Notes and Comment

Cornsweet contrast, shadow, and lightness: A critique of interpretations by Redding and Lester

PHILLIP L. EMERSON

Cleveland State University, Cleveland, Ohio

An experiment by Redding and Lester (1980) involved effects of depth and tilt, relative to the direction of the illuminant, on judged lightnesses of a target surface. The experimenters interpreted the results as supportive of an inferential-cue hypothesis, involving cognitive processes likened to Helmholtzian unconscious inference. Judged tilt seemed to affect judged lightness. It is proposed here that simple two-dimensional interactions, such as the processes underlying the Cornsweet illusion, account better for the data.

Using a vision tunnel roughly like that diagramed in Figure 1, Redding and Lester (1980) instructed observers to judge the lightness or brightness of a tilted target. The tilted target was about 4 in. square, as projected orthogonally toward the observer. The observer responded by selecting one chip, from among a calibrated series of 19 Munsell gray chips, that most closely matched the target with respect to lightness or brightness. The chips were viewed against the same background, for the different backgrounds, as was the target. The tunnel was lined with black felt to minimize ambient light, and the light source was a standard 75-W bulb. The tilted target was covered with calibrated Munsell gray paper of value N5.5/ for two sets of data and N6.5/ for another. The bulb was 10 in. above the viewing window. The tunnel was 96 in. long for Experiment 1 and 72 in. long for Experiment 2.

The two main independent variables of interest were background, white (N9.5/) vs. black (N3/), and viewing condition, monocular vs. binocular. Instructions to judge "lightness" vs. "brightness" were also varied, but the resulting differences were rather small and sometimes inconsistent.¹ With the darker target (N5.5/), they found significant main effects² for the viewing conditions and for the two different backgrounds, and a seemingly significant interaction between these two variables. With the light target (N6.5/), it seems that the data showed significant main effects for both variables, but not a significant interaction. Table 1 shows the means, as read approximately from Figures 1 and 2 of Redding and

Figure 1. Approximation to the geometry of the apparatus, not drawn to scale. The tilted target and the Munsell comparison chips were viewed against a black or white background shown as a thin layer at the end of the tunnel.

Lester (1980). They interpreted the observed BINOC-MONOC differences in terms of an inferential-cue theory of lightness constancy, which they likened to the Helmholtzian notion of unconscious inference. In this view, the visual system makes use of any cues to the location of the illuminant and the orientations of viewed surfaces, and then arrives at estimates of the albedos of surfaces by correcting according to the perceived angular relation between the surface and the direction of the illuminant. The details of their argument are not presented here. Parts of the argument concerned apparent incompatibilities of their data with alternate theories based simply on projected two-dimensional luminance ratios (Wallach, 1948) and on luminance ratios within two-dimensional slices of phenomenal space (Gilchrist, 1977). It will be shown here that their experimental results are quite compatible with an interpretation in terms of known types of interactions that arise from patterns in two-dimensional retinal projections. Thus, no subjective computations based on depth or tilt need be invoked, and any perceptions of the direction of the illuminant are beside the point.

The interpretation presented here involves the geometry of Redding and Lester's viewing conditions, which is pictured schematically in Figure 1. It will remain unexplained why the different backgrounds had measurably different effects. The target and comparison chips were always presented on the same background. Even in the presence of large contrast effects of the backgrounds, they should affect the lightness of both the target and the comparison chips. Mutual recurrent inhibition between the back-

Table 1
Approximate Mean Judgments of Munsell Value
of the Tilted Target

Experiment	Target	Background	Binocular	Monocular
1	5.5	3.0	6.12	5.55
		9.5	4.92	4.90
2	5.5	3.0	5.87	5.30
		9.5	5.26	5.20
2	6.5	3.0	6.80	6.70
		9.5	6.10	6.00

The author's mailing address is: Department of Psychology, Cleveland State University, Cleveland, Ohio 44115.

ground and the various stimuli viewed upon it (see, e.g., Emerson & Semmelroth, 1975) might lead to predictions of effects of size differences. Also, it is likely that the probability distribution of judgments using equally spaced Munsell comparison steps would be skewed away from the background, and especially the dark background, because of the non-linear effects of different backgrounds on the apparent spacing of equal Munsell steps (see, e.g., Judd & Wyszecki, 1975, pp. 281-292). These tentative accounts of the effects of overall background differences are unrelated to the hypothesis to be proposed. There is a preliminary correction that needs to be made, however, in order to clarify which of the other aspects of the data are in need of explanation.

