The Cornsweet effect

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The Cornsweet stimulus is a specific instance of a broad class of edge effects first described by Kenneth Craik in the 1940s (Craik, 1948/1966; see also O'Brien, 1959). Like standard stimuli used to elicit simultaneous brightness contrast, the stimulus generates a perception of brightness (or lightness) that fails to tally with photometric measurements; the Cornsweet stimulus, however, is quite different in structure from standard brightness contrast stimuli, depending on opposing light gradients that meet at an edge. In the usual presentation (Figures 1, A and B), the territory that adjoins the lighter of the gradients appears brighter (or lighter) than that adjoining the darker gradient (see Figure 1, C). That the basis of the effect resides in the nature of the edge that separates the two territories that look differently bright can be shown by blocking out this portion of the stimulus, which abolishes the perceptual difference between the flanking regions (Figure 1, D). Although Tom Cornsweet, the psychologist who described this phenomenon in 1970, and others have invoked lateral interactions between visual input neurons as the mechanism of the effect (Cornsweet, 1970, 1985), there is no generally accepted explanation of this phenomenon.

An alternative possibility is that the Cornsweet effect is a consequence of experience with what edges and light gradients in this configuration have generally turned out to signify about the world in past experience (Purves et al., 1999; Purves et al., 2001; Purves and Lotto, 2003). Gradients of light are typically generated in one of two ways, and thus signify one of two types of sources (Figure 2): (1) systematic variations in the *reflectance* properties of surfaces, or (2) systematic variations in the illumination of surfaces. Whatever the source, a luminance gradient arising from the reflectance properties of objects is routinely associated with adjacent regions of the scene that are under the same amount of illumination. A luminance gradient that arises from *illumination*, on the other hand, generally signifies a difference in the amount of light falling on the adjacent surfaces. Thus, absent other information, the provenance of the pattern of light intensities returned to eye from the Cornsweet stimulus is uncertain, the pattern being consistent with either of these major categories of experience with luminance gradients (see Figure 2).

When the source of a luminance gradient is, in reality, based on illumination, the territory flanking the lighter gradient area is typically under stronger illumination (and is therefore likely to be a less reflective surface) compared to a territory that returns the *same* amount of light to the eye per unit area but flanks the darker gradient. If the percept (i.e., the pattern of cortical activation) triggered by the Cornsweet edge is predicated on what the stimulus in question has turned out to be in statistical terms, it follows that the two territories adjoining the gradients will look differently bright. The rationale for this conclusion about the Cornsweet edge effect is, as noted above, that the sources of the ambiguous stimulus are often differently reflective surfaces in different amounts of illumination, and, that to be biologically useful, sources that are different must look different, and vice versa.

If this interpretation is correct, it should be possible to predict how any change in the presentation of the Cornsweet stimulus will affect the quality of the ensuing percept by understanding how such changes affect the probability distribution of the possible sources of the ambiguous luminance gradients (the luminance profile of the Cornsweet stimulus as such remaining unchanged). For instance, if the information in the overall scene is made more consistent with the gradients arising from systematic variations in reflectance (see the top panel in Figure 2), thus making it more likely that the flanking regions are uniformly illuminated, the perceived difference in the lightness or brightness of the equiluminant regions in the stimulus should *decrease*. This result is expected because, in past experience, the equiluminance of the adjoining territories will in this case have signified similar sources (i.e., two surfaces with more or less the same material properties under more or less the same illumination). Because the visual system has evolved to make stimuli that probably have the same physical sources look the same, the target surfaces should appear more similar. This prediction can be tested by embedding the standard Cornsweet stimulus in a surround that is identical in luminance to the surfaces flanking the gradients (Figure 3). Manipulating the presentation in this way increases the probability that the elements of the stimulus as such are in the same plane, consistent with the gradients arising from transitions in reflectance. As is apparent in the figure, the Cornsweet effect is abolished in this presentation, even though the luminance relationships in the stimulus itself are unchanged.

