Conditioning and blocking of the McCollough effect

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The classical conditioning explanation of the McCollough effect was extended by investigating blocking and allied phenomena predicted by the Rescorla-Wagner (1972) equations. The subjects were first exposed to colored gratings or moving spirals and then were tested after induction with a compound of both types of stimuli. The effects appeared to be additive, and the stronger stimuli overshadowed the weaker stimuli during compound training. Blocking of the McCollough effect, or of the spiral, was observed after prior training on the other stimulus. A supplementary procedure suggested that it was possible to unblock either effect by increasing color saturation and contrast. The results show close agreement with the predictions of conditioning theory.

The orientation-contingent color aftereffect first described by McCollough (1965) arises when orthogonally alternated gratings have been presented in association with complementary colors. Typically, a horizontal grating may have been paired with green, alternating with a vertical grating paired with magenta. When, following this induction procedure, one of the gratings is presented achromatically as a test stimulus, the person responding shows evidence of a color aftereffect complementary to the hue originally used. Thus, the horizontal grating appears to stimulate the experience of a weak magenta, whereas the vertical stimulates green.

In addition, color aftereffects may apparently be made contingent on such features as curvature (White & Riggs, 1974) or line angle (Hayman & Allan, 1980), although these findings have proven controversial. Other effects, such as tilt (Held & Shattuck, 1971) or movement (Mayhew & Anstis, 1972), may be made contingent on color. The variety of these effects, together with the extremely long duration of the McCollough effect, which can extend for several days despite repeated retesting (Riggs, White, & Eimas, 1974), has often been taken to indicate that the phenomenon is associative rather than deriving from physiological adaptation. There have been recent attempts (Grossberg, 1980; Kruger, 1979) to preserve a physiological level of explanation, but it is not yet clear whether all the associative features of the effect can be accommodated.

The predominant associative model of the effect has been based on classical conditioning. In the form advocated by Murch (1976), it is assumed that the inducing color provides an unconditioned stimulus (US), that the oriented grating provides a conditioned stimulus (CS), and that the response (UR or CR) consists of a shift in the

visual system toward the complementary color. Given this analysis, it follows that any test trial should constitute an extinction trial, since the grating is no longer reinforced by the unconditioned color stimulus. It is consistent with this analysis that avoiding extinction by withholding test trials has the effect of protracting the duration of the aftereffect over several months (Jones & Holding, 1975), although this result has been questioned (Skowbo, Garrity, & Michaud, 1985). The later finding that a single test trial seems to initiate a decay of constant duration (Holding & Jones, 1976) is less amenable to a simple conditioning explanation.

The value of the conditioning model was examined in a review by Skowbo (1984), who evaluated the findings on 14 features of conditioning. Although her conclusions failed to corroborate a conditioning approach, the cited studies indicated that the McCollough effect broadly resembles conditioning in most of these characteristics, including US-UR relations, US intensity effects, CR-UR relations, CS intensity effects, stimulus generalization, acquisition curves, longevity, extinction and spontaneous recovery, latent inhibition, and absence of backward conditioning. However, the available results were ambiguous with respect to trace and delayed conditioning, and were viewed as inconsistent with respect to effects of awareness of stimuli and contingencies, degree of permanence, reduced CS-US correlation effects, and certain practice effects. It might be argued that none of these points is conclusively established in the conditioning literature. Again, failure of the McCollough effect to yield interocular transfer of extinction (Savoy, 1984) has also been considered incompatible with the conditioning model. However, as in several of the above cases, the comparable findings for classical conditioning are poorly established.

At the time of Skowbo's (1984) review, no data were available on the susceptibility of the McCollough effect to the phenomena of overshadowing and blocking. Overshadowing, first observed by Pavlov (1927), occurs when

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a dominant stimulus prevents the simultaneous conditioning of a weaker stimulus. Blocking, as defined by Kamin (1969), occurs when prior conditioning to one stimulus prevents or impairs the subsequent simultaneous conditioning of a second stimulus. These phenomena have played a central part in the development of modern conditioning theory, and may be regarded as crucial in evaluating the conditioning model for the McCollough effect. An instance of blocking following brief induction trials has been reported (Westbrook & Harrison, 1984), although these investigators used unusually brief alternations during induction. Both overshadowing and unidirectional blocking have been observed in a compound McCollough stimulus figure (Siegel & Allan, 1985); however, the compound stimulus might be subject to Zöllner and/or Poggendorf illusion effects, and the authors make no use of independently processed simple aftereffects. In the present experiment we attempted to provide clear confirmation of the most important conditioning effects, including bidirectional blocking, while testing the predictions of a specific theoretical model.

