Changes in color appearance caused by perceptual grouping

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Abstract
How is chromatic induction affected by perceptual grouping? Chromatic induction has been studied extensively, as has grouping, but only a small number of experiments have connected them. Even fewer reports go beyond weakly controlled qualitative observations. We report here a new and substantial color shift caused by perceptual grouping: a shift in appearance due to chromatic induction in one part of the visual field occurs also in a separate region that belongs to the same group. The color appearance of a test square within various surrounds was measured by asymmetric matching. The test square was at the center of an “hourglass” structure formed by other elements in the surround. The test shifted in color appearance toward the appearance of these other elements, whose color was affected by local chromatic induction. Control experiments ruled out as explanations (1) direct chromatic induction from the other elements into the test area, and (2) the influence of background light occluded by introducing the elements forming the hourglass.

Keywords: Perceptual grouping, Chromatic induction

Introduction
Chromatic induction is a well-known perceptual phenomenon. The hue of one light is perceived to shift when presented in proximity to other light of a different chromaticity. While induction often is modeled using low-level mechanisms, such as retinal lateral inhibition for contrast (Jameson & Hurvich, 1961; de Weert, 1991) or physical light spread for assimilation (Smith et al., 1998), many studies posit a cortical mechanism because induction can be influenced by contralateral adaptation and by perceptual properties such as depth and form (Gilchrist, 1977; Adelson, 1993; de Weert & van Kruysbergen, 1997; Shevell & Wei, 2000).

Several perceptual properties, such as depth, form, and brightness, which affect chromatic induction, also play a role in perceptual grouping. This suggests a possible connection between chromatic induction and perceptual grouping. Perceptual grouping is a cornerstone of Gestalt psychology (Wertheimer, 1923/1938; Koffka, 1935). Wertheimer (1923/1938) observed that the phenomenon of apparent motion requires that observers perceive visual stimuli as well-organized patterns rather than as separate component parts. This implies that the whole is different than the sum of each part (Koffka, 1935). The visual world we see is a structured and cohesive “whole” rather than a group of isolated and independent fragments.

Perceptual grouping may cause components perceived in the same group to appear more alike than they actually are physically (Kaniza, 1988). A connection between induction and perceptual grouping, therefore, is implicit in some theoretical frameworks. King (1988, 2001), for instance, proposes that assimilation is due to the perception of fragments integrated into one “whole” (or group), whereas contrast is due to the perception of two “wholes”. We use the inclusive term “induction” to describe color-appearance changes that may be due to both contrast and/or assimilation.

Previous studies do not provide compelling evidence for a link between grouping and chromatic induction. Using a subtle demonstration from Fuchs (1923), van Lier and Wagemans (1997) find the judged color appearance of a target shifts toward to other objects in the same group. Their results, however, show only weak induced color-appearance changes. A more recent demonstration (de Weert & van Kruysbergen, 1997) does not include systematic measurements from a controlled laboratory environment. Rigorous quantitative experiments are necessary to assess whether large induced color shifts follow from perceptual grouping.

The current study defines perceptual grouping as a visual process that associates distinct, discrete physical elements in a scene with one another, based on specific features in common. Grouping is assumed to distinguish and segment structures or objects. The working hypothesis, from King (1988, 2001), is that chromatic assimilation occurs within a single structure or object.

Materials and methods

Apparatus
All stimuli were presented on a colorimetrically calibrated cathode ray tube (CRT) display (Sony CPD-G520, 75 Hz refresh rate), which was controlled by a Macintosh G4 computer with a Radius
video board (10 bits per gun). The program for the experiments, written in the C programming language, allowed stimuli to be specified according to their chromaticity values in a cone space derived from the Judd (1951) color-matching functions. The stimuli were viewed binocularly at a distance of 1 m. A chin rest maintained a stable head position.

Stimuli

The observers viewed two 5.5-deg square fields on an otherwise dark CRT screen with 1.9-deg separation between them (Fig. 1). The left field was composed of a comparison surround nearly metamic to equal energy white (EEW) and a comparison square of width 11 min of arc. The initial chromaticity of the comparison square was randomly selected at the start of each trial. A similar small test square (11 min of arc wide) was centered within a surround in the right field. A chin rest maintained a stable head position.

