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The quantitative measure of pattern representation in images using orientation-specific color aftereffects

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A quantitative method is developed for assessing the quality of pattern information in imagery, using the magnitude of color aftereffects as an objective index. Subjects were given instructions to project imagined bar patterns of particular width and orientation onto adapting color fields, in such a manner as to simulate standard conditions for establishing the McCollough effect. Our control procedures indicate that the resulting orientation-specific complementary color aftereffects cannot be attributed to the conditioning of particular directions of eye scanning movements to color processing during adaptation, or to other possible sources of experimental bias. Furthermore, subjects who rated themselves prior to the adaptation procedure as having relatively vivid imagery showed significantly larger aftereffects than those who reported having relatively low imagery. These results not only provide an important confirmation of our earlier finding that imagination can replace physical pattern information in the formation of basic color-feature associations in the human visual system, but also demonstrate that these aftereffects can provide a practical measure of the fidelity of pattern representation in visual images.

In a recent study (Finke & Schmidt, 1977), we reported that instructions to imagine horizontally and vertically oriented bar patterns onto an alternating sequence of two complementary, homogeneous fields of color physically presented, and paired in such a manner as to simulate standard adaptation conditions used to produce the McCollough effect (McCollough, 1965), resulted in the presence of weak orientation-specific complementary color aftereffects. Since pattern imagination had replaced the physical presence of pattern information during adaptation exposure tc the color fields, the existence of pattern-contingent color aftereffects upon subsequent viewing of achromatic patterned test fields provided a challenge to traditional models for explaining the process of color-pattern association in the human visual system, models which typically assume the exclusive operation of highly specialized neural analyzing mechanisms (e.g., Breitmeyer & Cooper, 1972; Fidell, 1970; Held & Shattuck, 1971; Lovegrove & Over, 1972; McCollough, 1965). In contrast, the presence of such aftereffects emphasized the importance of considering the effect of higher-level cognitive structures (such as images) in the formation of basic color-feature associations, with these results being more easily accountable by multistage learning models for the McCollough effect (Murch, 1976; Skowbo, Timney, Gentry, & Morant, 1975).

In addition, a number of recent reaction-time experiments investigating the structural nature of visual images (see Kosslyn, 1973, 1975; Kosslyn & Pomerantz, 1977) have shown that the representation of pattern in images contains properties of spatial extent, and that such images may be scanned in a manner analogous to the scanning of information presented visually. These findings suggest that our previous experimental procedures may also provide a quantitative method for measuring the level of pattern representation in imagery. That is, we propose that the magnitude of orientation-specific color aftereffects following the imagination of bar patterns onto adapting fields of color may provide a *quantitative measure* of the fidelity of imagined pattern information, similar to the manner in which the magnitude of the normal McCollough effect is known to depend upon various parameters of the adapting bar patterns, such as luminance (White, 1976) and spatial frequency (Stromeyer, 1972).

The present study was therefore designed both to

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replicate the somewhat controversial findings we reported earlier, and to extend our methods to explicitly address the problem of finding measurable indices of the structural character of imagined form. One prediction that we examine is that individuals who rate themselves as having relatively high imagery should show larger aftereffects following our pattern-imagination adaptation procedures than those who rate themselves has having relatively poor imagery, assuming that such ratings reflect a meaningful criterion for evaluating the subjective clarity of visual images. The present study also includes a control for the direction of eye movements when scanning imagined bar patterns during adaptation. This procedure is especially important when attributing the effects of imagination instructions to the structure of internal representations. By giving explicit instructions to scan the imagined bar patterns either parallel or perpendicular to their orientation, we control for the possibility that any color aftereffects appearing are simply the result of conditioned responses to eye-movement directions while the imagined patterns are projected onto the adapting color fields.

