



Pergamon

0042-6989(94)00298-3

*Vision Res.* Vol. 35, No. 15, pp. 2147–2155, 1995  
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0042-6989/95 \$9.50 + 0.00

# Luminance Discrimination, Color Contrast, and Multiple Mechanisms

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Received 26 January 1994; in revised form 18 July 1994; in final form 4 November 1994

**The purpose of this study was to investigate the effect of color contrast on luminance discrimination. Observers were required to indicate the more intense of two stimuli presented briefly in a surround. In some conditions the two stimuli were the same chromaticity as the surround, while in other conditions the stimuli differed in chromaticity from the surround. The luminance of the fixed test stimulus was varied in different conditions over a range from below the surround level to above the surround level. Difference thresholds were proportional to the luminance difference between test and surround over much of the range. However, difference thresholds were higher at low luminance contrasts when the chromatic contrast between the stimuli and the surround was high. Results also indicate that the effects of chromatic contrast may be mediated by local contrast mechanisms, but that the relationship between threshold and luminance contrast is not mediated entirely by these local contrast mechanisms.**

Contrast Discrimination Luminance Color

Luminance discrimination is most acute when the stimuli to be discriminated are similar in luminance to the surround or background against which they are viewed (Legge & Kersten, 1983; Whittle, 1986). The phenomenon was noted as early as 1916 by Cobb, who measured discrimination thresholds for white stimuli presented in a white surround. It is also apparent in the work on lightness scaling, where it was referred to as the “crispning effect” (Takasaki, 1966; see also review in Wyszecki & Stiles, 1982). Whittle (1986) showed that the discrimination threshold for two spatially separated patches of light was proportional to the luminance difference between test and surround when the test stimuli were similar in luminance to the surround. However, for large decrements in luminance, discrimination threshold was proportional to the test luminance level. Whittle suggested that these effects might result from the operation of two different mechanisms in the visual system. One of these mechanisms is sensitive to contrast and is responsible for the good discrimination of stimuli with luminances similar to the surround or background luminance. The other mechanism, which involves processes of dark adaptation that take place in fractions of a second, is sensitive to retinal illuminance and is responsible for the larger discrimination thresholds for stimuli with luminances much lower than the surround luminance.

Whittle (1992) noted that Takasaki (1967) had found a similar effect for chromatic discriminations

and suggested that the “crispning effect” might be a general principle in perceptual discriminations. Recent studies by Krauskopf and Gegenfurtner (1992), and Miyahara, Pokorny, and Smith (1993) also suggest that a “crispning effect” may occur for chromatic discriminations. Krauskopf and Gegenfurtner found that chromatic discrimination thresholds for stimuli that differed in chromaticity from the surround increased as the difference or chromatic contrast between the test stimuli and the surround increased. Miyahara, Pokorny, and Smith found similar results for both yellow–blue and red–green stimuli. These results are similar to Whittle’s result for luminance discrimination.

In a more recent paper, Whittle (1992) used an equal-interval brightness scaling procedure to study further the “crispning effect”. In these experiments the addition of a black outline, 6 min arc wide, around the test stimuli reduced the magnitude of the effect. This result further supported the notion that simultaneous contrast was important to producing the effect and further implicated the involvement of a local contrast coding mechanism. The black ring appeared to disrupt contrast signals based on local comparisons across edges. However, the introduction of a hue difference between stimulus and surround also reduced the “crispning effect”. For yellow test stimuli on a red surround there was no crispning at all. Whittle suggested that the reduction caused by the hue difference might be due to the computation of contrast within individual cone mechanisms, or alternatively, to masking of achromatic contrast by chromatic contrast as

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suggested by Switkes, Bradley, and DeValois (1988). Whittle's results suggest that luminance discrimination for test stimuli that differ from the surround in chromaticity may be mediated largely by mechanisms which code absolute luminance. These results raise questions about the generality of the "crispening effect" and contrast coding in the visual system.

Switkes *et al.* (1988) reported that red-green chromatic gratings masked the detection of a luminance grating. The masking was nearly independent of the relative phase of the gratings, but was dependent on the spatial frequency of the gratings. Very little masking occurred for spatial frequencies of 0.5 c/deg or less. For higher spatial frequencies, masking increased with spatial frequency up to 4 c/deg. The authors attributed the masking effect to inhibition of luminance contrast signals by chromatic contrast signals, or to an excitatory input from the chromatic contrast channel to a luminance contrast channel.

In contrast to the results of Switkes *et al.* (1988), Cole, Stromeyer, and Kronauer (1990) found that a chromatic difference between a test spot and a surround of equal luminance slightly facilitated the detection of a luminance increment or decrement in the test area (the "pedestal effect"). The facilitation was nearly independent of chromatic contrast. Cole *et al.* attribute their results to the use of circular test spots and to the size of the test spots. The largest spatial frequency component for their 1 deg test spots occurred at 0.5 c/deg. Switkes *et al.* (1990) found little masking at this frequency. The purpose of the experiments described in this paper was to explore further the effects of chromatic contrast on luminance discrimination. Luminance discrimination thresholds were measured as a function of test luminance level for white, red, and green test stimuli presented in a surround. The results suggest that a "crispening effect" occurs near the surround luminance regardless of the test color. However, high chromatic contrast does appear to mask the detection of a luminance difference when the test patch and the surround differ in luminance by less than 15%. The masking appears to occur within very local contrast coding mechanisms.

