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McCollough Effect to "Form": A Local Phenomenon

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S. Siegel, L. G. Allan, and T. Eissenberg (1992) recently reported a McCollough effect (ME) to "form" using a square and a tic-tac-toe grid. It is possible that the effect they reported could be the result of local adaptation to colored contours presented to different retinal areas, rather than a color aftereffect contingent on form. Three induction conditions tested this hypothesis. In Condition 1, Ss fixated on the center of the pattern during testing and induction. In Condition 2, Ss fixated on a corner of the pattern during testing and in the center of the pattern during induction. The Ss fixated on the 4 corners of the pattern during induction in Condition 3. An ME was observed in Condition 1 but not in the other conditions. These results support the hypothesis that the ME to form is a product of local color and contour pairing.

Color aftereffects contingent on pattern orientation were first reported by McCollough (1965) and have since been referred to as McCollough effects (MEs). The effect normally is induced by having subjects view alternate presentations of orthogonally oriented gratings composed of black and colored lines. Following induction, black and white gratings at different orientations appear to be colored. For example, a typical ME induction consists of alternate presentations of a green and black vertical grating with a red and black horizontal grating over a few minutes. Following this induction procedure, the white bars of a vertical test grating would appear to be a desaturated red, a horizontal grating would appear to be a desaturated green, and a diagonally oriented black and white grating would not appear to be colored.

Many findings suggest that the ME occurs at a relatively early level in the visual system. For example, the effect does not transfer from one eye to the other (McCollough, 1965; Murch, 1972); it is specific to retinal orientation, size and area (Ellis, 1976; Lovegrove & Over, 1972; McCollough, 1965; Stromeyer, 1972); and attention to the induction patterns is not necessary for induction (Houck & Hoffman, 1986). Several different theoretical accounts of the ME have been given, most of which have attempted to model the ME with relatively low-level mechanisms (for review see Dodwell & Humphrey, 1990; Humphrey, in press). One model of MEs holds that they result from a form of classical conditioning. Such a view was proposed by several researchers, perhaps first by Viola (1966, although she did not believe it could account for her results). Others have made similar proposals (e.g., Mayhew & Anstis, 1972; Murch, 1976; Skowbo, Gentry, Timney, & Morant, 1974). The classical conditioning account of the ME has been developed extensively by Allan and Siegel (1986, 1993).

There has been a continuing debate over the validity of the classical conditioning account of the ME (Allan & Siegel, 1986, 1993; Dodwell & Humphrey, 1990, 1993; Harris, 1980; McCarter & Silver, 1977; Murch, 1977; Skowbo, 1984, 1986). A strict reading of the classical conditioning account of the ME suggests that elicitation of an aftereffect color should follow induction with virtually any discriminable, patterned stimuli (Siegel, Allan, & Eissenberg, 1992). Contrary to this proposal, most researchers have found that MEs are based on a restricted range of patterns composed of differently oriented elements (Humphrey, in press; Stromeyer, 1978).

Two studies have attempted to find MEs contingent on forms composed of elements at the same orientation. The first study, conducted by Foreit and Ambler (1978), used as induction patterns a square constructed from magenta line segments and a cross constructed from green line segments. The presence of any aftereffect was evaluated by having subjects match perceived colors on test patterns to Munsell chips. Foreit and Ambler were unsuccessful in finding an ME to these patterns and concluded that higher-order form detectors are either not color-specific or are incapable of being associated with color.

Recently, however, Siegel et al. (1992) claimed to find MEs using stimuli similar to those used by Foreit and Ambler (1978). They repeated the experiment performed by Foreit and Ambler, but tested for the presence of an ME using a measuring technique based on a method of constant stimuli (Allan, Siegel, Collins, & MacQueen, 1989; Allan, Siegel, Toppan, & Lockhead, 1991). They found an ME after induction with a square and a cross in different colors (two different forms of the cross were used in parallel experiments; Siegel et al., 1992).

As noted above, research has demonstrated that the ME is specific to retinal orientation and location. For example, dif-

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ferent orientation-contingent aftereffects can be induced on different parts of the retina (Stromeyer & Dawson, 1978). Vertical bars may appear pink at one retinal position, but green at another. Stromeyer (1972) demonstrated that such aftereffects disappeared when the test pattern was moved as little as 0.5° off the induced area, and then reappeared when the test pattern was brought within about 0.3° of the induced area. It is possible that the MEs reported by Siegel et al. (1992) could be the result of local adaptation to colored contours presented to different retinal areas, rather than MEs specific to form.

