Color aftereffects contingent on perceptual organization

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The present experiment demonstrated that (a) cognitive organizational factors influence an orientation-contingent color (McCollough) aftereffect, and (b) adaptation to colored gratings affected the perceptual organization of a reversible figure. Following adaptation to colored gratings, color aftereffects were reported in only one of two organizations of a reversible figure, and the colors conformed to the subjective contours of the test pattern rather than exclusively to the regions defined by horizontal and vertical pattern elements. In addition, an organization of the reversible figure that segregated vertical and horizontal pattern elements was dominant subsequent to adaptation.

The McCollough effect (McCollough, 1965) is a long-lasting pattern-contingent visual aftereffect. The effect is typically obtained by alternately presenting two different colored line gratings in different orientations such as horizontal and vertical. Subsequent inspection of achromatic test gratings evokes color aftereffects that are contingent on the orientation of the gratings. For example, viewing an achromatic vertical test grating gives rise to a desaturated color aftereffect that is approximately the complement of the color used with the vertical grating during adaptation; similarly, a horizontally oriented test grating evokes the complement of the color used with the horizontal grating during adaptation. There is ample documentation that variation of many of the physical parameters of the adaptation and test patterns influence the strength and nature of these pattern-contingent aftereffects (see Skowbo, Timney, Gentry, & Morant, 1975, for a review).

The present study demonstrates that it is possible to produce changes in the appearance of these aftereffects without any physical alteration of the test gratings. To achieve this, the test pattern was a composite of horizontal and vertical line elements which produced a perceptually reversible figure. A reversible figure is a pattern which gives rise to qualitatively distinct perceptual states even though the physical properties of the pattern are invariant. In addition, typically there is spontaneous alternation between the states insofar as it is impossible to perceive both figures simultaneously. It is generally assumed that cognitive factors¹ produce these alternations insofar as it is independent of any vari-

ation of the physical properties of the stimulus figure.

The pattern shown in Figure 1² is a reversible figure and is similar to the test pattern used in the present study to evoke a pattern-contingent color aftereffect. One perceptual organization of this figure involves segregating the vertical and horizontal line elements such that a diamond-shaped horizontal grating appears to be surrounded by a background of a vertical grating. It should be noted that this

Figure 1. Perceptually reversible test figure.

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diamond is partially defined by subjective brightness contours. An unambiguous version of the "diamond" organization is shown schematically in Figure 2A. The other potential organization, shown unambiguously in Figure 2B, involves integrating the horizontal and vertical elements such that the test pattern appears as an upward and a downward nested series of incomplete (three-sided) rectangles. We investigated how the perceptual organization of the reversible test figure is influenced by adaptation to McCollough effect stimuli. This was accomplished by measuring observers' switching rate between the two perceptual organizations of the test figure before and after adaptation to McCollough effect stimuli. In addition, observers reported on the presence of color aftereffects for each of the organizations of the test figure to ascertain whether the state of perceptual organization influences these aftereffects.

METHOD

Subjects

The 27 observers were general psychology students at Kansas State University who served for extra class credit. Normal visual acuity or vision corrected to 20/30 was a prerequisite for serving in the experiment.

Stimuli and Procedure

In order to assess the rate of spontaneous alternation between the two different perceptual organizations, the observers viewed the reversible test pattern for 2 min. During this *preadaptation* period, each subject was to depress a pushbutton switch connected to an event recorder when the test pattern appeared to be organized as "diamond" and release the switch when the figure appeared to be "rectangles." The luminances of the black bars and white slits of the reversible test figure were 38 and 538 m L , respectively, and yielded a contrast ratio³ of 0.87. During inspection of the test figure, the observers were required to fixate a spot in the center of the figure so that systematic eye movements would not influence perceptual organization.⁴

Following the preadaptation period, the observers were alternately presented with two different chromatic square-wave gratings (experimental condition). One of the gratings consisted of black and magenta (Wratten #34a) stripes that were oriented vertically. The luminances of the black bars and magenta slits of this grating were 3 and 17 m L , respectively, and yielded a contrast ratio of 0.70. The other grating consisted of black and green (Wratten #53) stripes oriented horizontally. The luminances of the black bars and green slits of this grating were 5 and 43 m L , respectively, and yielded a contrast ratio of 0.79. The gratings were alternately presented every 5 sec for the 6-min duration of the *adaptation* period. To prevent the systematic buildup of negative afterimages, the observers were instructed not to fixate any particular region of the adapting figures, but rather to let their gaze wander around the colored gratings.

