Chapter 38

Color and Luminance

Afterimages, Combinations, and Flicker

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Afterimages

Color and luminance interact in many ways in the human visual system. For instance, the colors in an afterimage, which are due to adaptation of retinal cones, are especially vivid when test contours, presented after the adapting image, coincide with the blurred edges of the afterimage. Daw (1962) first discovered that colored afterimages were much more visible if they were superimposed on a congruent luminance-defined test pattern. A fine example is demonstrated in Sadowski's well-known "Spanish castle illusion" (see www.johnsadowski.com/big_spanish_castle.php).

Van Lier, Vergeer, and Anstis (2009) showed that the same adapting pattern can induce multiple, differently colored afterimages at test locations that were not adapted to color (Video III.38-1). This was because afterimage colors spread out and average spatially within test contours but not across them.

[insert Video III.38-1]
[insert Video III.38--2]

The adapting field in Video III.38-2 is a plaid composed of a horizontal red/green grating transparently superimposed on a vertical blue/yellow grating. Following adaptation to this plaid, if one inspects a plain white test field, one sees a conventional negative afterimage. But if the test field contains black horizontal lines, congruent with the edges of the adapting grating, the afterimage consists of a red/green grating. If the test field contains vertical lines, the afterimage is a blue/yellow grating.

[insert Video III.38-3]

Video III.38-3 shows that second-order test contours made of moving stripes can also constrain the spread of color just as effectively as the luminance test contours in Video III.38-2. Thus the observed filling-in of afterimage colors strongly depends on the test contours presented after the colored stimulus, revealing color–contour interactions that resemble filling-in of “real” colors. This suggests that afterimage colors tend to spread perceptually in a diffusion-like manner, until they encounter a luminance contour that arrests the spread (Grossberg, 2003; Kim & Francis, 2011).

Luminance Gates Color: Looking at Two Paintings at Once

Luminance signals are produced by the sum of the R, G, B retinal cones and color signals by the differences between these cones. Luminance and color pathways have very different spatial properties. Acuity is much higher for luminance contours than for color contours, and it seems that colors diffuse out until they meet a luminance contour (Grossberg, 2003; Kim & Francis, 2011). Thus if a colored picture is split into its luminance and color components, and the color component is blurred before the components are recombined, then the picture still looks much the same (Wandell, 1995). This difference can be brought out by a new *two-picture* effect (Anstis, Vergeer & Van Lier 2012a, b), which demonstrates how a grayscale picture can gate or select a fuzzy chromatic picture in the presence of noise. In short, two paintings, O1 and O2, are split into their luminance (greyscale) components L1 and L2 and their color components C1 and C2. The two color components C1 and C2 are transparently superimposed. Adding the greyscale of the first painting (= C1 + C2 + L1) looks like the original O1, while adding the greyscale of the second painting (= C1 + C2 + L2) looks like the original O2. In conclusion, the luminance contours select or gate the congruent–color contours and ignores noncongruent colors from the other painting. Two full-length portraits of about the same size and shape are superimposed in this example: *The Blue Boy* (1770), by Thomas Gainsborough (1727–1788), Huntington Art Gallery, San Marino, California; and *La Source* (1856), by Jean-Auguste-Dominique Ingres (1780–1867), Musee d'Orsay, Paris. These paintings have very different colorings. *The Blue Boy* is in cool bluish tones while *La Source* is infused with warm flesh tones. Each painting is first split into its luminance (greyscale) component and its chrominance (color) component, and each component is saved as a separate file (a web tutorial on this technique is given by John Sadowksi at http://www.johnsadowski.com/color_illusion_tutorial.html).

Of course simply superimposing the luminance and chrominance components of a single painting would restore the original. But instead, just the color components of *both* paintings are superimposed in Figure III.38-1. On its own, this looks like a fuzzy mess. But Figure III.38-1 shows two copies of this double-chromatic mess. On one is transparently superimposed the luminance component of *The Blue Boy* and on the other the luminance component of *La Source.*

[insert Figure III.38-1]

Thus each frame is a triple-layer sandwich of two chromatic pictures (same in both) and one luminance picture (different in each). These two frames are shown enlarged in Figure III.38-2. Although each frame is somewhat desaturated by a veil of color, *The Blue Boy* luminance picture makes the whole image look like the original *Blue*