METHOD

Subjects

The subjects were 36 undergraduate students enrolled in an introductory psychology course at the University of New Hampshire, and they participated in the experiment to satisfy a laboratory requirement for the course. Before experimentation, the subjects were tested for normal color vision with the Dvorine Color Vision Test, and for binocular acuity with a standard Snellen chart. All had normal color vision and an acuity (or corrected acuity) of 20/25 or better. Postexperimental questioning indicated that none of the subjects had previously heard of the McCollough effect.

Procedure

Experimental sessions consisted of three parts that always appeared in the same order: (1) imagery rating, (2) McCollough adaptation (including imagination instructions, eye-movement instructions, and presentation of adaptation stimuli), and (3) testing for color aftereffects. The 36 subjects were randomly divided into four groups of 9 for the purpose of administering different imagination and eye-movement instructions, and each group participated in a different experimental session. During a session, the 9 subjects sat in two rows of classroom desks parallel to and facing a wall 2 to 3 m away. A white projection screen was centered on the wall, and the stimuli were projected from behind the second row of seats.

Imagery rating. During the first part of the experiment, all subjects were administered the Marks Vividness of Visual Imagery Questionnaire (VVIQ). This is a 16-item, self-scoring questionnaire in which subjects are asked to rate the vividness of their imagery for various visual scenes that are described (see Marks, 1973). A 1-to-5-point rating scale is used to rate imagery on each item, with lower numerical ratings corresponding to more vivid imagery. This scale has previously been shown to be moderately successful in predicting individual performance on objectively assessed tests for accuracy of visual memory (e.g., Gur & Hilgard, 1975; Marks, 1973), and was administered first so that the imagery ratings would not be influenced by performance in the latter two sessions. Scores on the VVIQ provided a basis for separating subjects into high- and low-imagery groups as one factor in the experimental design.

McCollough adaptation. During the second part of the experiment, all subjects viewed the two adaptation stimuli shown schematically in Figure 1. These consisted of a square matrix of 36 small black squares on either a green or red background. These stimuli were alternated at 10-sec intervals throughout a 10-min adaptation period.

The adaptation patterns in this experiment differ from the usual McCollough effect adaptation stimuli in an important way. The McCollough effect is commonly obtained by exposing subjects to horizontal contours of one color and vertical contours of a complementary color. Here, the same pattern appears with both colors, and subjects were instructed to imagine that the rows or columns of these matrices formed solid bar patterns. This procedure therefore provided some control over the localization and width of the imagined bar patterns. Half of the subjects were told to imagine that the squares formed vertical bars on the red background and horizontal bars on the green background, and half were instructed to imagine the reverse color-pattern association, so that the pairing of color with orientation was counterbalanced. To assess possible effects of orientation-specific eye movements during adaptation to these stimuli, two different kinds of eye-movement instructions were given prior to adaptation. Half of the subjects were instructed to scan *along* the imagined bars (parallel to the imagined contours), and half were instructed to scan *across* the imagined bars (perpendicular to the imagined contours). The design of the experiment therefore contained a two-level Imagery factor by a two-level Scanning factor, counterbalanced for color-pair associations during adaptation.

For the "parallel scanning" conditions, these instructions were delivered as follows. When all subjects had completed the VVIQ, the green and black adaptation stimulus was projected onto the screen. Standing near the screen, the experimenter described the forthcoming adaptation procedure. He indicated that whenever this pattern appeared, subjects were to imagine that the squares formed vertical (or horizontal) bars. Then the red and black pattern was projected and the experimenter similarly explained that these squares were always to be

