

Research Report

Unconscious Color Priming Occurs at Stimulus- Not Percept-Dependent Levels of Processing

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ABSTRACT—Although past studies have shown that visual information can be processed without awareness, the types and levels of this processing have yet to be determined. We used metacontrast masking to explore unconscious priming effects of white, blue, and green stimuli generated on a color video display. We found that a white prime tends to act more like a green than a blue one. Color confusions among unmasked and masked primes and calibrations of the display phosphors show that physical rather than perceptual properties of the stimuli best explain the white prime's effects. We conclude that unconscious color priming in normal observers occurs at early wavelength-dependent levels of processing prior to later color-percept-dependent levels.

A leading issue in visual cognition and neuroscience is the distinction between unconscious and conscious information processing and the types and levels of brain activity corresponding to them (Crick & Koch, 1998; de Gelder, de Haan, & Heywood, 2001; Kihlstrom, 1996; Leopold & Logothetis, 1996; Mack & Rock, 1998; Metzinger, 2000; Milner & Goodale, 1995; Weiskrantz, 1997; Zeki, 1997). Prior studies with neurological patients (de Gelder et al., 2001; Milner & Goodale, 1995; Weiskrantz, 1997) have shown that a number of stimulus attributes, such as shape, color, and motion, can be discriminated without the patients' explicit awareness of these attributes, as indicated by their verbal reports. Related findings in intact observers have shown that a target followed by a mask can prime discriminative responses to the mask's shape via direct parameter specification (Neumann & Klotz, 1994), that is, when visual awareness of the target's shape is suppressed (Ansorge, Klotz, & Neumann, 1998; Klotz & Wolff, 1995; Neumann & Klotz, 1994). Related priming was recently reported when color was used as the relevant stimulus attribute; for example, positive response priming was observed when a green target disk was followed by a green annular mask, and negative priming was observed when the

same target was followed by a red mask (Schmidt, 2000, 2002). In the present study, which used the same paradigm, we chose to use desaturated blue and green colors because preliminary observations showed that they maximized the masking effect of the annuli and thus the number of trials on which the visibility of the disk primes was suppressed. Our results indicate that color-priming effects occur at physical, stimulus-dependent rather than percept-dependent levels of representation.

EXPERIMENT 1: EFFECTS OF CONGRUENT, INCONGRUENT, AND WHITE PRIMES

In this experiment, a white disk and desaturated blue and green disks were used as primes, and desaturated blue and green disks were used as masks (see Fig. 1). We tested a white prime because we reasoned that the sensation of white, a "neutral" achromatic color, should on a priori grounds act as a neutral prime. This reasoning, of course, assumes that the color-priming effects occur at percept-dependent levels of color processing. The prime-mask pairings thus resulted in the following congruency conditions: congruent (e.g. green disk followed by a green mask), neutral-white (e.g., a white disk followed by a green mask), and incongruent (e.g., a green disk followed by a blue mask).

Method

Participants

Sixteen students with no knowledge of the purpose of the experiment were selected from the Rice University undergraduate student population and served as observers. All observers had normal color vision.

Stimuli

The stimuli consisted of disks with a diameter of 6' of visual angle and of surrounding annuli with inner and outer diameters of 6' and 18', respectively. The stimuli were centered on a computer-driven 43.2-cm Sony GPS-220 Trinitron color video screen with a refresh rate of 70 Hz (14.3 ms per frame). The disks were presented for one frame (14.3 ms) and the annuli for two frames (28.6 ms) at an optimal metacontrast

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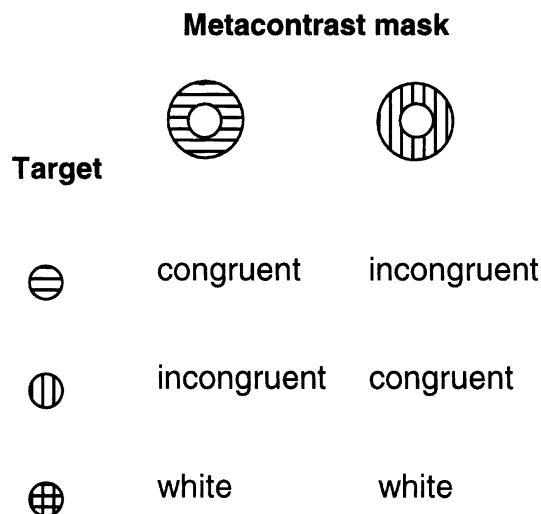