It seems important to establish to what extent the McCollough effect can be shown to follow the detailed predictions available for classical conditioning. The quantitative theory put forward by Rescorla and Wagner (1972) has met with considerable success, predicting a number of outcomes in addition to overshadowing and blocking. The basic equations may be rendered as:

$$\Delta V = \alpha\beta(\lambda - V_T)$$

and

$$V_T = V_A + V_B,$$

where V symbolizes strength of conditioning; A and B are individual stimulus components; T is their total; λ is the asymptote of conditioning; and α and β are empirical constants, associated respectively with the CS and the US. Hence, the equations state that the change in conditioning strength on any one trial is a weighted function of the difference between the current strength of a stimulus compound and the maximum strength attainable in the specified conditions.

It then follows, for example, that if stimulus component A is more salient than B , with a larger value of α , it will acquire response strength more rapidly and thus overshadow the conditioning of component B . Again, if component A is conditioned first, then V_A will approach asymptote, with the result that $\lambda - V_T$ will approach 0. Thus, in subsequent joint trials with A and B , the component V_B will fail to increase in response strength, having been effectively blocked by the massive contribution of V_A to V_T . In addition to subsidiary predictions, such as conditioned inhibition and extinction with reinforcement, derived from the use of negative values of ΔV , the model predicts a form of unblocking. If, following con-

ditioning of component A , the intensity of the US is increased, then a larger value of λ will be applicable during compound training, so that V_B will be unblocked.

In the present experiment, we examined overshadowing and blocking of the McCollough effect by a disparate contingent aftereffect, and also the reverse procedure, making a preliminary investigation of unblocking. Instead of using forms of crossed gratings as compound stimuli, because such compounds are potentially susceptible to geometric illusion effects, we made use of separate visual channels. Component A was the traditional McCollough grating, presented either horizontally or vertically, and component B was a rotating spiral. It had been ascertained in pilot work that a color aftereffect could be made contingent on the apparent expansion or contraction of such a spiral. In supplementary conditions of the experiment, we examined the effects of two durations of initial induction and attempted to assess short-term extinction effects.

METHOD

Subjects

Undergraduates from introductory psychology courses were screened for color deficiencies. The first 72 students who made fewer than two errors on the Farnsworth Dichotomous Test for color blindness, and who had no prior experience of color aftereffects, were allocated randomly to the three experimental groups.

Apparatus

The McCollough stimuli were horizontal or vertical gratings with spatial frequencies of 1.75 cpd, presented on a circular field of 9.37° visual angle at a viewing distance of 127 cm. The McCollough test stimulus comprised two semicircles, one containing each orientation. The motion stimuli were provided by an Archimedes spiral of the same dimensions, with a spatial frequency of .58 cpd, rotated by an electric motor at 50 rpm; such a spiral appears to expand when rotated clockwise and to contract when rotated counterclockwise. When the compound stimulus was required, the McCollough bars were projected onto the spiral disk. Alternation and sequencing of the various stimulus conditions was controlled by a series of Hunter timers.

During induction, color hues were provided by projecting through Wratten filters (#34A, magenta, or #53, green). The chromatic light was projected either through the grating slides or directly onto the spiral disk. For use in testing, a matching circle was located with its edge 5 cm to the left of the induction circle. When required, the matching circle was illuminated by the unfocused light from a second projector passed through a color-compensating slide. Filters #CC20M and #CC30G each composed half of this slide, which could be manually adjusted by a knob to provide hues varying from magenta to green. Displacement of the slide actuated a potentiometer that fed a digital ohmmeter, which was calibrated to yield linear response measurements on a scale from 1.38 to 3.62.

When required, the increase in US intensity was arranged by extinguishing a desaturating white light at 2 cd/m². This light was otherwise superimposed by a third projector on the chromatic induction stimuli, thus reducing both saturation and contrast during the first stages of the experiment.

The luminositities under all conditions, obtained by a Pritchett photometer and expressed in cd/m², were as follows: Achromatic test stimuli: white bars, 96; black bars, 2.5; contrast ratio, 38:1. Desatu-

rated chromatic induction stimuli: magenta bars, 12 (contrast, 3:1); green bars, 8 (contrast, 3.2:1). Saturated induction stimuli: magenta, 14 (contrast, 40:1); green, 9 (contrast, 36:1). The matching circle was approximately constant at 96 cd/m² for all settings.

Design and Procedure

We obtained preinduction baselines by having each subject match the achromatic test patterns, projected on the right, against the magenta-green matching circle on the left. Three such neutral settings were taken for each test pattern, and the median was used as the baseline value.