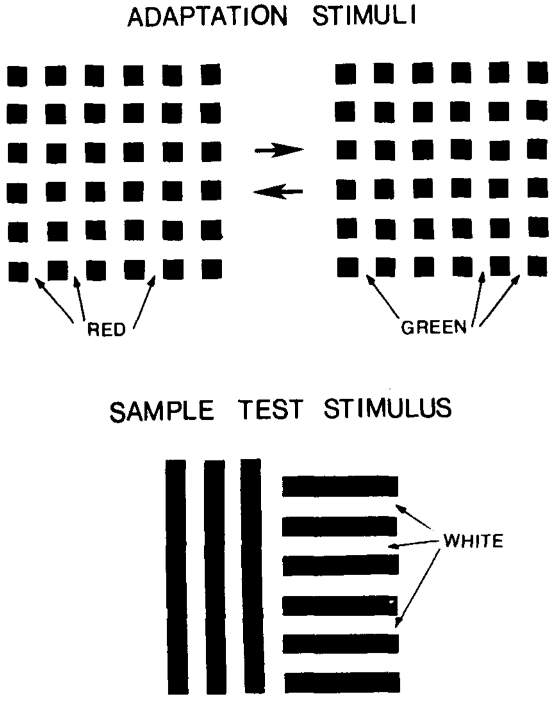

Figure 1. Schematic representations of adaptation and test stimuli.

imagined as forming horizontal (or vertical) bars. The subjects were instructed further that, "in order to help in imagining the bars," they were to move their eyes along one of the bars from end to end, and then do the same for the other bars in the pattern. For both stimulus patterns, the experimenter illustrated bar location and scanning instructions with finger movements on the projection screen. The subjects were further asked to minimize head movements and to pay close attention to the task throughout the adaptation period. The instructions were then repeated, and the subjects were given an opportunity to ask questions. The experimenter then went to the back of the room, the overhead room lights were turned off, and the adaptation period commenced.

A similar procedure was followed for the "perpendicular scanning" conditions. These subjects were instructed to move their eyes across the bars they were imagining; here, too, an explanation was given that these eye movements were to "help in imagining the bars." Again, the experimenter pointed out the desired eye movements on the stimulus patterns before the adaptation procedure began.

As indicated, the two adaptation stimuli were alternated at 10-sec intervals for a total adaptation time of 10 min. With each alternation, there was a 1.5-sec dark period between stimuli. During this period, the experimenter reminded the subjects of the orientation of bar patterns they were to imagine on the following slide, by announcing either "horizontal" or "vertical" each time.

For subjects sitting nearest the projection screen, edges of the adaptation squares subtended 0.33° of visual angle. Spaces between the squares were also 0.33°, and the matrices of squares were centered in 6° X 6° colored squares. Therefore, these subjects were instructed, in effect, to imagine six cycles of a 1.5-cycles/deg square-wave grating for each adaptation stimulus. For subjects sitting farthest from the screen, the small squares and spaces between them subtended 0.21°, the colored squares extended 3.8° X 3.8°, and the imagined gratings had a spatial frequency of 2.4 cycles/deg. For each subject, stimulus dimensions remained constant throughout the experimental session.

Adaptation stimuli were high-contrast transparency photographs of black and white paper constructions. The colored backgrounds were produced with Kodak Wratten gelatin filters having the following dominant wavelengths under tungsten illumination: red (No. 25), 617.2 nm; green (No. 57A), 520.8 nm. All adaptation and test stimuli were projected with a Kodak random-access Carousel projector using a 300-W tungsten illuminant.

Testing for color aftereffects. The final part of the experiment consisted of a forced-choice discrimination procedure to assess the presence of orientation-contingent color aftereffects. In this procedure, the subjects were presented with a sequence of 20 achromatic test patterns consisting of horizontal and vertical square-wave grating patterns in opposite halves of the projected stimuli. One of these test patterns is shown in Figure 1. These were also prepared as high-contrast black and white transparencies, projected on the viewing screen. As also shown in Figure 1, the spatial frequencies of test gratings are the same for each subject as those in the gratings imagined during adaptation. The subjects were instructed to select and write down on an answer sheet the half of each pattern that appeared most red, or, if only a greenish tint was present, the half that appeared least green. Prior to testing, the subjects were informed that colors on the test stimuli would be very weak (and much weaker than the colors on the adaptation slides), and that they were always to make the best guess for the presence of color, regardless of how difficult the discrimination appeared to be.

