Contrast Sensitivity For Lime-Purple and Cyan-Orange Gratings

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Abstract

Measurements of contrast sensitivity are well established[1-8] for modulations in luminance, red-green and yellow-blue color directions in color space. Relatively less work has been carried out, however, to measure contrast sensitivity in other color directions or to assess the effect of the average color of the stimulus has been largely ignored. In this study we have measured conventional contrast-sensitivity functions for iso-luminant red-green and yellow-blue gratings and for gratings in two other color directions that we have nominally called lime-purple and cyan-orange (selected so that they bisect the red-green and yellow-blue directions in Boynton-MacLeod cone space). The measurements were repeated for modulations of cone contrast on chromatic fields (for example, we measured sensitivity to modulations in yellow-blue for gratings whose means colors were either yellow, neutral or blue). Our data show that the contrast-sensitivity functions for all chromatic directions are consistently low-pass irrespective of the average colour of the stimulus. However, we find an interesting asymmetry in that sensitivity to yellow-blue contrast is reduced for blue gratings relative to yellow gratings. This asymmetry is not observed for the red-green colour direction and asymmetries in the lime-cyan and purple-orange colour directions are consistent with an effect of S-cone adaptation. If sensitivity to chromatic contrast depends upon the mean color of the image then sophisticated models of the contrast-sensitivity function (that include, for example, parameters to describe local mean color of the stimulus or image) may be required.

Introduction

The contrast-sensitivity function (CSF) measures the lowest contrast detectable at a given spatial frequency. Under photopic conditions the luminance CSF peaks at about six cycles per degree and falls off for both lower and higher spatial frequencies. Spatial frequencies of between fifty and sixty cycles per degree can be detected for stimuli of high mean luminance.[9] Regardless of the luminance level, sensitivity always decreases sharply with increasing spatial frequency but attenuation at low frequencies is most obvious under photopic conditions. As the luminance level is progressively reduced, the point of greatest sensitivity shifts to lower and lower spatial frequencies[1-3] and at scotopic light levels little attenuation is apparent and the luminance CSF becomes low pass. It is possible that some attenuation still occurs under these conditions but at spatial frequencies lower than those that can be conveniently measured.[4]

Contrast sensitivity has also been measured for iso-luminant stimuli where the modulation activates the red-green or yellow-blue opponent channels.[5-8] Sensitivity for such iso-luminant patterns falls off much more rapidly with increasing spatial frequency and there is little (if any) attenuation of sensitivity to low spatial frequencies. Thus, while the luminance CSF has a band-pass characteristic at photopic light levels, the chromatic CSFs are low pass. Whereas the luminance CSF is typically measured for adaptation fields that provide moderate activation of the luminance channel (luminance is typically modulated around a stimulus of 30-50 cd/m^2) the chromatic CSFs are usually measured for adaptation fields that do not activate the opponent mechanisms (chromatic cone contrast is measured for modulations around chromatically neutral stimuli). It has been tentatively postulated that this difference in the way in which the CSFs are measured could explain why the luminance CSF is band pass whereas the chromatic CSF is low pass.[10] The current study further addresses the issue of the stability of the chromatic CSFs by measuring chromatic CSFs for neutral, weakly chromatic and chromatic adaptation fields. The measurements are also extended to two novel color directions that we call lime-cyan and purple-orange.

Methods

Experiments were carried out using a VSG system and PSYCHO software (version 2.00). A PR650 spectroradiometer was used to characterize the display system. Horizontally orientated sinusoidal gratings were presented to observers who viewed the screen from a distance of approximately 1m in a darkened room. Observers were instructed to fixate to a central cross on the screen and to alter the contrast of the grating using a button box until they experienced a uniform field and could not perceive any detail in the grating. Heterochromatic flicker points were determined for each color direction and for each observer and these were used to ensure that the chromatic gratings were iso-luminant for each observer. The heterochromatic flicker points were determined at a single spatial frequency and assumed to hold for the range of spatial frequencies that were used. Previous studies have indicated that there is little effect on the heterochromatic flicker point with increasing spatial frequency.[11] Contrast sensitivity was measured for six spatial frequencies (2.53, 5.29, 9.7, 14.54, 19.39 and 29.09 cycles per degree of visual angle) and the Method of Limits was used to present each of the six spatial frequencies a total of five times each in a ramdom order. The experiments were carried out using the full field (8^o by 11^o) of the display device for the presentation of the stimulus. Five subjects (three male and two female, aged 24-38) took part in the experiments and they were all tested for normal colour vision using Ishihara plates and had normal or corrected-to-normal spatial acuity. Stimuli were defined in the physiologically based Boynton-Macleod cone space.[12]