A 2-min *postadaptation* period followed adaptation to the colored gratings to assess any change in the organization of the reversible test figure. All of the stimuli were 35-mm transparencies that were projected on a screen that was 6 m from the observer. The test figure subtended a visual angle of 4.8 deg vertically and 2.4 deg horizontally, and the adapting gratings subtended a visual angle of 4.8 deg vertically and 7.0 deg horizontally. The spatial frequency (i.e., the number of square-wave cycles/deg visual angle) of the adapting gratings and the composite gratings in the test figure was 2.2 cycles/deg. In other words, any black bar or light slit always subtended a visual angle of 0.23 deg.

Figure 2. Unambiguous representation of "diamond" (A) and "rectangles" (B) organizations of the reversible figure.

In addition to the experimental condition consisting of adaptation to colored gratings, each subject also served in one of two control conditions. One control condition (achromatic gratings) consisted of the two gratings used in the experimental condition. In this control, alternate exposure to achromatic horizontal and vertical gratings served as adapting stimuli. The luminances of these black bars and light slits were the same as those for the achromatic test figure. The other control condition (homogeneous colors) involved alternate exposure to the two colors used in the experimental condition. The adapting stimuli consisted of homogeneous colored fields (i.e., no stripes) for this control. The luminance of the magenta field was 17 and 43 m L for the green field. For any given subject, the interval between the experimental and control condition was a minimum of 48 h, and the order of these two conditions was counterbalanced between subjects. There were no systematic effects due to order of presentation for any of the dependent measures.

To determine the presence of color aftereffects, the observers were asked to fill out questionnaires concerning the presence of apparent colors in any region of the achromatic test pattern following the pre- and postadaptation periods. The questions were phrased such that subjects were free to respond whether or not they perceived colors in the test pattern and, if so, where and what these colors were. Specifically, the questionnaire consisted of the following items for the "diamond" organization: Do you see any colors in the light slits of the reversible figure when it is seen as "DIAMOND"? If so, what colors do you see in the *horizontal* light slits? What colors do you see in the *vertical* light slits? A similar series of three items was used to determine the presence of apparent colors in the "rectangles" organization.

RESULTS

Switching Time

Pre- to postadaptation differences in the amount of time that the test figure was organized as "diamond" were examined in order to assess the effect of the interpolated adaptation period on perceptual organization. The finding of primary interest was that only the experimental (chromatic gratings) adaptation condition produced systematic changes in the tendencies to organize the test pattern. Specifically, Table 1 shows that the mean *total amount of time* that the test figure was organized as "diamond" increased 13.6 sec (18%) between the pre- and postadaptation periods for the experimental adaptation condition. In contrast, the mean increase for the

Table 1
Mean Pre- to Postadaptation Difference Scores and 95% Confidence Limits

	Total Amount of Time		Duration		Number of Switches
	"Diamond"	"Rectangles"	"Diamond"	"Rectangles"	
Chromatic Grating (n = 27)	13.6 (± 7.5)	-13.6	17.4 (± 11.2)	-1.8 (± 3.3)	-3.3 (± 2.0)
Homogeneous Colors (n = 12)	5.2 (± 8.9)	- 5.2	3.2 (± 27.8)	.8 (± 1.3)	-2.2 (± 2.6)
Achromatic Gratings (n = 15)	.2 (± 8.9)	- .2	- .4 (± 6.4)	.6 ($\pm .8$)	-1.7 (± 2.5)

homogeneous color control condition was 5.2 sec (6%), and there was a 0.2-sec decrease for the achromatic grating condition. Of course, any change in the amount of time spent in "diamond" was reflected by a shift, in the opposite direction, for the total amount of time that the test figure was organized as "rectangles." Only the mean shift for the experimental condition was reliably different from zero, whereas this was not the case for either of the control conditions (based on 95% confidence intervals). In addition, direct comparisons between these mean difference scores indicated no significant difference between the two control conditions, $t(25) < 1$, but that there was a significant difference between the pooled control conditions and the experimental condition, $t(26) = 2.67$, $p < .01$.