By the same reasoning, it should be possible to manipulate the presentation of the Cornsweet stimulus to generate an opposite effect. Thus, if the information in the scene were to make the presentation more consistent with a transition in illumination (and therefore more likely that the sources of the equiluminant regions adjoining the gradients are differently reflective surfaces under different amounts of illumination [Figure 2, lower panel]), then the perceived brightness difference of the two equiluminant territories should *increase*. One way that this effect can be achieved is by using perspective to increase the probability that the sources of the opposing gradients that make up the Cornsweet edge are doubly curved, and thus that the flanking regions lie in different planes (Figure 4, A). As is apparent, this altered likelihood increases the perceived difference in the targets compared to the effect elicited by the same stimulus in Figures 1,B (see Purves et al., 1999 for details).

The perceived difference can also be enhanced (or diminished) simply by changing the orientation of the Cornsweet stimulus. The rationale for this effect is that when the dark gradient is above and the light gradient is below, the directions of both gradients with respect to the adjoining equiluminant territories (i.e., from light to dark) are consistent with a physical surfacein stronger illumination above, and a differently reflective surface in weaker illumination (shadow) below (Figure 4, B). Conversely, when the stimulus is rotated so that the directions of the two gradients are made relatively inconsistent with the predominant direction of illumination from above (but consistent with the less typical, but quite possible, condition of illumination from below), the probability of this possible difference in the sources is decreased, causing the equiluminant surfaces in the Cornsweet stimulus to appear more similar in brightness (Figure 4, C).

Finally, this empirical explanation of the Cornsweet effect (or of lightness/brightness percepts generally) predicts that a multiplicity of information that is *mutually consistent* with the source of the stimulus being differently reflective surfaces in different illuminants should greatly augment the Cornsweet effect compared with the effects elicited by the presentation of each category of information independently. The scene in Figure 5 shows that by combining information that is mutually consistent with the two territories in the Cornsweet stimulus being differently reflective surfaces in different amounts of illumination (the information is based on perspective, orientation, shadowing, texture, and other features of the scene), the perceived lightness/brightness difference of the territories adjoining the Cornsweet edge can indeed be increased well beyond the changes induced by each of the manipulations separately (compare the effect here with that in Figures 4, A and B; see Purves et al., 1999 for further details).

In summary, the sensations of lightness/brightness generated by the Cornsweet stimulus, like the simultaneous brightness contrast stimuli (see Chapters 3 and 4 in Purves and Lotto, 2003), are evidently determined by the relative probabilities of the possible sources of any particular constellation of luminances.

1. See also

Visual perception
Illusions
Visual aftereffects

2. References

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An interactive demonstration of the Cornsweet effect and other related demonstrations can be found at www.purveslab.net