Contrast-sensitivity functions were measured for iso-luminant red-green and yellow-blue directions gratings and for two other directions that we have called lime-purple and cyan-orange (selected so that they bisected the red-green and yellow-blue directions in Boynton-MacLeod cone space). Measurements were first made for each of the four color directions for stimuli whose average color was a chromatically neutral point (this was the white point of the monitor with CIE *xy* chromaticity co-ordinates of 0.314 and 0.324) denoted by the star in Figure 1.

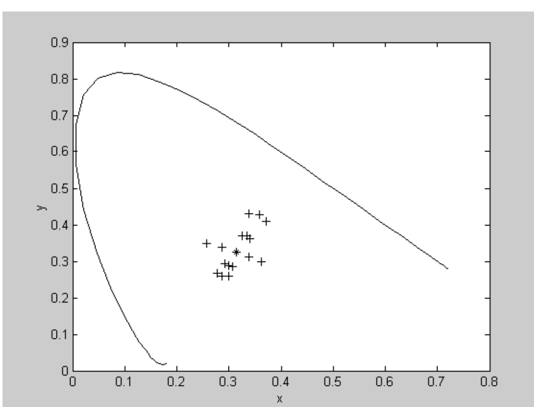

Figure 1. CIE chromaticity diagram to show the white point (asterisk) and the chromatic adaptation points.

CSFs were then measured using modulation around weakly chromatic and chromatic points along each of the color directions. Thus, for each color direction, measurements were made for modulation around each of four chromatic points. For example, the red-green direction was measured around a weakly chromatic (x = 0.339, y = 0.312) and chromatic (x = 0.363, y = 0.300) red field and a weakly chromatic (x = 0.287, y = 0.337) and chromatic (x = 0.257, y = 0.350) green field (see Figure 1).

In Figure 1 although it seems that the lime-purple, cyan-orange and yellow-blue directions are close together this is in fact a property of the CIE chromaticity diagram. In Boynton-MacLeod cone space the four chromatic directions are equally spaced (Figure 2).

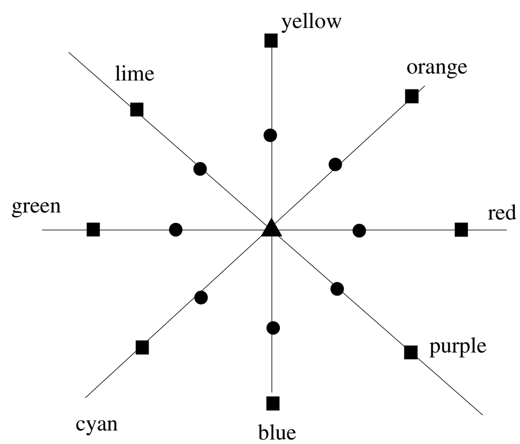

Figure 2. Schematic diagram to how the white point (triangle), weakly chromatic (circles) and chromatic (squares) stimuli definitions in Boynton-MacLeod space. Note that the horizontal (red-green axis) is a line of constant S-cone activation and the vertical (yellow-blue) axis is a line of constant L-M-cone activation.

Note that the four chromatic points for the red-green experiment and the white point of the monitor lay on a straight line of constant S cone excitation in the Boynton-Macleod diagram. Similarly, the four chromatic points for the yellow-blue experiment and the white point of the monitor lay on a straight line of constant L-M cone excitation. Figure 1 illustrates the chromaticities of the adaptation fields used for each of the color directions. For three of the color directions the chromatic adaptation point is between a third and a half of the way towards the spectral locus from the white point.