Boy painting, with *La Source* virtually invisible. Conversely, the original *La Source* painting is perceived when the triple-layer sandwich contains the *La Source* luminance picture, with *The Blue Boy* nowhere to be seen. Thus each greyscale picture perceptually amplifies the colors that are congruent with it and de-emphasizes the noncongruent colors. This is like a visual analog of the auditory cocktail party problem. It is as though the luminance contours pick out the colors that coincide with them but ignore noncoincident colors. Color filling-in phenomena like these are thought to occur by means of a contour-based filling-in mechanism (Grossberg, 2003). Thus luminance perception dominates and guides color perception.

insert Figure III.38-2

Flicker-Augmented Contrast

It is well known that a grey cross looks darker when it is on a light background and lighter when it is on a dark background (Heinemann, 1955). This is illustrated in the top row of Video III.38-4.

[insert Video III.38-4]

In 1998 Alan Ho and I (Anstis & Ho 1998) noticed an effect that we called "flicker-augmented contrast" (FAC). If the cross flickers between black and white at, say, 8Hz, instead of being a steady grey, the impression of simultaneous contrast is greatly enhanced, and a flickering cross looks black on a light background and white on a dark background (second row of Video III.38-4). It turns out that FAC does not work by enhancing the lateral inhibition that is thought to underlie simultaneous contrast (Creutzfeldt, 1993), since FAC is not an induction process but a selection process. The visual system selects the more salient edges, that is, those with the higher Michelson contrast, at the expense of the less salient. In the bottom row of Video III.38-4 the crosses are colored, alternating between dark blue and light yellow. Here a cross looks blue on a light background and yellow on a dark background. Clearly the achromatic light and dark backgrounds contain no colors themselves so they cannot induce colors into the cross. Instead, it is the difference in luminance between the cross and the background that determines the salience and drives the FAC selection process. The dark (blue) is more salient against the light background, and the light (yellow) is more salient against the dark background. When a stimulus appears to vary in salience over time, as the crosses do here, it makes sense for the visual system to pick the most salient and contrasty version of the stimulus.

References

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Video III.38-1.

A partly colored eight-pointed star is followed by two differently oriented four-pointed stars. The four-pointed star outline that includes the previously colored green points appears to be filled in with a red afterimage color, whereas the subsequently presented four-pointed star outline that includes the red points appears to be filled in with a green afterimage color. That is, the perceived colors of the afterimage depend on the geometry of black/white test contours.

Video III.38-2.

A single adapting pattern can give very different colored afterimages, depending on the test field. The adapting plaid was made by superimposing a vertical blue/yellow grating on a horizontal red/green grating. A uniform white test field would simply show a negative afterimage. But the thin black vertical lines in the test field enhance the blue/yellow vertical components of the afterimage, while the black horizontal test lines enhance the red/green horizontal components of the afterimage.

Video III.38-3.

Second-order test bars made of moving achromatic random dots also induce the colored afterimages.

Video III.38-4.

Flicker augmented contrast. Top row: Simultaneous contrast. The crosses are all the same grey, but the left-hand ones on the light surround look somewhat darker than the right-hand ones on the dark surround. Middle row: The crosses all flicker together between black and white. Now the simultaneous contrast is much enhanced; the leftmost cross looks almost black and the rightmost cross looks almost white. Bottom row: The crosses all flicker together between dark blue and light yellow. Now the leftmost cross looks dark blue and the rightmost cross looks light yellow. These apparent colors cannot be directly induced by the achromatic surround. Instead, the visual system selects the most salient edges with the highest luminance differences—blue/white on the left and yellow/black on the right.

Figure III.38-1.

The two original paintings, *The Blue Boy* (O1) and *La Source* (O2) are split into their luminance components (L1, L2) and their color components (C1, C2) (second row). These are recombined, and transparently superimposed, in a two-frame movie (third row). Frame 1 contains *both* color pictures plus L1, and frame 2 contains *both* color pictures plus L2. Result: The luminance pictures dominate and gate the colors, so Frame 1 looks like *The Blue Boy*, while Frame 2 looks like *La Source* (see also Video III.38-1).

Figure III.38-2.

(a) Contains C1 + C2 + L1 and looks like O1 (*The Blue Boy*). (b) Contains C1 + C2 + L2 and looks like O2 (*La Source*). Conventions same as for Figure III.38-1.