

Stimulus Size Affects Rod Influence on Tritan Chromatic Discrimination

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Abstract: A signal-detection procedure was used to measure the influence of rods on S-cone-mediated (“tritan”) chromatic discrimination in normal trichromatic human observers. Rod influence on discriminability of both increments and decrements in S-cone excitation was assessed by comparing cone-plateau (minimizes rod influence) and dark adapted (maximizes rod influence) conditions. For 1° stimuli, rods impaired tritan discrimination, especially for S-cone decrements. For 8° stimuli, rods had no systematic effects. This confirms that rods have the same direction of effect (impairment) on tritan discrimination as has been shown for Rayleigh (L-M) discrimination. However, the size dependence of the rod effect on tritan discrimination is opposite to that previously shown for either Rayleigh discrimination or hue appearance. This provides further evidence for separable rod influences on S-cone and L-M cone pathways. © 2000 John Wiley & Sons, Inc. *Col Res Appl*, 26, S65–S68, 2001

Key words: chromatic discrimination; hue; rod vision; S-cones; tritan; psychophysics; human color vision

INTRODUCTION

After a period of dark adaptation, signals from rod photoreceptors can influence observers’ reports of subjective hues of spectral lights^{1–4} and the spectral wavelengths (loci) associated with unique (single hue percept) and binary (two

equally balanced hue percepts) hues.^{5–7} Such rod influences affect the distribution across the 400–700 nm spectrum of all four basic hue percepts (red, green, yellow, blue) and all unique- and binary-hue loci. Rod influences on hue appearance are made most salient by using large, eccentrically viewed stimuli with light levels reduced to about 1.5 log scot td.^{1,6,7} Studies of the spectral distribution and time course of these effects suggest separable rod influences on hue are mediated by S-cone (tritan) and L-M (Rayleigh) pathways.⁸

Rods can also influence chromatic discrimination at mesopic light levels. In trichromatic observers, rod activity has been shown to *impair* both constant-luminance Rayleigh discrimination thresholds⁹ and S-cone mediated discrimination on the Farnsworth–Munsell 100-Hue Test.¹⁰ However, rod activity has been shown to *improve* wavelength discrimination in S-cone monochromats.¹¹ The basis for this difference between normal and color-deficient observers is not known.

The present study seeks to determine whether the apparent rod impairment of tritan discrimination found with the FM100 is replicated with more-rigorous psychophysical methods and control of stimuli and fixation. The present study also seeks to determine whether the rod influence on tritan discrimination grows larger with stimulus size, as has been shown for rod influence on hue^{5,6} and on Rayleigh discrimination.⁹ The finding of similar size dependence of all three effects would permit the most parsimonious modeling of rod influences on human color vision.

METHODS

Three color-normal adults (ages 24–42) served as observers. Females MP and BM, who were naive as to prior hypotheses, and male RK were kept blind to their experimental results until the completion of all conditions.

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TABLE I. Receptor stimulation changes during chromaticity shift.

	% Change in stimulation			Rods
	S	M	L	
1° Field				
Increment	+41.2	+0.56	-0.72	+2.7
Decrement	-38.7	-0.54	+0.75	-2.7
8° Field				
Increment	+7.5	+0.11	-0.15	+0.5
Decrement	-7.7	-0.11	+0.15	-0.5

A signal-detection psychophysical procedure was used to estimate the detectability of fixed-sized chromaticity shifts of a homogeneous stimulus field that was either 1° or 8° diameter and centered 7° eccentric in the temporal visual field. Two channels of a previously described¹ computer-controlled Maxwellian-view apparatus were used to present the test stimulus and a dim red 1°-square fixation cross. The chromaticity shifts produced increments or decrements of S-cone stimulation, with little change of stimulation of L or M cones or rods. A pair of interference filters, nominally 430 and 520 nm, was chosen that produced chromaticities *in situ* that fell close to a tritan confusion line. Flicker photometry (15 Hz sinusoidal exchanges) was used to adjust the two lights to equal luminance individually for each observer. The overall light level was adjusted to 1.6 log S-cone td (about 1.5 log scot td) at the starting chromaticity (0.131, 0.378 in 1931 CIE space), which was formed by nearly equal contributions of the two lights. S-cone increments and decrements were produced by exchanging the 430 and 520 nm lights at equal luminance.