## METHODS

### *Apparatus and stimuli*

Stimuli were generated on a Barco color monitor (CDCT 5151) driven by an AED 767 graphics generator. The AED was in turn controlled by an Apple IIe computer, which was programmed to generate the appropriate stimuli, collect the responses, and save the data. In the first two experiments the stimuli were two circular patches, 0.5 deg in diameter. In the third experiment the stimuli were squares of side 0.5 deg. In all experiments the stimuli were presented simultaneously as 200 msec flashes to the left and to the right of a small fixation dot, which was always visible. The luminance of the fixation dot was 7.5 cd/m<sup>2</sup>. The centers of the

stimulus fields were separated by 1.5 deg. They were presented either on a dark background or in a background with a luminance of 15 cd/m<sup>2</sup>. When presented on a background field the stimuli replaced the background rather than adding to it. White ( $x = 0.336$ ,  $y = 0.337$ ) and red ( $x = 0.455$ ,  $y = 0.273$ ) backgrounds were used in different experiments. The background was 11 deg wide and 8 deg high. The display was viewed binocularly from a distance of 2 m. A chin rest was used to stabilize head position and a joy stick was used to signal responses.

The monitor was calibrated with a Minolta chromameter (CS-100). The calibration data were used to establish voltage-luminance tables for each of the three monitor phosphors. The look-up tables were used in conjunction with a color generating program to generate stimuli of the desired luminance and chromaticity prior to the experiment. Dithering was used in Expt 3 in order to increase the resolution of the luminance steps that could be produced in the comparison stimulus. Because the AED provided only 8-bit resolution of the phosphor luminances, some of the thresholds measured in Expt 1 were nearly as small as the smallest luminance steps that could be produced. Comparison of the results in Expt 1 and 3 with each other and with the results of other studies (described below) suggests that the resolution of the system did not effect the thresholds measured in either experiment. Square stimuli were used in Expt 3 in order to simplify the dithering procedure. The pixels in the comparison patch were divided into three groups. Each group could be changed to the next highest luminance level independent of the other two groups. The dithering procedure allowed luminance steps that were one-third smaller in size. The dithering in the comparison stimulus was not visible even on close inspection of the stimuli and certainly was not visible at the normal viewing distance of 2 m.

### *Procedure*

A two-alternative forced-choice procedure with feedback was used. A tone signaled the beginning of a trial. After an interval of 400 msec, the stimuli appeared for 200 msec. The subject then signaled a response by moving the joy stick to the left or the right. Errors were signaled by another tone. Within each condition the luminance of one stimulus, the test stimulus, was presented at a fixed level while the luminance of the other, the comparison stimulus, was varied with a double-random staircase procedure. One staircase began with zero luminance difference between the two stimuli, while the other began with a large luminance difference that was clearly visible. In the first two experiments the comparison stimulus was always made brighter than the test stimulus, and the subjects task was to choose the brighter stimulus on each trial. In the third experiment the comparison stimulus was made dimmer than the test for conditions in which the test stimulus was dimmer than the background and the observer's task was to choose the dimmer stimulus. This difference had little

effect on results. Each trial was selected randomly from one of the two staircases. Within each staircase the luminance difference between the test and comparison stimuli was increased after one incorrect response, and was decreased after two consecutive correct responses. This procedure gives an estimate of the point on the psychometric function representing 71% correct (Levitt, 1971). Each staircase continued for 30–50 trials. Step size decreased with each response reversal until the smallest available step size was reached. The last four response reversals at the smallest step size in the staircase were averaged to give a mean for each staircase. On each trial the right or the left stimulus position was selected randomly as the variable comparison stimulus independently of which staircase had been selected.

Subjects viewed the monitor in a dark room. Typically, discrimination thresholds were measured at seven test luminance levels in a session lasting 1–1.5 hr. The order of the luminance levels was randomized within each session. Trials were presented approximately once every 5 sec. On some occasions two sessions were run back to back. However the same conditions were not run in back to back sessions. Each condition was completed four times on different days.

**RESULTS**

*Experiment 1*

In the first experiment difference thresholds were measured as a function of luminance level for white ( $x = 0.336, y = 0.337$ ), red ( $x = 0.455, y = 0.273$ ), and green ( $x = 0.261, y = 0.375$ ) stimuli presented on the white background. The white background had the same chromaticity as the white stimuli and its luminance level was fixed at 15 cd/m<sup>2</sup>. Results from five observers are shown in Fig. 1. The log of the threshold luminance difference is plotted against the log luminance of the test stimulus. Results obtained with white test stimuli are shown in Fig. 1(A), while those obtained with green and red test stimuli are shown in Fig. 1(B, C) respectively. Open symbols indicate means for individual observers while the solid symbols indicate overall means across observers. Error bars indicating  $\pm 2$  SEs of the mean are shown for only one observer, CO, but they are similar for other observers. The straight lines in each panel have a slope of one in accord with the predictions of Weber's law, and were drawn so as to indicate a Weber fraction of approx. 5%.

