Contrast variability lightens subjective figures

WAYNE HERSHBERGER
and STEVEN STALLARD

Northern Illinois University, DeKalb, Illinois

Prazdny (1983) has demonstrated that contours without a physical brightness gradient can be seen in displays constructed of inducing elements with opposite contrast. In two similar figures (1A and 1B), Prazdny induced the familiar "sun illusion" by superimposing a halo of 16 radiating lines or bars upon a uniformly gray background. In Figure 1A, the radiating bars are all black. In Figure 1B, eight white bars are alternated with eight black bars. Prazdny claims that the illusory contour visible in Figure 1B is "difficult (and probably impossible) to explain [as the direct effect of contrast; this, he argues, is] because the elements of opposite contrast induce simultaneous brightness contrast of opposite sign" (p. 403).

Whatever the merits of Prazdny's claim, his argument is flawed. Contrary to what Prazdny implies, two different inducing elements of opposite contrast to a common background do not necessarily induce opposite effects. Hamada (1984) has found that a gray field with an albedo of 40% may be darkened in appearance when striped with either lighter or darker gray lines of the same width. Day and Jory (1978) have cited Helson (1963) as providing similar evidence.

What appears remarkable to us about Prazdny's demonstration is not that the halo of radiating black and white bars induces a subjective sun illusion, but that that sun appears more luminous than one induced by an all-black halo. Contrary to his own interpretation, Prazdny's figures appear to demonstrate that the apparent lightness of the illusory sun depends upon the amount of inducing contrast: the black-and-white halo, incorporating more contrast, induces a lighter sun.

Note that the black-and-white halo incorporates more contrast only in the sense of providing a greater variety of inducing luminances; the number of inducing elements has not changed, nor has the absolute amount of contrast between any bar and its intermediate gray background been changed by substituting white for black bars. Hence, we are speaking here of contrasting contrast or variable contrast (cf. Petry, Harbeck, Conway, & Levey, 1983) rather than of contrast per se. For clarity, let us call it contrast variability.

The authors' mailing address is: Department of Psychology, Northern Illinois University, DeKalb, IL 60115.

The amount of contrast variability in the black-and-white halo, or in any other such aggregate of inducing elements, may be indexed simply in terms of a weighted mean square. Let C_i represent the algebraic difference between the luminance of the common background and the luminances of the respective inducing elements. And let P_i represent the proportion of the inducing elements (by area) dedicated to each C_i . Now, if we let the symbol M_c represent the average algebraic contrast of the inducing elements, $\Sigma C_i P_i$, contrast variability may be defined as $\Sigma (C_i - M_c)^2 P_i$.

Although Prazdny's two halos contrast with the gray background by the same absolute amount, the amounts of contrast variability in the two halos are considerably different, with the black-and-white halo having the greater amount for the obvious reason that the black halo has none. Hence, our observation that the sun induced by the black-and-white halo appears the lighter of the two implies that contrast variability may, perhaps, serve to lighten or brighten the induced effects of contrast per se. (The induced effects of luminance contrast per se include, but are not necessarily limited to, brightness assimilation, end-of-line brightness contrast, and simultaneous brightness contrast; see Day & Jory, 1978.)

In his recent review of the literature, Parks (1984) has noted that a number of researchers have found that luminance contrast is necessary if subjective figures are to be induced (Brigner & Gallagher, 1974; Frisby & Clatworthy, 1975; Gregory, 1977; Jory & Day, 1979; Spillman, Fuld, & Gerrits, 1976). Chromatic contrast, where the hue of the background and the hue of the inducing elements are isoluminants, "produces at best a relatively poor illusory figure" (Parks, 1984, p. 290).

Furthermore, and more directly to the present point, Petry et al. (1983) have reported that variable-contrast stimuli induce brighter subjective figures than do constant-contrast stimuli. Petry and her associates induced the sun illusion on a white background by superimposing a halo of radiating bars, each comprising an array of black dots. By systematically altering the density of the dots in each array, they varied the darkness of the bars from an intermediate gray (at their central ends) to solid black (at their peripheral ends). When compared with a gray halo of constant dot density, the halo with the variable dot density was found to induce a brighter sun. This is the basis for their claim that greater apparent brightness is yielded by "variable contrast stimuli" (p. 172). However, since a halo of solid black bars yielded an even brighter sun than the variable density stimuli, it appears that the systematic effects of con-

trast variability, if any, remain to be demonstrated. That is, since the all-black and all-gray bars afforded the most and least contrast, respectively, their experimental results may simply have reflected the effects of contrast per se.

In order to test the implications of Prazdny's demonstration, it is necessary to utilize stimulus configurations that allow the putative effects of contrast variability to be clearly distinguished from the effects of contrast per se. We designed the four stimulus configurations shown in Figures 1-4 for this purpose. We followed Prazdny's example in using black and white inducing elements on an intermediate gray background. We followed Kanizsa's (1979) example in using three sectorized disks to induce a subjective triangle. The subjective triangle was selected in order to demonstrate the generality of Prazdny's effects as well as to provide a robust illusion with which to explore the hypothesized effects of contrast variability.

Figures 1-4 differ from each other only in terms of their triangle-inducing disks. In Figure 1, the sectorized disks are solid black. In Figures 2-4, the disks comprise a series of concentric black and white bands with widths in the ratios (B/W) of 3/1, 2/2, and 1/3, respectively. Hence, in Figures 1-4 the proportion of each sectorized disk that is black, P_b , is approximately 1.00, .75, .50, and .25, respectively, and the proportion that is white, P_w , is about .00, .25, .50, and .75, respectively.