Results

Figure 3 shows CSFs measured for neutral adaptation fields pooled over all observers for four different mean luminance levels. There is some evidence that the sensitivity of the yellow-blue channel is less than that of the red-green channel. Figures 4-7 show data obtained each of the color directions using weakly chromatic and chromatic adaptation fields.

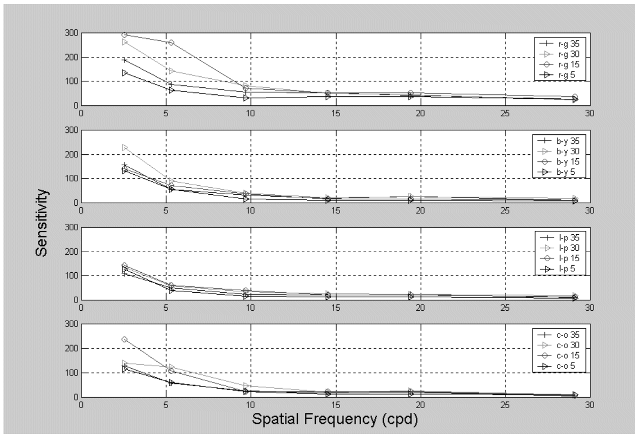

Figure 3. CSFs pooled for all observers and measured using chromatically neutral background.

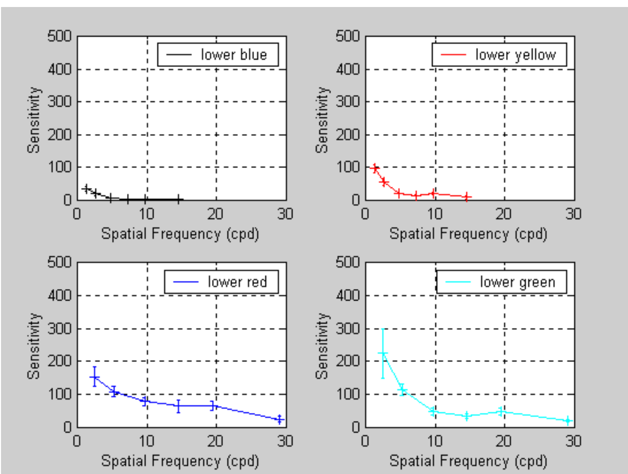

Figure 4. Red-green and yellow-blue CSFs measured for weakly chromatic background fields (pooled over all observers).

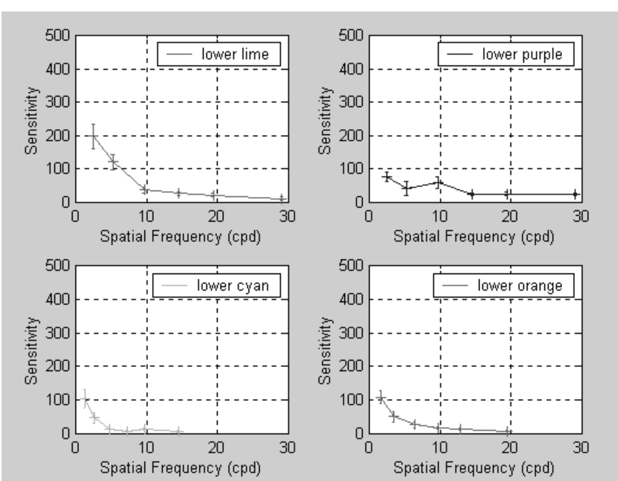

Figure 5. Lime-purple and cyan-orange CSFs measured for weakly chromatic background fields (pooled over all observers).

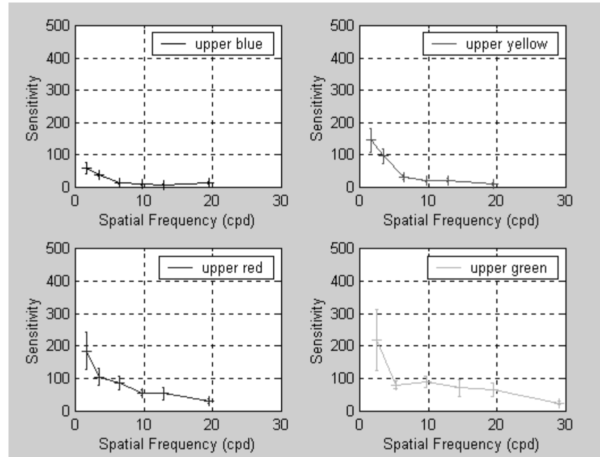

Figure 6. Red-green and yellow-blue CSFs measured for chromatic background fields (pooled over all observers).

