

Chapter 22

Perceived Lightness Depends on Perceived Spatial Arrangement

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A change in the perceived spatial position of a surface can change its perceived color from black to white or from white to black. This finding challenges the widespread view that denies any substantial role of depth perception in the perception of surface lightness (the shade of gray between white and black).

Since 1948, when Hans Wallach published his classic experiments in lightness constancy (1), a consensus in this field has held that perceived lightness is a function of luminance ratios between adjacent parts of the retinal image, regardless of where those parts are perceived to lie in three-dimensional space. Moreover, because of Wallach's emphasis on retinal adjacency, many researchers (2) have concluded that lateral inhibitory connections among retinal cells provide the neural mechanism underlying the ratio principle.

A number of investigators (3–7) have sought to show that retinal ratios do not tell the whole story. Essentially the approach has been to change the apparent spatial position of a target surface so that it either appears to lie in the same plane as that of its surrounding surface or in a different plane in order to determine whether the apparent spatial separation between the surfaces reduces their interaction and thus produces a different perceived color in the target even though the two-dimensional retinal pattern remains unchanged. Two studies (3, 4) reported changes as great as one and a quarter steps on the Munsell scale (8), or 17 percent of the difference between black and white. Most (5–7) have reported little or no change.

With a few exceptions (9), it is now generally agreed (10) that perceived lightness is essentially determined by the relative intensities of adjacent parts of the retinal array. The experiments that I report here grew out of a seeming inconsistency between the retinal ratio theory and everyday experience. Rarely are black, white, and gray surfaces grossly misperceived. Yet the retinal ratio theory would predict consistently

accurate lightness perception only when the difference in luminance at the retina is produced by a difference in the reflectance of the external surfaces. When the difference occurs because external surfaces that receive unequal amounts of illumination are imaged on adjacent parts of the retina, sizable lightness illusions should be expected. This difficulty is mitigated by the fact that the boundary between different levels of illumination is frequently gradual. However, illumination boundaries are by no means always gradual. For example, the retinal image can contain adjacent, sharp-edged patches of radically different luminances when two walls of equal color but unequal illumination meet at a corner, or when a near surface partially occludes an unequally illuminated far surface. Yet no one has suggested that lightness constancy is poorer near such corners.

Perceived lightness might be determined primarily by ratios within perceived planes rather than by all retinal ratios regardless of perceived depth. This "coplanar ratio hypothesis" is illustrated by the following experiment, in which a depth illusion is created in order to determine whether perceived lightness is affected. Observers looked through a pinhole in a screen (Fig. 22.1) through which they saw a dimly illuminated near wall. Through an opening in this wall, a brightly illuminated far wall could be seen. A piece of white paper (the target surface) and a piece of black paper were attached to the near wall so that they extended into the opening. Another piece of white paper (the same white as the target) was attached to the far wall and was partly overlapped by a gray strip, the purpose of which was simply to prevent the white piece from appearing to float in midair. Interposition cues were used to create two variations of the display. The unaltered square target (Fig. 22.1B) appeared to lie in the plane of the near wall. The target could also be made to appear on the distant wall by means of two notches, cut out of the corners of the target so as to coincide with edges of both the near black and the far white paper (Fig. 22.1C). A separate group of eight observers viewed each array and indicated the apparent lightness of the target by selecting a matching sample from a 16-step Munsell scale on which black was 2 and white was 9.5.

Changing the perceived location of the target in this way caused its perceived color to vary from white (near condition) to almost black (far condition) (Fig. 22.1C). Note that this difference was obtained without any significant change in the retinal pattern (11) nor any change in retinal intensities.