Since the albedo of the gray background is almost exactly intermediate between those of the black and white surfaces, the luminance difference between the gray and black, C_b , should always be about equal and opposite to the luminance difference between the gray and the white, C_w . Hence, the absolute contrast, $\sum |C_i| P_i$, provided by the four different disks in the four different figures is approximately constant. However, the mean contrast, $M_c = \sum C_i P_i$, varies systematically across the four figures. It is least (nearly nil) in Figure 3 where $P_w = P_b = .5$. In Figures 2 and 4 the average luminances of the disks are substantially less and greater than the background, respectively. Hence, in each of these two figures, M_c is substantial, but of opposite sign. Of all four figures, the greatest value of M_c is provided by the solid black disks of Figure 1.

Contrast variability, $\sigma_c = \sum (C_i - M_c)^2 P_i$, also varies systematically across our four figures, but σ_c is a maximum where M_c is a minimum (Figure 3) and a minimum where M_c is a maximum (Figure 1). The

Figures 1-4. The lightness of these four subjective triangles varies as a function of both mean contrast and contrast variability. Of the four triangles, the triangle in Figure 3, which has the most contrast variability but the least mean contrast, appears the lightest.

values of σ_c for Figures 2 and 4 are roughly equal and intermediate to the values for Figures 1 and 3.

Although both M_c and σ_c vary as a function of figure number, they covary in opposite directions: as one increases, the other decreases, and vice versa. Hence, one is able to distinguish their respective effects. First, consider the effects of M_c . Note that the subjective triangle in Figure 2 appears lighter than the gray background, whereas the subjective triangle in Figure 4, which has the same substantial value of M_c but of opposite sign, appears darker than the gray background. This difference is attributable to M_c , because these two figures have equivalent values of σ_c .

Now, consider the effects attributable to σ_c . Note that the subjective triangle in Figure 3, which combines a maximum value of σ_c with a minimum value of M_c , appears lighter than the subjective triangle in Figure 1, which combines a maximum value of M_c with a minimum value of σ_c . This difference, which effectively replicates Prazdny's demonstration, is clearly not attributable to M_c . On the other hand, the notion that this difference reflects the different values of σ_c appears entirely reasonable. Furthermore, a final observation appears to warrant that the notion is true. Note that the subjective triangle in Figure 2 appears lighter than the one in Figure 1 (cf. Varin, 1971) and darker than the one in Figure 3 (e.g., when we asked 17 naive subjects to "choose the lighter triangle," 15 chose Figure 3; $p < .01$). The fact that the apparent lightness of Figure 2 is intermediate to those of Figures 1 and 3 is precisely what the contrast variability hypothesis predicts. That is, if the triangle in Figure 2 appears lighter than the one in Figure 1 only because Figure 2 has more contrast variability, then the triangle in Figure 3 should also appear lighter than the one in Figure 2, for the same reason. It does.

Note, finally, that the present results, although fully consistent with the contrast variability hypothesis, do not appear amenable to theoretical explanations of the cognitive, "top-down" variety. For example, the sectorized disks of Figures 2 and 3 lend

themselves equally well to amodal completion (Kanizsa, 1979) and provide implicit depth cues in equal measure (Coren, 1972). Hence, cognitive considerations such as these do not appear to lead to any clear account of the perceptual differences apparent between those two triangles.

REFERENCES

- BRIGNER, W. L., & GALLAGHER, M. B. (1974). Subjective contour: Apparent depth or simultaneous brightness contrast? *Perceptual and Motor Skills*, **38**, 1047-1053.
- COREN, S. (1972). Subjective contours and apparent depth. *Psychological Review*, **79**, 359-367.
- DAY, R. H., & JORY, M. K. (1978). Subjective contours, visual acuity, and line contrast. In J. C. Armington, J. Krauskopf, & B. R. Wooten (Eds.), *Visual psychophysics and physiology*. New York: Academic Press.
- FRISBY, J. P., & CLATWORTHY, J. L. (1975). Illusory contours: Curious cases of simultaneous brightness contrast? *Perception*, **4**, 349-357.
- GREGORY, R. L. (1977). Vision with isoluminant colour contrast: 1. A projection technique and observations. *Perception*, **6**, 113-119.
- HAMADA, J. (1984). Lightness decrease and increase in square-wave grating. *Perception & Psychophysics*, **35**, 16-21.
- HELSON, H. (1963). Studies of anomalous contrast and assimilation. *Journal of the Optical Society of America*, **53**, 179-184.
- JORY, M. K., & DAY, R. H. (1979). The relationship between brightness contrast and illusory contours. *Perception*, **8**, 3-9.
- KANIZSA, G. (1979). *Organization in vision*. New York: Praeger.
- PARKS, T. E. (1984). Illusory figures: A (mostly) atheoretical review. *Psychological Bulletin*, **95**, 282-300.
- PETRY, S., HARBECK, A., CONWAY, J., & LEVEY, J. (1983). Stimulus determinants of brightness and distinctness of subjective contours. *Perception & Psychophysics*, **34**, 169-174.
- PRAZDNY, K. (1983). Illusory contours are not caused by simultaneous brightness contrast. *Perception & Psychophysics*, **34**, 403-404.
- SPILLMAN, L., FULD, K., & GERRITS, H. J. (1976). Brightness contrast in the Ehrenstein illusion. *Vision Research*, **16**, 713-719.
- VARIN, D. (1971). Fenomeni di contrasto e diffusione cromatica nell'organizzazione spaziale del campo percettivo [Phenomena of chromatic contrast and diffusion in the spatial organization of the perceptive field]. *Rivista di Psicologia*, **65**, 101-128.

(Manuscript received May 14, 1984;
accepted for publication May 23, 1984.)