Memory colors in afterimages: A bicentennial demonstration

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Six observers adjusted a colorimeter to match afterimages that resembled either a red, white, and blue American flag or a simple striped pattern. They matched the afterimages of stripes in a flag pattern as redder than afterimages of the same stripes in a simple striped pattern. The results suggest that the apparent color of an afterimage depends on memory color.

A complementary-colored American flag is currently used as a demonstration of negative afterimages in several introductory psychology textbooks. The usual pattern is an American flag design printed in colors that are approximately complementary to the usual colors, with green and black stripes, an orange field, and black stars. If viewers fixate the center of the flag for a short while and then look at a white surface, they usually see a red, white, and blue flag afterimage. Several different versions of this demonstration appear to work well despite rather large variations in the colors that are used to induce the afterimage. However, if the afterimages were strictly complementary to the inducing colors, not all the demonstrations would be so successful. Their success suggests that something more than simple afterimages is involved.

There are several lines of evidence to suggest that afterimages are attributable to peripheral processes in the visual system, such as photochemical changes or receptor adaptation (Craik, 1940). One should not assume that the process is completely understood, however. The whole visual system is involved in the perception of afterimages, and the spectacles of memory color, which tint the perception of visual objects, may also be used in seeing afterimages.

Hering introduced the concept of memory color: "What we see at a given moment is by no means determined only by the quality and intensity of radiation incident at the eye and by the momentary state of the total retinal mechanism. . . . [T]he color in which we have most consistently seen an external object is impressed indelibly on our memory and becomes a fixed property of the memory image.

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What the layman calls the real color of an object is a color of the object that has become fixed, as it were, in his memory; I should like to call it the *memory color* of the object" (Hering, 1964, pp. 6-7).

There have been many investigations of memory colors since Hering. For example, Adams (1923) documented the real-life occurrences of memory color effects, e.g., some of her subjects described the golden appearance of a yellow-tiled roof which they believed to be gilded. Also, Duncker (1939) showed that memory colors are important factors in color constancy. He reported that, under red illumination, a piece of green felt shaped like a leaf was matched with more green on a color wheel than was a donkey-shaped piece cut from the same material. See Hochberg (1972) for a review of recent experiments.

Although quantitative experiments are required in order to understand the conditions under which memory color effects occur, there have been few such investigations, and Katz (1935) explained why: ". . . [I]t is impossible, or at least very difficult, to arrange quantitative experiments with memory colors on account of their peculiar lability" (p. 162).

Lability is perhaps an even greater problem with afterimage colors, but research on afterimages has been more quantitative than studies of memory color. Experiments indicate that negative afterimages approximately match the complementary colors of the inducing patterns (Wilson & Brocklebank, 1955). But the measurement of afterimages by color matching is also fraught with difficulties. For instance, Padgham (1968) warned of the difficulties inherent in tracking the rapid color changes which occur in the afterimage of a bright light source.

In order to test for memory color effects in afterimages, observers formed afterimages of flag-like patterns or simple striped patterns and then adjusted a colorimeter field to match the afterimage colors. If the color of afterimages depended on

Figure 1. Afterimage-inducing stimuli: (A) The flag pattern and (B) the striped pattern.

memory color, then afterimages of the arbitrary vertical stripes would be approximately complementary to the colors of the inducing patterns, but the familiar red color in the flag would enhance the redness of the flag afterimage stripes.

METHOD

Observers

Six undergraduate psychology students volunteered for the experiment to fulfill a requirement of an introductory psychology course. All had normal or corrected visual acuity and normal color vision.

Stimuli

The afterimage-inducing stimuli are illustrated by black-and-white versions in Figure 1. One of the adaptation patterns, a complementary-colored American flag, is shown in Figure 1A. The stars were black, the field was orange, and the equal-width stripes were alternately black and one of two test colors. The other pattern, shown in Figure 1B, was simply a pattern of vertical stripes, which were alternately black and one of the two test colors. Vertical stripes were used instead of horizontal stripes to make the striped pattern appear less similar to the flag. Each pattern measured 9.5×6.3 cm, (7.2×4.8 deg of visual angle) and was centered in the upper half of a 17.6×27.1 cm white card. The lower half of each card contained a single black fixation point, 0.2 cm in diam.