From the distances reported by Redding and Lester (1980), it may be calculated that the rays from the light source struck the target at an angle of about 50 deg from the normal. They struck the comparison chips at an angle of about 9 deg from the normal. Using the cosine law, then, one finds that the target's luminance was about 65% of that of the comparison chip of the same Munsell value. These figures are rough because the light source and the surfaces were extended, and there was some illumination due to reflections, even from the black-felt lining of the vision tunnel. Rough as they are, they lead to a correction factor that is of some importance. Using the Ladd-Pinney (1955) cube-root approximation,

$$V = 2.468R^{1/3} - 1.636,$$

to convert from Munsell renotation value (V) to reflectance (R), and vice versa, one may correct the target value in each case, to an equivalent Munsell value corresponding to an effective reflectance of 65% of the reflectance corresponding to the calibrated Munsell value. Under this transformation, the target value of N5.5/ goes to N4.55/, and N6.5/ goes to N5.41/. Making these replacements in Table 1, one finds that the judgments on the white background all are now above the corrected values for the target. This seems to make most features of the results comprehensible in terms of shadows and the Cornsweet illusion, as follows.

Again examining the diagram of Figure 1, it seems clear that the tilted target would cast a shadow on the background. If the light source were an ideal point source and reflections from the interior of the tunnel were entirely eliminated, the shadow would have a shape somewhat as shown in Figure 2. In the ideal case, in which such a point source was located exactly at the viewer's ideal pinhole pupil, the target would exactly obscure its shadow. However, note that (1) the observer's pupil is not a pinhole, (2) the light source is not a point source, (3) the light source is considerably above and slightly in front of the plane of the pupil, (4) even with monocular viewing, the

Figure 2. Approximation to the shadow that would be produced by a tilted target connected to a vertical background at the bottom, where the illumination is from a point source above and slightly nearer than the observer. The diagram is not to scale, and the extent of the shadow is exaggerated for emphasis.

observer's pupil is unlikely to be lined up precisely in a vertical plane containing the centers of the source and the target, and (5) the contributions of reflections from the interior of the tunnel may not be negligible, especially from regions near the source. There is another possibility, too, that might have contributed further to the effects to be suggested: (6) there may have been reflected light from the background onto the back of the target, and thence back to the background.

These factors would result in the projection of bracketing graded shadow edges to the viewer. Consider the luminance pattern that would occur along a horizontal cross-sectional line through the background and target, somewhere near the center of the target. This problem must be broached in a quasi-analytical way, because an accurate mock-up or photograph of the display might lead to the same kind of illusion that probably affected the judgments of the observers in the actual experiment.

Figure 3 shows a probable approximation to the luminance cross section (3B) of the background near the edge of the partially obscuring target, under the departures from the ideal conditions mentioned above. Such departures cause the edges of the pro-

Figure 3. The effects of nonideal factors, such as a light-bulb source, on the edge of a shadow. (A) Near surface (top) and far surface (bottom). (B) Illuminance of the far surface. The far surface would receive a shadow with a graded edge.

jected shadow to be graded, rather than sharp. Figures 4 and 5 show approximately the resultant cross sections of luminance of the target and background combined, for the conditions of the black background (Figure 4) and the white background (Figure 5). These sketches may be exaggerated. It is impossible to be precise, since the appropriate photometric measurements are not available. However, the suggestion offered here is that the process underlying the Cornsweet (1966; see also Ratliff, 1965) illusion and the Craik (1966) and O'Brien (1958) effects, may have contributed a great deal to the differences found by Redding and Lester (1980). The "predictions" from this interpretation are all in the proper directions.