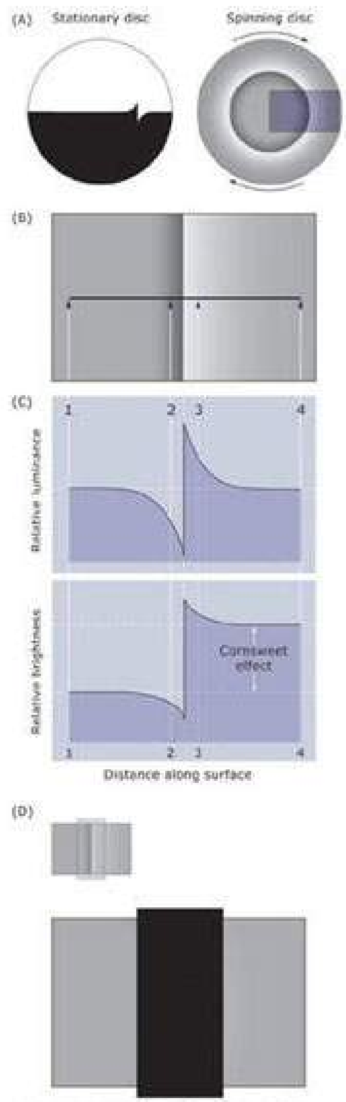

Figure 1. The Cornsweet edge effect. A, Diagram of the spinning disk used by Cornsweet to demonstrate that when two equiluminant regions are separated by an edge comprising a pair of oppositely disposed luminance gradients, the adjoining territories are "filled in" by different lightness/brightness values. B, Standard presentation of the Cornsweet stimulus, shown here as a blowup of a portion of the rotating disk (for the sake of simplicity, the edge in the blowup has been straightened). C, Comparison of the photometric and perceptual profiles of the stimulus in panel B. Despite the equal luminances of the territories adjoining the two gradients, the territory (1) to the left of the dark gradient (2) looks darker than the territory (4) to the right of the light gradient (3). D, This effect is abolished by covering up the opposing luminance gradients, as indicated by the inset. (After Purves et al., 1999)