The test stimulus configuration shown in Figure 1 was also presented in three other orientations. Thus, on different test trials, each orientation of bars appeared in left, right, top, and bottom halves of the test pattern. These four orientations were presented in five different random orders to make a total of 20 test trials. Each test presentation lasted 10 sec, after which the subjects were given a 5-sec period to record their color responses; the blank white projection light provided sufficient room illumination to write answers during these periods. To avoid confounding effects that might have resulted from the experimenters' expectations about the subjects' selections, the test slides were presented in such a manner that the experimenter did not know which half of the pattern would contain bars of a particular orientation. However, the experimenter did know how each slide would be divided, so that, before each trial, he announced either "top or bottom" or "left or right," to cue the subjects on the division of the next pattern.

The choices were scored in the direction corresponding to the standard McCollough effect. Consider, for example, a subject instructed to imagine horizontal bars on green background and vertical bars on red background during adaptation. Were this subject to select the half of a test pattern containing horizontal bars as being the redder half, the choice would be scored as a "McCollough effect" response. This would be the typical response had the subject adapted to physical, as opposed to imagined, bar patterns onto the color fields. With 20 test patterns, the number of McCollough effect responses for each subject could range from 0 to 20, with a score of 10 expected by chance.

Bias controls. In order to avoid possible bias effects in our results, we used the same bias controls employed in our earlier McCollough effect study with imagined stimuli (Finke & Schmidt, 1977). When required to make color judgments on split-field test patterns of horizontal and vertical orientation, subjects may base their responses not only upon actual color perceptions, but also upon deliberate associative strategies, and, of course, upon simple guesses. The use of a forced-choice procedure provides a sensitive control for random guessing, since each guess has a .50 probability of being in the direction of the McCollough effect, and consequently a sign test based on the binomial distribution can be used to determine the significance of high or low numbers of these responses for each subject. In previous experiments, we have found that, even with actual McCollough adaptation stimuli, subjects may not readily describe test pattern halves as appearing more red or green; however, such subjects will nearly always make forced-choice responses in the predicted directions.

We have also found that when these aftereffects are *very* weak (as when imagination replaces physical pattern during adaptation), subjects may simply base their responses on the *remembered* association of color and orientation during adaptation. This may occur even when explicit instructions are given to base choices only on the appearance of the test patterns, as in this experiment. By contrast, subjects unacquainted with the McCollough effect are extremely unlikely to devise a judgment strategy associating test pattern orientations with the *complements* of their adapting colors, for, as indicated below, all of the reported association strategies involved pairing the test pattern orientations with the adapting colors.

To detect the use of such strategies in making choices, the subjects were instructed at the end of the experiment to write down any strategies or systems used to make their responses, and to report anything else that might have affected their choices. Without regard to the experimental data, the two authors independently rated these reports, dividing the 36 subjects into one of three categories: (a) no-strategy subjects—those who followed instructions and based their choices on perceived color or guesses (or upon criteria totally unrelated to color-orientation pairing); (b) association-strategy subjects—those who indicated that they had used the remembered color-orientation pairing during adaptation as the basis for making all responses; and (c) mixed-strategy subjects—those who reported seeing colors on some of the trials, but used the association strategy on other trials. The detailed nature of the subjects' reports was such that they unambiguously fell into one of these three categories.[1]

Of the 36 subjects, 19 did not report using the association strategy, and fell into the first category, which constituted the primary data base. Four of the subjects reported deliberately pairing test pattern orientations with their adaptation colors as the basis for making all of their responses, and hence these subjects fell into the second category. Finally, 12 subjects indicated that they used the association strategy for at least some of their choices, and these subjects constituted the third category group. It is interesting to note that three of these subjects reported that they began the test session using the association strategy, but then deviated from that system in later trials because they saw colors on the test slides *opposite* from what they should have been. In other words, they dropped the association strategy when they unexpectedly saw colors in the opposite direction. Only one subject was not placed in any of these categories, since she failed to give any forced-choice responses during testing; she was excluded from further analyses.

