Green Vision and Binocular Fusion of Yellow

RECENT evidence disproving the binocular synthesis of yellow apparently destroys a major bastion of the Young-Helmholtz theory of color vision. The existence of a true binocular yellow from pure red and green would allow the fourth primary to originate in the cortex (*1*), although it does not exclude the retinal synthesis of yellow now established (*2, 3*) as existing also. Hurvich and Jameson's experiment (*4*) indicates that a "pure green" (495 mμ) and pure red (495 complement), seen binocularly, do not mix to yellow. They infer that Prentice (*5*) in mixing "pure green" (530 mμ) and "red" (685 mμ) to evoke binocular yellow really must have used a yellowish green, whose yellow component survives binocular cancellation of the complementary *R-G* components.

The evidence presented (*4*) falls short of disproof for several reasons: (1) To really test the theory of binocular yellow, a red and green should be used which mix to yellow monocularly. The wavelengths used by Hurvich and Jameson were complements binocularly, and hence probably monocularly also (normally 495 mμ and pure red mix to white [*6*]). For these observers, then, pure green and red seem to form white. This is incompatible with trichromatic theory, and it is also hard to see that they have tested the question of binocular yellow. (2) The data of Dimmick and Hubbard (*7*) do show one class of observers who see unique green at 500 mμ ± 5, but also, by the same criterion, another class of observers who see unique green at 525 mμ ± 2. This strongly bimodal distribution in the spectral location of mid-greens may result from a small population but has not been brought out in the literature. (Whether the complement of unique red varies likewise is not known.)

In any case, ten investigators (*8*) have reported a large class of observers whose pure green is located between 509 mμ and 550 mμ—that is, well away from the complement (497 mμ) of pure red. These observers, probably over half the total normal population, should indeed see a yellow from binocular fusion of their unique greens and reds. (3) The problem is confused because of the various criteria (*7*) used for "green." "Pure" green may mean (*a*) a "unitary" green defined as stable in hue with respect to radial movement of the test spot in the field; (*b*) a "unitary" foveal green defined as stable in hue when the adaptive level or brightness is changed; (*c*) a green that most nearly satisfies both *a* and *b*; (*d*) a "psychologically unique" green defined as midway between the bluish-green and yellowish-green limens. Dimmick used criterion *d*. Criteria *a* and *c* were used by the investigators cited (*4*) as supporting Hurvich and Jameson. They themselves used criterion *d* but with a test field mainly parafoveal (test spot 1.2° × 32°) as in *a*. However, the yellow sense is weaker in the fovea than in the parafovea (*2, 9*), in spite of the supposed suppression of blue foveally by the macula lutea; hence, green wavelengths become yellowish radially and blues greener. A 32°-test spot looks yellower than one confined to the central 10° because of the averaging effect of the greater extra-foveal area. It may be for this second reason that Hurvich and Jameson find unique green at 495 mμ, rather than because they see 495 mμ as green, foveally. (4) Furthermore, Prentice (*5*) showed that binocular yellow does not appear desaturated, as by the cancellation of red and green components of slightly yellowish test colors, but looks as saturated as a spectrally pure yellow. This is true at least for those who see unique green around 525 mμ. We must conclude that Prentice's confirmation of a "cortical yellow" mechanism is valid. Modern experiments on binocular yellow should take account of the distribution of yellow sense, increasing outward from zero (*2*) at the central fovea. Prentice's experiment, if done with a 10′ test field instead of 6°, should fail centrally, but succeed peripherally.

The main theories of color mechanism (*8, 10*), 3-color (Young, Von Kries, Schrödinger), or 4-color (Hering, Müller, Adams), require a unique green around 497 mμ, and do not account at all for the large class of normal observers who center green at 525 mμ. A set of 3 primaries like those of Ladd-Franklin (*9*) better approximates the average of the two classes; but the system of 4 primaries shown by Motokawa's retinal data (*2*) gives a better theoretical frame to account for those who see the longer-wave pure green. A detailed retinal mechanism on this basis, which admits both classes of green observers, has been proposed (*3*). Both cortical and retinal yellow-synthesizing mechanisms would seem to exist.