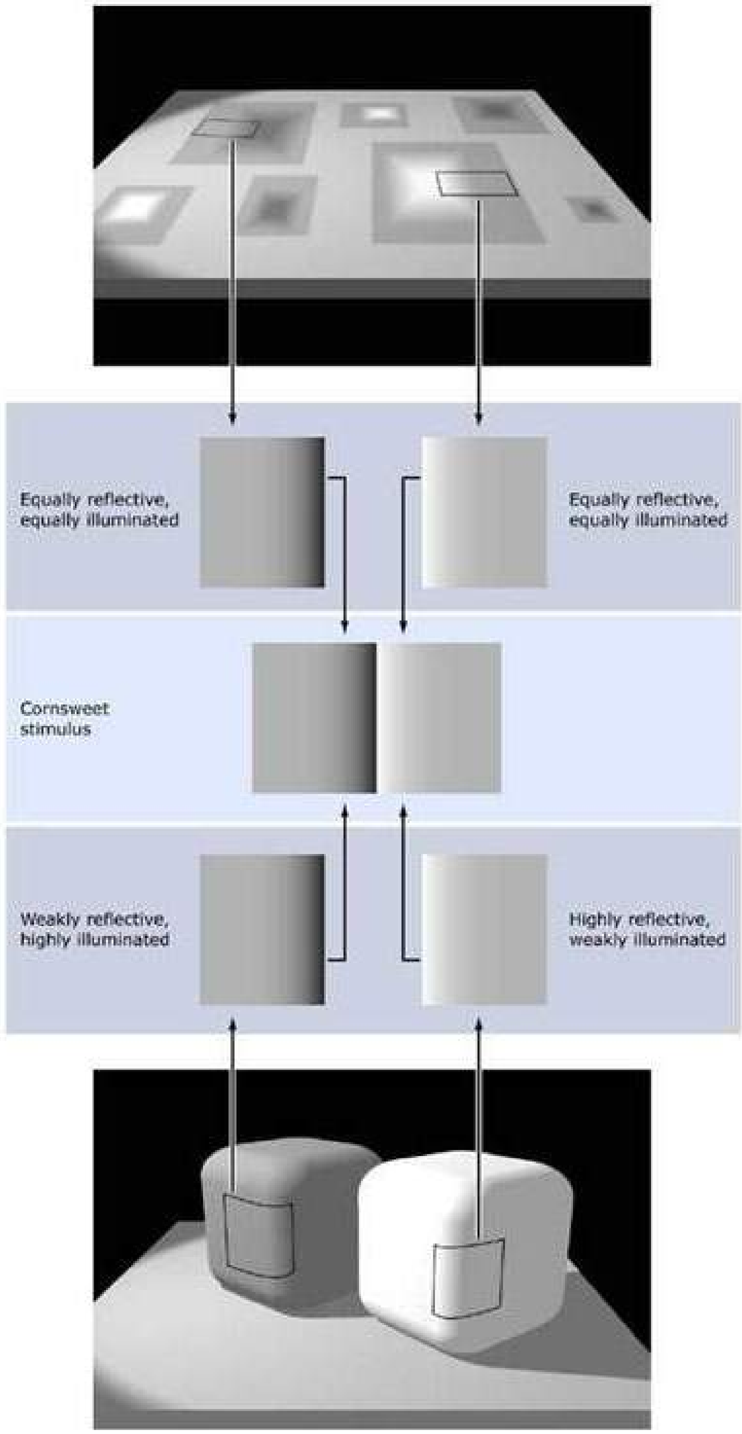

Figure 2. Possible physical sources of the Cornsweet stimulus. The luminance gradients in the standard Cornsweet stimulus (or anyplace else) could arise from *gradual changes in surface reflectance* adjacent to territories having the same reflectance properties and observed under the same illuminant (top panel), or from *gradual changes in illumination* of two surfaces that have different reflectance properties and are under different illuminants (bottom panel), or any combination of these possibilities. (Although the illuminated side of the darker cube and the shadowed side of the lighter one in the bottom panel look differently bright, they are actually equiluminant; the perceptual effects under discussion here cannot be avoided, even in a didactic illustration like this). The statistical significance of these different possible sources of the Cornsweet stimulus is that equiluminant territories adjoining gradients of reflectance are typically similarly reflective surfaces under the same illuminant, whereas territories adjoining gradients of illumination are typically differently reflective surfaces under different amounts of illumination. (After Purves et al., 1999)

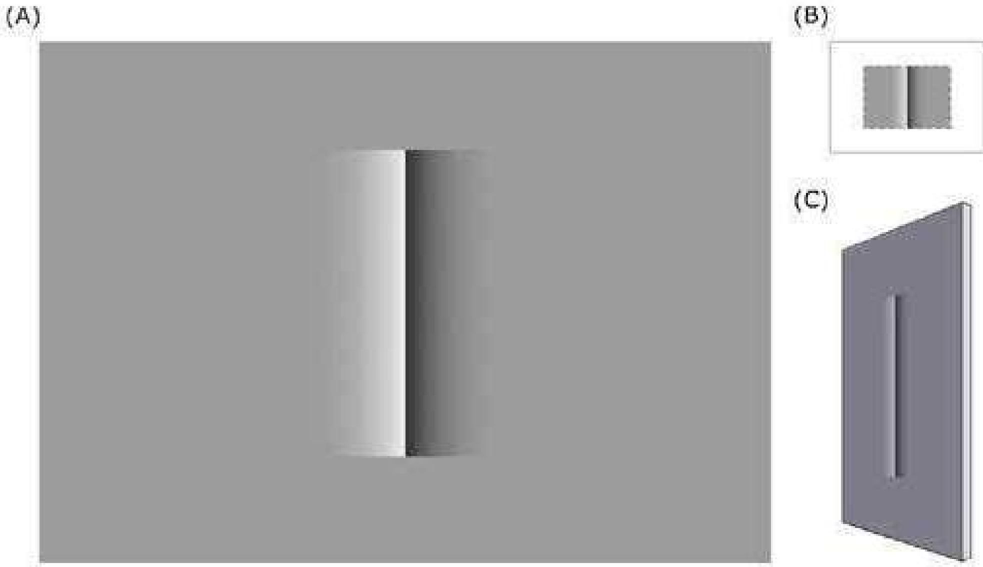

Figure 3. . Diminishing the Cornsweet effect by information that increases the probability that the Cornsweet gradients signify variations in reflectance. Panel A shows the standard stimulus presented such that the equiluminant territories adjoining the gradients now extend around the Cornsweet stimulus as such (see dotted outline in panel B). In this case, observers see the territories adjoining the Cornsweet edge as having about the same brightness. Panel C shows a perspective view to indicate the source that is made more likely by this presentation of the stimulus (i.e., a flat surface with the territories adjoining the Cornsweet edge receiving the same amount of illumination). (After Purves et al., 1999)