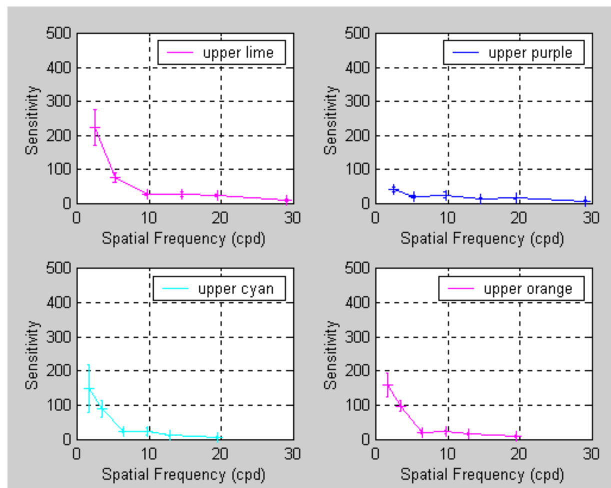

Figure 7. Lime-purple and cyan-orange CSFs measured for chromatic background fields (pooled over all observers).

There is little evidence that the chromatic CSFs exhibit band-pass characteristics when the cone signals are modulated around chromatic stimuli. There is, however, an interesting asymmetry; the sensitivity of the yellow-blue channel is greater when the adapting field is yellow than when it is blue. This asymmetry is observed for both weakly chromatic (Figure 4) and chromatic (Figure 6) adaptation fields.

Discussion

Guth suggested that the low-pass characteristic that is associated with measurements of the chromatic CSF might be caused by the fact that most measurements are made using a neutral adaptation field[10]. The measurements in this study, made for weakly chromatic and chromatic adaptation fields, consistently show low-pass shapes. However, we note that Guth used "purity" modulated iso-luminant red gratings that were highly chromatic. Further experiments to measure chromatic CSF for highly chromatic stimuli may yet reveal band-pass effects but this study shows that over a wide range of conditions the low-pass shape is reliable. However, some interesting asymmetries have been revealed in the data. The yellow-blue contrast sensitivity is much reduced when the modulations are around a blue field compared with modulations around a yellow field. The same asymmetry is not evident for the red-green data. One possible explanation for this is that the contrast sensitivity of the yellow-blue stimuli at threshold is proportional to the activation of the S cones. An equivalent effect might not be expected for the red-green channel because the red-green channel would be approximately equally excited (but with opposite sign) for both red and green fields. We might expect, however to find that sensitivity to lime-purple contrast would be greater for the lime adaptation point than for the purple adaptation point. Similarly, we would expect that sensitivity to cyan-orange contrast would be greater for the orange adaptation point than for the cyan adaptation point. The data shown in Figures 4 and 5 broadly agree with these expectations.

These asymmetries have implications for many models of visual processing that use estimates of the chromatic CSFs. If sensitivity to chromatic contrast depends upon the mean color of the image then sophisticated models of CSF (that include, for example, parameters to describe local mean color of the stimulus) or image may be required. Furthermore, recent experiments suggest that sensitivity to luminance contrast is greater when the luminance is modulated around an achromatic field than when it is modulated around a chromatic field13. Estimates of luminance contrast sensitivity derived from experiments using achromatic stimuli may therefore over-estimate the visual system's sensitivity to luminance contrast when colored scenes are viewed.

Acknowledgement

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Biography

Huw Owens obtained a BSc in Computer Science and Business Studies and an MSc in Machine Perception and Neurocomputing. He was recently awarded his PhD at the Colour & Imaging Institute at the University of Derby where he worked on spatiochromatic processing in humans and machines. He is currently working as a Research Fellow at the Colour & Imaging Institute in the area of image-quality assessment.