Mystery of the anti-McCollough effect

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Abstract The McCollough Effect (ME) is a complex perceptual aftereffect that remains of interest half a century after its discovery. It is argued that a recently reported variant, dubbed the *anti-McCollough effect*, is not the reverse of the ME, with aftereffect colors in the same direction as the inducing stimuli. A red–horizontal stimulus leads to a reddish aftereffect not *because* of red–horizontal pairings, but *despite* them. The anti-ME is a weak standard-direction ME produced by complementary afterimage colors (afterimage green with horizontal), rather than by environmental colors, first shown decades ago. It is not a new type of contingent aftereffect. The red–horizontal pair does not interfere with the afterimage green–horizontal pair it produces because a single color–orientation pairing provides more ambiguous input than does the standard two orientation–color pairings (red–horizontal, green–vertical) of the ME. It is also argued that not even one orientation-contingent color aftereffect is convincingly shown in the “anti”-ME, let alone, as has previously been suggested, two simultaneous orientation-contingent color aftereffects in opposite directions at different levels of the visual system, in which the higher-level effect suppresses the downstream effect from reaching consciousness. The “anti”-ME can be explained by existing theories of contingent aftereffects, including perceptual-learning theory.

Keywords Adaptation and Aftereffects · Color and Light: Constancy · visual perception

The McCollough effect remains an irksome visual phenomenon since its discovery nearly 50 years ago (McCollough, 1965). It consists of a very long-lasting color aftereffect that is seen only on stimuli in specific orientations. Figure 1 illustrates the stimuli used to produce the effect, along with the variants discussed in the present article. Sheth and Shimojo (2008) reported a variant that appears to be inexplicable by all current theories of contingent aftereffects. The purported finding is that a horizontal grating of alternating red and black stripes (red–horizontal) produces a reddish afterimage that is contingent on the horizontal orientation. The color of the afterimage is the opposite of that in the classic McCollough effect, in which red–horizontal exposure leads to horizontal lines appearing light green, not reddish. Consequently, they labeled their finding the *anti-McCollough effect*. If red–horizontal pairings do produce orientation-contingent aftereffects that are the same colors as their inducers then current theories would require at least some modification.

The results

However, Sheth and Shimojo (2008) have not found that red–horizontal induction leads to same-color afterimages. To get their effect, they alternated that grating with another horizontal grating that consisted of gray and black stripes (horizontal–achromatic). The finding of reddish afterimages seen on the horizontal orientation does not occur *because* of the red–horizontal pairing but, rather, *despite* it. During induction, it is the red color itself, not the red–horizontal pairing, that is the critical ingredient. They showed in their own Experiment 2b that by following only a red homogeneous field with the

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Fig. 1 Variants of the McCollough effect. Colors and spatial frequencies are shown equalized for comparison. **a** The classic McCollough effect (McCollough, 1965) stimuli. Alternate gaze between the two color-oriented grids for a few minutes and then look at the achromatic test pattern to the right for any long-lasting illusory color dependent on orientation. The effect is fussier for red inducers, and blue is frequently added (magenta) to produces a stronger effect. *Outcome*: light green seen on the horizontal, pink on the vertical. **b** Sheth and Shimojo's (2008) anti McCollough effect inducers. *Outcome*: pink seen on the horizontal, light green on the vertical. **c** McCollough effect induction based on afterimages (Murch & Hirsch, 1972), (Note that it would presumably work with a horizontal, instead of a vertical, grating.) *Outcome*: pink seen on

the vertical, light green on the horizontal. **d** Rarely used single-pair induction (e.g., Stromeyer, 1969) alternated with a black screen. *Outcome*: pink seen on the vertical, light green may or may not be seen on the horizontal. **e** Apparent destruction of the color-orientation relation with the addition of randomly presented oriented gratings without color (Siegel & Allan, 1987); one third of the trials were a homogeneous gray (not shown). *Outcome*: minimal pink seen on the horizontal and minimal light green on the vertical. **f** Rescuing a color-orientation relation by viewing the second and fourth stimuli with head tilted 90° (Bedford & Reinke, 1993). (Creating the inverse—spatial without a retinal relation—does not lead to an aftereffect.) *Outcome*: pink seen on the horizontal, light green on the vertical

horizontal–achromatic grating, they could produce the anti-McCollough effect. What this, in fact, showed is that red–horizontal pairings were an expendable part of the procedure, not a cause.