The results in Fig. 1(A) are very similar to those obtained by Whittle (1986) for white test stimuli on a white background. Difference thresholds clearly deviate from Weber's law near the background luminance (1.18 log cd/m<sup>2</sup>) for all five observers. Results obtained with the green test stimuli in Fig. 1(B) are similar to those obtained with the white test. In both panels thresholds at the lowest and highest luminance levels fall near the Weber line indicating a Weber fraction of 5%, but thresholds for luminance levels near the background level fall well below the line and indicate much smaller

Weber fractions of 1% or less when the test stimulus and the background are equal in luminance. Results for the red test stimuli [Fig. 1(C)] clearly differ from those obtained with the green and white test stimuli. Though difference thresholds again fall below the Weber line at luminance levels near the background luminance, the

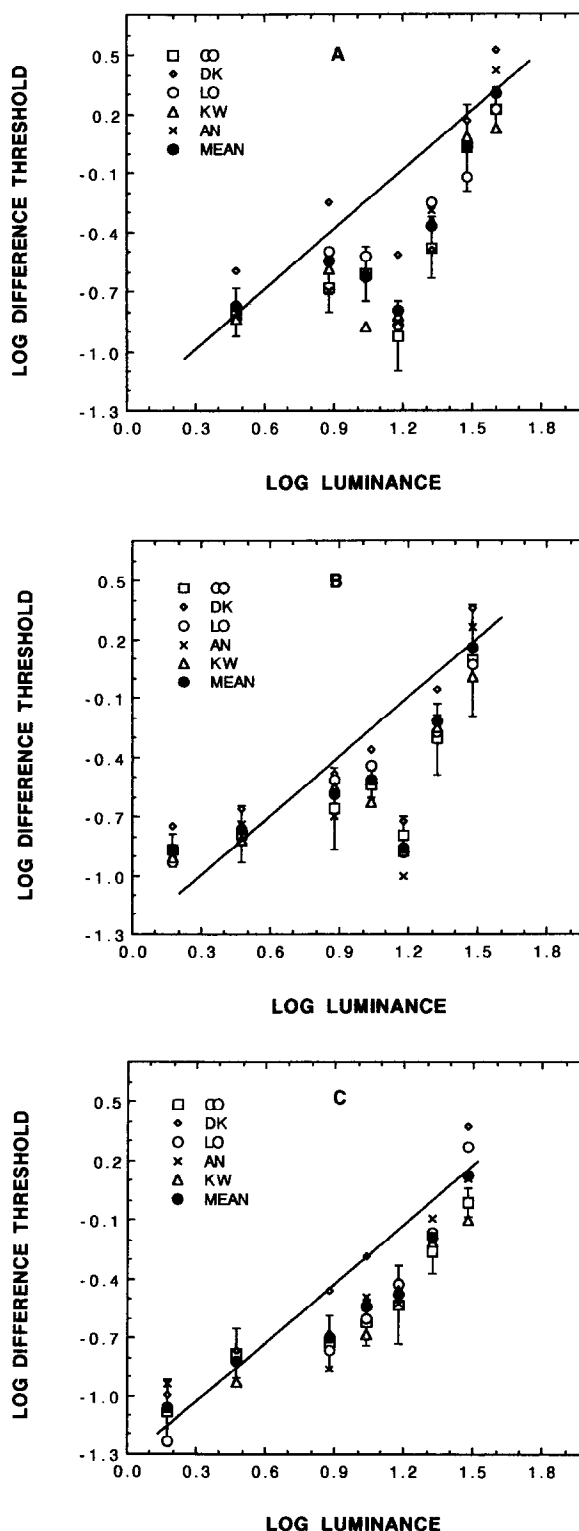


FIGURE 1. Log difference thresholds as a function of log test luminance level from Expt 1. (A), (B), and (C) give results for white, green, and red test stimuli on a white background respectively.

deviation is not nearly as pronounced. The Weber fraction was approx. 2% when the red test stimuli and white background were equal in luminance. As a control condition, thresholds were obtained for the same test chromaticities and luminance levels on a dark background. Four of the five observers from Fig. 1 participated. Difference thresholds fell along a straight line with a slope of one. There was little or no difference between the test colors and the mean Weber fraction across test colors and observers was approx. 10%.

In order to determine whether the color of the test stimulus or the chromatic contrast between stimulus and background was responsible for the shallow notch obtained with the red stimulus, the experiment was repeated with the red and white test stimuli presented against a red background. The chromaticity of the red background was identical to that of the red test stimulus and its luminance was fixed at 15 cd/m<sup>2</sup>. Results from three observers are shown in Fig. 2. The axes are similar to those in Fig. 1 and error bars again indicate  $\pm 2$  SEs of the mean for one observer (CO). Results obtained with the red test stimuli on the red background are shown in Fig. 1(A). Except for the rather high thresholds

