

Chromatic assimilation: spread light or neural mechanism?

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Abstract

Chromatic assimilation is the shift in color appearance of a test field toward the appearance of nearby light. Possible explanations of chromatic assimilation include wavelength independent spread light, wavelength-dependent chromatic aberration and neural summation. This study evaluated these explanations by measuring chromatic assimilation from a concentric-ring pattern into an equal-energy-white background, as a function of the inducing rings' width, separation, chromaticity and luminance. The measurements showed, in the *s* direction, that assimilation was observed with different inducing-ring widths and separations when the inducing luminance was lower or higher than the test luminance. In general, the thinner the inducing rings and the smaller their separation, the stronger the assimilation in *s*. In the *l* direction, either assimilation or contrast was observed, depending on the ring width, separation and luminance. Overall, the measured assimilation could not be accounted for by the joint contributions from wavelength-independent spread light and wavelength-dependent chromatic aberration. Spatial averaging of neural signals explained the assimilation in *s* reasonably well, but there were clear deviations from neural spatial averaging for the *l* direction.

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1. Introduction

The perceived color of a light is well known to depend not only on its spectral power distribution but also on other light nearby. The change in color appearance due to nearby light is called chromatic induction. There are two qualitatively different types of induction: chromatic contrast and chromatic assimilation. Chromatic contrast occurs when the color appearance of a test light shifts away from the color appearance of the nearby inducing light. Chromatic assimilation occurs when the appearance of the test light shifts toward the color appearance of inducing light.

Chromatic contrast has been studied extensively for more than 160 years (for example, Chevreul, 1839; Jameson & Hurvich, 1955; Shevell & Wei, 1998; von Kries, 1905; Ware & Cowan, 1982) but chromatic assimilation has received less attention. Assimilation was described in the 19th century by von Bezold (1876) and may, in fact, be more common than contrast (DeValois & DeValois, 1988). Powerful demonstrations of chromatic assimilation are given by Hurvich (1981) and Shevell (2003). The purpose of this study is to systematically measure chromatic assimilation and to assess the physiological mechanisms posited to mediate it.

1.1. Possible explanations for chromatic assimilation

The possible explanations for chromatic assimilation can be divided into two classes: non-neural and neural. Non-neural theories explain assimilation by changes

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that occur in the retinal stimulus, prior to transduction. Explanations that involve neural mechanisms include retinal and cortical processes. Some neural theories account for assimilation in terms of receptive-field organization (DeValois & DeValois, 1975; Hurvich & Jameson, 1974; Monnier & Shevell, 2004) or tuned spatial filters (Blakeslee & McCourt, 1999). Other theories suggest assimilation depends on higher-level perceptual cues, such as the geometric structure of the stimulus, perceptual organization, figure/ground segregation, or perceptual grouping (de Weert & van Kruysbergen, 1997; Festinger, Coren, & Rivers, 1970; Taya, Ehrenstein, & Cavonius, 1995; Todorovic, 1997; Zaidi, Spehar, & Shy, 1997).

Non-neural explanations for assimilation include wavelength-independent spread light and wavelength-dependent chromatic aberration (Helson, 1963; Smith, Jin, & Pokorny, 2001; Wright, 1969). Non-neural factors can lead to assimilation because they change the quantal absorption within the retinal area of the test region. Wavelength-independent spread light is due to optical imperfections and scattered light. Wavelength-dependent chromatic aberration occurs because the lens of the eye refracts short-wavelength light more than long-wavelength light. A distant short-wavelength target is never exactly in focus on the retina (Kaiser & Boynton, 1996) so short-wavelength light is blurred in the retinal image.

Smith et al. (2001) estimate the contribution of wavelength-independent spread light to assimilation for an equiluminant square-wave grating, using a line-spread function developed by Williams, Brainard, McMahan, and Navarro (1994). Their calculations show that chromatic assimilation with their gratings may be accounted for by spread light. At the same time, they conclude that chromatic aberration is not a major source of assimilation at spatial frequencies at or below 9 cpd.

Wavelength-independent spread light and chromatic aberration undoubtedly contribute to chromatic assimilation. Numerous studies, however, conclude that chromatic assimilation cannot be accounted for entirely by these non-neural processes (de Weert & van Kruysbergen, 1997; Fach & Sharpe, 1986; Helson, 1963; Longere, Shevell, & Knoblauch, 2000). These studies strongly suggest that neural processes contribute to chromatic assimilation.

Neural spatial integration within receptive field centers is proposed to explain assimilation (DeValois & DeValois, 1975; Hurvich & Jameson, 1974; Jameson & Hurvich, 1989). In a repetitive stimulus pattern causing assimilation, neurons with small receptive fields may resolve the pattern but, simultaneously, responses from the same photoreceptors may drive other neurons with larger receptive fields that combine responses from nearby photoreceptors. The net response from a neuron with a larger receptive field can lead to assimilation. In a sim-

ilar approach, de Weert and van Kruysbergen (1987) and de Weert (1991) propose that large receptive fields without center-surround antagonism account for assimilation. Assimilation would result from local averaging within these large receptive fields. Moulden, Kingdom, and Wink (1993) also propose neural summation to explain why a checkerboard consisting of alternating squares with complementary colors appears achromatic at higher spatial frequencies. Recent physiological evidence adds support to the proposal that there are two sets of neurons sensitive to chromatic information, one band pass and one low pass (Johnson, Hawken, & Shapley, 2001).

In contrast to models that incorporate neural responses from spatial filters, other investigators propose that assimilation is due to higher-level mechanisms of visual representation. For example, Fuchs (1923), King (1988) and Taya et al. (1995) argue that assimilation depends on object segmentation or perceptual belongingness. Other researchers posit that figure/ground segregation affects assimilation (de Weert & van Kruysbergen, 1997; Festinger et al., 1970).

While most studies agree that a neural process contributes to assimilation, the nature of the neural mechanisms remains unclear. The purpose of this study is to systematically investigate how chromatic assimilation varies with the width, separation, chromaticity and luminance of the inducer, using a stimulus pattern with both chromatic and luminance variation. These results rule out the possibility that spread light and chromatic aberration are a full explanation of chromatic assimilation, and support the view that neural summation contributes to chromatic assimilation.

2. Methods

2.1. Apparatus

All stimuli were displayed on a calibrated, high-resolution (1360 × 1024) color 21-inch Sony Trinitron CRT, which was controlled by a Macintosh G4 computer with a 10-bit Radius video board. The refresh rate was 75 Hz noninterlaced. The stimuli on the CRT were viewed haploscopically at a viewing distance of 1.15 m. The stimulus on the right side of the CRT screen was projected to the right eye and the stimulus on the left side of the CRT screen to the left eye. An adjustable chin rest maintained the observer's head position.

2.2. Stimuli

A test field and a uniform matching field were steadily presented through the haploscope (Fig. 1a). The uniform matching field was viewed by the observer's right eye. Its diameter was 3°. The test field, viewed by the ob-

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