Sheth and Shimojo (2008) suggested that the anti-McCollough effect is produced because red produces a simple green afterimage that is then paired with the subsequent achromatic horizontal grating. They may be correct, but this is not a new discovery. Just a few years after McCollough (1965) discovered the effect that bears her name, it was shown that color afterimages, as well as “real” colors, can produce the effect (Murch & Hirsch, 1972). In an article entitled “The McCollough Effect Created by Complementary Afterimages”, homogeneous colors were alternated with achromatic gratings every 10 s for approximately 7 min. This led to illusory contingent color such that, for example, vertical lines looked pink following induction with the alternation of homogeneous red and achromatic vertical lines. The researchers went a step further and showed that the afterimages were responsible by increasing the delay between the homogeneous color and the achromatic lines, which allowed the simple color afterimages to fade and eliminated the effect. Whoever should get the credit for the aftereffect of an aftereffect, to use Sheth and Shimojo’s terminology, note that the colors still remain opposite to the true inducers, just as in the classic McCollough effect. Consequently, afterimages are a long-known variant way of inducing the McCollough effect and do not generate a new type of contingent aftereffect.

Sheth and Shimojo (2008) packaged the effect so as to also allow a horizontal grating to go along for the ride when presenting the critical red field. We have already seen that this initial horizontal grating is not a causal or essential component. But why can it coexist? Why does it not reverse the direction of the McCollough effect in favor of the contingency from the real color or eliminate it entirely due to cancellation? Does that mean that they have discovered a new type of contingent aftereffect after all?

No. The procedure used by Sheth and Shimojo (2008) uses only a single color–orientation pairing. The classic McCollough effect uses two opponent color–orientation pairings, such as red (magenta)–horizontal and green–vertical stimuli. I have discussed elsewhere (Bedford, 1995) that single-pair induction provides only a degraded input to the processes that underlie the adaptation seen in the McCollough effect. That is, one pair creates an ambiguity that two pairs do not. For instance, a red–horizontal grating of 3.5 cycles per degree would also be consistent with color being contingent on spatial frequency, whereas both red–horizontal and green–vertical presentation makes it clear that color changes are controlled

by orientation and not by spatial frequency. As a result, one-pair induction has led generally to less consistent results in the literature. Some displays work reliably in pairs, but not when presented singly for all subjects (e.g., yellowish red–vertical and yellowish green–horizontal; Stromeyer, 1969). In addition, a single color–orientation pair sometimes will produce an effect on the noninduced orientation (e.g., Allan & Siegel, 1991), but sometimes will not (e.g., Humphrey, Dodwell, & Emerson, 1989). For instance, when a red–vertical pairing alternated with a dark screen produces a greenish afterimage on vertical lines, it may or may not produce the so-called *indirect effect*, a reddish aftereffect on the noninduced horizontal lines. Finally, Day and Webster (1989) were able to get afterimages to generate the McCollough effect in 5 min when red preceded vertical (i.e., green afterimage inducer, the same as Sheth and Shimojo’s selection), but not when green did.

Due to the ambiguity of a single color–orientation pairing,¹ the red–horizontal stimulus need not have induced much, if any, of an ordinary McCollough effect to compete with its green afterimage induction (the *anti-McCollough effect*). Not all of Sheth and Shimojo’s (2008) subjects had the same effect with the same inducers, consistent with the ambiguity of one pair. Robinson, Weiss and de Sa (2011) were recently unable to obtain the anti-McCollough effect at all and concluded that the effect is very weak, is dependent on specific experimental details, or is found in only a subset of the population.

Thus, a horizontal grating shown with the red inducer is not causal but can go along for the ride. It need not lead to an ordinary McCollough effect that interferes with afterimage induction because of the inherent ambiguity of a single color–orientation pairing.

The interpretation

Sheth and Shimojo (2008) further suggested that their results indicated that two opposite-direction orientation-contingent aftereffects were produced at different levels of the visual system simultaneously but that only the higher

¹ Simply doubling the Sheth and Shimojo (2008) procedure to the two standard oriented color gratings alternating with two achromatic oriented gratings would, however, also be problematic. While the unambiguous standard stimuli would now interfere with any weak effect produced by afterimages, interspersing achromatic oriented gratings would also interfere with the standard McCollough effect whether the achromatic stimuli are presented in strict alternation, as in red–vertical, achromatic–vertical, green–horizontal, or achromatic–horizontal, or randomly (as in Siegel & Allan, 1987). The colorless horizontal and vertical gratings would undermine the relation between color and orientation and attenuate or eliminate the regular McCollough effect as well.