The induction phase of the experiment consisted of presenting the stimulus patterns colored with magenta (or green, in half the cases) in one form of the pattern, alternating with green (or magenta) in the other. Each alternation lasted 7 sec, with dark intervals of 0.5 sec. For half of all subjects, the induction phase ended after 5 min; for the other half, induction continued for a total of 10 min. For one experimental group of 24 subjects, the stimulus patterns were chromatic gratings; for another group of 24, the stimuli were rotating spirals; and for a control group of 24 subjects, the stimuli were the compounds obtained by superimposing gratings over spirals. The association between hue and orientation or direction of rotation was randomized across subjects, but remained constant throughout the testing of each individual.

At the end of the induction period, all experimental subjects made three test matches with the achromatic form of the appropriate stimulus. McCollough aftereffect measurement involved matches to the test grating; spiral aftereffects were assessed by matching the subjective hue of an achromatic spiral rotating in the relevant direction; compound aftereffect measurement involved matches to the projected grating superimposed on the appropriately rotating spiral. Control subjects made three matches on both simple and compound patterns, in varied orders. The two experimental groups were then given induction training on the compound stimulus for either 5 or 10 min, in accordance with the duration of their initial induction. Three achromatic matches were again made, to determine the extent of blocking. Thus, the group initially trained on the grating was tested on the spiral, whereas the group trained on the spiral was tested on the McCollough grating.

Finally, all groups were reinduced with the compound stimulus at the higher US intensity made possible by increasing saturation, again for 5 or 10 min, reflecting the same experimental conditions as before. Median aftereffects were again obtained from three test matches. As a preliminary test of extinction, each subject then received, after a 5- or 10-min delay, a set of three achromatic trials with the appropriate test patterns, followed by a second and third set at 10-min intervals.

RESULTS

Planned contrasts and separate analyses of variance showed no significant differences for the spiral or the grating between 5- and 10-min induction periods, and these conditions were collapsed in subsequent analyses. All scores were reported as the increase in the proportion of the complementary color needed to match the test stimulus, where 50% green-50% magenta equals 0.00, and 0% green-100% magenta equals 1.00 (see Jones & Holding, 1975).

Additivity

Application of Rescorla and Wagner's (1972) equations requires the assumption that $V_A + V_B = V_T$. If V_T is represented by the aftereffect to the compound stimulus,

it may be expected that the strength of the compound effect should be approximately equal to the sum of the grating and spiral effects. The experimental design permits both between-group and within-group tests of this hypothesis. A comparison of the between-group means for strength of the aftereffect to the McCollough grating (.28) and to the spiral (.15), following single-stimulus training in the experimental groups, with the compound mean (.20) does not seem to support the assumption of additivity. However, it is possible that the discrepancy is due to sampling error. It may be more appropriate to compare the response strengths estimated in terms of the mean differences between the baseline matches and the tests following initial induction for the control group (.14 for the achromatic gratings vs. .10 for the spiral). The difference between the sums of these scores and the equivalent gains from baseline for responses to the compound test stimulus (.20) was nonsignificant [$F(1,44) = 1.58, p > .20$]. Since the test had a calculated power of .98 at the .05 level, it seems legitimate to conclude that the grating and spiral effects were additive.

Overshadowing

The McCollough effects cited above were much stronger than the spiral aftereffects following single-stimulus training [$F(1,87) = 13.09, p < .0005$]. Because the McCollough test figure, unlike the spiral, included both orientations, simultaneous contrast probably contributed to this result. To the extent that $V_A > V_B$, then V_A should secure a disproportionate share of the conditioning to V_T . Hence, it could be predicted that the response strength acquired by the grating should overshadow that of the spiral during the compound conditioning of the control group. The data are consistent with this hypothesis: the grating scores, over both desaturated and saturated induction compound groups, give a mean of .12 against a spiral effect of .08. The difference is significant [$F(1,44) = 6.02, p < .02$], as predicted on the basis of overshadowing.

Blocking

To the extent that V_A and V_B approach the asymptote λ during the original induction with simple stimuli, less conditioning strength is available for acquisition by V_T during later compound trials. It is therefore to be expected that induction with the grating should effectively block the subsequent conditioning of the spiral during compound training, and also that induction with the spiral should substantially block conditioning with the grating. Following Kamin (1969), we first tested this hypothesis as a main effect for blocking by comparing aftereffects to either the spiral or the grating for the control group (compound training only) to the aftereffects after compound training that followed initial single-component induction of the opposite stimulus component for the experimental groups. There was a highly significant difference between the experimental and control scores [$F(1,88) = 28.57, p < .0001$].

Figure 1. Blocking is revealed by comparing the strength of the aftereffect to a compound after compound training following previous induction with either the spiral (○) or the grating (□) with the strength of the aftereffect following no prior induction to either stimulus (● or ■).

