The Independent Yellow Channel For Tetrachromatic Imaging

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Abstract

Imaging systems tend at first to simulate the opponent yellow and blue vision channels (YB) even if that perceptibly violates trichromatic simulation of opponent red and green channels (RG). The preference is biologically traced: 8% male population are deficient in RG vision and only 0.003% in YB vision. The YB pair is not the usually assumed alternating combination of M, L, and S-cone responses (say, L+M-S): it is independent of RG sensations (L-M). The complementary yellow (570) and blue (465 nm) are seen after the RG pair has disappeared with decreasing illumination. The yellow is not seen after the 650-nm sensitivity limit of rhodopsin even if the red is over 50 nm more. The 'blue-cone monochromats' and some protanopes, having no M and L-cones, see the YB pair. Yellow adaptation eliminates the YB sensations but hardly influences the RG pair. Reflectometry of living retinas shows the 'M and S-cone pigments' rather to be long-living products of iodopsin (L-pigment) and rhodopsin.

The Two-Dimensional Chromaticity Space

Two and a half centuries ago in 1757, 'Michael Lomonosov reported on a theory of light and colors, which contained the fundamental ideas of three primary colors... named red, *yellow*, and blue... and proposed that all other colors are formed from the mixtures of these'.[1] Just two centuries ago in 1802, Thomas Young 'articulated his famous statement' of "the three principal colors, red, *yellow*, and blue... Each sensitive filament of the nerve may consist of three portions, one for each principal colour." The idea seems to be commonly accepted even if the accurate colorimetry studies showed that at least a half of XYZ chromaticity diagram not to be rendered with the weighted sums of any triad of primary colors, say the standard RGB triad of monochromatic radiations of maximum saturation.[2] The colors cannot be reproduced but can be 'matched' in an opponent way at a strongly lowered saturation level. One should add one of the primary colors not to the simulating mixture but to the original color itself. The operation is equivalent to adding a respective complementary color to the simulating mixture instead of an initial primary color.

If the approach is extended to another primary, every color can be 'matched' that way not with three but only two primaries at a very low level of saturation (a gray level). Ewald Hering[3] took notice of that in his opponent-color theory of late nineteenth century. The theory demonstrated that the chromatic properties of any color can be exhaustively described with using not three but only two color coordinates alternating at the transition from a primary color to its complementary counterpart.[4] A third chromatic primary was excessive. E. Hering proposed to consider a third achromatic 'blackness' component to describe the brightness coordinate.[5] One could pay attention to that the 'trichromatic colorimetry', even if starting with the three chromatic primaries tries approximately to operate within a two-dimensional space of the XYZ chromaticity diagram, which provides a formally non-negative matching in terms of the irreal primaries, and to relate the brightness coordinate to the Z axis.[2,6]

Nevertheless, if one needs not only accurately to describe every color but also accurately to render it, any three primaries do not suffice. All the possible colors, including the most saturated ones, could be precisely reproduced with using no less than four primary colors[7] as the RGB matching functions show.[2]

The Four-Dimensional Spectral Sensitivity Space

In 1956, Gunnar Svaetichin published his measurements of electrical potential responses from 'single photoreceptor cells' (later they were called the S-potentials).[8,9] Two kinds of alternating opponent chromatic responses were recorded: blue-yellow and red-green, along with an achromatic 'lightness response' at another depth of microelectrode penetration into the retina studied. The responses were later recorded in all the retinal layers along the neural pathways.[10] Owing to the peculiar charm of the trichromatic principle, the potentials were explained as resulting from interactions of the three cones.[1] The red-green opponent response was assumed to result from a difference between the responses of L- and M-cone. The blue-yellow opponent response was considered as resulting from a difference between the S-cone response and a sum of the L- and M-cone responses.

In the case, however, it is obvious from the optical physics that the yellow and red sensations should have the same long-wave limit around 700 nm and should be proportional to each other in its vicinity.[11,12] Related data published for the last three decades showed various psychophysical techniques to demonstrate that the yellow sensation

decreased after 600 nm to its long-wave limit around 650 nm, whereas the red sensation increased there.[13-17] The yellow limit was observed not only in protanopes who had no L-cones but also in the color normals and deuteranopes who were commonly assumed to have the L-cones. The incomplete achromats and some protanopes, having neither M- nor L-cones, saw the yellow and blue with their 'rhodopsin receptors.'[18,19]

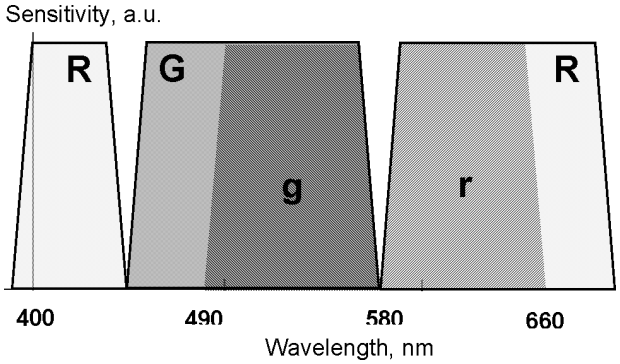

Figure 1. Correspondence of the sensitivity ranges of red and green channels in the modern color negative and reversal photographic films (r and g hatched) to those in the visual system (R, G).