Table 1 also shows that the pre- to postadaptation shift in the *number of switches* between the two perceptual states yielded a pattern of results similar to that of the previous analysis. Specifically, the increased time spent in the "diamond" organization subsequent to adaptation was accompanied by a reliable decrease in the number of oscillations for only the chromatic grating condition. Table 1 also indicates that there was a reliable increase in the average *duration* (i.e., the interval between two oscillations of figure organization) of the "diamond" percept subsequent to adaptation to the chromatic gratings ($\bar{X} = 17.4$ sec), and no reliable pre- to post-adaptation differences in the mean duration of the "rectangles" percept ($\bar{X} = -1.8$ sec) for this condition. There were also no systematic changes in the duration of either the "diamond" or "rectangles" organization of the reversible figure subsequent to exposure to the control conditions.

Color Reports

Subsequent to the experimental adaptation condition, 18 of the 27 participants reported a color difference between the horizontal and vertical regions of the test pattern that was consistent with the McCollough effect. (Reports of "green" in the vertical light slits and/or "red" or "pink" in the horizontal light slits of the test pattern were considered to be responses consistent with the

McCollough effect.) Furthermore, of the 18 observers who met our criterion for the McCollough effect, 15, or 83%, reported seeing colors in the test pattern only when it was organized as "diamond" and not when it was organized as "rectangles." That is, these subjects typically reported that the color aftereffects completely washed out or disappeared when the perceptual organization of the test figure changed from "diamond" to "rectangles." One observer reported color just in the "rectangle" configuration, and the other two reported color in both perceptual organizations of the test figure. In contrast to the data from the experimental condition, only one observer (in the homogeneous color condition) reported a McCollough effect color subsequent to either of the control adaptation conditions.

It should be noted that the absence of subjective colors in the "rectangles" organization was not simply due to an inability to organize the test pattern as "rectangles." Subsequent to adaptation to the chromatic gratings, each subject was in the "rectangles" organization for an average of 31.0 sec, and the mean duration of a "rectangles" percept was 3.1 sec. These times were 28.9 and 3.6 sec, respectively, for those 15 subjects who reported colors only in the "diamond" organization. Therefore, although the average total time in "rectangles" decreased from pre- to postadaptation, there was ample opportunity for observers to ascertain if colors were present in that organization.

Supplementary Experiments

An additional experimental adaptation condition was run to counterbalance color and orientation of the gratings. In this supplemental experiment, 26 observers were required only to make judgments regarding the presence of colors in the reversible test pattern before and after adaptation. The viewing conditions for this adaptation condition were similar to those of the previous chromatic grating condition, with the major exception being that in the present condition color and orientation were reversed so that adaptation consisted of alternate exposure to a black-and-green vertical grating and a black-and-magenta horizontal grating. In addition, no measures

of perceptual switching were obtained for the supplementary experiment. Twenty-three of the 26 participants reported a color difference between the horizontal and vertical regions of the test pattern that was consistent with the McCollough effect. Of the 23 subjects meeting this criterion, 20, or 86%, reported seeing the colors only when the test pattern was organized as "diamond."

To test whether the absence of perceived colors when the test figure is organized as "rectangles" is unique to subjective color aftereffects, an additional independent control experiment was conducted. Using real (i.e., objective) colors in the slits of the reversible test figure, a group of 11 observers filled out a questionnaire concerning the presence of colors for the two organizations of this figure. A desaturated green was in the vertical slits and a desaturated pink in the horizontal slits. These colors were, in the experimenters' estimation, approximately equivalent to the color aftereffects produced by exposure to McCollough effect stimuli. In all cases, the reports of the presence of colors was the same for both organizations of the test figure.

DISCUSSION

The findings that subjective colors were generally not reported in the "rectangles" organization of the test pattern, and that the mean duration of a "rectangles" percept remained unchanged subsequent to adaptation to chromatic gratings, suggest that the "rectangles" organization was unaffected by the experimental adaptation condition. In contrast, color aftereffects were reported by most observers when the reversible test pattern was organized as "diamond," and, furthermore, there was a pre- to postadaptation increase in the mean duration of a "diamond" percept for the chromatic grating condition. These findings suggest that the presence of apparent colors in the test figure stabilized its organization in "diamond." It is not surprising that the "diamond" organization predominated following the experimental adaptation condition, insofar as color differences between the horizontal and vertical regions of this pattern would increase the salience of a central diamond on a surround of a different hue. However, the data do not unequivocally support this hypothesis because an increase in the duration of the diamond percept subsequent to the experimental adaptation condition was not contingent upon the report of the McCollough effect colors in the "diamond" configuration. This inconsistency might have been due to the failure of some subjects to report color differences which were, in fact, perceived. It should be noted that free reports regarding the presence of color aftereffects is a somewhat more conservative measure than the two-alternative (viz., red or green) forced-choice technique which is a

criterion frequently used for the McCollough effect.