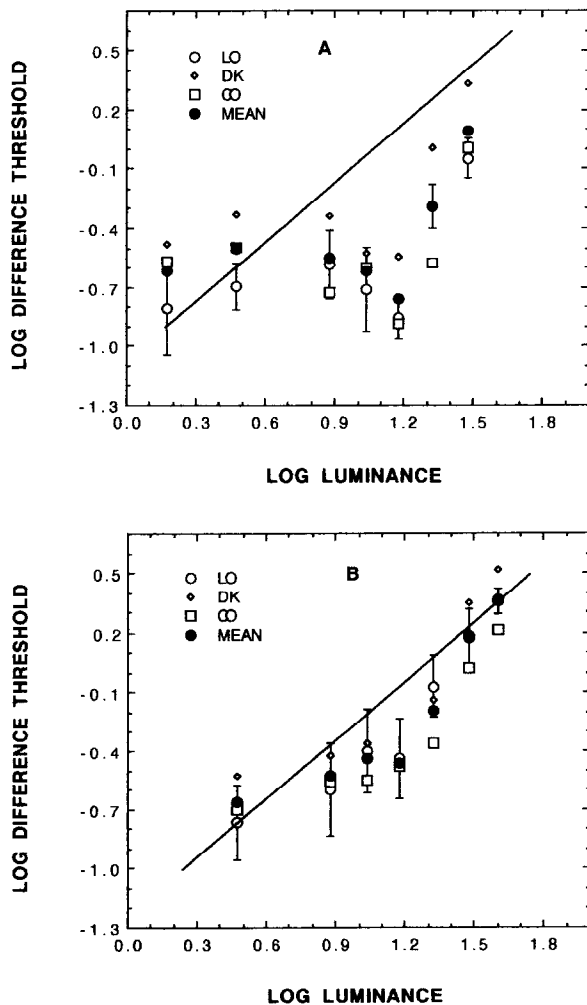


FIGURE 2. Log difference thresholds as a function of log test luminance level from Expt 1. (A) and (B) give results for red and white test stimuli on a red background respectively.

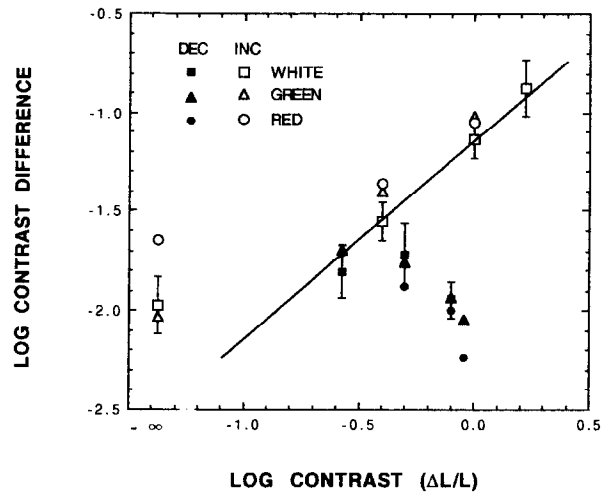


FIGURE 3. Thresholds from Fig. 1, expressed as the log contrast difference and plotted as a function of test contrast. Overall means across observers are shown for the white, green, and red test stimuli on a white background.

at the two lowest luminance levels, the results are similar to those obtained with the white test stimuli on the white background. A large deviation from the Weber line occurs near the background luminance and the Weber fraction is approx. 1% when the test stimulus and the surround are equal in luminance. The results obtained with white test stimuli on the red background, shown in Fig. 1(B), are similar to those obtained with the red test in Fig. 1. Though the deviation from the Weber line is clearly present, it is not nearly as pronounced. The Weber fraction at equal luminance is approx. 2% as it was in Fig. 1(C). This result clearly indicates that it is the chromatic contrast between the test stimuli and the background that is responsible for the shallower deviation from the Weber line, and not the use of red test stimuli.

In Fig. 3 the overall means across the five observers for each test color on the white background (data from Fig. 1) are replotted in a contrast plot. The log contrast between the test stimulus and the background ( $\Delta L/L$ ) is plotted on the abscissa and the log of the difference in the contrasts of the test and comparison stimuli at threshold is plotted on the ordinate. Different symbol shapes indicate the red, green, and white stimulus colors. Open symbols indicate that the luminance of the test stimulus was greater than or equal to the background luminance and solid symbols indicate that the luminance of the test stimulus was less than the background luminance. Error bars indicate  $\pm 2$  SEs of the overall mean calculated from the means for the individual observers.

In Fig. 3 it is apparent that there is very little difference between the test colors except at zero contrast or equal luminance (points at far left) where the threshold contrast difference is clearly higher for the red test stimuli. For incremental test luminances the thresholds fall along a straight line with a slope of one, indicating that the threshold contrast difference is proportional to the

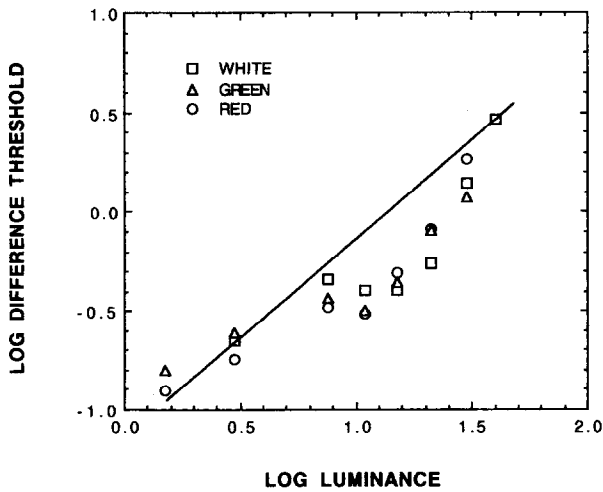


FIGURE 4. Log difference threshold as a function of log test luminance level for stimuli presented with a black ring in Expt 2. Overall means across observers are shown for the white, green, and red test stimuli.