Both the stimuli and measurements were represented along the \( l = L/(L+M) \) and \( s = S/(L+M) \) axes of a modified MacLeod–Boynton isoluminant cone excitation diagram (MacLeod & Boynton, 1979). The modification was that the unit of \( s \) was normalized to 1.0 for EEW, unlike the original MacLeod–Boynton diagram. Alternating purplish and greenish stripes in the test surround had, respectively, \( l \) and \( s \) chromaticities (0.665, 1.79), labeled \( +s \), and (0.665, 0.25), labeled \( -s \). Three test chromaticities were used, all of which were equal in \( s \): (0.685, 1.02), (0.665, 1.02), and (0.645, 1.02). The chromaticity of the comparison background was (0.665, 1.02). The choice of chromaticities of the surrounding stripes and the tests was based on previous work (Monnier & Shevell, 2003), in which large induced color shifts were observed along the \( S/(L+M) \) direction. The luminance of both the comparison and the test surrounds was fixed at 15 cd/m². The luminance of the test square and the physically identical inducing bars was fixed at 20 cd/m² so the test was a luminance increment relative to its surround. A higher luminance of the test than the surround was used to reduce the influence of spread light into the test area and to prevent border fading under equal luminance.

Procedure

Asymmetric color matches assessed the appearance of the test square presented with various surrounds. Observers used a Gravis gamepad to set the hue, saturation, and brightness of the comparison square so that it matched the appearance of the test square. Observers practiced color matching in preliminary sessions prior to data collection.

The experiments were conducted in a dark room. A 3-min period of dark adaptation was followed by a 1-min period of light adaptation to the two surrounds. Then the test and comparison squares were introduced, and the observer adjusted the comparison square to match the appearance of the test square. No fixation point was presented; observers were free to move their gaze across the display. Five consecutive matches (a “block”) for each test condition, defined as a given test-square chromaticity and surround, were made in each session. All test chromaticities were tested within a session. The test-chromaticity blocks were randomly ordered in every session. Each experimental condition was repeated on 3 days. The means and standard errors in plots were computed from three average measurements, each from a block run on a different day.

Observers

Two observers (age 25 and 27 years) participated in the experiments. Observer R.S. was naïve about the purpose of the study. Author S.X. had previous experience with color matching and was aware of the experimental design. Both observers had normal color vision as determined by Rayleigh matching. The experimental stimuli were adjusted for equiluminance for each individual using

![Fig. 1. A schematic diagram of the stimuli (see text).](image-url)
heterochromatic motion photometry (Anstis & Cavanagh, 1983). In addition, for each observer, a tritanopic confusion line was determined at equal luminance using the minimally distinct border technique (Tansley & Boynton, 1978). The observers completed consent forms in accordance with the policy of the University of Chicago’s Institutional Review Board.

Results

Experiment 1: Grouping alters color perception

The first experiment tested whether grouping affected the color appearance of the test square when inducing bars were introduced into its surround, and the test square was perceived as part of the hourglass structure formed with the inducing bars.

As a control, isomeric matches were measured with a uniform EEW test surround (solid gray circles, Fig. 2). Each panel shows measurements from a different observer. The original test chromaticities are shown as small solid circles, and are very close to the isomeric matches.

Measurements with various test surrounds and with the test square on a +s (or −s) surrounding stripe are shown in Fig. 2a (2b). Induction from the alternating purplish and greenish stripes (no inducing bars) caused shifts toward the stripe chromaticity above and below the test square (open circles, Fig. 2). These were baseline measurements for all other conditions, which considered the influence of grouping. Note the shifts were away from the isomeric match and primarily in the s direction. The test-square’s appearance shifted in the greenish (lower s) direction when it was on a +s (purplish) surrounding stripe, and in the purplish (higher s) direction when on a −s (greenish) stripe. These results were consistent with a previous study that examined chromatic induction from patterned chromatic surrounds (Monnier & Shevell, 2003).

Next, consider cases with the test square on a +s surrounding stripe. When six inducing bars that formed an “hourglass” struc-

![Fig. 2. Color-appearance matches from Experiment 1 for two observers. (a) The top two panels show measurements with the test square on a + s surrounding stripe. (b) The bottom two panels show measurements with the test square on a − s surrounding stripe. In all panels, solid black circles represent physical test chromaticities; solid gray circles represent isomeric matches; open circles represent measurements with a single test square and surrounding stripes (no inducing bars); upward-pointing triangles represent measurements with inducing bars on the same chromaticity of stripes as the test; downward-pointing triangles represent measurements with inducing bars on a different chromaticity of stripes than the test; black or gray Xs represent matches to the longest inducing bar presented alone on a + s or − s stripe, respectively.](image-url)
ture with the test square were also on $+s$ surrounding stripes, the test square’s appearance shifted further in the greenish direction, to even lower values of $s$ than without the inducing bars (upward-pointing triangles below open circles, Fig. 2a). On the other hand, when these six inducing bars were on $-s$ surrounding stripes, the measurements usually shifted in the purplish direction (higher values of $s$; downward-pointing triangles above open circles and shifted back toward the isomeric matches, Fig. 2a).