We repeated and extended one of the experiments performed by Siegel et al. (1992, Experiment 1B). In that article, there was no indication of what instructions were given to subjects with regard to eye movements or direction of gaze during induction and assessment phases. If the ME to form reported by Siegel et al. depends on local color and orientation contingencies, it should be disrupted by changes in the locus of fixation between induction and test phases, or if eye movements were made during induction but not during test phases.

We examined the role of fixation locus and eye movements in three separate conditions. In Condition 1, subjects were instructed to fixate on the center of the pattern during testing and induction. According to the local color and contour orientation contingency account, an ME would be expected, because the patterns would fall on the same retinal loci during testing and induction. In Condition 2, subjects fixated on the top left-hand corner of the patterns during induction and on the center of the patterns during testing. According to the local account, MEs would not be expected, because of the difference in fixation between induction and testing. In Condition 3, subjects were asked to fixate on different positions in the stimuli during induction, but to fixate the center of the stimuli during testing. Again, the retinal loci of induction and testing differ, and MEs to the forms would not be expected according to the local account.

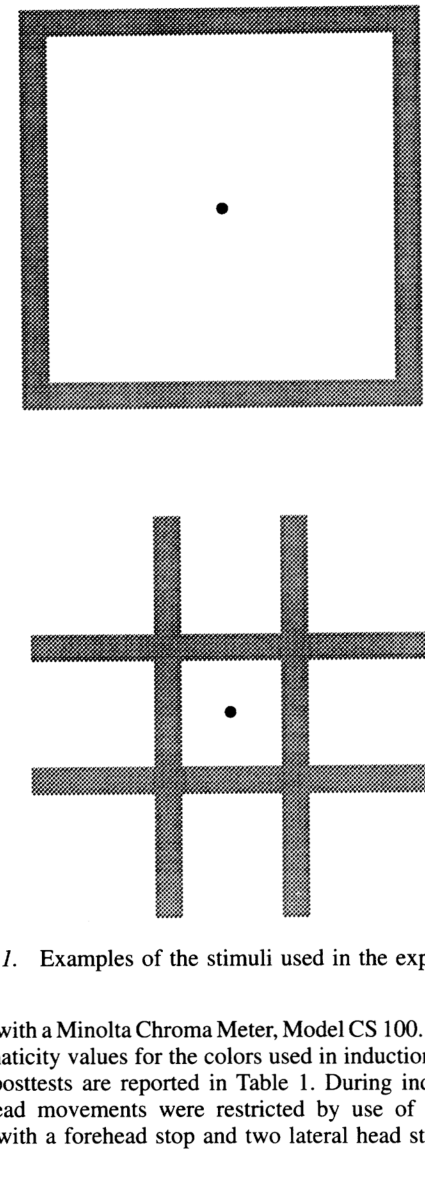

Figure 1. Examples of the stimuli used in the experiment.

Method

Subjects

The same 6 subjects were used in each condition. At the beginning of the experiment, 3 of the subjects were experienced ME observers and the others were inexperienced observers. All of the subjects were affiliated with the Department of Psychology at the University of Western Ontario.

Stimuli and Apparatus

The induction stimuli were colored geometric forms (a green square and a red tic-tac-toe grid) presented on a black background (see Figure 1). The stimuli were presented in the center of a 13-in. (33 cm) Macintosh high resolution color monitor screen. Each form consisted of four 64 mm × 4 mm line segments. There was a small white dot in the center of each stimulus to be used for fixation (approximately 1 mm in diameter). The viewing distance was 98 cm. Chromaticity (Commission Internationale de l'Eclairage, or CIE, x and y coordinates) and luminance (cd/m^2) of the forms were measured with a Minolta Chroma Meter, Model CS 100. Luminance and chromaticity values for the colors used in induction and in the pre- and posttests are reported in Table 1. During induction and testing, head movements were restricted by use of a chin rest equipped with a forehead stop and two lateral head stops.