contrast between the test stimulus and the background. This result is consistent with Weber's law behavior for contrast. The straight line drawn in the figure indicates a Weber fraction of approx. 7%. For decremental test luminance levels only the points at the lowest contrast fall near the Weber line. At higher decremental contrasts, thresholds begin to decline, indicating that threshold is more nearly proportional to the absolute luminance level of the test stimulus rather than contrast. The results are very similar to those obtained by Whittle (1986, see especially Fig. 3) with white stimuli and a white background. The important point here is that there is little difference between test colors except at equal luminance or zero contrast. At all other luminance contrast levels thresholds for the red and green test stimuli are very similar to the thresholds for the white test stimuli.

*Experiment 2*

In the second experiment, the stimuli were flashed with a contiguous black ring 6 min arc wide surrounding each stimulus. In his later paper Whittle (1992) found that a black ring surrounding the stimuli reduced the "crispens effect" for white test stimuli on a white background, though it did not completely abolish it. This result supported the notion that the "crispens effect" was due largely to local contrast mechanisms that signaled contrast across the edges of the stimuli. Here, the black ring and a white background were used in conjunction with all three of the test colors used in the first experiment in order to test the hypothesis that the differences between the test colors were mediated largely by local contrast mechanisms. Methods and procedures were identical to those used in Expt 1. Three of the observers who had participated in the first experiment continued as observers in this experiment.

In Fig. 4, the log of the luminance difference at threshold is plotted against log test luminance level. Overall means across observers for all three test colors

are shown. The straight line drawn in the figure again has a slope of one and indicates a Weber fraction of approx. 7%. Thresholds for all three test colors again deviate from the Weber line near the background luminance (again 1.18 log cd/m<sup>2</sup>), but here the deviation is similar for all three test colors and is not nearly as

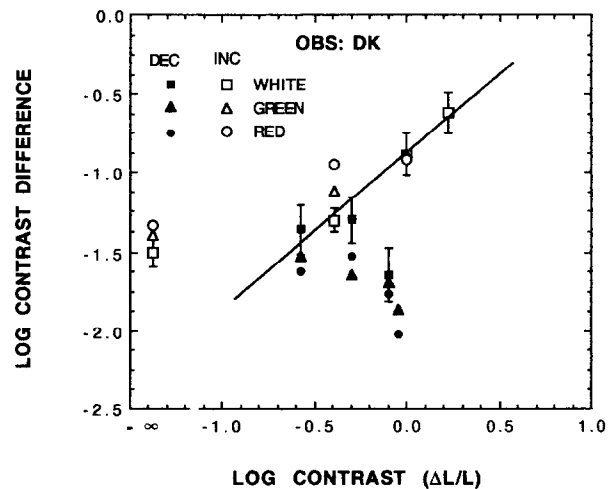
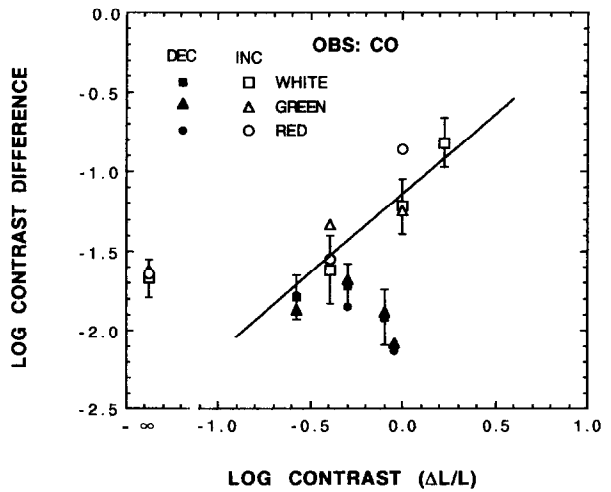
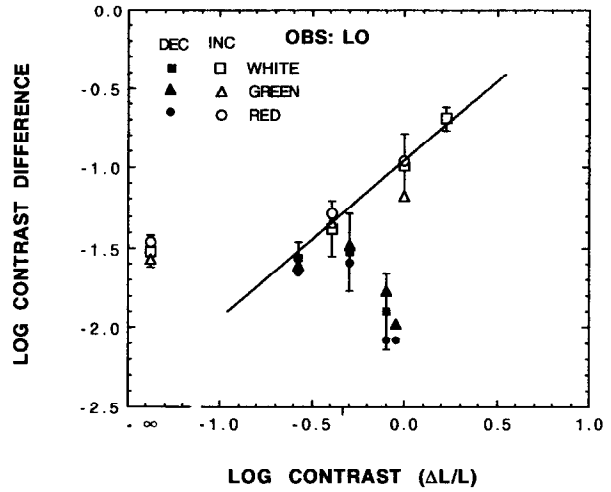


FIGURE 5. Log contrast difference at threshold plotted as a function of test-surround contrast for Expt 2 with the black ring. Mean data from individual observers LO, CO, and DK are shown.

pronounced as it was for white stimuli on a white background in Expt 1. The data from individual observers have been plotted in a contrast plot in Fig. 5. The thresholds, expressed as log contrast differences, are plotted against the log contrast of the test stimulus.