The two test colors were blue-green (approximately Munsell 5BG 5/6) and yellow-green (approximately Munsell 5GY 7/10). Their chromaticities are plotted as circles in Figure 2. The two test colors and two patterns were combined to make four adaptation patterns: a blue-green flag, a yellow-green flag, blue-green stripes, and yellow-green stripes.

The patterns were illuminated by a 60-W incandescent lamp in a reflector housing about 40 cm above the table. The luminances of the test colors were 19 cd/m^2 for the blue-green and 71 cd/m^2 for the yellow-green, as measured

with a Salford Electrical Instruments exposure photometer. The luminances of the white card and black stripes were 103 and 12 cd/m^2 , and the orange field's luminance was 94 cd/m^2 .

Apparatus

The colorimeter was designed to facilitate fast color matches by relatively untrained observers (White, Wolbarsht, & Tieger, 1975). Light from a xenon arc projected through a filter slide onto one end of a diffusing bar. The filter slide was a combination of red, green, and blue filters attached to the movable arm of an X-Y plotter. When the filter slide moved to a new position in the light beam, the diffused color mixture at the viewing end of the bar changed according to the relative contribution of each filter. The observer used an electronic joystick to control the plotter. By moving the joystick in two dimensions, the colorimeter field could be adjusted to any chromaticity within the triangle formed by the chromaticities of the primary filters. A PDP-8/L computer converted the plotter voltages to CIE chromaticity coordinates and printed the results after each colorimeter setting.

Procedure

Each observer began with a few direct matches of the adapting stimuli and their white background, which served as practice at operating the colorimeter. The experimental series consisted of 30 matches in six blocks, each including four afterimage matches and one white background match in random order. During the experimental series, the observers fixated a dot near the center of one of the adapting patterns from a viewing distance of 75 cm. Four observers fixated each target for 20 sec on each trial. The other two observers had difficulty seeing afterimages clearly after only 20 sec; one of them fixated for 30 sec, and the other for 35 sec. After adapting to the pattern, the observers fixated the dot on the lower half of the white card for 5 to 15 sec while observing the afterimage. Then they turned to view the colorimeter and quickly adjusted it to match the colored stripes in the afterimage that they had just viewed on the white paper.

RESULTS

The matches of afterimages of stripes in the flag pattern were more red than the matches for stripes of the same color in the vertical stripes. The arrows in Figure 2 indicate the color shifts attributed to the memory color effect. The direction of the differences agreed with that expected from the flag's familiar color, which is more saturated than the afterimage matches.

Figure 2 depicts the mean results for all six observers on the CIE x, y chromaticity diagram. As expected, the matches of the striped patterns (shown by squares) were approximately complementary to the chromaticities of the afterimage-inducing patterns (shown by circles). The complementarity is indicated by the fact that the dashed lines pass nearly through the mean match for the white background (shown by W). The slight reddish deviation of the yellow-green pattern's afterimage agrees with the small, but consistent, deviations reported by Wilson and Brocklebank (1955).

The memory color effect is represented by the differences between the matches of the flag afterimages (triangles) and the striped afterimages (squares). The effect for the blue-green patterns

(filled symbols) indicates differences in purity, which correspond to saturation differences; that is, the flag matches were farther from the white point than were the stripe matches. In the case of the yellow-green patterns (open symbols), there was a slight increase in purity, but the main effect was to produce a change in hue from reddish purple toward red. Thus, the effects for the two test colors represent increasing redness by both hue and saturation differences.

The average results were reflected in the results for individual observers, shown in Figure 3. There were considerable individual differences in the sizes of the chromaticity shifts produced by the flag pattern, but the directions of the shifts were remarkably uniform. Eleven of the 12 shifts were in the direction of the red corner of the x, y diagram.