More data are needed on the locus of unique green and of red-complement for the two kinds of normal green vision, to correlate them with the trichromatic anomalies and with practical color-matching. A seasonal variation in the blue-sense (*3*) (related perhaps to vitamin A) outside the macula lutea should not be overlooked in determining the yellow content of green. Pickford (*11*) has described a large class of individuals with deviant color sense (for green in particular), a defect genetically distinct from anomalous trichromacy and from dichromacy, not continuous with them, and not sex-linked in heredity. The deviations in Rayleigh balance of blue and yellow reported, although extensive and suggesting a wide scatter in locus of pure green, did not refer to psychological uniqueness. Pickford cannot be cited, therefore, as confirming this bimodal population for "unique green," which seems to explain the controversy about the existence of a "binocular yellow."

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TALBOT presents four reasons why he believes the evidence offered by us falls short of disproof of the binocular synthesis of yellow. Our reactions to his four major points are as follows:

1) A real test of the theory that the yellow sensation results from the combined action of two receptor systems that are qualitatively unique in yielding green and red sensations, respectively, would seem to us to demand the mixture of stimuli that evoke pure green and pure red sensations when viewed independently. The requirement is the same whether the mixture is monocular or binocular. Our treatment of the problem as a specifically binocular one was dictated simply by the historical development initiated by the Hecht demonstration. To select stimuli for the binocular experiment by a criterion which requires that they mix to form yellow monocularly, as Talbot suggests, is, unfortunately, to select stimuli which, viewed independently, evoke yellowish-red and yellowish-green sensations. Just such stimuli have been used by Hecht, Prentice, and Trendelenburg. As we stated in our paper, we have no difficulty in confirming their results.

2) A possible bimodal distribution in the spectral location of pure green seems to us to be irrelevant to both the logical and experimental analysis. The spectral wavelength which evokes a pure green sensation may indeed differ for different observers: witness our own results. Whatever the wavelength of a stimulus that evokes a pure green sensation, by definition it excites no yellow. If our result cannot be generalized for normal observers, a visual mechanism would be required for which the mixture of pure green and pure red sensations would yield an achromatic fusion product when the green process is excited by one wavelength for one observer, and a yellow fusion product when the green process is excited by another wavelength for a different observer.

3) The problem is indeed confused because of the various criteria used for "green." Our criterion was that of "psychological uniqueness" (*d*), and every experimental datum cited in our summary table is a wavelength locus of a "pure hue" based on the same criterion of psychological uniqueness. Any values reported by the investigators we cite, for which different criteria such as *a* or *b* were used, were deliberately excluded from the table.

4) Prentice's stimuli were not selected on the basis of the uniqueness of the green and red sensations evoked by them. Consequently the fact that the peak transmission of his green filter occurs approximately at 530 mμ gives no clue to the spectral locus of pure green for his observers. The narrow band interference filters used by Prentice were selected on the basis of their nonoverlapping spectral transmissions, as a quite logical experimental step in answer to criticisms of the filters used in Hecht's original demonstration. Since there was no attempt to mix a psychologically pure green and psychologically pure red in the Prentice experiment, our analysis of the problem stands as originally presented.

On the basis of both our own experiments and our analysis of the earlier studies we can only reaffirm that, whether a cortical or retinal locus is assumed, "yellow-synthesizing mechanisms" appear to operate only when yellow is already present to some degree in either or both of the "red" and "green" mixture components.

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Book Reviews

Tables for Microscopic Identification of Ore Minerals. W. Uytenbogaardt. Princeton, N. J.: Princeton Univ. Press, 1951. 242 pp. $5.00.

This book as published had its inception in tables prepared by Westerveld, of the University of Amsterdam, before the war. Later, while working in the Mineralogical Department of the University of Stockholm, the author translated and reorganized the original tables, amplified them considerably, and brought them up to date in their present form.

The book will be found to be a usable laboratory manual for the microscopic identification of metallic minerals on polished surfaces. It tabulates in convenient form recent data in a field of considerable importance.

The author records tests for some 230 recognized minerals that are often opaque and also lists a considerable number of discredited species that might otherwise be confused with valid minerals. Mineral tables comprise approximately three quarters of the book, with the minerals arranged in order of increasing hardness, galena, chalcopyrite, and pyrite serving as reference hardness standards to define general groups.

Reflectivity, color, etch tests, Talmadge hardness, and occasional special tests furnish criteria for identi-