Fig. 1. Schematic representation of the combinations of disk primes and annulus masks used in Experiments 1 and 2. Horizontal, vertical, and crosshatched patterns designate blue, green, and white colors, respectively. In congruent and incongruent trials, blue and green primes were presented with either blue or green annuli. In addition, white primes were paired with blue and green annuli.

stimulus onset asynchrony of 43 ms. The white background of the screen was set at a luminance of 6.0 cd/m^2 . On this background, desaturated blue stimuli were generated by adding a uniform white increment of 7.5 cd/m^2 , on which in turn was added a luminance increment of 2.4 cd/m^2 of the blue phosphor. The desaturated green was generated by adding 9.8 cd/m^2 of only the green phosphor. Thus, the total luminance of the blue stimuli was 15.9 cd/m^2 , and the total luminance of the green stimuli was 15.8 cd/m^2 , as measured by a Tektronix J16 luminance probe. The luminance of the white disk, set at 14.9 cd/m^2 , was as close as possible to the luminances of the blue and green stimuli.

Procedure

Each observer was run in a single session lasting about 30 min. All observers binocularly viewed the display screen at a distance of 142 cm in a dimly lit room. A trial consisted of the following sequence of events. While the observer fixated the center of the screen, a disk, presented for one frame (14.3 ms), was followed by a blank screen lasting two frames (28.6 ms); the blank screen in turn was followed by a mask presented for two frames (28.6 ms). The observer had to respond as quickly and accurately as possible by pressing one of two response keys to indicate whether the annulus was blue or green. In addition, for every trial the observer indicated whether he or she had seen the disk. If the disk was seen or if the response was incorrect, the trial was invalid and the choice reaction time (RT) was not used in the analysis. The intertrial interval was 1.5 s. For every observer, at least 40 valid trials were obtained for each of the congruency conditions. Mean RTs were computed for each observer. These values were in turn averaged to obtain grand means for each of the combinations of annulus color and congruency condition. Using cross-randomization methods within a session, we devoted an equal number of trials to each of the annulus-color and prime-color pairings. Thus, there were equal numbers of congruent (blue-blue or green-green), incongruent (green-blue or blue-green), and “neutral” (white-blue or white-green) prime-annulus pairings (see Fig. 1).

Results and Discussion

Our results showed that the white disk did not have the effect of a neutral prime; rather, the effect of the white disk depended on the color of the annulus. A 2 (annulus color) \times 3 (congruency) repeated measures analysis of variance revealed a single significant effect of congruency, $F(2, 30) = 14.03$, $p < .001$. Figure 2a shows that for both the blue and the green annuli, choice RTs were significantly faster in the congruent than in the incongruent condition, $t(15) = 7.39$, $p < .001$, for the blue annulus and $t(15) = 2.68$, $p < .02$, for the green annulus. However, the white prime raised the choice RT to the blue annulus by 24.5 ms relative to the congruent condition, $t(15) = 2.99$, $p < .01$, and raised the choice RT to the green annulus by a much smaller 3.2 ms relative to the congruent condition, $t(15) = 0.375$, $p > .7$. Figure 2b illustrates this difference in terms of incongruency effects (increases in choice RT relative to the congruent condition) for the white primes for each of the annulus colors. The incongruency effect of the white prime was significantly larger for the blue than for the green annulus, $t(15) = 2.27$, $p < .04$.

Thus, the white disk acted like an incongruent green prime for the blue annulus significantly more than it acted like an incongruent blue prime for the green annulus. For the green annulus, in fact, it did not act differently from a green prime. The question remains as to what sort of visual processes are responsible for the differential effects of the white prime (and, by extension, of the blue and green primes) on the responses to the blue and green annuli.

