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Extremely Long-Term Persistence of the McCollough Effect

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The question has been raised whether an associative mechanism is responsible for the persistence of the McCollough effect. Since current estimates of its rate of decay are derived from procedures in which subjects are repeatedly tested, it was hypothesized that the measured effects might be attenuated by the testing process. Accordingly, a comparison was made between repeated testing and time-elapse testing. A conventional group of 16 subjects had repeated testing at 0, 8, 24, 56, and 120 hr. after induction. Five other groups of 16 were run, each at one of the time delays, with no intervening tests; an additional measure was taken where appropriate at 120 hr. A magenta-green nulling procedure was used to assess the aftereffect. The repeated-test group showed a linear decrease of effect against the stated delays, reaching zero at 120 hr. In contrast, the time-elapse groups showed little decline up to 120 hr. Those groups *re*tested at 120 hr. showed declines due to prior testing. When four more groups were subsequently tested at intervals up to 2,040 hr., the effect remained at better than half strength.

McCollough (1965) was the first to observe the effect now named after her. Alternating a pattern of horizontal stripes on a blue background with a pattern of vertical stripes on an orange background resulted in the perception of an orange aftereffect when a black and white horizontal grating pattern was viewed, and a blue aftereffect when a vertical black and white grating was seen. Based on Hubel and Wiesel's (1959, 1968) reports that the visual system contained orientation-specific edge detectors, McCollough explained her finding as the adaptation of color-specific edge detectors. Harris and Gibson (1968) have proposed a simpler "dipole" model, based on an hypothesized physiological mechanism, to account for similar results.

Since the publication of McCollough's paper, a variety of other contingent aftereffects has been reported including, but not limited to, color-contingent tilt aftereffect (Held & Shattuck, 1971), color-contingent motion aftereffect (Favreau, Emerson, & Corballis, 1972), and motion-contingent color aftereffect (Hepler, 1968; Stromeyer & Mansfield, 1970).

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The plethora of contingent aftereffects makes it extremely unlikely that adaptation or fatigue in a single cell or class of cells in the visual system is responsible for the various contingent aftereffects. For that to occur, the number of classes of specialized cells needs to be the same as the number of contingent aftereffects; this number seems to grow with each issue of a psychological journal. Moreover, the duration of such effects is far greater than would be expected from simple fatigue of a physiological mechanism. An alternative hypothesis, advanced by Murch (1972), among others, is that such effects are mediated by a linkage between specialized neurons at two different levels of the central nervous system. Although the mechanism of linkage is not known, it might be analogous to associative learning and therefore subject to many of the same types of interference, practice, and extinction effects as associative learning. For example, the current estimates of the persistence of the McCollough effect (cf. MacKay & MacKay, 1974; Riggs, White, & Eimas, 1974) are based on repeated testing of subjects over some time period. The process of testing, which consists of presenting one of the two paired associates, possibly interferes with the aftereffect. The following experiment was designed to test that hypothesis by comparing repeated-test groups with five time-elapse groups.

Experiment 1

Method

Subjects. Volunteer subjects were 96 students at the University of Louisville. None had previously been exposed to the McCollough effect.

Apparatus. The stimuli consisted of horizontal and vertical gratings (Ronchi rulings) photographed on 35-mm film and projected by means of a Kodak Carousel 850-H projector. Each bar subtended .4° of visual angle and the extent of the entire grating pattern was 10.4° in both the horizontal and vertical directions. The induction figures were projected through either a Kodak Wratten 34A filter (violet) or a Kodak Wratten 53 filter (green). Luminances of the violet, green, white, and black bars were, respectively, 25.46 cd/m^2, 19.10 cd/m^2, 31.83 cd/m^2, and .95 cd/m^2. Immediately in front of the projector lens was a color mixer employing a fixed polarizer in front of which, on a rotating plane surface, were alternating squares of Kodak CC20M (magenta) and CC30G (green) color compensating filters whose axes of polarization were orthogonal. These particular color compensating filters were chosen because they are nearly equal in excitation purity.[1]

Procedure. Each subject was first shown the achromatic test slide in one of its two possible orientations, projected through the color mixer, and was told to rotate the color mixer until the white lines in the slide appeared as colorless as he could make them. The median of three settings was taken as a subject's neutral point and all induction slides were projected through the color mixer set at that value. As an appropriate test for color vision, any subject whose neutral point differed from the complementary point (50% magenta–50% green) by more than ±10% was terminated without further testing. Each subject was then exposed for 15 min. to alternating magenta (or green) vertical gratings and green (or magenta) horizontal gratings. The duration of each exposure was 7 sec with a 1-sec dark interval between exposures.

