Presence and absence of color selectivity in the motion aftereffect

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It is controversial whether the magnitude of the motion aftereffect is greater when both inspection and test stimuli are the same color rather than different colors (color selectivity). The present experiments show that the extent of color selectivity in the classical motion aftereffect depends upon (1) the duration of the interval between inspection and test, and (2) the nature of the stimulation during this interval. These findings are consistent with previous reports of two phases in the motion aftereffect and are interpreted in terms of the known properties of sustained and transient cells in the human visual system.

It has been demonstrated that the magnitude of the classical motion aftereffect is greater when both inspection and test stimuli are viewed in the same colored light than in different colored light under monoptic viewing conditions (Lovegrove, Over, & Broerse, 1972; Mayhew, 1975). With dichoptic viewing, the color relationship between the inspection and test stimuli has no effect on the magnitude of the aftereffect. These results were interpreted as indicating that at some level of the visual system there exist cells which are exclusively monocular and selective not only for direction of motion, but also for color (Lovegrove et al., 1972). A number of studies of contingent aftereffects in which subjects alternately view opposite color-motion combinations during inspection have also reported color selectivity in the motion aftereffect (Favreau, 1976; Favreau, Emerson, & Corballis, 1972; Mayhew, 1972, 1975; Mayhew & Anstis, 1972; Murch, 1974). In contrast, Day and Wade (1979) failed to demonstrate color selectivity in a series of experiments in which subjects viewed only one color-motion combination during inspection. They interpreted their results as evidence against the existence of color-motion detectors and for a distinction between classical and contingent aftereffects.

In a reply to Day and Wade (1979), Lovegrove, Over, and Broerse (1979) argued that the discrepant results might arise from the existence of two different phases in the motion aftereffect (Bonnet, Bouvier, & Petiteau, 1976; Bonnet & Pouthas, 1972; Favreau, 1976; Taylor, 1963).

Bonnet and Pouthas (1972) found that fast, vivid movement was visible on a noise background immediately following inspection of moving lines, but thereafter the aftereffect took the form of slower and less vivid movement which was seen best when the inspection and test stimuli were similar. In the first stage reported by Favreau, the motion aftereffect

showed rapid decay and was sensitive to brightness-contrast but not to color, while in the second stage the aftereffect decayed slowly and was color-selective. In this case, color selectivity would depend on the duration of the interval between inspection and test, with Phase 1 effects normally being seen before Phase 2 effects. Lovegrove et al. (1979) also proposed that transient and sustained cells might underlie Phase 1 and Phase 2 aftereffects, respectively. There is both psychophysical and electrophysiological evidence that transient cells are relatively insensitive to spatial detail and lacking in color selectivity, whereas sustained cells exhibit spatial and color tuning (Dow & Gouras, 1973; Gouras, 1974; Tolhurst, 1977).

Day and Wade (1979) used a 1-sec interstimulus interval, thus possibly measuring Phase 1, whereas Lovegrove et al. (1972)¹ used a 15-sec interstimulus interval and possibly measured Phase 2. The present paper reports two experiments which support the above proposals.

Experiment 1, therefore, was conducted to determine whether the extent of color selectivity in the motion aftereffect depends on the duration of the interval between inspection and test.

EXPERIMENT 1

Method

Subjects. Twelve subjects with normal or corrected-to-normal vision participated in this experiment. All subjects were screened for abnormalities in color vision on the Ishihara test for color blindness.

Apparatus. The square-wave moving gratings used as inspection stimuli were produced by attaching black tape to a white belt which was driven by a small motor. The test pattern was produced by attaching black tape to white cardboard. The inspection and test patterns were presented in Fields 1 and 2 of a Scientific Prototype three-field tachistoscope (Model GB). An achromatic 1.1-cycle/deg square-wave grating print surround, subtending 9×9 deg with a Michelson contrast of .6 and space-average luminance of 4.4 cd/m², was presented in the third field of the

tachistoscope. The circular inspection and test patterns both subtended 1 deg 44 min in diameter, had Michelson contrasts of .6, spatial frequencies of 1.1 cycles/deg, and space-average luminances of 1.1 cd/m². Both inspection and test stimuli could be displayed in red (Wratten filter 26; dominant wavelength 620.6 nm in illuminant A) and green (Wratten filter 55; dominant wavelength 524.1 nm in illuminant A) light. The Wratten filters were trans-illuminated by the tachistoscope light source. The grating moved from left to right at 2.5 cycles/sec.