EXPERIMENT 2: PERCEPTUAL COLOR CONFUSIONS AMONG UNMASKED AND MASKED PRIMES

If the greenlike bias of the white prime is due to its percept-related activation, then perceived unmasked white primes should be perceptually confused more frequently with green ones than with blue ones. One also could argue that the disks in this paradigm are not entirely masked and that the mask changes the percept-dependent activity of the primes in such a way as to render the white masked primes more confusable with the green ones than the blue ones in terms of either color or some other salient property such as luminance.¹ Thus, according to this explanation also, the (partially) masked white disks should be perceptually confused more frequently with green than blue ones.

Method

Participants

Twenty-six naive observers with normal color vision were obtained from the undergraduate student population of Rice University. Fourteen were assigned to the unmasked-disk condition and 12 to the masked-disk condition.

Stimuli

The same blue, green, and white disks and blue and green annuli used in Experiment 1 were employed in Experiment 2.

Procedure

For each condition, 120 trials, 40 trials for each of the three disk colors, were presented in random order to observers. In the unmasked

¹We thank Thomas Schmidt and Werner Klotz for suggesting this as a possible reason for the effects of the white prime.

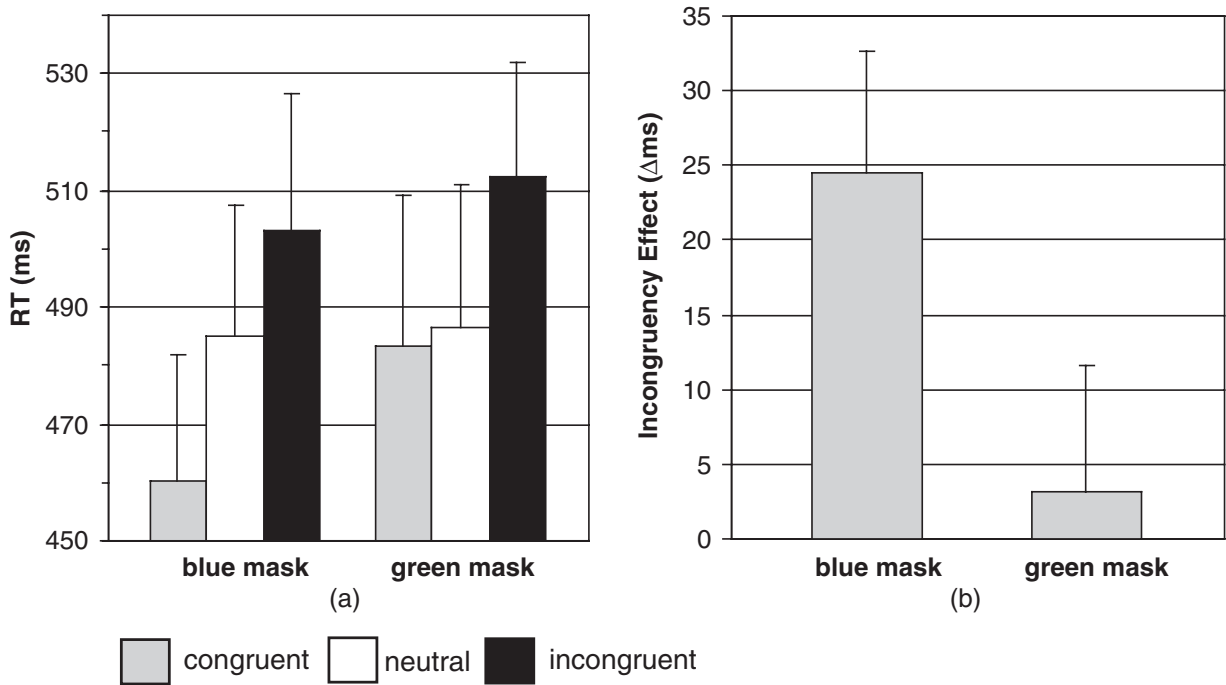


Fig. 2. Mean choice reaction times (RTs; a) and incongruity effects (b) in Experiment 1. RTs to blue and green annuli (masks) are shown separately as a function of congruency with the prime. Incongruity effects were calculated as the increase in choice RT to the white prime relative to RT in the congruent condition, for both blue and green annuli. Vertical bars indicate 1 SEM.

condition, the disks were not followed by a mask, and they were clearly visible. In the masked condition, the disks were followed by a mask using the same stimulus-timing parameters as in Experiment 1; the disks were not visible on most or all of the trials. In both conditions, after each trial observers were required to indicate, by pressing one of three buttons, which of the three colors the disk appeared to be.