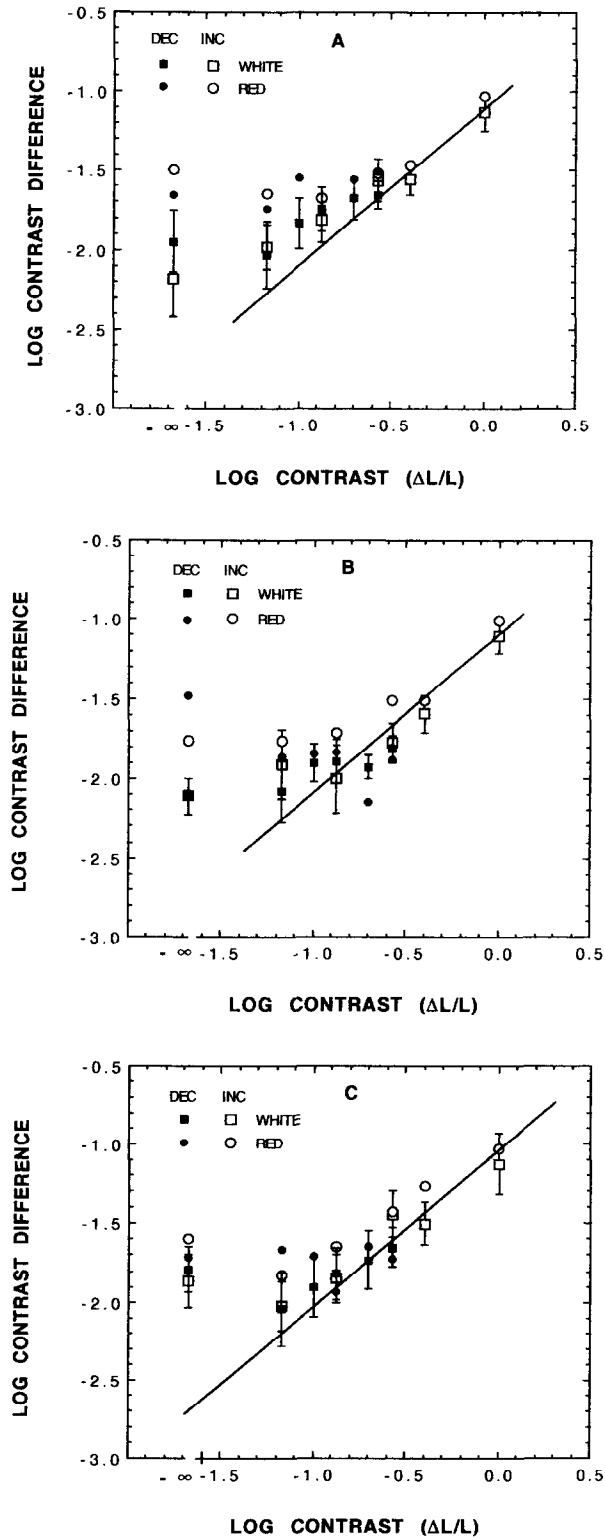


FIGURE 6. Log contrast difference thresholds plotted as a function of contrast for the white and red test stimuli on a white background in Expt 3. Results from individual observers LO, CO, and DK are shown in (A), (B), and (C) respectively.

There is little difference between test colors even at equal luminance or zero contrast. The results indicate that for luminance increments, threshold is still proportional to the luminance contrast when the stimuli are surrounded by the black ring. The ring also has little effect on difference thresholds for luminance decrements. The largest effect of the black ring is on the difference thresholds at equal luminance or zero contrast.

### Experiment 3

In the third experiment we attempted to determine whether the difference thresholds for the red and white test stimuli differed only at zero luminance contrast or equal luminance. We repeated the white background condition of Expt 1 with several low contrast test luminance levels. Only the red and white test colors were used in this experiment, since the results for the green test stimuli were very similar to those obtained with white stimuli. Methods and procedures were very similar to those used in the first two experiments with three exceptions. The test stimuli were squares whose sides subtended 0.5 deg arc. Thus the total stimulus area was slightly larger than in the first two experiments with circular test stimuli. For decremental test stimuli the comparison stimulus was darker than the test stimulus rather than brighter as in the first experiments, and dithering was used to increase the resolution of the luminance differences that could be generated. The three observers from Expt 2 continued in this experiment. Results from individual observers are shown as contrast plots in Fig. 6(A, B, C). The results are similar across observers. For log luminance contrasts  $> -0.75$ , thresholds fall along a straight line with a slope of one for both the red and white test stimuli. At log contrasts less than this level, thresholds for both the red and white test stimuli begin to deviate from the line and flatten out. For observers LO [Fig. 6(A)] and CO [Fig. 6(B)], thresholds for the red and white test stimuli also begin to separate at this level. The separation between the thresholds for the red and white test stimuli becomes more pronounced with decreasing contrast and is at its maximum at zero contrast (points on far left). For observer DK [Fig. 6(C)] there is a similar trend but the differences between the thresholds for the red and white stimuli are smaller. The difference between thresholds for the red and white test stimuli at zero contrast was also smaller for this observer in Expt 1. The results clearly indicate that the color of the test stimulus affects the difference threshold only at luminance contrasts below about 15%. The masking effect is largest when the test stimuli and the background are approximately equal in luminance and becomes smaller as the luminance contrast between test and surround increases.

