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A Unilateral Defect Resembling Deuteranopia

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The problem of determining the color sensations of the red-green blind is traditionally solved by studying individuals whose color blindness is confined to one eye, the other eye being more or less normal. Many such cases are discussed by JUDD [1948]. Only a few of JUDD's cases are true dichromats, however, and among these only two that are considered to have a genetic basis have been studied in any detail: first, the celebrated Hermann Goldenberg [HOLMGREN, 1881] who was probably a protanope; and second, the unilateral deuteranope examined by SLOAN and WOLLACH [1948]. In a more recent case described by GRAHAM *et al.* [1961], the luminosity curve of the dichromatic eye was suggestive of deuteranopia, but this diagnosis is contradicted by the wave-length discrimination and color matching data which exhibit striking and unique features never observed in deuteranopia [WALLS, 1959]. Only the observer of SLOAN and WOLLACH [1948], then, can be considered a unilateral deuteranope.

The subject of our experiments is R. H., a man who enjoys fully trichromatic vision when using his left eye but becomes red-green blind if he uses only his right eye. He is similar in many respects to the observer of SLOAN and WOLLACH. Tests with the Nagel anomaloscope showed that the trichromatic left eye is not normal but deuteranomalous. Using this eye, R.H. makes the Rayleigh equation with a typically deuteranomalous greenward deviation and a small matching range; normal matches are emphatically rejected. But using his right eye, he can match either the red primary or green primary to yellow. A physical examination by Mr. P. G. WATSON, employing the ophthalmoscope, Amsler charts, and fluorescein angiography, disclosed no sign of disease or damage. Both eyes appear normal except for the deutan defects, and visual acuity is as good as in

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the best normal eyes. R. H. was surprised to learn that his two eyes were dissimilar.

Relatives tested with the Ishihara plates include both parents, the maternal grandfather and a maternal uncle. All have normal color vision in both eyes. This pedigree is not inconsistent with inheritance of a D or a DA gene at the deutan locus.

We were able to learn more about the color vision of R. H. when Dr. PAUL WHITTLE kindly made available his 6-channel Maxwellian view optical system [WHITTLE and CHALLANDS, 1969]. In this instrument, each eye may receive light from three independently controllable beams. Monochromators in two of the beams provided stimuli of continuously adjustable wavelength and of bandwidth less than 10 nm.

Wavelength Discrimination

The two monochromators provided a test field and an adjacent comparison field at retinal illuminations in the range 30–100 td. R. H. viewed them with either the left eye or the right eye. For each measurement the wavelength of the test field was set at a fixed value. Then, controlling the comparison field wavelength, R. H. set it to be just noticeably different from the test field in one direction or the other. He carefully corrected any brightness differences by an intensity adjustment before each decision. The just noticeable wavelength difference, $\Delta\lambda$, was defined as half of the average difference between these two settings.

Wavelength discrimination for the left (trichromatic) eye is well maintained across the spectrum and is as good as for a normal observer. The right eye discriminates best near 495 nm, and at this wavelength the two eyes are about equal in keenness of discrimination. But the discrimination of the right eye fails totally for wavelengths longer than 530 nm, yielding a wavelength discrimination curve of the parabolic form characteristic of deuteranopia [PITT, 1935].

Color Matching by the Dichromatic Eye

For these measurements, the test field was filled with monochromatic light from the spectral range 460–650 nm. The comparison field, alongside it, contained a mixture of red (dominant wavelength 650 nm) and blue

(460 nm). For each monochromatic light, R. H. was able, using his right eye, to find some purple mixture that was visually indistinguishable from it so that the bipartite field appeared uniform when viewed with that eye. The indistinguishable purples chosen by R. H. were characteristic of deuteranopic color matching: the confusion lines of bilateral deuteranopes meet the extension of the long wavelength spectrum locus at points within the range (1.08, -0.08) to (1.70, -0.70) [NIMEROFF, 1970], and so do most of R. H.'s confusion lines.

Luminosity Curves

By flicker photometry, we measured the luminosity curves of the left and right eyes for wavelengths from 420 to 680 nm. They turned out to be identical: the differences between left and right eyes were always less than 0.05 logarithmic units, and probably originate from random matching error. This is a surprising result if the left eye contains a green sensitive pigment absent from the right eye. However, since in further tests spectral adaptation of the left eye to red and green backgrounds of 1,000 td failed to measurably deform its luminosity curve between red and green, it is likely that the luminosity curve of the left eye, as well as that of the right eye, is closely approximated at long wavelengths by the spectral sensitivity of the red-sensitive pigment alone, with the result that the presence or absence of the green-sensitive pigment is not detectable by luminosity measurements.

Binocular Matching

When lights from the red-green spectral range were viewed by the dichromatic eye, all could be matched exactly to a light of 610 nm viewed by the trichromatic eye. Blue or violet lights could be matched to a light of 474 nm viewed by the trichromatic eye. When asked to produce lights that looked not at all reddish or greenish, R. H., with his trichromatic eye, selected the two wavelengths 466 nm (± 4 nm) and 589 nm (± 4 nm); he described the colors seen by the dichromatic eye as greenish blue and orange.

By providing such a clear exception to the rule that yellow and blue are the only colors perceived by the red-green blind, these observations of R. H. destroy the last remaining support for 'opponent process' interpretations of

color blindness and particularly of deuteranopia. But the support afforded to opponent process interpretations by the earlier unilateral cases was in any case flimsy. Binocular matches can lead to rigorous conclusions about retinal events only if a binocular match is a match at the retinal level, and this cannot be guaranteed unless the afferent pathways from left and right eyes are similar. The necessary assumption of afferent identity is difficult to justify in unilateral cases, for it is clear from experiments such as those of HIRSCH and SPINELLI [1970] that different 'stimulus histories' for left and right eyes may bring about differences of organization in the afferent pathways at stages prior to binocular combination.

Summary

We describe a person who is red-green blind in his right eye only. His left eye is deuteranomalous, with good wavelength discrimination. The wavelength discrimination and color matching functions of the right eye are characteristically deuteranopic. The luminosity curves of the left and right eyes are not distinguishable. Binocular matching experiments showed that the colors seen with the red-green blind eye are 'orange' (610 nm) at long wavelengths and a somewhat greenish blue (474 nm) at short wavelengths.

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