level one reached conscious threshold. Multiple contingent aftereffects that would otherwise cancel one another have been shown capable of coexisting if they have a feature to be contingent upon. For instance, an expanding moving spiral that is red on the left half and green on the right half alternating with a contracting spiral that is green on the left and red on the right leads to an achromatic expanding spiral that appears green on the left and red on the right and to an achromatic contracting spiral that elicits the reverse colors (Stromeyer & Mansfield, 1970). If Sheth and Shimojo have additionally found that there can be multiple contingent color aftereffects at different levels of the visual system and, moreover, that one of the effects suppresses the other from reaching consciousness then these would be exciting new findings. Unfortunately, it is premature, on the basis of their experiments, to reach this conclusion, for four reasons: (1) The data do not show convincingly that even one orientation-contingent aftereffect was produced, let alone two at different levels; (2) it is not obvious why the presence of both real colors and afterimage colors in the same display would cause multiple aftereffects; (3) demonstrating a new type of higher-level effect requires stronger evidence than the presence of interocular transfer; and (4) a claim that there is a color aftereffect present which is prevented from reaching conscious perception requires evidence.

First, a green afterimage paired repeatedly with horizontal lines causes achromatic horizontal lines to appear reddish. Sheth and Shimojo (2008) also tested vertical lines and found them to look greenish. (Note, incidentally, that this would be the *indirect effect*, because the induction presented only horizontal lines.) Presumably, this finding led to the conclusion that induction was successful at producing an orientation-contingent color aftereffect. However, no other stimulus different from the training stimulus was tested to determine whether it, too, looked greenish. It is possible that a horizontal grating with a spatial frequency different from that used in induction would, if tested, also look greenish. The reddish color may appear only on the training stimulus, and perhaps, any test stimulus different from the induction stimulus would look greenish by comparison. In order to demonstrate specifically a *contingent* color aftereffect, the color must be shown to be under the control of a specific feature (dimension) of the stimulus, such as orientation. This was not shown in the experiments. There may not have been even one effect contingent on orientation, a defining feature of orientation-contingent aftereffects.

Second, color afterimages on gratings and real color on gratings interact in near additive fashion (e.g., Georgeson & Turner, 1985), suggesting that there is nothing about their coexistence that would of necessity drive a resolution based on multiple levels of the visual system. While this

does not rule out such an interpretation, there is no need to invoke one.²

Third, interocular transfer following monocular induction is interesting, but the interpretation requires caution. Sheth and Shimojo (2008) found that when the ordinary McCollough effect with real colors dominated in their experiments, it did not transfer to the unexposed eye, but when the afterimages induced the effect, it did transfer. They suggested that interocular transfer implicates a new kind of contingent aftereffect at a higher level of the visual system than the usual McCollough effect. While it is well known that contingent color aftereffects induced in one eye do not transfer to the other eye, it has nonetheless been reported that first testing the induced eye before testing the noninduced eye reveals transfer (Shute, 1979). In addition, by using diffuse white light rather than covering the noninduced eye during adaptation, interocular transfer occurs (Kaufman, May, & Kunen, 1981; Shute, 1979). While it is a reasonable assumption that Sheth and Shimojo used the same test procedure for all of their conditions (they do not report details of the interocular testing), the scattered findings in the literature suggest that procedural factors can be influential for transfer from one eye to the other and, therefore, do not necessitate an interpretation based on a high-level effect. It is also unknown how a possible failure to get any orientation-contingent aftereffect in the anti-McCollough effect, as discussed above, may have played a role in transfer of seen color in only that condition.

To demonstrate a new effect at a higher level than ever previously reported, the first step is to specify what is meant by *high level*. Did Sheth and Shimojo (2008) mean a contingent aftereffect that is less tied to the kinds of local specific features favored early in visual processing? If so, does that then imply that color can be made contingent on the spatial or perceived orientation, rather than on the retinal orientation? The regular McCollough effect is contingent on retinal, not spatial, orientation (e.g., McCollough, 1965) and, moreover, cannot be made contingent on the spatial orientation (Bedford & Reinke, 1993). Spatial orientation likely reflects a “higher level,” in the sense of a later step in visual processing, because it corresponds to what subjects perceive, in contrast to retinal orientation, which is processed earlier. While contingency on spatial versus retinal orientation is not the gold standard test of late versus early visual processing, it may not be influenced by

² Could the very different saturations of afterimage colors and environmental colors cause the colors to be kept separate in two different competing contingent effects? Possibly, but they would be more like the Stromeyer and Mansfield (1970) effects noted, not effects at “different levels,” as claimed. There has also, thus far, not been any evidence of two effects in the afterimage paradigms.

unrelated procedural details, as interocular transfer appears to be, and, moreover, can be part of a battery of tests tailored specifically to what is meant by *high level* in this context.