Procedure

There were three phases in each experimental condition: a pretest, an induction period, and a posttest. The subjects were given a 5-min rest period in normal room illumination between induction and the posttest. The pre- and posttests followed the procedure used by Siegel et al. (1992). In the assessment procedure there were 50 presentations of the square and 50 presentations of the grid. On each presentation the forms were colored faintly with one of the following: one of two shades of pale pink (P1 and P2, with P2 being more saturated than P1); one of two shades of pale green (G1 and G2, with G2 being more saturated than G1); or white (0) (see Table 1). Form and color were randomly ordered with the restriction that each color–form pairing was presented 10 times. On each presentation, the subject had to make a binary response—"green" or "pink"—by pressing an appropriate key on the keyboard. The stimulus was displayed until a response was made. The results of the pre- and posttests were compared to generate estimates of the extent of adaptation in each condition.

Table 1
Luminance and Chromaticity Values of the Colors of the Experimental Stimuli

	Luminance (cd/m^2)	Chromaticity	
		x	y
Black	0.1	—	—
Induction colors			
Green	52.7	.295	.590
Magenta	18.7	.367	.200
Test colors			
Light green (G2)	79.1	.279	.305
Lightest green (G1)	79.4	.279	.302
White (0)	83.7	.280	.298
Lightest magenta (P1)	80.0	.279	.293
Light magenta (P2)	78.9	.279	.291

The induction phase followed the following framework: The square was presented in green, and the grid in magenta (see Table 1); each stimulus was presented in the center of the screen against a black background for 3 s, with a 1-s blank interval between induction stimuli. There were 200 presentations of each stimulus during induction, lasting for approximately 27 min. Three induction and test combinations were tested: In Condition 1, the subjects fixated on the center of the pattern during induction and the pre- and posttests; in Condition 2, the subjects fixated the upper left-hand corner of the pattern during induction but fixated the center of the pattern during the two test phases; and in Condition 3, the subjects fixated on each of the four corners of the figures during induction, as follows. Upon presentation of the induction stimulus, the observer fixated on a corner of the pattern (the same point on the screen for both the square and the grid) for the duration of the stimulus presentation. On successive presentations of that induction stimulus the next corner clockwise around the figure was fixated, so each corner of the patterns was fixated for equal periods of time. During the testing phases the observers fixated the center of the patterns.

Results

In Figure 2, psychometric functions are plotted for each condition of the experiment. These functions relate the mean probability of subjects who reported that the test stimuli appeared green [P(G)] to the actual color of the assessment stimuli (ranging from P2 to G2 through white). Each point represents an average of 60 observations; 10 responses of each color–form combination for each of 6 subjects. The data from the green and magenta induction conditions are plotted separately on each graph. An ME is indicated by a shift in P(G) after induction. Posttest curves shift upward from the pretest curves for the magenta-induced cases, and the opposite occurs for the green-induced pre- and posttest functions when an ME is present.

An ME was observed in Condition 1 (Figure 2a). The pretest functions were similar for both patterns, and the two posttest functions diverge after induction. To evaluate statistically the shifts in psychometric functions, the mean number of green responses over the five test colors (which could range from 0 to 10) were subjected to a 2 (induction color—magenta or green) × 2 (assessment phase—pretest or posttest) repeated measures analysis of variance (ANOVA) for each condition. In Condition 1, the interaction of induction color and assessment phase was significant, $F(1, 5) = 45.9$, $MS_e = 45.6$, $p < .01$. There was no main effect of the assessment phase, but the main effect of induction color was significant, $F(1, 5) = 136.8$, $MS_e = 25.9$, $p < .001$). Clearly, the number of green responses made to the two patterns depended on assessment phase. Analysis of simple main effects indicated that the number of green responses did not differ in the pretest condition, but differed after induction, $F(1, 5) = 136.0$, $MS_e = 40.8$, $p < .001$ (Figure 2a).