With decreasing illumination, the yellow/blue opponent pair disappears independently after that red/green.[20] Yellow or blue adaptation can eliminate both the yellow and blue sensations simultaneously, whereas the red/green pair remained.[21,22] And finally, the long-wave limits of the S-potential of yellow/blue opponency regularly lies by ~50 nm lower than the limits of the red/green opponency also in the retinas of other species.[23,24] The physiological mechanisms for the opponencies were described earlier.[7,11,25]

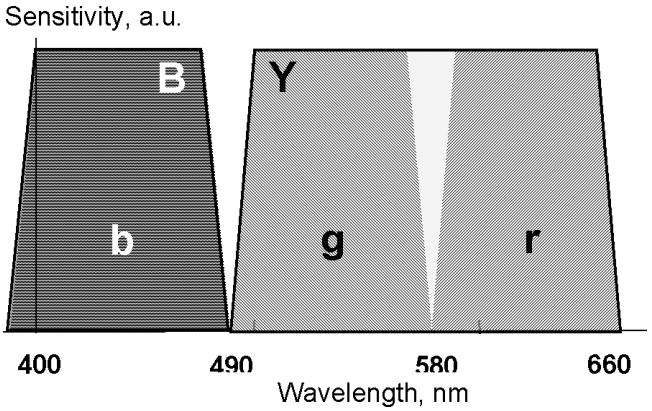

Figure 2. Correspondence of the sensitivity ranges of blue and composed yellow channels in the modern color negative and reversal photographic films (b and g+r hatched) to those and in the visual system (B, Y).

So being two-dimensional in the opponent chromaticity space, the color vision is four-dimensional in the sensitivity space, with every chromatic half-axis related to its own spectral sensitivity range.[26-28]

The Additional Yellow Imaging Channel

Our previous studies showed that the best trichromatic imaging systems tend to as accurately as possible to simulate the principal properties of the tetrachromacy of human vision: before all the two main neutral points and at least three unique hues of the blue-yellow and red-green opponencies and.[7,28] It is clear, that no trichromatic imaging system can simulate all of the four unique hues with their independent spectral sensitivity ranges.

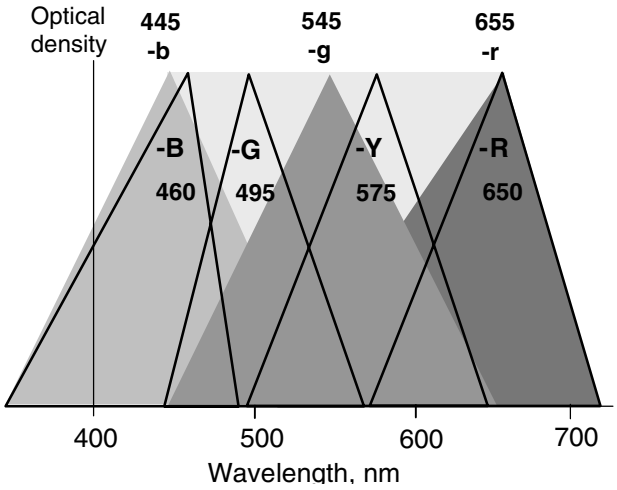

Figure 3. The spectral absorption of the three positive dyes in the modern color photographic papers and reversal films (-b, -g, -r) and those to correspond to the unique hues of visual system (-B, -G, -Y, -R).

Figures 1 and 2 demonstrate the main differences between the channel sensitivities in the systems. It can be seen before all that the vision system has an additional independent yellow channel, whose sensitivity is simulated with only the sum of green and red imaging channels in the trichromatic systems. To simulate the blue-yellow opponency with its neutral point at 490-495 nm (Fig. 2), the systems are forced incompletely to simulate the spectral sensitivity ranges of the opponent green and red vision channels (Fig. 1). Their non-hatched regions are the main issue of the incorrect hue rendering even in the best color photographic systems.[28-30] Fig. 3 shows the necessity of replacement of the actual averaged magenta dye with two independent dyes: red and blue-violet, subtractively to control the primary hues of the green and yellow vision channels, respectively. Using such four dyes is expected strongly to increase the saturation of many problematic colors.[7,28]

Conclusion

An independent yellow channel with its own spectral sensitivity range and a means to control the respective unique hue of the vision system is required for to eliminate the typical hue and saturation distortions of even the best trichromatic imaging systems. Its spectral properties should simulate those of the yellow vision channel. Variations in the unique hues, spectral saturation, and neutral zones of the rhodopsin YB opponency in the rod, caused by different measurement techniques, should be further analyzed to meet the typical viewing conditions, quality requirements, and technical metamery of imaging colors.

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Biography

Vitali V. Gavrik received his first-class M.S. degree from the Leningrad Institute for Cinematography and Television (1965), Ph.D. in Imaging Sci. & Technol. (1974) and D.Sc. Phys. & Math. (1996) from the All-Russian Research Center "S.I.Vavilov State Optical Institute", St.Petersburg where headed the Laboratory for Imaging Science. His research work has focused on the perceptual image quality, color vision, physics and chemistry of imaging. Member of IS&T, New York Academy of Sciences, Russian Optical Society. E-mail: gavrik@metronet.de