Table I shows the % changes of excitation of all four receptor types that accompanied the chromaticity shifts for both 1° and 8° fields. The sizes of the chromaticity shifts were selected, on the basis of pilot testing, to be slightly above threshold for each stimulus size and were, therefore, smaller for the 8° field and larger for the 1° field. For a specific field size, increments and decrements were of equal apparatus stepper-motor change and nearly equal chromaticity shifts. Calculations are based on the DeMarco *et al.* cone fundamentals¹² with foveal macular pigment densities removed and the CIE scotopic luminosity function. The spectral irradiance of the two mixture lights and of each combination was measured at 3-nm intervals by means of a Gamma Scientific spectroradiometer, calibrated against a recently certified standard source.

The observer initiated each trial onset, typically with delays of 10–20 s between trials. The test field came on at the beginning of the trial and remained on throughout the 4-s duration. On “signal” trials, the chromaticity shift (either increment or decrement of S-cone stimulation) began 2 s after trial onset and 250 ms after a warning tone. The smaller chromaticity shifts used for the 8° field took 200 ms for completion. The larger chromaticity shifts used for the 1° field took 1000 ms (and entailed exactly 5 times the excursion of the apparatus stepper motors). The chromaticity remained at the target setting for the remainder of the

trial. On “blank” trials, the warning tone sounded but the chromaticity did not change.

The observer’s task was to say at the end of a trial whether it had been an increment signal trial, a decrement signal trial, or a blank trial. Noise delivered through headphones and movement of identical but functionally irrelevant stepper motors provided auditory and vibrational masking of extraneous stimuli. Increment trials and decrement trials were randomly mixed with blank trials in blocks of 20 trials. Half the trials in each block were actually blanks, the other half were evenly split between increments and decrements. Observers received no feedback after their response. Detectability (d') was calculated on the basis of 50 signal and 100 blank trials spread over 10 blocks.

The effect of rods on these tritan discriminations was assessed by comparing performance with the same physical stimulus, but under two different adaptation conditions. In the “bleached” condition, all measurements were made on the cone plateau between 3–8 min after a xenon flash bleach, when rods could contribute minimally, if at all. In the “dark-adapted” condition, all measurements were made after the observer had been dark adapted for at least 30 minutes, when rods could contribute maximally. Both dark-adapted and bleached conditions were run in the same daily session, with initial adaptation condition counterbalanced across days.

RESULTS

The preselected chromaticity shifts yielded fairly comparable detectabilities for the 1° and 8° fields, as shown in Fig. 2. Values for d' ranged mostly between 1.0–2.0 for the 8°

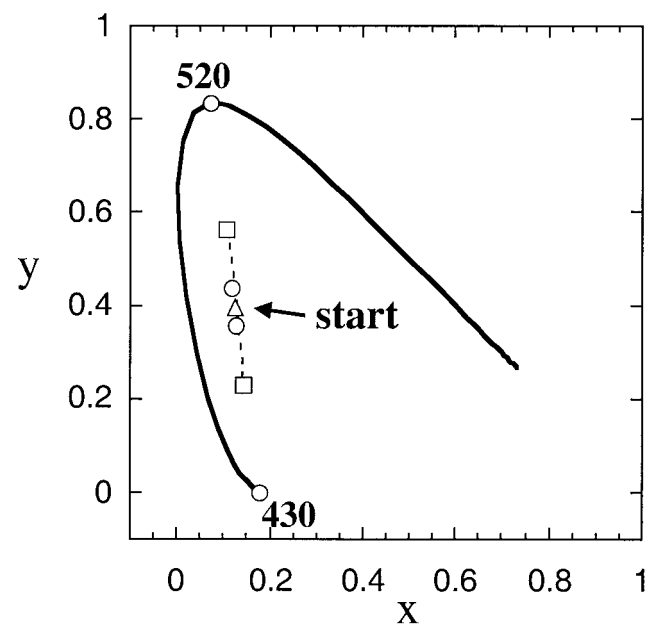


FIG. 1. Coordinates of start (triangle) and ends of chromaticity shifts used for the 8° field (circles) and 1° field (squares). S-cone decrements are toward 520 nm; S-cone increments are toward 430 nm.

