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The Effects of Luminance Boundaries on Color Perception

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19. ABSTRACT (Continue on reverse if necessary and identify by block number) Extensive measurements were made for detecting luminance and red-green flashes in the center of a bright yellow field. Thresholds, plotted in L and M-cone contrast coordinates, indicate that chromatic flashes are more visible than luminance flashes even at very small size (2' diameter). Over a wide range of flash diameters and durations the chromatic flashes are detected with considerably higher efficiency (in units of cone contrast energy) than the most detectable luminance stimuli (small drifting gratings). The higher gain of the chromatic mechanisms has important physiological implications and is potentially useful in display technology. Detailed studies with luminance and chromatic stimuli suggest that the chromatic mechanisms have a constant spectral tuning, even for spots as small as 2': the chromatic response is determined by a <u>constant</u> , equally weighted difference of L and M cone contrast. A suprathreshold luminance flash (a pedestal) facilitates detection of a <u>coincident</u> chromatic flash. Earlier studies suggested that the facilitation will grow strongly when the stimuli were decreased in size. In contrast, we find that facilitation is constant (2-3x) for stimuli from 2' to 2° diameter.					
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## The Effects of Luminance Boundaries on Color Perception

Period Covered: March 15, 1991 to March 14, 1992

### Summary

This report covers our activities since March 15, 1991. Our main accomplishments have been to: 1) Finish experiments on detection of small spots by luminance and red-green mechanisms, examining the role of a luminance pedestal in facilitating chromatic detection at small spot sizes. 2) Show that the red-green mechanism is more efficient than the luminance mechanism in contrast detection. 3) Consider further the roles of cone-selective adaptation and 'second-site' adaptation in controlling the sensitivity of the red-green detection mechanism. 4) Continue work on the spectral nature of the inputs to motion detection mechanism.

### Luminance and red-green mechanisms at different spot sizes

On a large, bright yellow field we deliver a foveal flash consisting of simultaneous incremental and decremental red and green components. Detection thresholds are measured for many different red:green amplitude ratios, and thresholds are plotted as detection contours in cone contrast coordinates,  $L' = \Delta L / L$ ,  $M' = \Delta M / M$ . A luminance mechanism linearly sums  $L$  and  $M$  cone contrast ( $L'$  and  $M'$ ), whereas the red-green mechanism responds to an equally-weighted difference of  $L'$  and  $M'$ , and thus has a detection contour of slope  $+1.0$  (see figures in enclosed manuscript by Chaparro et al., 1992).

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Using a 200 ms test flash, we demonstrated the existence of the red-green mechanism by measuring detection contours for spots over a size range of 2.3' to 1° diameter. At the largest size the red-green mechanism is 10x more sensitive than the luminance mechanism, and this ratio decreases as the spot is made smaller, but the red-green mechanism is about 2x more sensitive even at the smallest size.

The most efficiently detected stimulus on the bright yellow field

These experiments were extended to determine "What the eye sees best?" measured in terms of contrast energy of the stimulus. Watson, Barlow and Robson (1983) attempted to answer this for stimuli in the luminance domain. They measured contrast energy thresholds (the square of contrast integrated over the spatial and temporal dimension of the test stimuli), using both incremental spots and small patches of a drifting grating. The best grating had an energy threshold 3x less than the best spot and identifies approximately the shape of the most sensitive luminance receptive field (one that matches the most efficient stimulus). We measured spot luminance thresholds over a wide range of flash sizes and durations. Our luminance spot energy thresholds agree very well with those of Watson et al. Our best-detected red or green chromatic spot has a cone contrast energy threshold 5-8x lower than our best luminance spot and about 3-8x lower than Watson et al.'s optimal grating. The higher sensitivity for the chromatic stimulus is not solely due to better spatial and temporal integration in the chromatic pathways, for there is a clear

chromatic advantage even when the chromatic spot is matched in size and duration to the optimal luminance spot.

The higher sensitivity to color is surprising, but may be consistent with recent findings of R.M. Shapley and colleagues (largely unpublished) on retinal ganglion cells. It is well known that the M ganglion cells have higher contrast gain than do the color-opponent P cells when tested with a luminance grating. However, when tested with a chromatic grating, matched in cone contrast to the luminance grating, then the P and M cell have similar contrast gains. The P cells are much more numerous, and their receptive fields often have largely overlapping L and M areas with similar weights but opposite signs, making them especially sensitive to color, and much less sensitive to luminance.

Our work is described in the enclosed paper (Chaparro et al., 1992), which we intend to submit to Nature.

Chromatic facilitation by luminance pedestals at small spot size

A suprathreshold luminance flash of  $1^\circ$  diameter presented simultaneously with a red or green equiluminant chromatic flash facilitates the latter's threshold by 2x. Earlier work by Hilz, Huppmann and Cavonius (1974) led us to suspect that the facilitation would grow much larger when the pedestal and chromatic flash were concomitantly reduced in size. However, we find that facilitation remains approximately constant at 2-3x, as measured by forced-choice methods, for flashes from  $2.3'$  to  $1^\circ$  diameter.