### DISCUSSION

Results obtained with white test stimuli on the white background essentially replicate similar experiments by Whittle (1986), Legge and Kersten (1983), and Cornsweet and Pinsky (1965). In the experiments

reported here, luminance discrimination thresholds for stimuli that are increments relative to the surround, are proportional to the luminance difference between the test and surround except for very small differences where the curves flatten out. The pedestal effect or "dipper function" which occurs in the results of Whittle (1986), Legge and Kersten (1983), and Cole *et al.* (1990) is not apparent in our results because we did not use test luminance levels that were near or somewhat below detection threshold. The resolution of our system was not sufficient to measure the pedestal effect accurately. However, the pedestal effect has been quite well established in the studies cited above and Cole *et al.* (1990) show that it also occurs when the pedestal is defined by color contrast. The goal of the experiments described above was to investigate the effect of color contrast on luminance discrimination in the region well above detection threshold. Nevertheless, the measures of detection threshold, the threshold measured at equal luminance or zero contrast, obtained with the white test stimuli on the white surround can be compared with similar thresholds measured in the three studies cited above. Data taken from the most similar condition in each of these studies was used to estimate detection threshold at the surround level used here assuming Weber's law holds. Whittle's results (1986) suggest that this assumption is reasonable. Our measure of  $\log \Delta L$  (luminance units) averaged across observers was  $-0.80$  in Expt 1 and  $-0.87$  in Expt 3. The estimates obtained from Legge and Kersten (1983), Whittle (1986), and Cole *et al.* (1990) were  $-0.82$ ,  $-0.67$ , and  $-0.75$  respectively. The results from all four studies agree remarkably well given the many differences between the four studies, and show that the resolution of our system was sufficient for accurate measures of the detection threshold.

For stimuli that are luminance decrements relative to the background, the difference threshold is proportional to the luminance difference between test and surround only at moderate levels. For large decrements, thresholds appear to be proportional to the absolute luminance level of the test stimuli. This aspect of the results is also prominent in Whittle's experiments, but is not quite as apparent in the data of Legge and Kersten (1983) largely because the largest decremental contrast used in their experiments was approx. 40%. Cornsweet and Pinsker (1965) did not investigate decrements. Whittle suggested that local fast adaptation mechanisms were responsible for the switch to absolute luminance coding at high decrement contrasts. In support of this hypothesis, both Whittle and Legge and Kersten found that difference thresholds are proportional to the luminance difference between test and surround over the entire measurable range of decrements for very brief test stimuli, that do not permit such adaptation.

Results for the red and green test stimuli on the white background also suggest that luminance discrimination threshold is proportional to the luminance difference between test and surround except for very small increments and decrements. Chromatic contrast affects difference thresholds only at luminance contrasts

$< 15\%$ , where the threshold vs contrast curves begin to flatten out (Fig. 6) and threshold is no longer strictly proportional to the luminance difference between test and surround for the white stimuli. Thus our results are only partially in agreement with the conclusions drawn by Whittle (1992) from equal-interval scaling experiments. Chromatic contrast does have some effect on luminance difference thresholds, but over much of the range, it does not disrupt the proportional relationship between the difference threshold and the luminance difference between test and surround.

There may be three major reasons for the difference in the results of the two studies. Whittle's brightness scaling technique required observers to make judgments of absolute brightness. Brightness judgments are presumably influenced by overall activity in both chromatic and achromatic mechanisms. Thus these judgments may be mediated by a different collection of mechanisms than the mechanisms mediating the difference judgment. The contribution from additional mechanisms to brightness may wash out the crispening effect which is already small with chromatic contrast. Second, Whittle continuously presented 25 stimuli in the same display in fairly close proximity to one another, while we presented only two stimuli at a time very briefly. This difference in procedure may have also contributed to the difference in results, though it does not seem to have had much effect on results obtained without chromatic contrast. Third, the red background field used in Whittle's study was more saturated than the red stimuli and the red background used in this study and thus may have resulted in a larger masking effect.

The effects of chromatic contrast at low luminance contrast are consistent with the work of Switkes *et al.* (1988), who found that chromatic contrast masked the detection of luminance contrast. Equal luminance red-green sinusoidal gratings masked the detection of a sinusoidal luminance grating when the frequencies of the test and masking gratings were  $> 0.5$  c/deg. The 0.5 deg stimuli used in the experiments described above would generate fundamental frequencies of 1 c/deg. Cole *et al.* (1990) found that chromatic contrast between test and surround actually facilitated the detection of a luminance difference between the test and surround. Their circular test stimulus was 1 deg in diameter with a fundamental frequency of 0.5 c/deg. The difference in stimulus size appears to be the most likely explanation for the difference between their results and those presented here.

