Motion Perception: A Color-Contingent Aftereffect

Abstract. *When observers who watched repeated alternations of a red contracting spiral and a green expanding spiral were later shown stationary spirals, red and green, the red stationary spiral appeared to be expanding and the green stationary spiral appeared to be contracting. These color-contingent motion aftereffects complement reports of motion-contingent color aftereffects and suggest that both may reflect adaptation of detectors specific to color and motion.*

Research in human vision has emphasized the importance of units sensitive to certain features in the visual field, such as specific colors, orientations, and directions of motion. In a germinal experiment, McCollough (*1*) reported that observers who watched grids of horizontal blue and black lines alternating with grids of vertical orange and black lines later perceived horizontal white and black lines to be tinged with orange and vertical white and black lines to be faintly greenish-blue. She suggested that selective adaptation of detectors specialized for both color and orientation was responsible. This hypothesis has been strengthened by a report (*2*) that the contingency of color aftereffects on orientation can be reversed. When observers watched alternating red and green stripes, the red stripes tilted clockwise off vertical and the green tilted counterclockwise; when they were later shown vertical red and green stripes, the red stripes appeared to be tilted counterclockwise and the green, clockwise.

Opposite color aftereffects also occur when red and green are paired with lines that are moving upward and downward (*3*) or with spirals rotated to produce apparent expanding and contracting patterns (*4*). The contingency of color aftereffects on direction of motion is important because the analysis of motion involves temporal perception, which must occur at a fairly high level of visual processing; effects contingent on motion, unlike those contingent on orientation, cannot be attributed to retinal afterimages (*5*). However, if the explanation lies in the selective adaptation of detectors specialized for both color and motion, it should also be possible to reverse this contingency, that is, to produce motion aftereffects contingent upon color.

We report that the contingency can be reversed (*6*). When observers received appropriate adaptation, they perceived a stationary spiral to be expanding or contracting, depending on its color. We chose to study aftereffects of spiral motion rather than linear motion because they are less easily explained in terms of eye movements.

The observers, tested individually, were 24 women between 16 and 28 years of age, who were not told about color and motion aftereffects. Each observer sat 80 cm from a screen. A projector illuminated a patch of the screen, 33 by 33 cm, with either white, red, or green light (*7*). A three-turn arithmetic spiral (diameter, 7.62 cm) with equal proportions of black and white was mounted in the center of the illuminated patch, at eye level. Clockwise rotation of the spiral made it appear to contract, and counterclockwise rotation, to expand. Rotation in either direction was at 80 rev/min, so that the contours of the spiral moved through a visual angle of 1.14° per second.

All observers watched the spiral motion of alternating direction for six 10-minute adaptation sessions. Observers were divided equally into four groups; for these groups, the direction of motion was changed every 10, 30, 60, and 150 seconds, respectively. Within each group, three observers saw the spiral contracting in green light and expanding in red light; for the other three, the relation between color and direction was reversed. All observers were instructed to fixate the center of the spiral throughout. The projector provided the only illumination during adaptation and testing.

After each adaptation session there was a 5-minute rest interval during which the room light was turned on and the spiral was covered up. After the interval, the observer was tested for aftereffects. She was shown the spiral rotating in each direction in white light and was asked to describe any color she saw; she was also shown the stationary spiral in red, green, or white light and was asked to report any apparent motion. The instructions were to report no effect if she saw none, but to describe any effects, even very small ones, as accurately as possible. The order of testing for color and motion aftereffects was reversed on successive test sessions and counterbalanced between observers. Presentation of the different colors and directions of motion was also partially counterbalanced. No single test presentation lasted longer than 5 seconds. An additional test session was given 24 hours after the sixth one, without any intervening adaptation period.

