Attention, Perception, & Psychophysics
2010, 72 (4), 891-893
doi:10.3758/APP.72.4.891

Metameric intransitivity

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There are two kinds of afterimages. In negative afterimages, looking at a blank field after staring at a colored figure gives a figure whose color is complementary to that of the original figure. Less well understood and studied is the phenomenon of induced positive afterimages, in which staring at a colored area surrounding a small white test patch produces an afterimage in which the hue of the surround is transferred into the previously white area. Using these differences between positive and negative afterimages and also simultaneous color contrast, which has an effect on a test patch different from either of the afterimage effects, we describe a new effect, metameric intransitivity, in which perceptually similar images can generate markedly different afterimages, whereas perceptually different images can generate indistinguishable afterimages. Supplemental figures depicting the stimuli, results, and method for generating the intransitive metamers in this study may be downloaded from http://app.psychonomic-journals.org/content/supplemental.

It is well known that if one stares at a small color patch on a white background and then looks at a blank white page, one will again see the color complementary to the original color patch—the negative afterimage. Many years ago in this journal, Shively (1973) described what he thought was a novel type of afterimage: After staring at a small white square surrounded by a colored background and then looking at a blank page, one sees the hue of the surround transferred into the previously white area, not the complementary color as in the negative afterimage. (It turns out that this effect had been described previously [Purkinje, 1825; Ferree & Rand, 1912], but Shively gave a clear and striking description of the effect and brought it into the consciousness of researchers in the field.) There has been some important subsequent work on positive afterimages, but they have not been studied as much as negative afterimages and are less well understood. Anstis, Rogers, and Henry (1978) gave evidence for two mechanisms for positive afterimages. (1) The background could induce its complement on a test patch by simultaneous color contrast, and then the negative afterimage of this has the final result of a positive afterimage of the background at the location of the test patch. (2) The surround generates a negative afterimage during the adaptation period that, by simultaneous color contrast during the test period, then results in a positive afterimage of the test patch. Takahashi, Ejima, and Akita (1988) studied properties of the positive afterimage, finding, for example, that the chromaticity difference between a surround and test patch necessary to produce an observable positive afterimage increased with a decrease in the luminance of the surround.

Not inconsistent with this prior work, in studying and discussing the negative and positive afterimage effects, one of us (C.W.T.) then pointed out that this would permit the existence of intransitive metamers—images that look different but have afterimages that appear the same, and vice versa. The existence of intransitive metamers would be consistent with adding in a linear fashion to form a perception. Indeed, we have been able to make such images (Figure 1).

To study our observations more formally, we tested 10 subjects (8 of them female), naive as to the purposes of the experiment, all with normal or corrected-to-normal vision and normal color vision (University of Medicine & Dentistry of New Jersey IRB approved). (Testing stimuli shown in Figures S1 and S2 in the online supplement; results shown in Figure S3.) Five out of 10 subjects reported that the two test squares in Figure 1A were the same color, and the other 5 reported that the two squares were very similar shades of yellow. For the afterimages, none of the subjects reported that the two test squares were the same color. The subjects found the afterimage of the left test square to be pink and the afterimage of the right square to be purple. Taking a Bernoulli trial model where the squares are reported as either the same or different colors, for the direct image of the test squares we cannot

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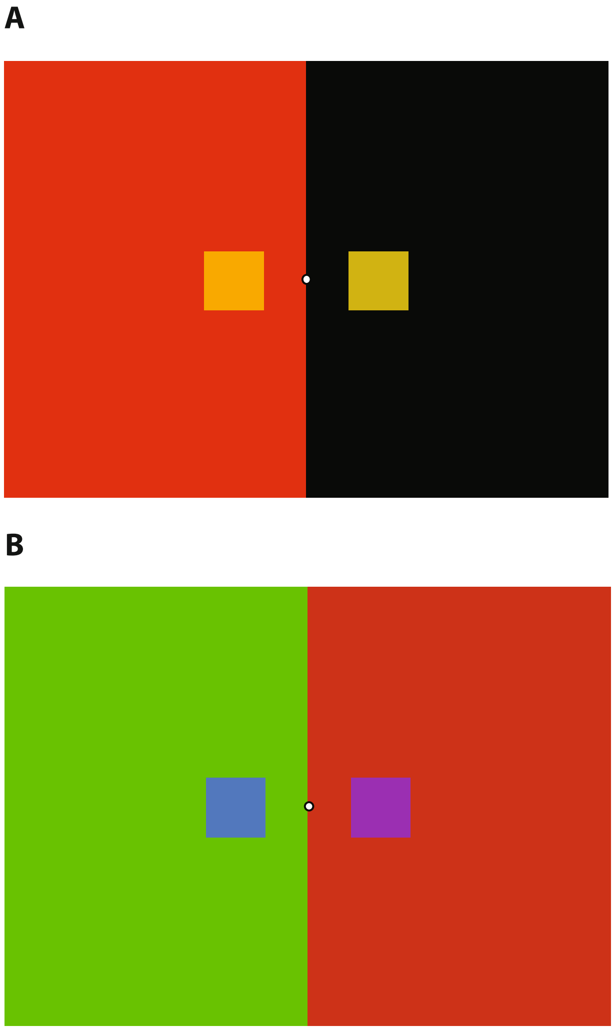