Results and Discussion

The results showed that perceptual blue-white confusions were much more common (23.3%) than green-white confusions (6.45%) among unmasked primes (Fig. 3a), $\chi^2(1, N = 14) = 9.55, p < .005$. Moreover, green-white confusions were only slightly and not significantly less common than the “baseline” green-blue confusions (8.45%),

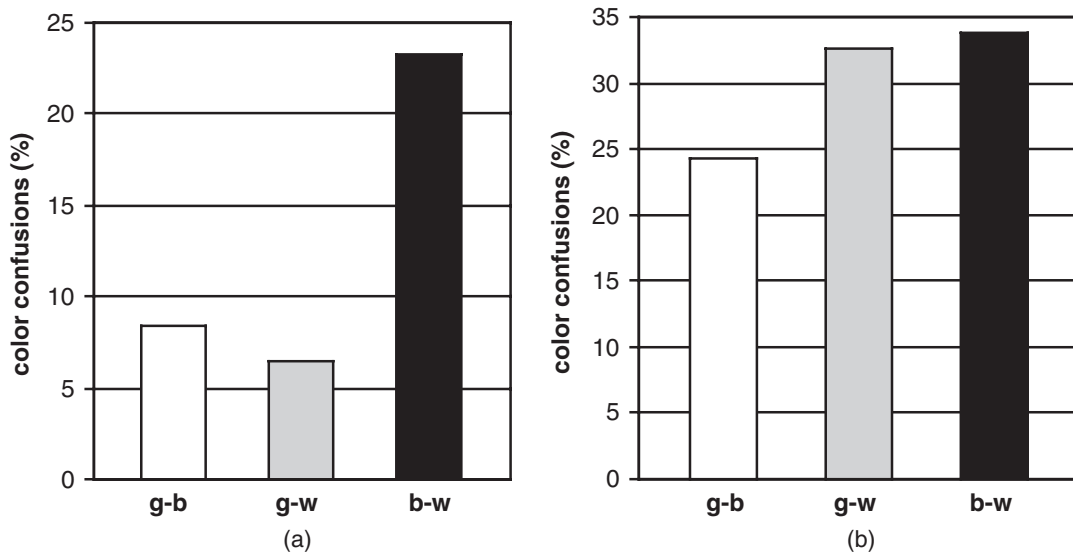


Fig. 3. Percentage of perceived green-blue (g-b), green-white (g-w), and blue-white (b-w) color confusions for unmasked primes (a) and masked primes (b) in Experiment 2.

$\chi^2(1, N=14)=0.13, p > .75$. If the greenlike effect of the white prime in Experiment 1 were due to percept-dependent processes, one would have expected greater perceptual confusion between the white and green disks than between the white and blue ones in the unmasked condition of Experiment 2. Similarly, given the results of the unmasked condition of Experiment 2, if the effect of the white prime had occurred at a percept-dependent level of processing in Experiment 1, one would have expected the white prime to act like the blue prime, with which it is perceptually more confused, rather than like the green prime. Thus, these results are not consistent with percept-dependent color processes being a source of the priming effect.

Unlike the results for the unmasked primes, the results for the masked primes (see Fig. 3b) showed that the proportion of perceptual blue-white confusions (.338) was nearly identical to the proportion of green-white confusions (.326); the difference between these two proportions was not significant, $\chi^2(1, N=12)=0.022, p > .85$. If the white prime's greenlike bias in Experiment 1 were due to mask-induced changes of percept-dependent processes in partially masked primes, one would have expected greater perceptual confusion between the white and green disks than between the white and blue ones, which clearly was not the case. Thus, these results, like those for the unmasked condition, rule out percept-dependent neural activity as a source of the unconscious priming effect.