The 'variable tuning' hypothesis advanced by Finkelstein and Hood (1984) postulates that the mechanism used to detect chromatic spots will change in its spectral sensitivity with variation of the test spot size. Our results would seem to be at variance with this view. Even for the smallest spots our red-green detection contours have a slope of +1.0, indicating that L and M cones contribute with equal and opposite weights (over the measured size range 2.3' to 1°). A luminance pedestal has a polar vector direction of +45° in the L',M' coordinates, approximately parallel to the red-green contour--thus stimulating the red-green mechanism very little. A 2.3' diameter luminance pedestal flash of even 25x threshold does not mask the chromatic flash, consistent with the view that the chromatic contour does have a constant slope of approximately +1.0--not of variable tuning.

A surprising feature, remarked upon by Hood and Finkelstein (1984) is that small colored flashes with a strong luminance component (near the luminance axis in the L',M' plane), and presumably below the threshold of the red-green mechanism, appear colored reddish or greenish when only very slightly suprathreshold. We have confirmed this and shown that the results are quantitatively consistent with the view that the luminance pedestal starts to facilitate the red or green chromatic test when the pedestal reaches its own threshold. Thus there is a facilitating interaction between luminance and chromatic mechanisms that can explain the appearance of color of flashes that are near the luminance axis. We have shown that the threshold for identifying the hue of the test (red vs green) is well

predicted from the curve relating luminance pedestal amplitude and chromatic (facilitated) detection thresholds.

We are presently writing up the results; the experiments are completed.

#### Mechanisms of adaptation in the red-green pathways

Previously we (Stromeyer, et al., 1985) observed that on bright chromatic adapting fields, the sensitivity of the red-green detection mechanism is controlled by two adaptation mechanisms. First, the L and M cones differentially adapt (or the L and M cone-selective pathways differentially adapt) following Weber's Law, so that the red-green detection contour maintains a slope of about +1.0 in the L',M' coordinates for different colored adapting fields. Second, there is also second-site adaptation, which reduces sensitivity at an opponent site via response saturation when the adapting field is strongly chromatic (producing an extreme in the ratio L/M for mean adaptation). The second-site adaptation cause the red-green detection contour to move outward from the origin in the L',M' coordinates, reflecting reduced sensitivity.

Krauskopf and Gegenfurtner (1991) measured red-green detection thresholds on different colored fields with test stimuli restricted to the equiluminant plane. They found surprisingly little influence of field color on threshold and argued that first-site adaptation plays little role in determining equiluminant red-green sensitivity. We have shown, however, (Eskew, Stromeyer and Kronauer, 1992) that these results are consistent with both first- and second-site adaptation. The

difficulty associated with stimuli restricted to the equiluminant plane has to do with the fact that, although this plane is 2 dimensional, one dimension is assigned to S cone stimulation (the so-called blue-yellow axis) so that only one dimension remains for the L/M cone system. Therefore only a highly limited view of L/M cone interaction is seen in the isoluminant plane. Rather one should measure the full red-green detection contour in the L',M' cone contrast coordinates, since the effects of adaptation are particularly evident near the unique L' or M' axis. When we restrict our detection data to the isoluminant conditions of Krauskopf and Gegenfurtner we find results very similar to theirs. Since Krauskopf and Gegenfurtner's data were obtained at lower adapting levels than we used, we intend this summer to make thorough measurements of the red-green contour, in the L',M' coordinates, for a range of adapting colors and mean levels, to assess the role of the two postulated adaptation mechanisms.

#### Cone inputs for motion detection

A large part of our recent effort has been devoted to carefully assessing the spectral nature of mechanisms detecting motion. Thus far we have been examining the L and M cone signals. The observer views a 1 cpd vertical red-plus-green grating that moves left or right on a 3500 td yellow field. We typically measure contrast thresholds for discriminating motion (left vs right). As described in our previous progress report, we have identified two spectral motion mechanisms, which are distinct from the red-green hue mechanism. The latter hue mechanism has a constant slope of +1.0 in the L',M' cone contrast coordinates



(measured by simple detection or hue identification). The two motion mechanisms are a luminance type mechanism and a spectrally-opponent mechanism. The latter responds to the differences of L and M cone contrast, but the M cone contribution drops rapidly as velocity is increased. The luminance mechanism responds to the sum of L and M cone contrast signals: at high velocities the two cone types contribute with similar weights, while at low velocities the mechanism becomes L-cone dominated. Similar temporally-dependent properties of L and M inputs have been observed in macaque phasic ganglion cells by Lee, Martin and Valberg (1989).

We have shown that the outputs of the luminance and spectrally-opponent motion mechanisms eventually summate within opponent motion mechanisms that are sensitive to the differences of right and left motion components.

We have obtained very extensive measurements on three observers, but still have considerable data to collect, especially pertaining to the summation of signals from the different spectral mechanisms.

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#### Participating Professionals

Professor Richard E. Kronauer  
Dr. Charles F. Stromeyer III  
Dr. Rhea T. Eskew, Jr.  
Dr. Alex Chaparro

#### Publications and Publications in Progress

Chaparro, A., Stromeyer, C.F. III, Huang, E.P., Kronauer, R.E., and Eskew, R.T., Jr. (1992). What the eye sees "best": Colour. To be submitted shortly to Nature (**manuscript enclosed**).

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