for detectors with spectral sensitivities proportional to $S(\lambda)$, or orthogonal to ϕ_1 minus ϕ_2. A detector with any other spectral sensitivity must respond differentially to the two papers, which allows for a potentially easy discrimination.

An additional artifact is that the matching procedure used in Retinex experiments equates only light meter readings, not radiances or energies as stated, since a correction is apparently not made for the spectral sensitivity curve $S(\lambda)$ of the light meter at each wavelength within the pass-bands of the filters.

It might still be stated that, although such artifactual spectral differences exist, they are too small to be detectable, but no Retinex experiment has yet been reported that describes the spectra of the light entering the eye. However, a computation based on a plausible realization of the experiments shows large artifactual effects.

For the illuminant $h(\lambda,T)$, I used the blackbody spectrum (*3*, p. 14), corrected for the emissivity of tungsten (interpolated from *3*, p. 16). Ingle (*1*) did not specify the filters he used. I therefore assumed they were the standard 50-nm bandwidth filters used in Land's Retinex experiments (*2*). To investigate the effect of filter bandwidth, I also used the 10-nm bandwidth filters of McCann *et al.* (*4*), assuming exponential falloff from the peak transmittance.

Ingle also did not specify the paper reflectances. I therefore chose the 14 test samples recommended by the International Commission on Illumination (CIE) for calculating color-rendering indexes (*5*, pp. 473–474) and a "neutral" patch with constant 50% reflectance. These are likely to encompass the range of papers used by Ingle. The light meter used in Land's Retinex experiments has an S-11 photosensitive surface (*2*), for which a typical spectral curve has been published (*6*). The values of T_2 were set so that the chromaticity coordinates (x and y) of the neutral gray paper were 0.3333 and 0.3333, respectively. With these known functions and values (none of which were critical except filter bandwidth) it was then possible to compute T_1 with the use of a successive approximation procedure so that Eq. 2 was satisfied for any filter and paper. Calculations were carried out to 14 decimal places, from 380 to 700 nm at 10-nm intervals, and all matches were made to the sixth decimal place or more. The final T_1 values were within the standard tungsten range of 2150 K to 3450 K (*6*). These procedures determined completely $\phi_1(\lambda)$ and $\phi_2(\lambda)$. The CIE tristimulus values of the reflected light from the "strong" hues in the set of 14 reflectances (*3*, p. 174) are plotted in Fig. 1 for the 50-nm and 10-nm filter conditions.

Figure 1 shows that "identical" reflected lights, although constrained to match radiometrically according to the Retinex criteria, are still different enough to be easily discriminable in chromaticity by a human. Goldfish chromatic discrimination capabilities have yet not been adequately tested, but the available data (*7*) indicate that their wavelength discrimination capabilities are sufficiently close to those of humans that such large chromatic differences should also be discriminable by them. Furthermore, as seen in Fig. 1, the variations turn out to be in just such directions that the object-color hues can be determined directly from the chromaticity space without the need for Retinex processing.

Equally large and generally even larger chromaticity differences were found with the use of (i) other published $S(\lambda)$ curves, (ii) other sets of Munsell reflectance curves, (iii) radiance values corrected for the spectral sensitivity of the radiometer at each wavelength in the pass-bands of the filters, (iv) other chromaticities of the neutral point, or (v) neutral density filters rather than variations of color temperature to vary intensity. The only way I found to limit the magnitude of the artifacts was to reduce the spectral bandwidth of the illuminants. With monochromatic illuminants (bandwidth = 1 nm) the artifacts vanished completely—all the papers became chromatically identical to neutral.

Land (*8*) used monochromatic lights in some early color experiments, but not with the Retinex experimental paradigm. Also, the single-element Littrow monochromators (*3*, p. 66) he used are prone to stray light and higher order spectral artifacts (*3*). No Retinex experiments have yet been reported with controlled monochromatic lights.

This analysis suggests that some refinements and controls are needed in the Retinex experiments before they can be truly said to demonstrate that identical stimuli can produce different responses (*9*).

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9. The scope of this comment is limited to stimuli "equated" by means of the Retinex methodology. I do not maintain, nor do these results indicate, that the wavelength-energy distribution reaching the eye can always explain perceived hue under other, non-Retinex viewing conditions. Likewise, these results say nothing about the validity of the Retinex theory per se; it is shown only that the Retinex theory is not needed to explain Retinex data for "equated" stimuli. However, the scope of the comment does extend to the "equated" paper results in all Retinex experiments conducted to date, as well as to all alternative explanations of such results by other investigators who have used different color theories, who likewise appear to have overlooked the artifacts raised here.
10. I thank Michael H. Brill for insightful discussion.

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Response: Young suggests that two colored papers we presumed to be "equated" for spectral reflectance are not sufficiently equated and may thus be perceived by a fish as being of different colors. The main point of a color constancy demonstration, however, is that areas with vastly different spectral characteristics look "the same" to the goldfish, as to the human observer. At the same time we showed that our equated papers can look very different: for example, they can appear as green, gray, or even yellow, depending on the nature of the surrounding array of colors. Young does not tell us how different his "replications" of our equated colors actually look to a human observer. In Land's experiments equated patches look the same when viewed against a dark background, but suddenly change to different colors when a complex colored background is added. So the differences in color that are to be explained by Retinex theory are not evident in the spectral differences between areas when the colors are viewed against a dark background.

Young uses the response curve of an uncorrected S-11 photomultiplier tube as the basis of his computations. A meter with this tube was used in some of Land's earlier work, but was nevertheless equated for equal energies. The references and notes from our paper specifically mention the Spectra-Prichard 1980A. This photometer has a specially selected S-20ER photomultiplier tube and is used in conjections with a radiometric filter designed to produce a spectral response that is relatively flat from 450 nm to 700 nm. This total system greatly reduces any effect contributed by the spectral distribution of the band-pass filters specified.

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