Figure 1. Intransitive metamers. Compare the direct images by fixating on the small circle. View the afterimages by then looking to the white space on the right. (A) Direct images perceived as the same, afterimages perceived as different. (B) Direct images different, afterimages perceived as the same.

reject the hypothesis that the squares are perceived as the same color, whereas for the afterimages we can reject this hypothesis ($p < .05$). Conversely for the test squares in Figure 1B, none of the subjects reported that the direct images were the same color. The subjects reported that the left square was blue and the right square purple. But 5 of the subjects reported that the afterimages of the two squares were the same yellow color, with the other 5 subjects reporting the afterimages to be of similar shades of yellow. Thus, here we can reject ($p < .05$) the hypothesis that the direct images are perceived as the same color but cannot reject the hypothesis that the afterimages are perceived as the same color.

How are the intransitive metamers produced? See Figure S4: The perception of the direct image of the test patches is a combination of the true (physical) hue of the test square modified by the background acting on the test square via simultaneous color contrast (SCC). SCC is still not completely understood or characterized, but we have found that it acts by "pulling out" from a test square the colors shared by the test square and background. The extent to which SCC pulls out a color common to the background and test square, and whether this is the same for all combinations of background and test square colors, is still not completely characterized. Now, the perception of the afterimages of our test squares is a superposition of the negative afterimage of the test square—complementary color and complementary lightness—and the color and lightness of the background (the positive afterimage). Thus, one can see the possibility, by choosing the right colors for the test squares and backgrounds, of making intransitive metamers. Take two combinations of different pairs of backgrounds and test patches such that the superposition of the color of the background plus that of the complementary color of the test patch give afterimages that appear the same/similar. One then needs to adjust the pairs to ensure that the perceptions of the direct image of the test patches—the true color of the test patch with the color common to the test patch and background partially "pulled out" by SCC—are different. One can similarly select pairs of backgrounds and test patches such that the perception of the direct images of the test patches is the same but their afterimages appear different.

We have not seen previously discussed, or at least not emphasized or so dramatically demonstrated, the linear combination of the positive and negative afterimages. Takahashi et al. (1988) studied only 2 subjects, both of whom were also authors of the article. Nevertheless, their findings about the positive afterimage are most interesting: Takahashi et al.'s finding that the chromaticity difference between a surround and test patch necessary to produce an observable positive afterimage increased with a decrease in the luminance of the surround is easily understood in this context of our results. Consider a surround and test patch of nearly similar color. The perception of the afterimage of the test patch will be the combination of the positive afterimage of the surround and the negative afterimage of the test patch. Now, let us decrease the luminance of the surround. If the luminance of the surround is decreased, the chromaticity difference between the surround and test patch must be increased so that the positive afterimage induced from the surround is able to be sufficient to counteract the negative afterimage of the test patch (positive afterimage of surround plus negative afterimage of test patch of nearly the same color is thus achromatic), with sufficient color left for the perception of a positive afterimage.

Along with the two possible explanations given by Anstis et al. (1978) for the positive afterimage, there may be others—for example, there may be a relationship between the mechanism that produces the positive afterimage and the one that produces the neon color spreading effect. We hope that the intransitive metamers presented here will be helpful in further study of afterimages—for example, the processes that lead to positive afterimages and the physiological mechanisms subserving them. As well, another recent illusion using the positive afterimage—the "color dove illusion" (Barkan & Spitzer, 2009), showing that the positive afterimage can be induced by a narrow chromatic inducer in a short time period—and further experiments on the findings of Takashi et al. (1988) on the positive afterimage as a function of the spatial frequency of the adapting grating pattern and saturation of the background should be useful in the elucidation and understanding of the mechanisms and properties of positive afterimages.

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SUPPLEMENTAL MATERIALS

Color figures depicting the stimuli, results, and method for generating the intransitive metamers in this study may be downloaded from http://app.psychonomic-journals.org/content/supplemental.

(Manuscript received June 30, 2009;
revision accepted for publication January 31, 2010.)