The subjects were divided into six groups ($n = 16$). The repeated-test group was tested immediately after induction and at intervals of 8, 24, 56, and 120 hr. after induction. Five time-elapse groups were tested *for the first time* after delays of 0, 8, 24, 56, or 120 hr. (5 days) after induction. The first four time-elapse groups were subsequently retested at 120 hr. after induction. Pairings of grating orientation with color, orientation of the first grating presented, and orientation of test grating were counterbalanced within each group.

Each test required that a subject view either a horizontal or a vertical achromatic grating projected through the color mixer and rotate the color mixer to achieve the maximum achromaticity. The median of three such settings was recorded as the postinduction neutral point.

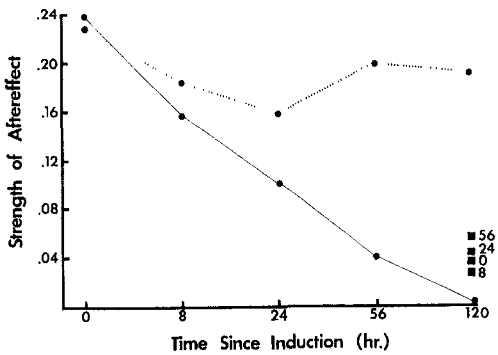

FIGURE 1. Comparison of decay of aftereffect in repeated-test group (solid line) and time-elapse groups (dotted line) at each of five time delays. (Squares indicate the results of retest at 120 hr. of time-elapse groups tested at 0, 8, 24, and 56 hr. as indicated. See text for full description of ordinate units.)

Results

Figure 1 shows the results of testing at various times after induction for each of the groups. The data are plotted in terms of the deviation from the preinduction neutral point. A value of 1.0 on retest would indicate that a subject whose original neutral point was 0 (50% magenta–50% green) would require, after induction, either 100% green to cancel the "pink" afterimage or 100% magenta to cancel the green afterimage. Since all reported aftereffects were in the predicted direction (i.e., complementary to the color originally paired with a particular grating orientation), data for the pink and green are pooled in the figure as are data for both grating orientations.

The effect of repeated testing is a linear decrease, over the geometric intervals chosen, with the effect reaching zero at the end of 120 hr. In contrast, the time-elapse groups do not show a significant decrease in the strength of the effect even at the end of 120 hr. The difference in the strength

[1] We are grateful to Keith D. White, who patiently explained the construction of such a color-mixing device at the fall 1973 meeting of the Optical Society of America.

of the aftereffect at each time interval was compared for the two groups by means of t tests. Differences between repeated-test and time-elapse groups were significant at 56 hr., $t(30) = 6.67$, $p < .01$, and 120 hr., $t(30) = 6.45$, $p < .01$. Differences between the two groups at 0, 8, and 24 hr. were not significant, but an increasing difference is apparent at each time interval.

A one-way analysis of variance on the 120-hr. tests indicates a significant difference among groups at that interval, $F(5, 90) = 10.04$, $p < .001$. Subsequent Newman-Keuls tests showed the difference to be between the 120-hr. time-elapse group and all other groups. The retest groups did not differ significantly from one another regardless of the time since the first test or the number of previous tests.

Discussion

The obvious difference between the repeated-test group and the time-elapse groups with increasing delays indicates that the strength of the McCollough effect is adversely affected by testing. Simple decay seems to have little or no effect over the intervals tested.

The strength of the effect for the 120-hr. time-elapse group raises the question of how long the McCollough effect will last in the absence of tests. The following experiment was designed to answer that question.

Experiment 2

Method

Subjects. Subjects were 40 volunteers from various psychology classes at the University of Louisville.

Apparatus. The apparatus was identical to that used in Experiment 1.

Procedure. Preinduction and induction sessions were identical to those described in the first experiment. Subjects were randomly assigned to one of four time-elapse groups which were tested one time each at 248, 504, 1,016, and 2,040 hr., respectively, after induction. These time intervals are, in order, approximately 10 days, 21 days, 1½ mo., and 3 mo. Because of semester break, 3 mo. is the practical upper limit of delay.