Theories that emphasize retinal interactions would have predicted no differences in the study just described. On the other hand, the results follow from the coplanar ratio hypothesis. That is, the perceived lightness of the target is governed by the luminance relationships between the target and whatever regions are seen as coplanar. The luminance relationship

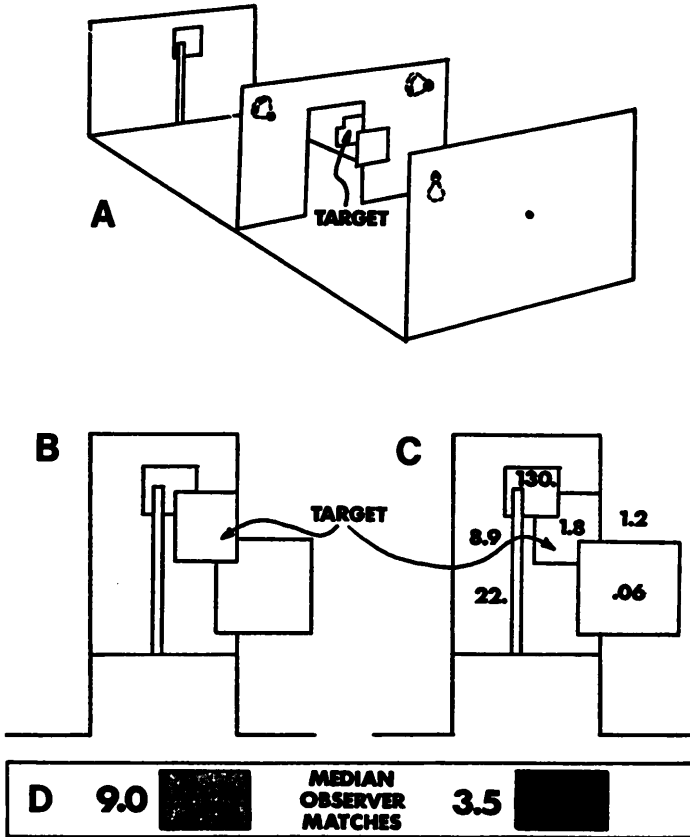


Figure 22.1

(A) Perspective view of the apparatus showing hidden light bulbs. The displays (as seen through the pinhole) in which the target appeared to be located either (B) in the near plane or (C) in the far plane. (D) The average match from a Munsell chart for the two displays. Luminances (C) are in foot-lamberts.

between the target and noncoplanar regions (despite retinal adjacency) is substantially irrelevant to the lightness of the target.

It is possible to construct a critical test in which the coplanar ratio hypothesis would make opposite predictions to those of a retinal theory. In the stimulus display shown in Fig. 22.2, the horizontal plane contained a large white square with a black trapezoidal tab that extended outward toward the observer. The vertical plane contained a large black square and a small white tab that extended upward. The tabs were trapezoidal in order to permit a spatial position illusion (4, 5). Seen with one eye through a carefully positioned hole, each tab appeared to be a square

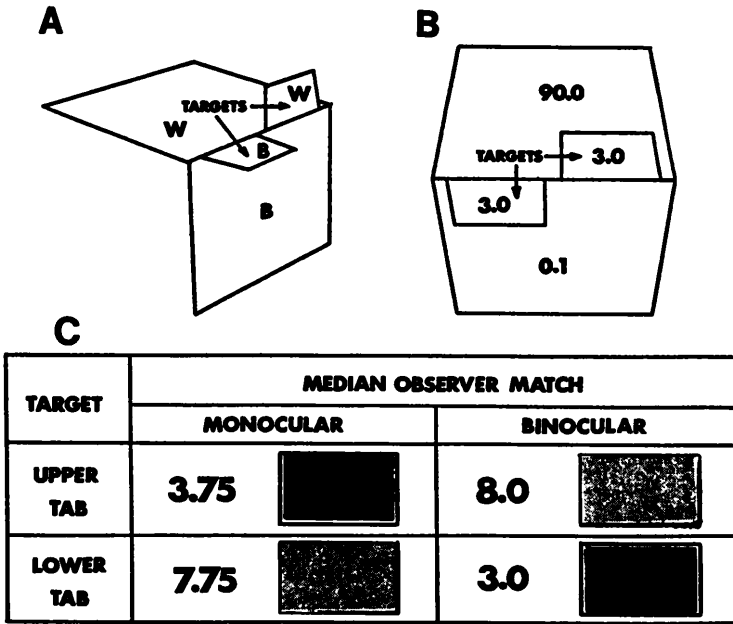


Figure 22.2

(A) Perspective view of the stimulus display showing color (B, black; W, white) of each part. (B) Monocular retinal pattern showing luminances in foot-lamberts. (C) Average Munsell matches for monocular and binocular viewing conditions.

lying in the same plane as the larger square that surrounded it on three sides. Seen with both eyes the tabs were seen to be trapezoids lying in their actual planes. A light bulb, unseen by the observer, was located above the display so that the horizontal surfaces received 30 times as much illumination as the vertical surfaces. Therefore the tabs were equal in luminance.