A similar pattern of results was found with the test square on a $-s$ surrounding stripe. Six inducing bars on $-s$ surrounding stripes caused the test-square’s appearance to shift in the purplish direction toward higher values of $s$ (upward-pointing triangles above open circles, Fig. 2a). When the inducing bars were on $+s$ surrounding stripes, however, the measurements were shifted in the greenish direction (lower values of $s$; downward-pointing triangles below open circles, Fig. 2b). In sum, the color appearance of the test square shifted when the inducing bars were moved from the purplish to the greenish surrounding stripes.

To reveal the direction of the test’s color shift in relation to the locally induced color appearance of the inducing bars, the appearance of the widest inducing bar, presented alone, was measured on either a $+s$ or $-s$ surrounding stripe (black or gray X, Fig. 2). No other inducing bar or test square was presented. Compared to the original chromaticity of the bar, the appearance of the bar shifted in the greenish direction (lower in $s$; downward-pointing triangles below open circles, Fig. 2b). In sum, the color appearance of the test square shifted when the inducing bars were moved from the purplish to the greenish surrounding stripes.

Fig. 3. Color-appearance matches from Experiment 2, in which the test square was presented with vertical inducing bars. Diamonds represent results with vertical inducing bars; crosses represent matches to the longest vertical inducing bar presented alone. Other symbols are as in Fig. 2.
shown in Fig. 2, this shows that introducing inducing bars to form an hourglass structure caused the test square to shift toward the appearance of the inducing bars with which the test was grouped.

Experiment 2: Vertical inducing bars

According to the main hypothesis, grouping causes an object (the test square) to look similar to other elements (the inducing bars) within the same structure (the hourglass). This was tested further with inducing bars rotated 90 degrees so they were vertically positioned beside the test square, while still maintaining the hourglass structure. First, measurements of the longest vertical inducing bar presented alone showed that its color appearance was closer to the isomeric match than to the test square alone (compare black crosses to open circles, Fig. 3). Then, with the vertical inducing bars in the surround, the test was found to shift toward the isomeric matches (both black and gray diamonds closer to isomeric matches than both open circles, Fig. 3). These results again were consistent with the hypothesis that chromatic assimilation occurs among elements belonging to the same group.

Experiment 3: Controls

Two control conditions ruled out explanations based on separate effects of the inducing bars and of the surrounding stripes. First, in order to evaluate induction from the inducing bars alone, the appearance of the test square was measured on a uniform EEW test surround with the six inducing bars forming the hourglass structure...
(solid black circles, Fig. 4). The results were very similar to the isomeric matches, which showed that induction from the inducing bars alone was negligible.

Second, note that the inducing bars replaced some of the light in the purplish and greenish surrounding stripes. A control experiment tested whether light removed from the surrounding stripes could explain the color-appearance shifts caused by the inducing bars. Removing light in the region of the inducing bars, so this area was dark, did not affect the color appearance of the test square (see overlapping triangles, diamonds, and open circles, Fig. 4).

Discussion

In the experiments described above, inducing bars caused the color appearance of a test square to change. The change in appearance of the inducing bars within different surrounds is an example of local chromatic induction (Monnier & Shevell, 2003). Local chromatic induction was used here to make physically identical inducing bars appear different, depending on nearby surrounding light. The color appearance of the noncontiguously located test square was shown to shift toward the appearance of the inducing bars. Traditional mechanisms of chromatic induction cannot explain the color-appearance changes in the test square.

The appearance of the test square was altered by distant inducing bars at the same chromaticity, which appeared different only because of local chromatic induction. The process mediating the color of the test must follow local induction, implying a higher level visual mechanism. Perceptual grouping was posited here to cause the test-square’s change in color appearance. The working hypothesis, that chromatic assimilation occurs among objects perceived to belong to the same group, accounts for all of the measurements.

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References