Our procedure for classifying subjects into these three categories always assumed that they reported accurately and truthfully about their response strategies. Of course, it is possible that unreported association strategies may have been used by some of the subjects in our "no-strategy" group, but the effect of this would be to *favor* the null hypothesis of no McCollough aftereffects in our primary data base. It should be emphasized that, as in our 1977 study, it was clearly necessary to divide subjects into different groups in this manner, because many subjects, when faced with a difficult color discrimination, spontaneously infer that the task involves the memory of previous color-orientation associations. However, the subjects could not be instructed beforehand to avoid using this association strategy as a basis for making responses, because such instructions would have biased them against making selections in the direction opposite to the McCollough effect. In addition, it must be emphasized that the a posteriori classification of subjects was based solely on their postexperimental reports, without regard to their data, and that all subjects excluded from the primary data base reported either partial or complete reliance on the association strategy.

For each of the three strategy categories, the responses for all subjects were evaluated using the sign test. Under the null hypothesis that each response had a .5 probability of being in the direction of the McCollough effect, significant differences from chance in the scores for each subject were determined using a binomial distribution having the following parameters: $n = 20$, $p = q = 0.5$, $M = 10.0$. A further analysis was then conducted on the data from the no-strategy group, to assess the effects of imagery rating and scanning direction. The imagery scores for the subjects in this group were divided as follows. The nine subjects having the lowest mean VVIQ scores were designated as the "high-imagery" group, while the nine subjects having the highest mean VVIQ scores were designated as the "low-imagery" group. Because the primary data base had an odd number of members, the subject with the median VVIQ score was assigned to neither group. These two levels of the Imagery factor were crossed with the two levels of the Scanning factor (across and along bars) in an unweighted-means ANOVA.

Table 1
Imagery Ratings and Color Responses for Individual Subjects in Each Strategy Category

Subject	Mean VVIQ Score	Within Set Rank on the VVIQ	McCollough Effect Responses
		No Strategy Category (Primary Data Base)	
N.M.	1.00	1	20†
M.M.	1.25	2	20†
R.P.	1.38	3.5	18†
N.M.	1.38	3.5	13
K.D.	1.50	6	20†
H.M.	1.50	6	14
J.P.	1.50	6	20†
D.C.	1.56	8	13
A.B.	1.63	9	16**
K.B.	1.88	10	(4**)
C.P.	2.00	11.5	7
S.T.	2.00	11.5	6
P.F.	2.13	13.5	12
A.B.	2.13	13.5	20†
D.H.	2.38	15.5	(3**)
C.M.	2.38	15.5	19†
M.B.	2.50	17	13
K.T.	2.63	18	15*
W.V.	3.00	19	8
Mean	1.88		13.74
		Mixed Strategy Category	
K.M.	1.38	1	(4**)
D.B.	1.44	2	(3**)
F.B.	1.88	3.5	(2†)
D.J.	1.88	3.5	(0†)
B.L.	2.00	5.5	13
J.M.	2.00	5.5	17**
W.L.	2.06	7	(1†)
P.S.	2.19	8	10
D.C.	2.38	9	6
J.K.	2.44	10	(2†)
M.R.	2.75	11	10
T.H.	2.81	12	(3**)
Mean	2.10		5.92
		Association Strategy Category	
R.W.	1.56	1	(0†)
B.B.	1.75	2	(0†)
D.C.	1.81	3	(0†)
P.M.	2.25	4	(0†)
Mean	1.84		0.00

Note—Low numerical scores on the VVIQ indicate high imagery ratings. Parentheses indicate significant responses in the direction opposite to that of the McCollough effect. A score of 10 is expected by chance. *$^{*}p < .05$ $^{**}p < .01$ $^{†}p < .001$*

RESULTS

The results for subjects in each strategy category are summarized in Table 1. For the no-strategy group, 14 of the 19 subjects had more than half of their forced-choice responses in the direction of the McCollough effect. Individual two-tailed sign tests showed that 10 of these 14 scores were significantly above the expected chance score of 10. Furthermore, 5 of these subjects had all 20 of their responses in the predicted direction. As also shown in this table, 2 of the subjects in this group (K.B. and D.H.) had scores significantly below chance level.