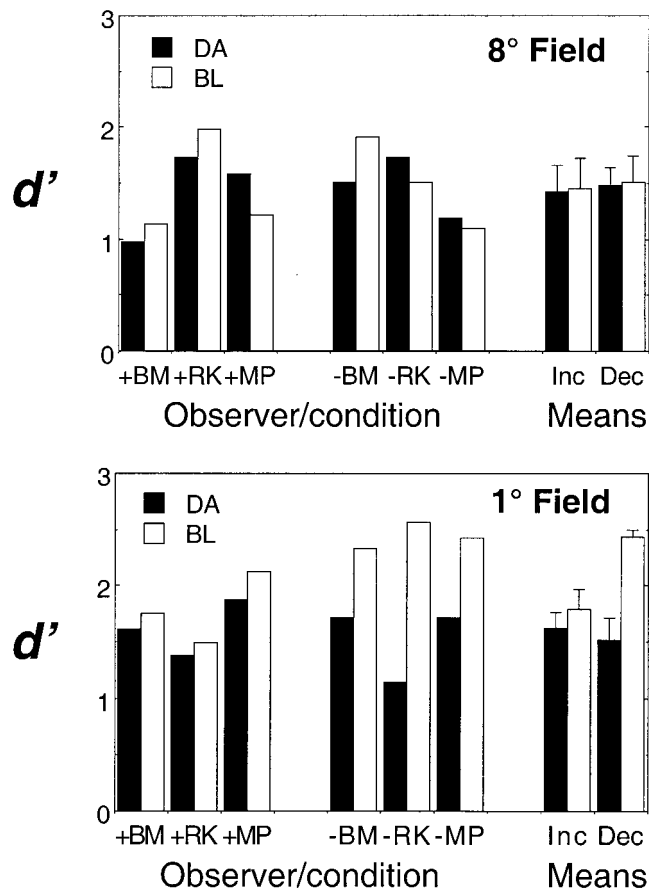


FIG. 2. Detectabilities (d' values) calculated from signal-detection procedure for (top) 8° field and (bottom) 1° field for both S-cone increment (+ or Inc) and S-cone decrement (- or Dec) conditions. Data for individual observers are shown at left and center and for means (± 1 s.e.) across observers at right. Rod influence on tritan discrimination is shown by differences between dark-adapted (DA, filled) and bleached (BL, open) bars.

field and between 1.5–2.5 for the 1° field. The overall hit and false-alarm rates for the tritan chromaticity shifts were generally 60–70% and 10–20%, respectively.

Figure 2 (top panel) shows the d' values for the 8° field for both dark-adapted (DA) and bleached (BL) conditions for both increments (+ or INC) and decrements (- or DEC) of S-cone stimulation for all three observers and for the means across observers. Figure 3 shows the influence of rods on tritan discrimination directly as the arithmetic difference in d' ($\Delta d'$) between dark-adapted and bleached conditions for each observer and shift direction. Positive values indicate that rods enhanced detectability; negative values indicate rods impaired detectability. The figures make clear that, for the 8° field (top panel), no two observers show the same pattern of direction of rod influence on S-cone increments and decrements, and there is no net rod effect on either increments or decrements across observers.

Figures 2 and 3 also show that, for 1° fields (bottom panels), the pattern of results is quite different. All three observers show small but consistent rod impairments of

detectability of tritan increments and much larger rod impairments of detectability of tritan decrements.

DISCUSSION

The results show, by means of a rigorous psychophysical procedure and careful control of stimuli and fixation, that rods can impair tritan chromatic discrimination. This is consistent with our previous report¹⁰ of selective rod-mediated impairment of tritan discrimination on the FM100. The failure to find a conspicuous or consistent rod influence using the 8° field is also consistent with our prior investigations¹³ that have used other psychophysical methods (method-of-adjustment, Boynton and Kambe¹⁴) and explored a range of light levels and starting chromaticities. Both studies that found rod effects on tritan discrimination have used small stimuli ($1\text{--}2^\circ$ extent). All our work with 8° stimuli show no pronounced or consistent rod effect. A surprising aspect of this size dependence of rod influence on tritan discrimination is that it is opposite in direction to the size dependence found for rod influence on either Rayleigh discrimination⁹ or hue appearance.^{5,6} The basis for this difference is unclear, but ultimately has to be accounted for as part of a comprehensive account of rod influence on color vision.

