The Chromatic Contrast Sensitivity Myth

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Abstract

A universally accepted conclusion about contrast sensitivity functions (CSF's) for spatially modulated sinusoidal gratings is that luminance-modulated CSF's are band-pass, whereas equal luminance chromatically-modulated CSF's are low pass. This conclusion does not follow logically from available data. If the existing chromatic CSF's are compared to *low level* luminance CSF's, as they should be, then both classes of functions are low-pass. In order to be comparable (possibly) to high level luminance CSF's, chromatic CSF's should be centered at a point in chromaticity space that appears highly saturated, and modulation should be along the line that goes through that point from the spectrum locus to the white point. Very tentative results for two subjects with such purity modulated red gratings show small band-pass effects.

Introduction

The sinusoidal spatial frequency gratings that underlie contrast sensitivity functions (CSF's) for chromatic systems are created by modulating chromaticity around some center mean value while maintaining constant luminance. Luminance CSF's modulate the luminances of white or colored lights around some mean level. All CSF graphs show, for a range of spatial frequencies, the minimum modulations that subjects require in order to detect the presence of a grating.

For CSF's obtained at high or medium mean luminance levels, it is universally agreed that luminance CSF's show band-pass characteristics, whereas chromatic CSF's show low-pass characteristics. That is, luminance CSF's peak at medium frequencies, whereas those for chromatic systems tend to be maximum and flat at low and medium frequencies. (Note that, at these levels, luminance variation is sufficient to yield band-pass CSF's for both achromatic and chromatic lights, so both are classified as luminance CSF's.) These band-pass vs low-pass differences, such as are illustrated in fig. 1, have been at the center of much theorizing about the processing of spatial information by the chromatic and luminance systems.

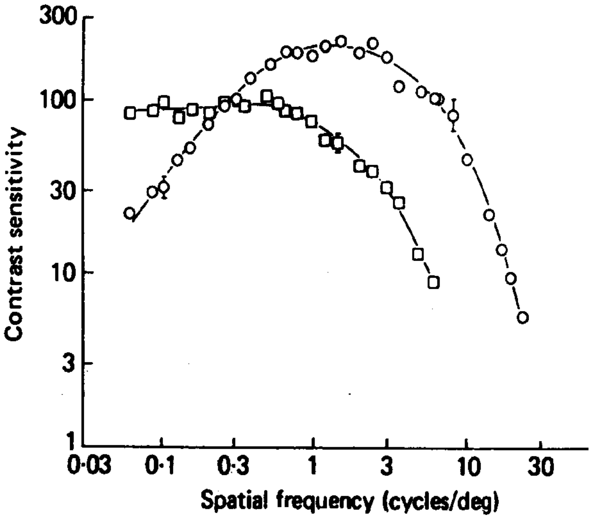

Figure 1. Luminance (circles) and chromatic (squares) blue/yellow contrast sensitivity functions after Mullen.[1]

Notwithstanding the data shown in fig. 1 and additional very extensive experimental and theoretical literature that seems to support the idea of major differences in spatial processing between chromatic and luminance systems, very elementary theoretical considerations demand that the best guess that can be made from published CSF's is that the chromatic and luminance systems are basically the same. Furthermore, new (but tentative) chromatic CSF's that are presented here suggest that the theoretically-based "best guess" might be correct.

The assertion that existing data suggest a correspondence between the luminance and the chromatic systems is based on the fact that the low-pass chromatic sinusoidal CSF's have been obtained only under conditions that should map to low-level luminance CSF's, which also are low-pass. Representative data that show how luminance CSF's shift to low-pass as light levels decrease are shown in figs. 2 and 3.

By way of explanation, consider, for example, chromatic

CSF's for equal-luminance gratings that are modulated from reddish-to-greenish around unique yellow. Subjects typically show superb sensitivities to these modulations, and, by definition within opponent colors theory, the red or green neural activity associated with even the peaks of a full cycle of such a just-detectable grating will be close to zero, even if the mean luminance is very high. That is, by definition, the neural activity in the red/green channel is at zero when a cycle of the grating is at its middle unique yellow point, and the neural activity is just-noticeably different from zero when the grating is at its (slightly) reddish or (slightly) greenish peak. (The yellow signal itself is relatively constant in this range, and, relative to other hues at any given luminance level, yellow has minimal neural activity.) A similar analysis holds for equal-luminance chromatic CSF's for blue-yellow modulation around the white point (such as shown in fig. 1). According to theory, then, in regard to the red/green signal, the most appropriate luminance CSF to compare to existing chromatic CSF's would be one obtained at low luminance levels, where neural activity was being modulated from near zero to some just-noticeably higher level. As already mentioned, and as shown in fig. 2, such low-level luminance CSF's are also low-pass; therefore, the most reasonable tentative conclusion that can be reached from existing data is that luminance and chromatic CSF's are similar.

