Brightness contrast inhibits color induction: evidence for a new kind of color theory

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Abstract—A gray region can be made to look colored by a colored surround. This phenomenon, chromatic induction, depends on color differences around the boundary of the region. We performed experiments on chromatic induction with small, initially achromatic, targets on nine different colored surrounds ranging in color from blue to red. Using scaling of saturation as our measure of perceived color strength, we found that chromatic induction is at its maximum when the brightness contrast at the boundary between target and surroundings is minimal. This implies that the neural mechanism in the cerebral cortex that mediates the appearance of brightness at a boundary inhibits the activity of chromatic mechanisms at that same boundary. Observers matched the apparent brightness and luminance of each of the colored surrounds. For surround colors where brightness and luminance matches differ, brightness contrast, not luminance contrast, controls chromatic induction. These new findings, taken together with other evidence, require a new theory of color appearance that includes mutually inhibitory interactions between color and brightness mechanisms that are sensing color and brightness contrast at visual boundaries.

Keywords: Color induction; brightness contrast; color contrast; saturation; mutual inhibition; edges; Kirschmann’s 3rd Law.

INTRODUCTION

The perception of the color of a surface depends strongly on the color difference across the boundary of the surface, on visual edge contrast (Krauskopf, 1963; Yarbus, 1967; Valberg, 1974; Grossberg and Mingolla, 1985; Krauskopf et al., 1986; Ratliff, 1992; Shevell and Wei, 1998). One of the most striking visual phenomena illustrating the power of edges to influence the visual perception of surfaces they enclose is chromatic induction: the visual perception of surface hue on an achromatic surface caused by the hue around its boundary. Even though

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one is aware that the interior surface has not changed physically, it changes hue perceptually. There are some results that suggest that much of the hue assigned to a surface by the brain is a result of edge contrast rather than local reflectance. In stabilized vision, hue fills in long distances from an unstabilized boundary (Krauskopf, 1963; Yarbus, 1967), and this can even be seen with voluntary fixation in the periphery of the visual field (Krauskopf, 1963).

Mysteriously, chromatic induction can be variable in strength, and sometimes seems weak, especially in unconvincing textbook demonstrations. This variability can be accounted for in part by our present findings that magnitude of brightness contrast at an edge reduces chromatic induction from that boundary. Figure 1 is a demonstration of what we have found: this figure shows the induction of hue into gray targets by a green background. In this figure, the large surrounding regions are uniform in brightness and chromaticity — green to the left and gray to the right. The surrounds are adjusted to be approximately the same perceived brightness. On each surround there is a column of square-shaped targets that increase in brightness from bottom to top. At each height in the figure, the square in the gray surround and the square on the green surround are physically identical. The maximal induction of redness occurs in the targets in the middle of the figure on the green surround. These are the squares whose brightnesses are nearly equal to that of the green surround (see Fig. 1, legend). In perceptual experiments using many different background hues, we measured that maximal chromatic induction occurs always at or around the point of equal brightness between target and surround, whatever the hue of the inducing background. When the target is brighter or darker than the surrounding colored region, the induced hue is less. This implies that there are inhibitory interactions in the visual system between achromatic and chromatic signals evoked at surface boundaries.

Our findings bear on a long-standing dispute about the fundamentals of spatial effects on color perception. The laws of chromatic induction were early findings in psychophysics. Kirschmann’s 3rd Law (Kirschmann, 1891) stated that chromatic induction was greatest when brightness contrast was minimal. Subsequently the 3rd Law was disputed, particularly by Kinney (1962), who stated that chromatic

Figure 1. (See color plate V) Demonstration of dependence of chromatic induction on brightness contrast. There are nine square targets on each rectangular surround; each horizontal pair of targets is identical in spectral energy distribution and brightness. On an achromatic surround each target appears colorless (right panel) and target brightness increases from bottom to top. On the green surround (left panel), the targets near the middle of the picture take on a pink hue complementary to the hue of the surround.

The two surrounds are approximately matched for brightness, and the fifth target in the middle of the vertical array is equal in brightness (this may vary somewhat across observers and across displays) to the brightness of the gray surround — so the small square target disappears on the right hand side because the small square and the background are the same brightness (that is, there is zero contrast). For most subjects the fifth target in the left (green) panel is perceived as the most saturated pink of the nine targets; it is the target with least brightness contrast. Saturation decreases for targets both below and above this target.