Fourth, there is a nonparsimonious claim that the anti-McCollough effect really is two contingent aftereffects present simultaneously, only one of which reaches consciousness. This claim implies that the dominant effect can be unmasked so as to reveal the purported hidden effect. No such evidence has been provided.

Theory

Finally, Sheth and Shimojo (2008) maintained that their new contingent aftereffect cannot be explained by Pavlovian conditioning or by Dodwell and Humphrey's (1990) view that the McCollough effect is caused by a conflict with learned statistical regularities between color and orientation. As is argued here, however, the anti-McCollough effect is not new but, rather, a known effect of using afterimages rather than real colors. Although Day and Webster (1989) stated that induction with afterimages argues against a Pavlovian account, most researchers have not found the substitution of afterimage colors for environmental colors to be problematic for any theory of the McCollough effect, because of their equivalent processing by the visual system.

This does not mean that the theories are correct explanations of contingent aftereffects, and indeed, I have argued that they are not. According to perceptual-learning theory (Bedford, 1993, 1995, 1997; see also 1999) as applied to the McCollough effect, the changes are part of preserving perceptual constancy. Perceptual-learning theory is a general theory that applies to other perceptual changes besides contingent aftereffects, such as adaptation to prism-displaced vision. The McCollough effect stimuli of red-vertical and green-horizontal indicate that the color of an object has changed when the orientation of that object with respect to the observer has changed. Just as perceived orientation of an object should not change when retinal orientation does (primary constancy), neither should perceived color (secondary constancy). Environmental stimuli that appear to do so nonetheless will then indicate that there is an internal error, rather than indicating that there is a new fact about the world to be assimilated. Rather than using the stimulation to learn something new about the world, it is used to correct the inferred internal error by neutralizing the detected erroneous change in color. The color change that results is manifested as the McCollough effect when viewed on achromatic gratings. Moreover, we come prepared to make this particular color correction when needed, because misalignment of eye axes is a naturally occurring situation that produces color fringes at edges that will change with head tilt (Held, 1980).

According to perceptual-learning theory, Dodwell and Humphrey's (1990) theory is wrong because violations of a learned statistical regularity between color and orientation are not capable of producing changes in actual perception. Such statistical violations will lead to learning about the world, but not to changes in perception, because these violations indicate something new about the world, rather than indicating an internal error. Detecting more vertical grids colored red than ever before and more horizontal green gratings indicates only that there are more red vertical grids in this world and so on, and not that there is something wrong with the observer's machinery. In perceptual-learning theory, perception should never change unless circumstances indicate specifically something wrong with self. It is a sticky problem because the same information that is conveyed by the senses must be attributed to the correct source: external world or internal self. Ordinary discrepancies from expectation lead to learning about the world, which can change beliefs, expectations, thoughts, and reflexes, but not perception (Bedford, 1999). Dodwell and Humphrey's theory, like Pavlovian conditioning, is more of a world-learning theory than a perceptual-learning theory.

Perceptual-learning theory can, of course, also account for any anti-McCollough effect based on induction with afterimages. Because afterimage colors are functionally equivalent to actual colors, the explanation for the McCollough effect will not change in this theory either. For one-pair induction, such as used by Sheth and Shimojo (2008), an error can be detected despite the ambiguity of one pair that was noted earlier. One color-orientation pair can still satisfy the condition that an object should not change its color when retinal orientation does and, therefore, can lead to orientation-contingent color aftereffects. Further discussion can be found in Bedford (1995; see section 8, "One Pair Training"), with comments by Allan and Siegel (1997) and replies by Bedford (1997; see sections 2.8, "Dimensions and Correlations," and 2.9 "Dimensions and One-Pair Induction").

Conclusion

The discussion may seem to be overly picky. However, it is very important that the next generation of vision researchers not be misled by reports of an anti-McCollough effect. The anti-McCollough effect is well within the known family (perhaps, instead, "Aunty McCollough effect?") of contingent aftereffects and does not require a new theory.

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