The statistical significance of the observed differences was tested by separate repeated-measures analysis of variance (2 patterns by 2 colors by 6 observers by 6 matches per cell) on the x and y chromaticity values. The difference between afterimage matches of the striped and flag patterns was significant for the x values [$F(1,5) = 8.58$, $p = .032$], but not for the y values. The pattern effect reflected the shift toward higher x values for the flag pattern. The two test colors were significantly different for both the x values [$F(1,5) = 170.32$,

Figure 2. Colorimeter matches for afterimages of stripes in the flag patterns (triangles) and the striped patterns (squares). Arrows indicate the direction and extent of the color differences attributed to the memory color effect. Also shown are chromaticities of the afterimage-inducing stimuli (circles) and the white background (W). Filled symbols indicate the blue-green adaptation patterns; open symbols, the yellow-green pattern. Mean results for all six observers.

Figure 3. Results for individual observers. Arrows are drawn from each observer's average match for the striped pattern's afterimage to that observer's average match for the flag afterimage. Filled circles represent blue-green inducing patterns; open circles represent yellow-green patterns. The average white setting (W) is also shown for each observer.

$p < .001$) and the y values [$F(1,5) = 24.16$, $p = .005$]. The test color effect corresponded to the different chromaticities of the afterimages produced by the yellow-green and blue-green stimuli. The interaction effect of pattern and color was significant only for the y values [$F(1,5) = 7.37$, $p = .042$], not for x .

DISCUSSION

The results indicate that afterimages which represent familiar objects are affected by the colors in which the objects normally appear, not simply by the spectral distribution of the afterimage-inducing pattern. Thus the way we see afterimages depends on what the afterimage represents.

The conclusion contradicts a previous report by Leibovich and Paolera (1970), who found no significant differences in afterimage colors between stimuli whose shapes suggested colors (e.g., a strawberry or a canary) and shapes with arbitrary colors (e.g., a ball or a dress). They concluded that memory color effects which occur in direct vision do not occur in the case of afterimages. Their negative results may have been due to the insensitivity of their color-matching procedure or to the youth of their school-age subjects. In either case, the present experiment shows that their conclusion does not hold for adult perception.

Several objections might be raised about the

methods of the present experiment. The first is that the stripe patterns and the flag patterns differ not only in the degree to which they are associated with familiar colors, but also in the orientation of their stripes. It is difficult to imagine how color-orientation aftereffects might have contributed to the results, since the matching field was a uniformly luminous square area.

A more plausible objection to the stimuli we used concerns the presence of another color in the flag that was absent in the striped pattern. The orange field around the stars produced a blue afterimage, which conceivably could have affected the apparent color of the flag's stripes by simultaneous contrast. Similar color contrast effects were reported by King and Wertheimer (1963). Given the spatial separation between most of the stripes and the orange field, not much simultaneous contrast would be expected. A control experiment was conducted, however, to rule out such effects. Two new observers made afterimage matches of rectangular patches of both test colors with and without an adjacent orange patch. As expected, there was no discernible effect of the orange field on the afterimage matches.

The most serious objection concerns the sequential matching procedure. The reported color differences may have been due to the observer's matching the memory of the afterimage, rather than matching the afterimage directly. (See Hochberg, 1972, p. 425, for discussion.) This alternate interpretation cannot be ruled out, but other observations suggest that, at best, the explanation is incomplete. If observers fixate a point midway between a flag pattern and a striped pattern during the adaptation period and then compare the afterimages simultaneously, some observers report that the flag stripes appear redder than the others. Other observers are unable to decide, however. Apparently there are complications due to foveal and peripheral differences with large targets and uncertainty about nonfoveal color judgments, which make such judgments very difficult.

Questions for further research concern the boundary conditions of the memory color effect on afterimages, especially what kinds of patterns are effective and how much experience is necessary. For example, various patterns of stars and stripes could be used as afterimage-inducing stimuli. The size of the memory color effect might depend on the similarity of each pattern to the flag. In addition,

other familiar afterimage demonstrations, such as the green heart, may be more effective because they combine successive contrast effects with memory colors of familiar objects. It would also be interesting to know how much experience is necessary before a figure acquires memory color. For instance, would the flag experiment work in populations with different national emblems? Or, could an observer be so highly trained with an arbitrary figure that its afterimage color would change? Finally, would the flag experiment work as well if the pattern to be matched were a real flag instead of an afterimage? Perhaps not, since afterimages are more ambiguous, and memory color effects are greater with ambiguous stimuli (Bruner, Postman, & Rodrigues, 1951). Additional research along these lines should elucidate the effects of memory color on afterimages.

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