Procedure. The general procedure followed that used by Lovegrove et al. (1972). Data were collected in four separate experimental sessions which followed one practice session. The five sessions were separated by at least 24 h. In any one session, the subjects adapted to only one color (initially for one period of 4 min and then for seven 1-min periods) and were tested in only one interstimulus interval condition. Four measures of the motion aftereffect were taken on both the red and green targets following either a 1- or 15-sec interstimulus interval. Half of the subjects received the 1-sec delay condition first, and the other half the 15-sec delay condition first. Similarly, half the subjects adapted to moving gratings in green light first and the other half to red light first. Order of testing was randomized for each subject in a session, and viewing was monocular. The magnitude of the aftereffect was measured by subjects moving a pen laterally at the same apparent speed as the aftereffect. In the 1-sec interstimulus interval condition, the subjects continued to look at the patterned surround in the tachistoscope, whereas during the 15-sec interstimulus intervals they looked at a brick wall.

Results and Discussion

The mean magnitude of the aftereffect (mean pen displacement in 15 sec) for each color combination at interstimulus intervals of 1 and 15 sec is shown in Figures 1a and 1b.²

Since the data contained evidence for nonadditivity (inspection of the raw data indicated a strong interaction between subjects and conditions), a logarithmic transformation was applied before analysis in this and in the subsequent experiment. The analysis of variance showed that the difference between the 1- and 15-sec interstimulus interval conditions was significant [$F(1,11) = 10.86$, $p < .01$]. There was no significant effect of inspection color [$F(1,11) =$

1.26 , $p > .05$] or test color [$F(1,11) = .25$, $p > .05$]. A significant inspection-test color interaction [$F(1,11) = 17.93$, $p < .01$] shows the presence of color selectivity. The three-way interstimulus interval-inspection-test color interaction was significant [$F(1,11) = 14.6$, $p < .01$], indicating a significant difference between the amount of color selectivity obtained with a 1- and 15-sec interstimulus interval. This experiment clearly shows that color selectivity in the motion aftereffect depends on the duration of the interval between inspection and test. Immediately after inspection, there is a strong motion aftereffect which is not color-selective. Fifteen seconds after inspection, the magnitude of the aftereffect is reduced and is dependent on the color relationship between inspection and test stimuli.

EXPERIMENT 2

The preceding experiment suggests that color-contingent components of motion aftereffects, like pattern-contingent components, are not found until the initial phase has been dissipated. This dissipation may, however, depend on not only the presence of an interstimulus interval, but also the presence of stimulation during that period. The motion aftereffect is known to show little reduction when a dark period is interpolated between the inspection and the test periods (Spigel, 1962; Wohlge-muth, 1911), and Bonnet et al. (1976) report storage of both noncontingent and pattern-contingent phases during relatively brief dark intervals. As subjects received patterned light stimulation during the 15-sec interstimulus interval in Experiment 1, the following experiment was conducted to determine whether this factor was important in demonstrating the contingent component.

Method

Subjects. Twelve subjects participated in this experiment.

Apparatus. The apparatus was the same as for Experiment 1, with one exception. During the 10-sec light interstimulus interval, a gray card covered by randomly positioned black dots and having a space-average luminance of 4.4 cd/m² was placed in the blank field of the tachistoscope.

Procedure. The procedure was similar to that of Experiment 1 in most respects. Two interstimulus interval conditions, both of 10 sec, were used. In the dark condition, the subjects looked into the completely darkened tachistoscope, whereas in the light condition, they viewed the random-dot card described above. In this experiment, the subjects tracked the apparent movement of the test stimulus for 10 sec rather than 15. The data were collected over four sessions. In any one session, the subjects adapted to only one color and tracked apparent movement on two test colors following either the dark or light interval. Presentation of conditions was counterbalanced across subjects.

Results

The mean magnitude of the aftereffect (mean pen displacement in 10 sec) for each color combination following light and dark intervals is shown in Figures 2a and 2b.

Figure 1. Mean magnitude of the motion aftereffect (mean pen displacement in 15 sec) with various combinations of inspection and test colors. In (a), the ISI was 1 sec, and in (b), the ISI was 15 sec.

Figure 2. Mean magnitude of the motion aftereffect (mean pen displacement in 10 sec) with various combinations of inspection and test colors. In (a), the 10-sec ISI was dark, and in (b), the 10-sec ISI was bright.