GENERAL DISCUSSION

Given that percept-dependent activity can be ruled out as an explanation of this priming effect, our explanation relies on the physical, or wavelength, properties of the primes. We made photometric measurements of our display screen and found that the blue, green, and red phosphors of the video display contributed values of 0.788, 4.025, and 1.25 cd/m^2 , respectively, to the uniform white background of

roughly 6.0 cd/m^2 on which all stimuli were presented. Relative to these background values, the blue and green phosphors' contributions were increased, respectively, by 1.028 and 5.859 cd/m^2 to produce the white disk. These values represent 12% and 68%, respectively, of the entire increment for the white disk (the remaining 20% of the increment was contributed by the red phosphor). On the basis of these percentages, one would expect the white disk to act more strongly like the desaturated green disk than the desaturated blue disk. In contrast to a percept-dependent viewpoint, a stimulus-dependent one can explain why the white prime acted more like the green than the blue prime.

In two follow-up experiments, we replicated the main finding that the white disk acted more like a green than a blue one. Here we summarize the findings of one of the experiments, in which we modified the procedure used in Experiment 1 by having observers not only generate choice RTs but also indicate which of the three prime colors were presented.

Figure 4a shows the choice RTs, and Figure 4b shows the incongruity effects produced by the white prime. Note that the results replicate the findings of Experiment 1 shown in Figure 2, as well as a significant Annulus Color \times Congruency interaction, $F(2, 22)=8.30, p < .004$. The white prime, relative to the congruent blue prime, raised the choice RT to the blue annulus by 42.7 ms, $t(11)=4.81, p < .001$, and, relative to the congruent green prime, raised the choice RT to the green annulus by a much smaller 12.7 ms, $t(11)=2.69, p < .03$. The effect of the white prime was significantly larger for the blue than for the green annulus, $t(11)=3.59, p < .004$. Hence, again, the white disk did not act as a neutral prime; it resembled more the green than the blue prime. Regarding prime visibility, forced-choice prime-identification performance showed that the proportion of correct prime identifications, .352, did not deviate significantly from .333, the chance guessing probability, $t(11)=1.66, p > .125$. We thus conclude