It is possible that the absence of colors in the "rectangles" organization can be explained by the figure-ground characteristics of this perceptual organization. Perception of the "diamond" organization involves the segregation of the horizontal (figure) and vertical (ground) elements of the test pattern, whereas the black vertical and horizontal line elements appear to be integrated as rectangular figures superimposed on a homogeneous white background in the "rectangles" organization. Color aftereffects obtained only when the vertical and horizontal line elements were perceptually segregated, and not in the "rectangles" organization when there were no elements of form associated with the white field.

The finding that the presence of the color aftereffects was related to the manner in which the test pattern was organized seems to suggest that cognitive factors, as well as physical characteristics of the test figure, can influence pattern-contingent color aftereffects. An additional anecdotal finding that provides further support for this conclusion is that those subjects who reported a color difference for the horizontal and vertical regions of the "diamond" organization of the test figure also typically reported that the color extended beyond the horizontally bounded region into the upper and lower vertices of the central diamond (i.e., the diamond-shaped region bounded by dashed lines in Figure 2A). Strictly speaking, these regions are part of a vertical light slit, yet the perceived color seems to conform to the subjective contours of the diamond rather than exclusively to the region defined by horizontal gratings.

A different explanation for the organizational contingency of the color aftereffects might be applicable if the subjective colors oscillate in strength. As was stated earlier, perhaps the presence of the color aftereffects increased the salience of the diamond organization. If the color aftereffects were sufficiently salient, it might be the case that it would be possible for the reversible test figure to shift back to the "rectangles" organization only when the strength of the color aftereffect waned. And, of course, a decrease in the strength of the color aftereffects would be accompanied by reports of the absence of subjective colors; a reinstatement of the colors would drive the organization back to the "diamond" configuration. While the present results do not rule out this possibility, there is no research to date suggesting transient oscillations in the strength of the McCollough effect under conditions of steady viewing of the test pattern.

Most attempts to account for the McCollough effect have been based on feature extraction models. McCollough suggested that the phenomenon was due to "color adaptation of orientation-specific edge-detectors" (1965, p. 1115) similar to those found in

cats and monkeys. This explanation is but one of a general class of neural analyzer models that postulate that the McCollough effect is due to adaptation or fatigue of some kind of neural unit with specific trigger features (see Harris, in press, for a review of these models). According to this type of model, orientation-contingent color aftereffects are dependent on the degree of similarity between the trigger features of the neural analyzers and physical parameters of the inducing stimuli. Thus, when it was demonstrated that aftereffects could be contingent on parameters other than orientation [e.g., spatial frequency (Stroymeyer, 1972), direction of movement (Helpler, 1968), and curvature (Riggs, 1973)], the feature extraction models merely assumed neural units with trigger features sensitive to those parameters. However, the organization effects reported here suggest that pattern-contingent aftereffects might not be as dependent upon stimulus parameters as simple feature extraction models would suggest, in which case a purely stimulus-bound model cannot provide a complete explanation of the aftereffect. For any explanation to provide a complete account, it must be assumed that cognitive factors can influence both the nature and extent that the underlying mechanisms (whether it be edge detectors, dipoles, or Fourier spatial frequency channels) are involved in the processing of pattern information. For example, it could be the case that the two independent organizations of the reversible figure might involve different populations of feature analyzers, and adaptation to orthogonally oriented chromatic gratings affects only one of these populations.

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NOTES

1. The term "cognitive factors" as used in this paper is best defined as a higher order process that is not stimulus bound (cf. Howard, 1974). It should be noted that this definition does not preclude, nor is it incompatible with, neurophysiological description.
2. This pattern is a modification of one typically used to demonstrate Gestalt principles of organization and very similar to one employed by R. B. Lawson and S. Packard (1977).
3. Defined $C = (L_{\max} - L_{\min}) / (L_{\max} + L_{\min})$.
4. The literature is divided on the role of eye movements on the perceptual oscillations experienced with reversible figures. For example, Howard (1961) demonstrated that eye movements do not affect the time to the first reversal of the Necker cube. On the other hand, Chastain and Burnham (1975) showed that the direction of the first glance determines the initial organization of the "rat-man" reversible figure. In a subsequent study, we instructed observers to try to hold the figure in either the "diamond" or the "rectangles" organization with no fixation point, and obtained the same overall pattern of results.

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