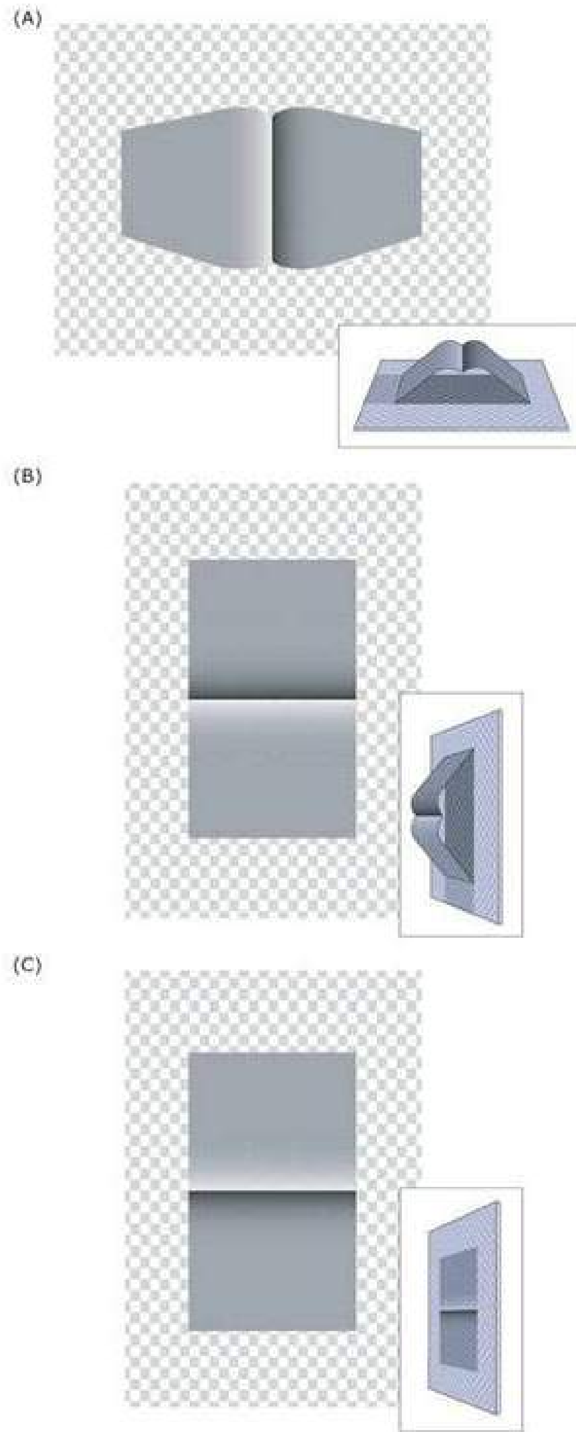

Figure 4.Enhancing the Cornsweet effect by information that increases the probability that the Cornsweet gradients signify variations in illumination. A, The stimulus here is presented in perspective, i.e., the way a 3-dimesnional object extending away from the observer would project onto the retina. The addition of foreshortening enhances the difference in brightness between the two territories compared with the standard presentation (e.g., compare the effect here with that elicited by Figure 1,). Inset shows the source of the stimulus that is made more likely by this presentation. As in all the other manipulations shown here, the addition of perspective alters only the probability distribution of the possible stimulus sources, because the two territories could still lie in the same plane if their shapes implied a diminution of size with distance only coincidentally. B and C, Given that illumination usually comes from above, a similar enhancement occurs when the Cornsweet stimulus is rotated so that the dark gradient is above the light gradient, as in panel B. Conversely, placing the stimulus in the opposite configuration makes it more likely that the source is similarly reflective surfaces under the same illuminant. As a result, the Cornsweet effect in panel C is diminished in comparison with the effect in panel B, even though the structure of the stimulus is unchanged. (After Purves et al., 1999)