A retinal ratio theory would predict that, as the upper tab is surrounded on three sides by a very intense region, it should appear darker than the lower tab, which is mostly surrounded by a very dark region.

The results were the opposite of this prediction (Fig. 22.2C). When viewed binocularly and the actual spatial layout was correctly perceived, the upper tab was seen as near white, the lower tab as black. When viewed monocularly so that each tab appeared to lie in the plane of its principal background, the perceived colors reversed, the upper appearing black, the lower, white.

The central conclusion of this research is that perceived surface lightness depends on ratios between regions perceived to lie next to one another in the same plane. Kardos (12) proposed the similar idea that rela-

tive luminance within coplanar spatial regions determines perceived lightness, because illumination tends to be uniform within planes but separate planes tend to be unequally illuminated. This view, however, reflected the general opinion of that period that the perception of lightness depends on the prior registration of the level of illumination.

Koffka (13) argued that perceived lightness depends on gradients of light intensity (at the retina) but added the important qualification that some gradients are more effective than others with regard to lightness. Gradients of intensity between coplanar surfaces, he said, are more effective than those between noncoplanar regions.

Gogel and Mershon (6) interpreted their results in terms of simultaneous lightness contrast governed by the adjacency principle. Their view is that the degree of simultaneous lightness contrast is inversely related to the separation of the target and "induction" surfaces, both in depth (as they showed) and laterally [as others have shown (14)]. Thus the present results would have been predicted, at least qualitatively, by their adjacency principle (15).

We can now understand why previous studies (4-7) have shown such a small effect of depth on perceived lightness. If lightness is a frame of reference phenomenon, as the coplanar ratio principle implies, then it is not sufficient to merely remove the target surface from the plane of its retinally neighboring surface. The array must be such that the target will be seen as a member of one coplanar ratio when it appears in one spatial position, but a member of quite a different ratio when seen in the alternative plane (16).

These experiments show that the perceived lightness of a surface can vary from white to black depending merely on its perceived spatial position, without any significant change in the retinal array. This result implies that lateral inhibition at the retina has little to do with everyday perception of lightness. Certainly the available theories that reduce lightness perception to lateral inhibition are in error.

Another important implication also follows. If the perceived lightnesses of surfaces depend on their perceived location in space, depth processing must occur first and be followed by the determination of surface lightness. That is, processing is initiated by a pattern of intensity differences on the retina; then the nervous system uses various depth cues to construct a spatial model to fit the retinal pattern. As this spatial model is completed, lightnesses are assigned to the various surfaces in accord with the coplanar ratio principle.

References and Notes

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11. Although the area of each square changed somewhat as a result of the notches, the length of contour shared by the target and each retinally neighboring square did not.
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15. Two features of the adjacency principle suggest ways in which it could be tested against the coplanar ratio principle. (i) According to the adjacency principle, the perceived lightness of a target should move continuously through the gray scale as its apparent position between two inducing fields is varied continuously. The coplanar ratio principle would predict a sharp break in perceived lightness at whatever point in space the target changes its plane of reference. (ii) Gogel and Mershon use adjacency to describe the workings of contrast. The coplanar ratio principle need imply no contrast process. Indeed, a subsequent article will provide further evidence that lightness perception does not involve contrast in any important way (A. L. Gilchrist, in preparation).
16. Mershon (3) did provide separate inducing fields for two of the depth planes in which the target appeared. Presumably his results involved less change in lightness than those reported here, because even when his target and inducing fields were coplanar, they were still somewhat separated retinally. In addition, both of his inducing fields had luminances greater than that of the target whereas, in the present studies, the luminance relationship of the target and the surrounding coplanar surfaces reversed for the two different conditions of each experiment.
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