For the mixed-strategy group, only 1 subject showed a significant score in the direction of the McCollough

Table 2
Analysis of Variance on the Primary Data Base

Source	df	SS	MS	F
Scanning Direction	1	3.10	3.10	.12
Imagery Rating	1	124.68	124.68	4.93*
Scanning by Imagery	1	.40	.40	.01
Error	14	353.72	25.26	

Note–Unweighted means analysis, with the harmonic mean of cell sizes = 4.21. Actual cell sizes ranged from 3 to 6.
*$p < .05$

effect (J.M.), while 7 of the 12 subjects showed significant effects in the opposite direction. This result is to be exptected, assuming that these subjects based many of their responses on the association strategy, as they had indicated in their postexperimental reports. However, it is worth noting that three of the subjects in this group had spontaneously reported that they deliberately employed the association strategy during the early trials of the test session, but then began to see colors on the test slides opposite to those predicted by this strategy. The color responses of two of these subjects clearly showed a shift towards the direction of the McCollough effect, departing from an initial reliance upon the association strategy. Thus, *contrary to their initial expectations*, several of these subjects began to experience genuine color aftereffects in the predicted direction.

The four subjects in the pure-association-strategy group all had scores of 0, indicating that they correctly reported having used the association strategy as the basis for making all of their responses. The mean forced-choice color responses for each of these groups was 13.74, 5.92, and 0.00, respectively. The mean VVIQ scores for each group was 1.88, 2.10, and 1.84; none of the imagery means differed significantly from one another.

The results of the ANOVA on the primary data base are summarized in Table 2. These results show, first of all, that the subjects in the high-imagery group had significantly larger McCollough effect responses than those in the low-imagery group, $F = 4.93$, $df = 1$, $p < .05$. The presence of stronger complementary color aftereffects for the high imagers is also indicated by the individual responses, as shown in Table 1. This analysis also reveals no effect for the direction of scanning eye movements, and no interaction between the imagery and scanning factors. The mean McCollough effect scores for each cell in the experimental design are represented in Figure 2. This figure clearly shows the difference between the high and low imagers with regard to their color aftereffect responses, and likewise shows the lack of any effect due to the direction of eye-movement scan.

DISCUSSION

The results of the study have two major implications. First, they provide an important confirmation of our earlier discovery that imagination instructions can replace physical pattern information in the formation of basic color-feature associations, as indicated by the presence of weak McCollough aftereffects. In the present experiment, our control for scanning eye movements during adaptation dismisses an alternative account of this effect based on the conditioning of color afterimages to particular eye-movement directions; furthermore, this control addresses the possible criticism that subjects might have formed bar pattern images during adaptation by simply "smearing" the square matrix patterns across the retina along the direction of eye movement.

One could argue that perhaps the authors' knowledge of the expected effects could have in some way introduced demand characteristics into the experimental situation, thereby biasing the subjects' responses in the predicted direction. However, the results of the subjects' postexperimental reports indicated that any such bias was in the *opposite* direction. That is, nearly half of the subjects voluntarily reported that they perceived the nature of the task as one involving memory for the color-feature associations presented during adaptation, while none of the subjects indicated that they deliberately associated orientation with the *complement* of the adapting colors. Thus, the nature of the experiment was such that any intrinsic bias served to favor an effect opposite to that expected. It could be argued further that perhaps subjects were actually responding to weak color biases in association with orientation, which may have been present before adaptation, but such effects cannot explain the results we obtained, since adaptation colors and orientations were counterbalanced across all conditions.