The graded contours in Figure 4, for the case of a black background, would tend to cause the target lightness to be "pushed away" from that of the background. Since the background was black, the lightness of the target would be elevated relative to that of the comparison chip of equal luminance. Both the target and comparison chips should be equally subject to ordinary contrast effects, neglecting the effects of size, since they were viewed on the same background. The process underlying the Cornsweet illusion could be responsible for the finding that the target appeared lighter than an equally luminous chip.

Figure 4. Cross section of luminance pattern projected to the viewer from a light target in front of a dark background, taking into account the shadow cast by the target onto the background. (A) Albedos of target and background. (B) The luminance of the background as affected by target shadow under nonideal conditions. (C) Combined luminance pattern projected from target and background.

Figure 5. Same as Figure 4, except that the relative albedos of target and background are reversed.

The Munsell-value correction for the target, discussed earlier, was meant to make the Munsell values of the target and comparison chips more comparable in absolute terms. Curiously, it seemed to place the observed target lightnesses on the white background above where they should be when simple luminance and reflectance considerations are taken into account. The luminance pattern in Figure 5 would account for such a phenomenon. As Arend, Buehler, and Lockhead (1971) and others have shown, the Cornsweet illusion works in reverse when the conditions are reversed. Thus, with the luminance pattern shown in Figure 5, the target lightness would be "pulled toward" the background lightness. Since the background was white, in this case, the direction would be upward relative to the comparison disk of the same luminance.

One may then consider the differences observed by Redding and Lester (1980) between the monocular and binocular viewing conditions. If the foregoing discussion applies to the monocular condition, then what changes with binocular viewing? Neglecting the effects of stereopsis, a greater lateral extent of the shadow gradient is available binocularly than monocularly, on the average. If one eye is centered, the other will be off center. If each is equally off center by half, then the shadow edges will be equally visible on both sides of the target. In any case, the scallops at the edges of Figure 4 will become effectively deeper, and the rounded shoulders in Figure 5, deeper and broader. On the dark background, then, the target lightness would be pushed even further from that of the background. On the light background, the target

lightness would be pulled even further toward that of the background. This interpretation agrees with the general findings, as presented in Table 1.

One must ask whether the widths of these graded shadow edges would be great enough to produce any appreciable amount of illusion. Dooley and Greenfield (1977) found a slight amount of illusion when the graded segment of the luminance pattern subtended an angle as small as .1 and .2 deg. The effect became quite appreciable at .5 deg. It accelerated rapidly between .2 and .5 deg, and then increased further in a rather regular manner with widths of 1, 2, and 3 deg. From the geometry of the Redding and Lester (1980) apparatus, the extendedness of the 75-W bulb (about 2.5 in.) would, in the absence of other factors, yield a width of the graded portion of the shadow of only about .07 deg of visual angle for the observer at 96 in. from the display (their Experiment 1) and about .09 deg for the observer at 72 in. from the display (their Experiment 2). The extendedness of the light-bulb source alone, then, would seem to yield too small a width to produce much illusion. Of the many other factors that would act further to widen the graded portions of the shadow edges, consider reflections from the wall behind the bulb, for example. Even black felt reflects light. Viewing the interior of such a box from the target end, with the bulb occluded from view by a circular mask of just the right size, would surely reveal a halo about the disk due to light reflected from the wall. If this halo were of appreciable intensity out to two or three radii of the bulb itself, then the widths of the graded portions of the shadow would fall in the range .2 to .5 deg, at which small changes in width make large differences in the magnitude of the Cornsweet illusion (Dooley & Greenfield, 1977). Since one effect of binocular viewing would be effectively to further increase the exposed portions, the consequence would be an increase in the magnitude of the illusion.