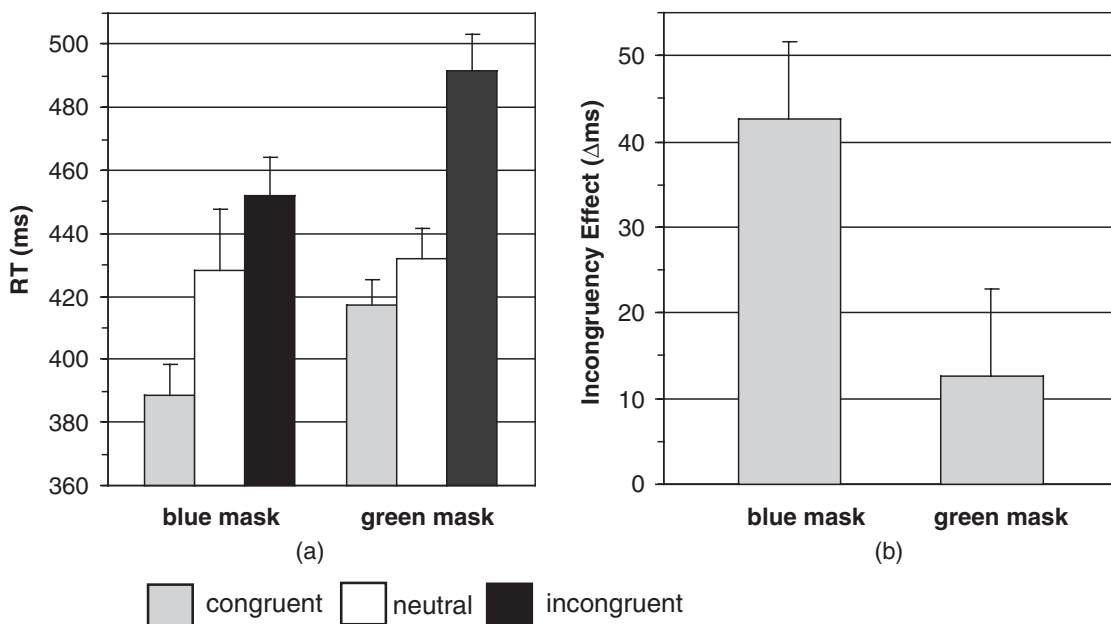


Fig. 4. Mean choice reaction times (RTs; a) and incongruity effects (b) in a follow-up experiment. RTs to blue and green annuli (masks) are shown separately as a function of congruency with the prime. Incongruity effects were calculated as the increase in choice RT to the white prime relative to RT in the congruent condition, for both blue and green annuli. Vertical bars indicate 1 SEM.

that the primes were invisible, as reflected in the observers' subjective reports.

Our results indicate that the white prime and, by extension, the blue and the green ones, when visually suppressed, act at a level of processing that is stimulus- rather than percept-dependent. Several investigators (Lamme, Super, Landman, Roelfsema, & Spekreijse, 2000; Leopold & Logothetis, 1996; Super, Spekreijse, & Lamme, 2001) have made the distinction between early stimulus-dependent and later percept-dependent cortical activity. The suppression of the later response components in V1 in monkeys and in early visual cortex in humans has been implicated in metacontrast masking (Bridgeman, 1980; Ro, Breitmeyer, Burton, Singhal, & Garcia, 2003). Moreover, Leopold and Logothetis (1996) argued that a majority of neurons in later stages of cortical processing (e.g., V4), but only a minority of neurons at earlier levels (e.g., V1), tend to respond in a percept-dependent manner. Thus, reentrant activity originating from higher percept-dependent visual areas could modulate the late response component of those V1 neurons showing percept dependency (Lamme et al., 2000; Super et al., 2001). Given these distinctions, the present results suggest that stimulus-dependent color priming occurs at cortical levels as early as area V1; this conclusion is consistent with claims that humans are unaware of activity in this visual cortical area (Crick & Koch, 1995).

This interpretation also agrees with Zeki's (1997; Bartels & Zeki, 1999; Moutoussis & Zeki, 2002) findings that the response magnitudes of color-selective cells at early (e.g., V1 and V2) levels of processing vary substantially with the wavelength of a color-constant stimulus, whereas neural responses at the V4 level show color constancy by not varying their magnitudes appreciably despite changes in the wavelength composition of the stimulus. There currently is some uncertainty as to where in humans the analogue or homologue of the monkey "color center" is located. Although Zeki (1997; Bartels & Zeki, 1999) has argued that the human color center consists of areas V4 and V4 α , other researchers (Hadjikhani, Liu, Dale, Cavanagh, & Tootell, 1998; Heywood, Kenridge, & Cowey, 2001) have argued that it consists of area V8, located anterior to human area V4. Despite this uncertainty, it is clear from our findings that the unconscious response priming by colored stimuli results from visual processing at relatively early, stimulus-dependent stages of color processing. Results of recent studies (Breitmeyer, Ogmen, & Chen, in press) confirmed this conclusion, but in addition showed that unconscious response priming by form occurs not at an analogous early level, but rather at later levels where conjunctions of edge orientation yield more complex form features such as corners and vertices and perhaps even whole objects (Breitmeyer, Ogmen, Ramon, & Chen, in press).

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REFERENCES

Ansorge, U., Klotz, W., & Neumann, O. (1998). Manual and verbal responses to completely masked (unreportable) stimuli: Exploring some conditions for the metacontrast dissociation. *Perception, 27*, 1177–1189.