Motion aftereffects for the red and

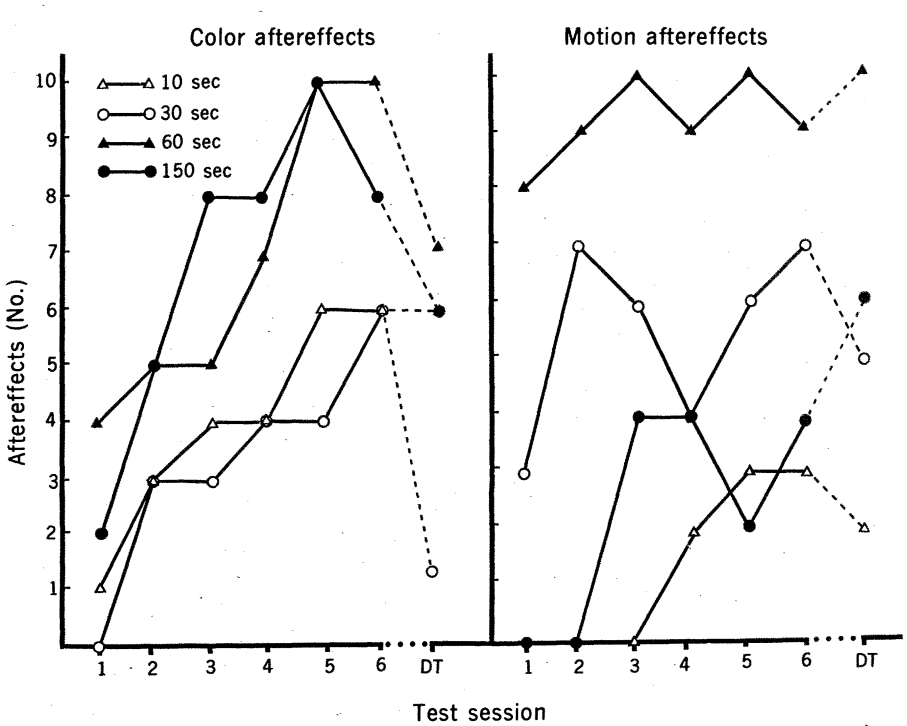

Fig. 1. Appropriate color aftereffects and motion aftereffects in each test session. Data are graphed separately for each rate of alternation of stimuli; *DT*, 24-hour delayed test.

green stationary spirals were judged appropriate if the reported direction of motion (expansion or contraction) for a color was opposite to that associated with the color during training. Color aftereffects contingent on a direction of motion were judged appropriate if the reported color was roughly complementary to the color paired with that motion in training. Acceptable colors reported for a motion paired with red included green, blue, blue-green, and lime, and for a motion paired with green included red, pink, orange, purple, lilac, and beige.

Out of the possible 336 color-contingent motion aftereffects and 336 motion-contingent color aftereffects, the observers saw 133 appropriate motion aftereffects and 145 appropriate color aftereffects, and only 4 inappropriate aftereffects in each category. The stationary white test spiral only once induced an aftereffect; for one observer, this spiral appeared to be expanding in the last test, delayed 24 hours. There were 47 instances when an observer saw both motion aftereffects in one test session and 52 instances when this happened for both color aftereffects. Thus, nearly all motion aftereffects were contingent on color and nearly all color aftereffects were contingent on motion, even though last-seen training stimuli or test stimuli might have caused aftereffects for which these contingencies would not apply.

Table 1. Appropriate aftereffects. Data are test sessions, out of seven, when each observer saw appropriate aftereffects (obs., observer; exp., expanding; cont., contracting; RC-GE, red contracting spiral alternated with green expanding spiral; RE-GC, red expanding spiral alternated with green contracting spiral).

Contingency	Obs.	Color aftereffects		Motion aftereffects	
		Red	Green	Exp.	Cont.
		10-second alternations			
RC-GE	1	0	1	0	0
	2	0	0	2	0
	3	7	6	0	0
RE-GC	4	6	4	0	0
	5	3	3	4	4
	6	0	0	0	0
		Total	30	Total	10
		30-second alternations			
RC-GE	7	1	0	3	2
	8	6	0	7	0
	9	0	0	4	0
RE-GC	10	5	1	7	5
	11	3	0	3	6
	12	5	0	1	0
		Total	21	Total	38
		60-second alternations			
RC-GE	13	7	4	7	7
	14	4	4	7	2
	15	7	7	7	7
RE-GC	16	0	0	1	6
	17	2	4	7	2
	18	6	3	6	6
		Total	48	Total	65
		150-second alternations			
RC-GE	19	7	7	5	5
	20	4	0	0	0
	21	5	1	3	3
RE-GC	22	6	6	0	0
	23	0	0	0	0
	24	5	5	2	2
		Total	46	Total	20

Table 1 gives the numbers of tests when observers saw appropriate aftereffects. Analysis of variance showed that the effects of alternation rate and type of aftereffect (color or motion) were both significant ($P < .05$). Separate tests for each type of aftereffect showed the alternation effect to be significant ($P < .01$) only for the motion aftereffects (*8*). The frequency of motion aftereffects was greatest when alternation occurred every 60 seconds.