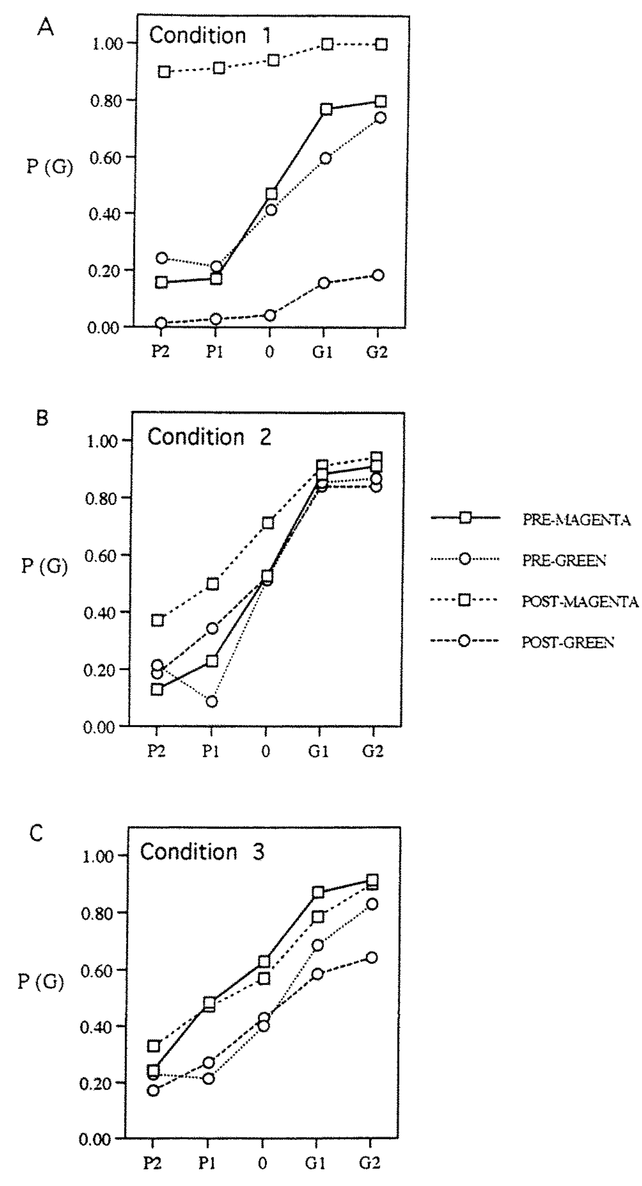

Figure 2. Pre- and posttest psychometric functions obtained in each condition of the experiment. See text for explanation.

There were no significant differences in the pre- and posttest results in Condition 2, in which the fixation point for testing differed from that for induction (Figure 2b). In this condition, the main effect of induction color was significant, $F(1, 5) = 8.1$, $MS_e = 15.0$, $p < .05$, but the main effect of assessment and the interaction of induction color and assessment phase were not significant. Condition 3 yielded similar results; there was a significant main effect of induction color, $F(1,5) = 19.3$, $MS_e = 49.2$, $p < .01$, but there were no significant differences in the pre- and posttests (see Figure 2c).

Discussion

The results of the present experiment support the view that the MEs to form recently reported by Siegel et al. (1992) are better accounted for in terms of local adaptation to color and contour contingencies. In Condition 1, the same pattern locus was fixated during induction and testing, and an ME was obtained. If the induction had occurred to forms, a change in the retinal position of the contours at posttest relative to their position during induction would not be expected to disrupt the effect. Such changes in contour position failed to produce MEs in Conditions 2 and 3, suggesting that the effect does not occur to forms. We suggest that the aftereffect depends on a match in the retinal locus of the contours between assessment and induction.

Foreit and Ambler (1978) did not induce an ME to forms that were similar to those used in Experiment 1A of Siegel et al. (1992), in which an ME was reported. In Foreit and Ambler's experiment, the forms were scanned during induction (most similar to our Condition 3), and the results were similar to those reported in this article, despite differences in the assessment procedure.

In Conditions 2 and 3, observers reported the appearance of "patchy" colors on the grid and square in the posttest phase. This is consistent with the local adaptation account. Observers had been instructed to make responses based on the color they perceived as strongest in the test figures. In Condition 1 there were no "patchy" reports such as these.

Siegel et al. (1992) did not give explicit instructions to their subjects on where to fixate during testing or induction. We can only speculate that their subjects may have tended to fixate the same position on the patterns during induction and the posttest. It may be that without instructions, subjects tend to fixate the center of the patterns. If we assume that the subjects in Siegel et al.'s experiment were looking at the center of the stimuli, then the experiment would be similar to Condition 1 in this experiment, in which we were able to induce an ME.

In conclusion, we believe that recent findings of MEs to forms are based in fact on local orientation and color contingencies. Broerse and Grimbeek (1994) reported results that led them to the same conclusion. It will be of interest to see how these effects can be reconciled with existing models of aftereffects based on early visual processing.

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