- Bartels, A., & Zeki, S. (1999). The clinical and functional measurement of cortical (in)activity in the visual brain, with special reference to the two subdivisions (V4 and V4 α) of the human colour center. *Philosophical Transactions of the Royal Society of London B, 354*, 1371–1382.
- Breitmeyer, B.G., Ogmen, H., & Chen, J. (in press). Unconscious priming by color and form: Different processes and levels. *Consciousness and Cognition*.
- Breitmeyer, B.G., Ogmen, H., Ramon, J., & Chen, J. (in press). Unconscious priming by forms and their parts. *Visual Cognition*.
- Bridgeman, B. (1980). Temporal characteristics of cells in monkey striate cortex measured with metacontrast masking and brightness discrimination. *Brain Research, 196*, 347–364.
- Crick, F., & Koch, C. (1995). Are we aware of neural activity in primary visual cortex? *Nature, 375*, 121–123.
- Crick, F., & Koch, C. (1998). Consciousness and neuroscience. *Cerebral Cortex, 8*, 97–107.
- de Gelder, B., de Haan, E., & Heywood, C. (Eds.). (2001). *Out of mind*. Oxford, England: Oxford University Press.
- Hadjikhani, N., Liu, A.K., Dale, A.M., Cavanagh, P., & Tootell, R.B.H. (1998). Retinotopy and color sensitivity in human visual cortical area V8. *Nature Neuroscience, 1*, 235–241.
- Heywood, C.A., Kenridge, R.W., & Cowey, A. (2001). Colour and the cortex: Wavelength processing in cortical achromatopsia. In B. de Gelder, E. de Haan, & C. Heywood (Eds.), *Out of mind* (pp. 52–68). Oxford, England: Oxford University Press.
- Kihlstrom, J.F. (1996). Perception without awareness of what is perceived, learning without awareness of what is learned. In V. Velman (Ed.), *The science of consciousness* (pp. 23–46). London: Routledge.
- Klotz, W., & Wolff, P. (1995). The effect of a masked stimulus on the response to the masking stimulus. *Psychological Research, 58*, 92–101.
- Lamme, V.A.F., Super, H., Landman, R., Roelfsema, P.R., & Spekreijse, H. (2000). The role of primary visual cortex (V1) in visual awareness. *Vision Research, 40*, 1507–1521.
- Leopold, D.A., & Logothetis, N.K. (1996). Activity changes in early visual cortex reflect monkey's percept during binocular rivalry. *Nature, 379*, 549–552.
- Mack, A., & Rock, I. (1998). *Inattention blindness*. Cambridge, MA: MIT Press.
- Metzinger, T. (Ed.). (2000). *Neural correlates of consciousness*. Cambridge, MA: MIT Press.
- Milner, A.D., & Goodale, M.A. (1995). *The visual brain in action*. Oxford, England: Oxford University Press.
- Moutoussis, K., & Zeki, S. (2002). Responses of spectrally selective cells in macaque area V2 to wavelengths and colors. *Journal of Neurophysiology, 87*, 2104–2112.
- Neumann, O., & Klotz, W. (1994). Motor responses to nonreportable, masked stimuli: Where is the limit of direct parameter specification? In C. Umiltà & M. Moscovitch (Eds.), *Attention and performance XV* (pp. 123–150). Cambridge, MA: MIT Press.
- Ro, T., Breitmeyer, B., Burton, P., Singhal, N., & Garcia, J. (2003). *Unconscious color and form processing*. Unpublished manuscript, Rice University, Houston, TX.
- Schmidt, T. (2000). Visual perception without awareness: Priming responses by color. In T. Metzinger (Ed.), *Neural correlates of consciousness* (pp. 157–169). Cambridge, MA: MIT Press.
- Schmidt, T. (2002). The finger in flight: Real-time motor control by visually masked color stimuli. *Psychological Science, 13*, 112–118.
- Super, H., Spekreijse, H., & Lamme, V.A.F. (2001). Two distinct modes of sensory processing observed in monkey primary visual cortex (V1). *Nature Neuroscience, 4*, 304–310.
- Weiskrantz, L. (1997). *Consciousness lost and found*. Oxford, England: Oxford University Press.
- Zeki, S. (1997). The color and motion systems as guides to conscious visual perception. In K.S. Rockland, J.H. Kaas, & A. Peters (Eds.), *Cerebral cortex: Vol. 12. Extrastriate cortex of primates* (pp. 777–809). New York: Plenum.

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