] On the tests used, see the following. S. Ishihara, *Tests for Colour-Blindness* (6th ed.; Tokyo:

Kanehara, 1932); E. Hertel, *Stilling's Pseudo-isochromatische Tafeln* (Leipzig: Georg Thieme, 1936); I. Dvorine, *Dvorine Pseudo-isochromatic Plates* (2d ed.; Baltimore: Waverly Press, 1953); American Optical Company, *A-O Pseudo-isochromatic Plates* (Philadelphia: Beck Engraving, 1940); D. Farnsworth, *Farnsworth-Munsell 100-Hue Test* (Baltimore: Munsell Color Co., 1949); D. Farnsworth, *The Farnsworth Dichotomous Test for Color Blindness* (New York: Psychological Corporation, 1947); L. H. Hardy, G. Rand, and M. C. Rittler, *H-R-R Pseudoisochromatic Plates* (1st ed.; American Optical Co., 1955); E. Rabkin, *Polychromatic Plates for Testing Color Vision* (2d ed.; Kiev: State Medical Publishing House, 1939); C. D. Boström and I. Kugelberg, *Plates for Testing Color Vision*, Vol. I (Stockholm: Kifa, 1943).

[5] On the Helmholtz color-mixer see S. Hecht and S. Shlaer, *J. Gen. Physiol.*, **20**, 57, 1936. On the Hecht-Shlaer and also the Nagel anomaloscope see M. P. Willis and D. Farnsworth, *Med. Research Lab., U.S. Submarine Base*, Vol. **11**, No. 7, Rept. No. 190, 1952.

[6] Log_{10} energy values for threshold in the two eyes of our subject. [Log threshold values relative to the average log threshold energy values for 7 normal subjects (in reference of footnote 3) with unit determined by setting log energy = 0 at 545 mμ, the maximum of the luminosity curve. Absolute energy for average threshold of the normal subjects is (interpolated) 3.5×10^{-8} erg (about 10,000 quanta) at 578 mμ.] Log_{10} energy values for the trichromatic (normal) eye of our unilaterally color-blind subject at steps of 10 mμ beginning with 430 mμ and ending with 740 mμ are as follows: 1.71, 1.57, 1.42, 1.33, 1.13, 1.01, 0.82, 0.48, 0.45, 0.33, 0.26, 0.27, 0.25, 0.37, 0.33, 0.33, 0.44, 0.38, 0.48, 0.54, 0.73, 1.00, 1.13, 1.30, 1.71, 1.95, 2.38, 2.71, 3.01, 3.32, 3.42, 3.72. Comparable data for the dichromatic (left) eye for the same spectral range are as follows: 2.04, 1.95, 1.86, 1.67, 1.50, 1.36, 1.34, 1.05, 0.94, 0.91, 0.74, 0.79, 0.67, 0.75, 0.75, 0.63, 0.67, 0.44, 0.69, 0.62, 0.87, 0.99, 1.14, 1.42, 1.76, 2.13, 2.40, 2.82, 3.05, 3.46, 3.48, 3.74.