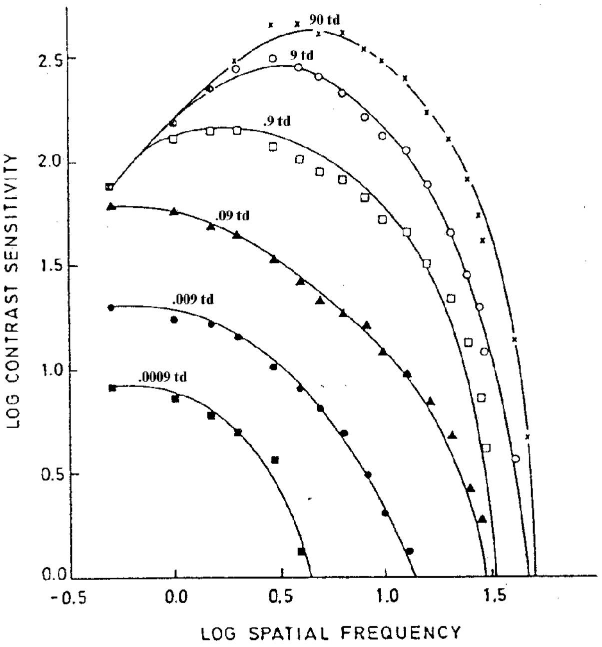

Fig. 2. Luminance contrast sensitivity functions from van Nes and Bouman[2] after a replot by Rohaly and Buchsbaum.[3]

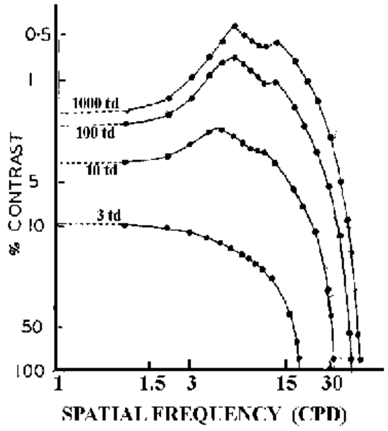

Figure 3. Luminance contrast sensitivity functions from Patel.[4]

Heretofore, an equal-luminance chromatic CSF that *might* be comparable to a high-level luminance CSF has not been determined. The colors of sinusoidal gratings for such a CSF would be centered at a point in chromaticity space that appears highly saturated (i.e., that is associated with high chromatic activity) and they would be modulated (at equal-luminance) along the line that extends from the white point through that center point. That is, the grating would involve purity modulation near the spectrum locus and along an equal-luminance line of constant dominant wavelength. (Or, almost equivalently, it would involve saturation modulation of a highly saturated light along an equal luminance line of constant hue.) With such stimuli, chromatic CSF's would be determined for variations in high levels of chromatic activity just as band-pass luminance CSF's are determined for variations in high levels of luminance activity. (A set of chromatic CSF's, which *might* appear most similar to a luminance set such as shown in fig. 2, would be a very high intensity purity modulation series, with centers varying along a constant dominant wavelength line from near the spectrum locus to near the white point.)

It is important to understand why the word "might" is italicized in the preceding paragraph. For all psychophysical results (not just CSF's), it is generally not possible to compare luminance data with chromatic data without reference to a full model of color vison. In the present context, the question that would have to be answered before even a rough comparison could be made between a given chromatic (say, red) CSF and one from an intensity series of luminance (say, achromatic) CSF's would be, "Which luminance CSF from the intensity series should be assumed to be associated with the same (achromatic) magnitude of neural activity as is associated with the neural signal in the red channel"? That question cannot be answered without reference to a model that quantitatively specifies the relationship between stimulus magnitude and levels of neural signals in the channels that mediate the psychophysical response. (As a matter of fact, as a starting point in theory building in this area, it would be possible to *define* chromatic and achromatic lights as being "equal" when their associated CSF's were identical. The idea might be short-lived, but it would certainly be a reasonable starting point.)

Because it is not possible to vary chromatic signals in the absence of an underlying achromatic signal (as it is possible to vary an achromatic signal--white--in the absence of a chromatic signal) there can be no conceptually neat comparison of CSF's for the luminance channel alone (which is the same as the scaled achromatic channel[5]) with a chromatic channel, alone. However, modulating the luminance of a more or less desaturated unique red (say) light by adding and subtracting whiteness is conceptually mirror-symmetrical to equal luminance purity modulation along the unique red line in chromaticity space. Neurally, the former involves only achromatic modulation on a constant redness background, and the latter involves only redness modulation on a constant achromatic background.

The following text describes an exploratory study of CSF's for a highly saturated, purity modulated red light.