An analysis of variance showed that the difference between the dark and light interstimulus interval conditions was significant [$F(1,11) = 12.00$, $p < .01$]. There was no main effect of inspection color [$F(1,11) = 1.16$, $p > .05$], but test color was barely significant [$F(1,11) = 4.92$, $p < .05$].³ The presence of a significant inspection-test color interaction [$F(1,11) = 20.69$, $p < .001$] confirmed the existence of color selectivity. The three-way interaction was not significant [$F(1,11) = 2.53$, $p > .05$].

To clarify this situation, the data from the dark and the light interval conditions were analyzed separately. Under these circumstances, a strong inspection-test color interaction was still found for the light-interval data [$F(1,11) = 11.06$, $p < .01$], but there was no indication of any corresponding interaction for the dark-interval data [$F(1,11) = .004$, $p > .05$].

The results support the hypothesis that, in the absence of stimulation, the initial Phase 1 of the motion aftereffect will not be dissipated and will continue to obscure the later second phase. Informal observations suggest that, as would be expected from previous studies (Ross & Taylor, 1964; Spigel, 1962), higher luminance levels accelerate the dissipation of the initial phase. These factors may, however, be of importance only for relatively short interstimulus intervals. In reporting that both phases are stored to some degree during short periods of darkness, Bonnet et al. (1976) also noted that only the pattern-contingent phase was present after longer dark intervals. Supporting this are the results of a minor supplementary experiment with eight subjects, in which significant color selectivity was found after a 30-sec dark interstimulus interval [$F(1,7) = 9.50$, $p < .05$]. Due to the relatively informal circumstances under which this experiment was conducted (subjects were

simply asked to close their eyes for 30 sec), it is, however, impossible to be certain that there was a total absence of retinal stimulation throughout the interstimulus interval.

DISCUSSION

The experiments reported here clearly demonstrate color-selectivity in the "classical" motion aftereffect. Color selectivity primarily depends on the duration of the interval between inspection and test.⁴ In experimental conditions similar to those used by Day and Wade (1979), there was no evidence that the motion aftereffect is color selective. Experimental conditions using an interstimulus interval similar to that used by Lovegrove et al. (1972) did demonstrate color selectivity. The latter depends, however, on the nature of the stimulation during this delay. This evidence supports earlier proposals of two distinct phases in the motion aftereffect, with the first phase not demonstrating color selectivity while the second phase does. It is argued that Phase 1 effects result from adaptation of transient cells whereas Phase 2 effects result from adaptation of sustained cells.

The theoretical and methodological considerations raised in this paper have relevance beyond the original issue of the conditions under which color selectivity in the motion aftereffect occurs. First, these considerations are likely to be of equal relevance to the study of *any* contingent components in the motion aftereffect. Second, if the identification of the two phases of the motion aftereffect with the sustained and transient systems is correct, their relative strengths will be altered by manipulating variables such as rate of motion and contrast which differentially affect the two systems (Keck, Palella, & Pantle, 1976; Pantle, Lehmkuhle, & Caudill, 1978). Third, even though there may be a number of ways to distinguish classical from contingent motion aftereffects, the presence or absence of color selectivity is not one of these. Rather, there are two ways of inducing motion aftereffects; inspection of a single color-motion stimulus as used in this paper and alternate inspection of opposite color-motion combinations (Favreau, Emerson, & Corballis, 1972). The former induces a motion aftereffect with both a simple and a contingent component, whereas the latter has only contingent components.

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NOTES

1. Neither Lovegrove et al. (1972) nor Day and Wade (1979) specified the interstimulus interval duration used in their experiments.
2. The absolute magnitude of the aftereffects measured in this experiment is smaller than that reported by Lovegrove et al. (1972). It is, however, the relative magnitude of the aftereffect under same and different color conditions rather than absolute aftereffect magnitudes which is crucial to the argument presented in this paper.
3. This significant target-color effect appears to have resulted from the small aftereffect seen in the green-green condition by one subject. In this condition, 9 out of the 12 subjects experienced more aftereffect on the green-green than on the red-green condition. Two of the remaining subjects experienced slight reversals, whereas the third subject experienced such a large reversal that his "reverse" color selectivity was equal to the total color selectivity experienced by the other 9 subjects.
4. In further experimentation, using 1-, 5-, and 15-sec interstimulus intervals, the dependence of color selectivity on interstimulus interval duration was even more clearly demonstrated. The 1-sec condition produced no color selectivity, the 5-sec condition produced color selectivity on one test stimulus color only, and the 15-sec condition produced color selectivity on both test stimulus colors.

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