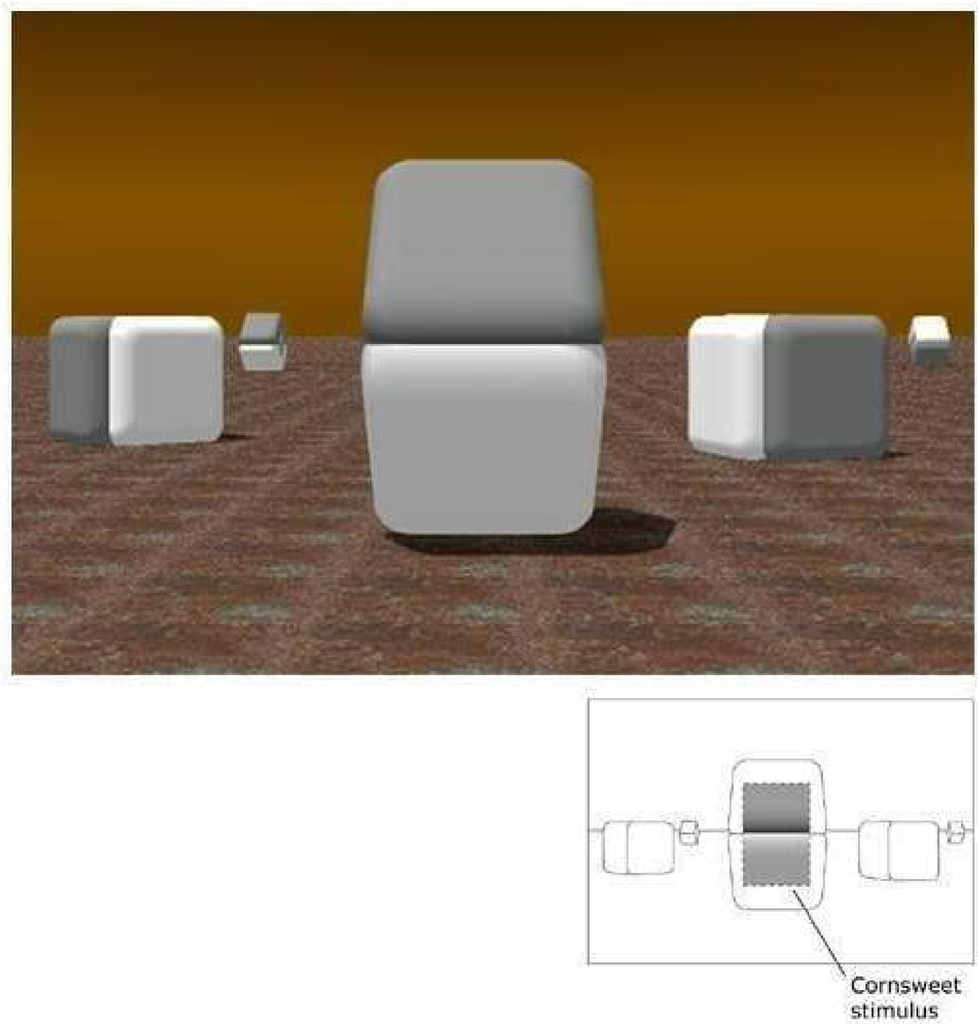

Figure 5. Further enhancement of the Cornsweet effect by combining concordant information about the possible sources of the stimulus, which increases the probability that the source of the territories adjoining the opposing luminance gradients is two differently reflective surfaces under different amounts of illumination. The inset shows the location of standard Cornsweet stimulus in the scene. By combining a variety of mutually reinforcing information in a more "natural" scene, the Cornsweet effect can be enhanced more than 10-fold over its usual presentation (Lest the effect be thought abetted by the influence of unrecognized local contrast effects, it should be noted that the areas surrounding the two surfaces, i.e., the "sky" and "ground," have the same average luminance). (After Purves et al., 1999)