Another fact would provide an explanation of Redding and Lester's (1980) different findings for the light and dark targets, which did not seem explainable on the inferential-cue hypothesis. Dooley and Greenfield (1977) found that Cornsweet contrast combines with real contrast produced by an actual difference in levels on the two sides of the Cornsweet scallops. However, the additional Cornsweet contrast decreases as the amount of real contrast is increased. Converting the Munsell values in Table 1 to reflectances and using the 65% correction for target reflectances, as before, one can calculate approximations to the contrast ratios, $|(R_t - R_b)/(R_t + R_b)|$, for the various values of target reflectance, R_t , and background reflectance, R_b . They are approximately .71 for the dark target on the light background, .41 for the dark target on the dark background, .56 and .60 for the light target on the dark and light backgrounds, respectively. These

are "real" contrasts that would be augmented by Cornsweet contrast. The lowest of these, .41, is for the condition in which the greatest differences were found between monocular and binocular viewing. Perhaps the real contrasts were too high under the other conditions for additional Cornsweet contrast to have very much additional effect. Rough extrapolations from Figure 9 of Dooley and Greenfield (1977) indicate that, at a real contrast ratio of .41, an additional .5 deg Cornsweet edge would be about 80% as effective as an equal addition to the real step edge; at .56, .60, and .71 contrast ratios, the percentage effectiveness would be reduced to about 60%, 50%, and 25%, respectively. For a narrower Cornsweet edge, the reductions would be relatively more extreme at the higher contrast ratios. Thus, Cornsweet contrast would be appreciably most effective just with the target-background combination that yielded the large difference between the effects of monocular and binocular viewing. This completes the argument for the Cornsweet-illusion hypothesis.

It would probably be foolish to try to use the Cornsweet illusion to account for all aspects of lightness and its interactions with spatial relations. For example, the present type of interpretation probably would not succeed as well in accounting for the results of Beck (1965), Gilchrist (1977), and Hochberg and Beck (1954). On the other hand, Cornsweet contrast due to graded shadows may frequently contribute noninferential influences on lightness, under natural viewing conditions. It might be unsuspected, although effective, in particular cases because the graded shadow edges are not perceived as such either by the experimental observers or by the experimenters. To assess the likelihood of contributions from the Cornsweet illusion in a particular case, it would be very useful to have scanning microphotometric readings across the display. Perhaps simpler controls could be imposed in cases in which the contributions of Cornsweet contrast are not of primary interest.

CONCLUSIONS

The present hypothesis, involving the Cornsweet illusion, can account for the fact that the target stimuli were judged lighter, on the average, than an equally luminous comparison chip, under all conditions. The inferential-cue hypothesis does not seem to yield such a prediction. The present hypothesis can account for the greatest difference in effects between binocular and monocular viewing under the condition of lowest target-background contrast and, generally, for the different effects of the light and dark targets. The inferential-cue hypothesis seems to make no predictions on this point. Both hypotheses can account, in a qualitative way, for the general direction of the overall binocular-monocular differ-

ences. Neither hypothesis, it seems, can account for the overall difference between the effects of the light and dark backgrounds. Redding and Lester (1980) seemed to attribute that difference to simple non-inferential contrast effects, but there are problems with that interpretation because the comparison and test stimuli were presented on the same backgrounds.

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NOTES

1. Additional data from pre- and postexperimental questionnaires were also collected, to provide information on how well the subjects understood the instructions, whether they thought the target was tilted or vertical, and what they thought the shape of the target was.
2. The description of their design mentioned the order of presentation of the two backgrounds as a between-subjects experimental variable. Curiously, though, the description of the analysis and the reported degrees of freedom for the F tests indicate that this order variable was ignored in the analysis. Such counterbalancing unaccompanied by the appropriate analysis, tends to inflate the error terms for the F tests. One wonders if there might have been rejections of more null hypotheses, especially those involving order, in the full analysis.

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