The finding of much greater rod influence on S-cone decrements than on S-cone increments was unexpected.

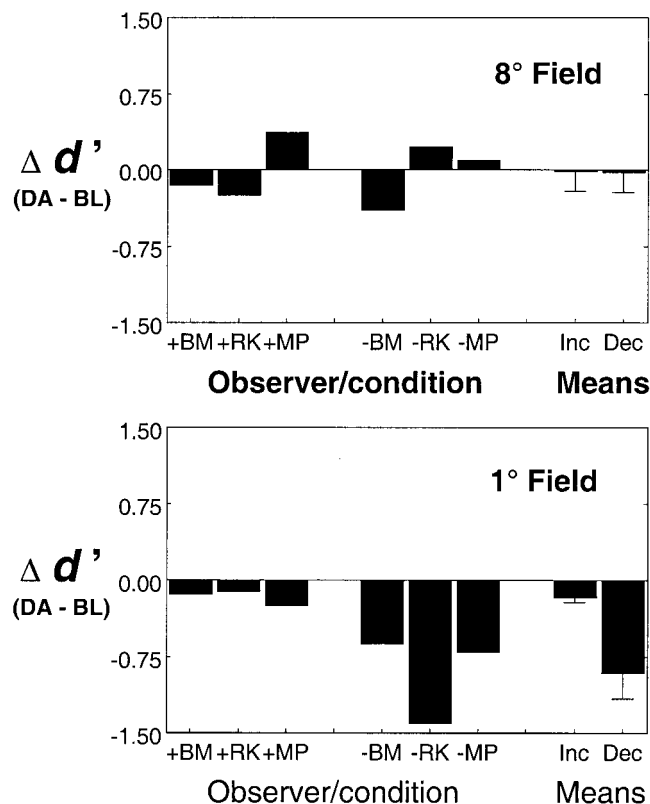


FIG. 3. Rod influence on tritan discrimination as shown by difference in d' values ($\Delta d'$) for dark-adapted and bleached conditions. Positive values indicate rod enhancement. Negative values indicate rod impairment.

Because rod stimulation levels changed so little with the chromaticity shifts used in the present study, and the increment/decrement rod effect asymmetry was so pronounced, it seems unlikely to be related to differences or artifacts based on rod difference thresholds. Further work is needed to uncover the basis of the asymmetry.

The present results also sharpen the apparent discrepancy between the impairment of chromatic discrimination that rods can produce in normals and reports of enhancement of chromatic or wavelength discrimination in S-cone monochromats.¹¹ However, a reconciliation of these apparent discrepancies may still be possible. For S-cone monochromats, rod and cone excitations can simultaneously change substantially, sometimes even in counterphase, as wavelength changes. However, for normal observers, the constraint of keeping LM-cone stimulation constant results in stimulus situations in which rods happen not to be so strongly modulated and may instead provide an effectively steady signal. As is embodied in the Boynton and Kambe¹⁴ model of chromatic discrimination, visual signals may influence discriminability in either an opponent or a nonopponent fashion. Increasing a nonopponent influence always reduces discriminability, but increasing an opponent influence can either increase or decrease discriminability, depending on whether that influence increases or decreases the polarization of the opponent site. Possibly the studies to date with normal observers have revealed only a nonopponent impairment of chromatic discrimination due to rod signals. Perhaps rod signals might also enhance discriminability in normals by reducing opponent polarization, if they could be more strongly modulated.

Finally, although it is unconventional to comment on the percepts underlying chromatic discrimination judgments, we want to point out that our observers' phenomenal reports raise the possibility that the 8°-field discriminations were more clearly based on hue changes than were the 1°-field discriminations (even though the cone-plateau d' values indicate that the chromaticity changes were more detectable to cone-mediated vision for the small field than for the large field). By their nature, chromatic discriminations made under different conditions may be based on changes along different perceptual dimensions, which may in turn reflect either quantitative or qualitative differences in the contribu-

tions of underlying substrate pathways. Perhaps rods have less influence on the discriminability of S-cone-mediated hue changes, which may have dominated on 8° fields, than on the discriminability of saturation or brightness changes, which may have dominated on 1° fields. Hopefully, future studies can assess the perceptual specificity of rod influence on chromatic discrimination and help us understand its relationship to the interaction of rod and cone signals in specific neural pathways.

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