Results

The mean aftereffect scores, expressed as deviations from the preinduction neutral point are as follows: 22.7 (248 hr.), 16.0 (504 hr.), 23.0 (1,016 hr.), 11.5 (2,040 hr.).

A least squares best fit, plotted by computer gave the equation: $y = .20192 - .003008x$, where y is strength of effect and x is elapsed time in hours.

The least squares fit projects to 0 at 6712.5 hr. (approximately 9 mo.), but caution is necessary in extrapolating from these data. In the first place, the equation accounts for only 27% of the variance, no doubt due to the "noisiness" of the data for the last four groups. Moreover, the y-intercept, .20192, is well below the value obtained for the 0 delay groups which was determined for 32 subjects (16 each in the repeated-test group and time-elapse group). In addition, the 24-hr. time-elapse group seems spuriously low. These factors suggest a somewhat steeper rate of decay as a function of time than that computed from the data. The practical projection for the curve, therefore, is closer to 6 mo. than to 9 mo.

Discussion

The persistence of the McCollough effect, which is at nearly half strength after 2,040 hr., indicates that the physiologically based models suggested by McCollough (1965) and Harris and Gibson (1968) are not adequate. It is difficult to imagine a physiological mechanism which would remain fatigued for such extended periods or one whose recovery would be hastened by exposure to test gratings. Both the extremely long persistence of the McCollough effect and the marked differences found between repeated-test and time-elapse groups lend support to the hypothesis that contingent aftereffects must be accounted for by means of an associative mechanism.

The marked differences in Experiment 1 between the two conditions suggest the existence of an associative process between grating and color, the strength of which is diminished by testing with the stimulus item (grating) alone. If we posit an association between the gratings and the color that each was paired with during the induction series, then the test trial might serve to weaken the association by exposing the subject to one of the two stimuli without the presence of the other. In fact, Skowbo, Gentry, Timney, and Morant (1974) have provided recent evidence which strengthens this suggestion. In their experiment, subjects were adapted to gratings similar to those used in the present experiment and then subjected to 50 min. of postadaptation exposure to various visual stimuli. When the original cue was used as the postadaptation stimulus, decay was rapid, in comparison to the effects produced by other forms of visual stimulation. During test trials in the present experiment, a subject is exposed to a grating with the apparent complement of the color with which it was originally paired. If the same associative process is operating during testing as during induction we might expect some decrement of strength of effect as the result of pairing the grating with an incompatible color. However, such an association would have to result from only three test trials in the present experiment.

The effect might depend upon the consolidation process common to the literature on human and animal learning (see Posner, 1973, for a discussion of human learning, and Spear, 1973, for a review of the animal learning literature). Thus, two possible interpretations of the data from the present experiment are (a) Exposure to the grating without concomitant exposure to the previously paired color is analogous to exposure to cue without "reinforcement," that is, an extinction trial, and (b) the act of "recalling" the learned association renders the memory trace labile and subject to interference. Either of these hypotheses could account for the slow fading of the untested association during the 120-hr. period, inasmuch as subjects are probably exposed to other vertical and horizontal grating patterns, such as picket fences and venetian blinds, which would interfere with the previously learned association; however neither is entirely satisfactory. Many other interpretations are also possible but further speculation is probably premature in view of the paucity of evidence. However, the original explanations, based on adaptation or fatigue of single cells or classes of cells, are clearly untenable. Whatever explanation is adopted will need to take account of the evidence that introducing a test seems to begin a decay process.

Examination of the results of the tests at 120 hr. shows that the strength of the aftereffect is not significantly different from zero for those groups for which the 120-hr. test was a retest, whereas the group whose first test occurred at 120 hr. shows little loss of strength of the effect. Since these retests include groups whose first tests were at 0, 8, 24 and 56 hr. it seems that the process of decay is begun by a single test session and essentially complete by the end of 64 hr. (the difference between 120 hr. and 56 hr.—the shortest elapsed time between tests at this point). Inasmuch as there are no 64-hr. gaps in the repeated-test group until the last one, it is impossible to determine from these data the quantitative effect of repeated testing. That is, a *single* prior test may be sufficient to begin the process of decay; it may or may not be affected by subsequent tests. The effects of various delays after a single test are currently under investigation.

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