The results for the green and white stimuli are nearly identical in the first experiment, indicating that the chromatic contrast has no effect on the difference thresholds here. The chromatic contrast between the green test and the white background, specified by the difference in chromaticities in the cone excitation diagram (MacLeod & Boynton, 1979), is less than half that of the red test on the white background. One possibility is that the chromatic contrast of the green stimuli was not great enough to have an effect on the difference thresholds. However, Switkes *et al.* (1988) found that

chromatic contrasts of about 5 times threshold were large enough to have some masking effect on the detection of a luminance grating. The chromatic contrast of the green test stimuli was certainly more than 5 times the threshold contrast in the experiments described above. Another possibility is that the masking occurs only with long wavelength light. Long wavelength light has been found to have an inhibitory or suppressive effect on the magnocellular pathway (De Monasterio & Shein, 1980; Livingston & Hubel, 1984; Derrington, Krauskopf & Lennie, 1984). Breitmeyer, May and Heller (1991) (see also Breitmeyer & Williams, 1990) found that metacontrast masking is not as strong on red backgrounds as on white backgrounds, and attributed this effect to suppression of signals in the magnocellular pathways. However, results of Expt 1 are not consistent with this hypothesis, suggesting instead that the chromatic contrast between the test stimuli and the background is important. Further work in which chromatic contrast level is varied systematically might help to answer questions about the differences between the red and green test colors.

The results of our experiments suggest that a spatially local mechanism may contribute to luminance discriminations at low test-surround contrast levels, while thresholds at higher levels are mediated primarily by a more global or less finely tuned spatial mechanism. Whittle (1992, p. 1505) also suggested that in addition to a local mechanism, a less finely tuned mechanism might be involved in his results. The results of Expt 2 suggest that the dependence of the difference threshold on the luminance difference between test and surround is little affected by the black ring at moderate to high levels of luminance difference between the test and surround, suggesting that this relationship may be mediated by long range spatial interactions. Several recent psychophysical studies suggest long range interactions between responses to suprathreshold stimuli well above threshold. The perceived brightness (Reid & Shapley, 1988), perceived contrast (Cannon & Fullenkamp, 1991), and perceived color (Wesner & Shevell, 1992) of a test stimulus are affected by light falling in retinal regions not contiguous to the test stimulus. Valberg, Lee, Tigwell and Creutzfeldt (1985), Kastner, Creutzfeldt, Li, Crook and Xing (1991), and Desimone, Shein, Moran and Ungerleider (1985) have found that responses of cells in the parvocellular pathway, and in the more central projections of this pathway (area V4 of the cortex), are influenced by light falling outside the traditional receptive field over retinal areas as large as 50 deg in diameter. Thus cells in the parvocellular pathway could serve as a physiological substrate for long range interactions at high contrast levels.

For small luminance differences between the test and surround, both chromatic contrast and the black ring increase the luminance discrimination thresholds. However, these effects do not appear to be additive. That is the combined effect of chromatic contrast and the black ring is not much larger than the effect of either alone. The similarity of the effects and the lack of additivity

suggest that the increase in threshold may occur as a result of the disruption of the processing of local contrast across the edges between the stimuli and the surround in both cases. The black ring cannot produce a contrast of 100% at the edge because of stray light scattered into the ring from both the stimuli and the surround (Shevell & Burroughs, 1988), but it presumably results in a high enough contrast at the edge to saturate or nearly saturate the responses of local mechanisms. Chromatic contrast may disrupt local processing at edges either because contrast is computed within each cone mechanism, as suggested by Whittle (1992), or because responses in the chromatic pathways mask or inhibit responses in the local mechanisms (Switkes *et al.*, 1988). We favor the second alternative because of the phase independence and the spatial frequency dependence of the chromatic masking effect found by Switkes *et al.* (1988). Further experiments on the spatial frequency dependence of the chromatic masking effect and on the spatial relations between stimulus and background that are necessary for the dependence of the difference threshold on the luminance difference between test and surround would be useful here.

Several investigators have suggested that luminance information is processed within both the parvocellular and magnocellular pathways (Ingling & Martinez-Uriegas, 1985; Lennie & D'Zmura, 1988; Merrigan, 1991; Rodieck, 1991; Schiller, 1991; Shapley, Reid & Kaplan, 1991). Magnocellular cells respond to luminance contrasts as low as 1–2%, but their responses begin to saturate at contrasts of 10–15% (Shapley, Kaplan, & Soodak, 1981; see also Lee, 1991). Parvocellular cells are not very sensitive to low luminance contrasts but their responses grow with increasing contrast at a slower rate and saturate at much higher contrasts. Visually evoked potentials (VEP) recordings in both human and monkey indicate that the functions relating VEP amplitude to contrast are composed of two distinct linear functions, which may reflect magnocellular and parvocellular activity (Campbell & Maffei, 1970; Kulikowski, 1977; Fiorentini, Burr & Morrone, 1991; Nakayama & Mackeben, 1982). It is tempting to identify the local and global mechanisms implied by our experiments with the magnocellular and parvocellular pathways respectively. However, much more psychophysical work must be done to firmly establish whether separate local and global mechanisms play a role in luminance discrimination thresholds.

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