Method

Sinusoidal gratings were viewed monocularly (natural pupil) by 2 color-normal subjects at a distance of 27 in. The display appeared in a full-field black surround and used 8 bits/primary ("Full Color") on a Dell 17LS color monitor with a 1024 x 768 image that was 10.75 in. wide and 8 in. high. The center point of the modulated gratings was at CIE values x = 0.58, y = 0.33, and equal-luminance modulation (with Y = 39 cd/m^2) was along the line in CIE space that connected the monitor red primary (x = 0.61, y = 0.34) to the white point (x = 0.29, y = 0.30). The dominant wavelength of that line is 607 nm. All light measurements were made with a SpectraScan #714 radiometer.

Although a dithering algorithm was used to enhance color resolution, some very recent observations have suggested that there might have been image resolution problems. Accordingly, the data here must be considered tentative.

Subjects instructed the experimenter to increase or decrease purity contrast until they were satisfied that threshold was reached. Frequent zero contrast and high contrast fields were shown to the subjects to aid them in maintaining their criteria for threshold, and to insure that they knew the spatial frequency being presented. Viewing durations were subject-determined, but the highly practiced subjects usually made judgments within one or two seconds.

For subject WW, data were collected at 9 spatial frequencies ranging from 0.3 to 8.4 cpd. Across a total of 5 sessions, the number of observations made at each spatial frequency ranged from 34 (at 0.3 cpd) to 5 (at 8.4 cpd). Over 3 sessions, subject RM was tested at 0.3, 1.2, 2.1 and 4.2 cpd, with the number of observations for each (successively) being 14, 15, 6 and 4. Within session standard errors were too small to plot on the data graphs. Between session means were more variable as shown below.

Figure 4 shows mean CSF's for both subjects. Although

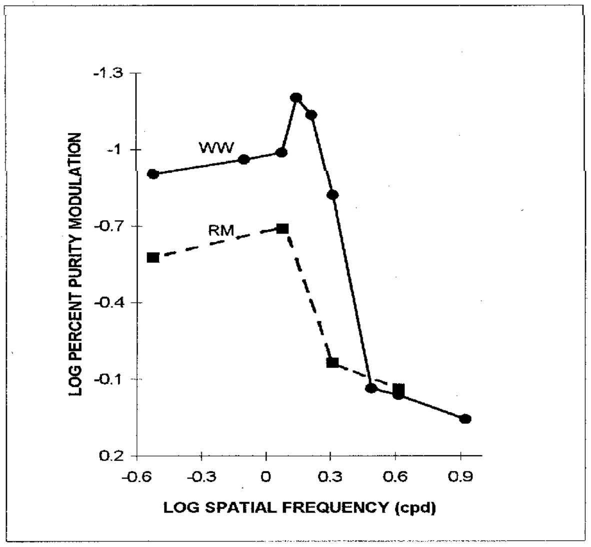

Fig. 4. Mean contrast sensitivity functions for two subjects. Equal luminance purity modulation was around a highly saturated red (dominant wavelength of 607 nm). Plotted values are for the total threshold modulation distance, rather than one-half that value, which is traditionally shown.

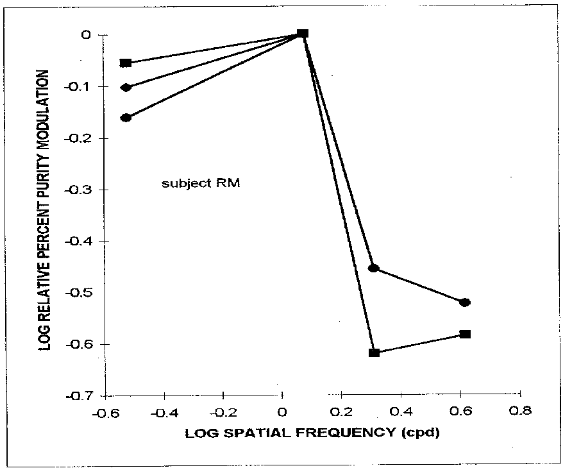

Fig. 5. Results from 3 sessions (one of which involved only 2 spatial frequencies) that together compose the mean function for RM shown in fig. 4. Within-session data are normalized to the value of maximum sensitivity for that session.

the band-pass effect of a drop in sensitivity at low spatial frequencies seems evident, it is small and statistically significant only for subject RM, whose data from each of her three sessions is shown in fig.5. (For reasons that might relate to the image resolution problem that was mentioned earlier, the effect is much smaller than was shown consistently by the author when less systematic pilot data were collected.)

Conclusions

Given the uncertainties associated with the data presented here, it is clear that the question regarding spatial CSF's remains open. However, until it is demonstrated that high intensity and high saturation, purity modulated chromatic gratings have CSF's that are not band-pass, the conclusion that chromatic and luminance CSF's are basically different will remain an unsubstantiated myth.

References

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