The separate blocking effects for the orientation-contingent gratings and the motion-contingent spirals are shown in Figure 1. To confirm that blocking had occurred in both directions between these effects, we performed separate analyses. The difference between the initial control scores for the grating effect (postinduction-baseline) and the experimental group scores blocked by superimposition of the spiral (postcompound-baseline) was highly significant [$F(1,88) = 17.15, p < .0001$], as was the corresponding blocking of the spiral by the grating [$F(1,88) = 11.68, p < .001$]. The results therefore confirm that blocking is a substantial feature of aftereffect acquisition.

Unblocking

In the later phases of the experiment, the saturation and the contrast of the stimuli were increased. These increases should raise the value of λ and thus of $\lambda - V_r$, thereby making available more conditioning strength and unblocking the acquisition of ΔV during the compound trials. We tested this hypothesis with the compound control group by comparing the initial scores for both grating and spiral effects with the corresponding scores obtained after induction at the higher intensity. Response strength increased to .27 on the gratings and to .15 on the spiral. The combined difference due to the increase in intensity was highly significant [$F(1,44) = 15.85, p < .001$], and is thus consistent with the conclusion that it is feasible to conduct unblocking with contingent aftereffects.

Extinction

Repeated achromatic test presentations are unreinforced by the US, and should function as extinction trials. However, because Holding and Jones (1976) had found that extinction followed a longer time course than that explored

in the present experiment, we expected little extinction to occur over the available period of 30 min. In the event, the grating and spiral effects showed minor drops; however, the combined extinction effect did not approach significance [$F(1,71) = .21, p > .50$].

DISCUSSION

The results as a whole lend substantially greater plausibility to the idea that McCollough effects and other contingent aftereffects are analogous to classical conditioning. In accordance with Rescorla and Wagner's (1972) assumptions, the data show apparent additivity between the orientation and motion aftereffects. Moreover, there is evidence for overshadowing of the weaker motion aftereffect by the stronger orientation aftereffect. The major phenomenon of blocking occurred in both directions between the two relatively disparate aftereffects. These results run counter to Siegel and Allan's (1985) finding of only unidirectional blocking, although this discrepancy might be ascribed to inadequate transfer from single to compound stimuli in their experiment. In any case, the present experiment, again as predicted by conditioning theory, provided evidence that unblocking may be brought about by increasing US intensity.

It is unfortunate that the different induction periods we used did not give rise to differing response strengths, and thus to the opportunity to test more complex implications of the conditioning theory. Nevertheless, we can conclude that the mechanism of blocking is clearly applicable to McCollough training, as has also been evidenced by other research (Siegel & Allan, 1985; Westbrook & Harrison, 1984). In the present circumstances, the nature of the two aftereffects suggests that the blocking effect takes place at a relatively central level. Orientation-sensitive and motion-sensitive mechanisms appear to reside at separate neural locations, at least to the extent of showing independent adaptation characteristics (Frisby & Clatworthy, 1974), so that the existence of peripheral interference between the two contingent aftereffects seems implausible. One might therefore conclude that the color-adaptation response (UR) itself may occur peripherally, as do many other URs in classical conditioning, but that the contingencies between this response and the visual stimuli that come to elicit the response are associatively mediated at a higher level. At the very least, it is clear that describing the McCollough and related effects in the terminology of classical conditioning leads to viable predictions across a wide variety of experimental conditions.

It must be admitted that the conditioning analogy still lacks empirical support in certain other areas. One problem arises from the widespread use of induction time as the determining variable for strength of aftereffect. If contingent aftereffects do correspond closely to conditioning phenomena, the determinant for response strength should be the number (and probability) of CS-US pairings, rather than the length of the induction period. However, Skowbo and White (1983) found that trial

length determined aftereffect acquisition, independently of the number of CS-US pairings, and Skowbo and Forster (1983) found that homogeneous chromatic fields interspersed randomly with induction patterns did not weaken obtained aftereffects. A different kind of problem is posed by the practice of alternating magenta and green pairings, or expanding and contracting spirals, during induction. It is possible, as Murch (1976) suggested, that the function of this procedure is primarily to strengthen the color response rather than to provide for the stimulus contingencies, but there is too little research with single-color induction to ensure that the laws of classical conditioning still obtain under this restriction.

Although the hypotheses tested in the present experiment were derived from Rescorla and Wagner's (1972) equations, we made no attempt to compare these with the predictions from other conditioning models. Contingent aftereffects may follow equally well the predictions of Frey and Sears (1978), which allow for attentional variables and for abrupt changes in responsiveness, or the improvements proposed by Pearce and Hall (1980), which stem from the assumption that additional stimuli are processed in a different manner from the stimuli responsible for blocking. Again, we have made no attempt to rule out eventual explanations at a physiological level, which must be as feasible for conditioning phenomena as for the contingent aftereffects.

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