The incidence of both aftereffects tended to increase on later test sessions (Fig. 1), although the data for motion aftereffects were relatively unsystematic. Furthermore, both effects remained clearly present on the 24-hour delayed test. The frequency of motion aftereffects, in particular, showed virtually no overall decline over the 24-hour interval, a result that suggests that color-contingent aftereffects for spiral motion can be as long lasting as aftereffects for spiral motion which are not contingent on color (*9*).

Although we did not measure the magnitude or duration of the motion aftereffects, observers' descriptions indicated that these effects were weak and faded fairly rapidly, usually within the 5-second test. In another experiment, we told observers to indicate the effect's duration and found that the effect usually lasts only a second or two but occasionally persists for up to 10 seconds. The fading appears to be due to some inhibitory process during a test exposure, since the aftereffects reappeared on the 24-hour delayed test without any further adaptation. Similarly, Mayhew and Anstis (*10*) showed that a color-contingent motion aftereffect can be repeatedly induced with each new presentation of the test stimulus, even though the effect may fade within presentations.

Do color-contingent motion aftereffects and motion-contingent color aftereffects depend on adaptation of the same detectors? The answer is not yet clear. It is possible to maintain that they do, even though the motion aftereffects seemed to depend more critically on the rate of alternation of the inducing stimuli. The difference may lie in the nature of the stimuli used to test the effects. The black and white spirals used to test for color aftereffects presumably affect detectors sensitive to all colors, since white light includes all visible wavelengths. The influence of any specific color adaptation should therefore be apparent. On the other hand, a stationary test pattern probably does not affect all movement detectors equally, but is perhaps "tuned" to only a limited range of detectors. Consequently a motion aftereffect might occur only if adaptation had affected, not just the detectors specific to the adapting motion, but detectors sensitive to the stationary spiral as well. This reasoning is supported by the data of Mayhew and Anstis (*10*), which show that strong color-contingent spiral aftereffects are obtained when the adapting spirals are alternated rapidly every 5 or 10 seconds) but when rotation speed is very slow (5 rev/min).

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References and Notes

1. C. McCollough, *Science* **149**, 1115 (1965).
2. R. Held and S. Shattuck, *ibid.* **174**, 314 (1971).
3. N. Hepler, *ibid.* **162**, 376 (1968).
4. C. F. Stromeyer and R. J. W. Mansfield, *Percept. Psychophys.* **7**, 108 (1970).
5. C. S. Harris and A. R. Gibson [*Science* **162**, 1506 (1968)] report an orientation-contingent color aftereffect that cannot be attributed to afterimages, but it is still possible that afterimages may have at least contributed to the aftereffects in other experiments.
6. This was also demonstrated informally in 1968 by C. F. Stromeyer (personal communication).
7. Red and green lights were produced by slides made from Wratten filters No. 92 (dominant wavelength, 646.2 nm in tungsten light) and No. 74 (dominant wavelength, 538.0 nm in tungsten light), respectively. White light was provided by the projector lamp. The luminances of the color surfaces were 1075 mlam for the white, 32.89 mlam for the red, and 37.27 mlam for the green.
8. We recognize that the data are scarcely appropriate for analysis of variance. In an attempt to compensate at least for floor and ceiling effects, we applied an arcsin transformation to the data [B. J. Winer, *Statistical Principles in Experimental Design* (McGraw-Hill, New York, 1962), p. 221], and repeated the analysis. This resulted in slightly increased *F* ratios.
9. R. Masland [*Science* **165**, 819 (1969)] reported motion aftereffects for spirals which lasted up to 20 hours.
10. J. E. W. Mayhew and S. M. Anstis, *Percept. Psychophys.*, in press.
11. We share authorship equally. We thank D. Bindra, A. S. Bregman, D. C. Donderi, and C. S. Harris for helpful comments. Supported by a grant from the National Research Council of Canada to D. C. Donderi and a grant from the Defence Research Board of Canada to M.C.C.
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19 October 1971; revised 29 December 1971