We therefore propose that our findings are not the result of artifacts in our experimental procedure, but favor instead the existence of basic perceptual-like associations between color and form, resulting from the projection of imagined form onto physical color

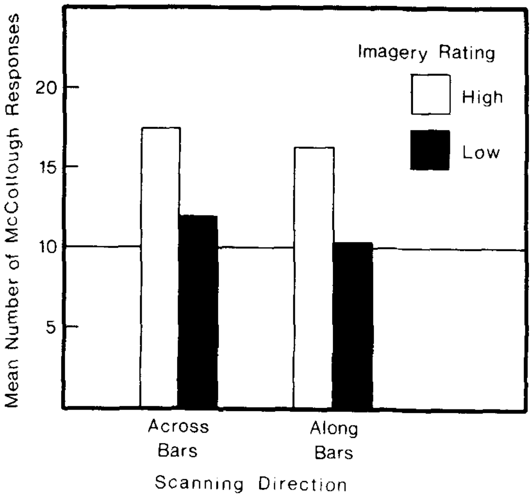

Figure 2. Mean McCollough effect responses as a function of scanning direction and imagery rating (N = 19).

fields. Such associations are not addressed by models of the visual system which only consider the operation of narrowly tuned neural analyzers selectively responsive to a specific set of physical parameters. In addition, however, our findings also have important implications for the measurement of pattern representation in visual images. Because we found that eye movements are not relevant to the establishment of the obtained color aftereffects, the association of color with form during adaptation must have involved the mapping of *internally constructed* spatial representations of form onto color, with the magnitude of the orientation-specific aftereffects providing a measure of the fidelity of these representations. Thus, we argue that color aftereffects established in this manner can serve as a quantitative metric of the individual representation of visual form in images. This claim is supported in part by our obtained difference between subjects rating themselves as relatively high and low imagers in the number of their McCollough effect responses. However, even assuming that such ratings correspond roughly to proficiency in constructing vivid mental images, our procedures provide a more sensitive method for inferring the quality of pattern information in imagery, based on the presence of stable, measurable, perceptual-like aftereffects.

One additional criticism that may be directed at our study is that what we might be measuring by our aftereffects is the extent of perceptual "grouping" of elements in our square matrix patterns during adaptation. Such a criticism would seem to be appropriate in light of recent demonstrations showing that the perceptual organization of pattern information in test patterns can determine the presence of the usual McCollough effect (e.g., Uhlarik, Pringle, & Brigell, 1977). Our obtained differences between high and low imagers might therefore be attributed to corresponding differences in Gestalt organization. While the controls used in the present study do not dismiss the possibility, it should be noted that in our 1977 study, similar color aftereffects were obtained by having subjects imagine bar patterns onto *unpatterned*, homogeneous color fields. Consequently, we believe that these aftereffects reflect actual spatial properties of constructed pattern information in visual images.

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NOTE

1. The objective criteria for classifying reports into one of these three categories was specified as follows: (a) *Association-strategy category*—Reports which stated explicitly that color selections for all responses were based on the remembered association between color and orientation presented during the adaptation procedure. (b) *Mixed-strategy category*—Reports which indicated that at least some, but not all, responses were based on the association strategy. (c) *No-strategy category*—Reports which contained no reference to having used the association strategy at any time during the testing procedure. This included *all other* strategies besides deliberate color-orientation pairing. A fourth category, that of deliberately associating the *afterimages* of color observed during adaptation with orientation, was also established, although none of the subjects reported having used this particular strategy.

The subjects' reports were categorized using the above criteria independently by the two authors, without regard to their objective responses. A reliability coefficient of 0.93 was obtained for these two sets of ratings, with agreement on 33 of the 35 reports. For the two reports that received different category ratings, discussion indicated that the discrepancy was due to ambiguous wording in their written descriptions, and an agreement on a single rating was then reached. An additional rater, naive to the purpose of the study and the expected outcomes, was also asked to categorize these same reports using the above criteria, and was informed only that an exposure procedure involved pairing particular colors with particular orientations prior to a testing procedure for assessing the presence of colors on split-field gratings. The reliability between his ratings and those of the authors was also 0.93, with agreement on 33 of the 35 reports. While these procedures indicate that the subjects' written reports could be classified with little difficulty into one of the three categories, a simplified method would be to present these categorical descriptions to all subjects at the end of the experiment and have them rate their own strategies.

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