A criticism of the diffraction theory of some geometrical illusions

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Chung Chiang (1968) invoked diffraction in the eye to explain Poggendorff's illusion and extended the discussion to account for other geometrical illusions produced by intersecting lines. But diffraction in the eye cannot account for the displacement and rotation of lines assumed by Chung to produce Poggendorff's illusion. And even if displacement and rotation do occur, the theory does not account for all illusions of the type considered.

Chung Chiang (1968) outlined a theory invoking diffraction of light in the eye to explain geometrical illusions produced by lines crossing at acute angles. His discussion may be divided into five main points:

(1) Due to the diffraction of light, and other optical distortions of the eye, the retinal image of an object is not a true representation of that object.

(2) The diffraction image of a slit source is a band of light, broader than would be expected by geometrical optics (Jenkins & White, 1957, pp. 288-309). When two slit sources are sufficiently close, their diffraction patterns overlap, interference occurs, and the resulting pattern has a maximum lying in the geometrical shadow between the slits.

(3) If two slit sources are arranged to form an acute-angled V, the lines of maximum intensity corresponding to the two slits will come together above the point corresponding to the true point of intersection of the two slits. These lines of maximum intensity will also be rotated relative to the slits and so the apparent angle will be larger than the actual acute angle between the slits.

(4) Diffraction in the eye (Point 1) is assumed to cause an analagous effect of rotation and displacement of lines (Point 3) when black lines on white paper are viewed in normal light. Thus the Poggendorff illusion is explained.

(5) The Zöllner, Hering, Wundt and other illusions produced by lines intersecting at acute angles are explained by applying this reasoning to each intersection.

This theory may be conveniently examined point by point. It is certainly true that retinal images are blurred because of diffraction in the eye. Riggs (1965) concluded that diffraction is an important determinant of visual acuity and quoted the analyses given by Byram (1944) and Fry (1955) of the distribution of illumination produced on the retina by black lines on a white background. The discrepancy between the lines and their retinal images is a blurring of edges produced by diffraction in the eye of light reflected from the lines and their background. This situation must be clearly distinguished from that described by Jenkins and White (1957, pp. 288-309). They consider the remarkable patterns produced when diffraction occurs at narrow slits. For example, the central maximum in the diffraction pattern of a slit of width 0.05 mm is about 1 deg and so would appear about 1 cm wide on a screen 60 cm from the slit. As the slit is made narrower the diffraction pattern expands. The pattern produced by diffraction at two adjacent slits is a complicated series of light and dark bands (Jenkins & White, 1957, p. 312) with a maximum in the geometrical shadow of the slits. But, to observe these effects, it is essential that the light used is very nearly monochromatic, as that from a sodium vapor lamp, and that the light from the two slits is coherent. The pattern produced by two slits results from interference as well as diffraction and a visible interference pattern is only obtained if there is a constant phase relationship between light leaving the two slits at any instant. Thus each slit would have to be illuminated by a laser beam, or the two slits by the same point source, such as a pinhole in another screen.

Diffraction patterns produced by more complicated openings are not easily predicted by addition of simple patterns (Jenkins & White, 1957, pp. 376f). So the pattern for crossed slits, even with monochromatic coherent light, is more complicated than is suggested by Fig. 3 of Chung's (1968) paper.

To observe these diffraction and interference patterns light must be diffracted at the slits and then cast on a screen. But when an observer looks at a Poggendorff figure, light is reflected from the figure and then diffracted in his eye. Even if the figure were illuminated with monochromatic, coherent light, diffraction in the eye would not produce the effects obtained when diffraction occurs at narrow slits. The blurring caused by diffraction at the eye may lead to misjudgement of the width of a line, but cannot be the cause of any perceived rotation or displacement of a line. Thus the assumption of Point 4 of the diffraction theory may be seen to be invalid.

Further, the diffraction theory as presented by Chung predicts that the size of the illusion varies with the color of the figure, being more than half as much again with a red figure as with a blue figure. Observation, however, shows this not to be the case.

Even if the detailed diffraction explanation is omitted and the theory postulates an unexplained displacement and rotation of lines intersecting at acute angles, some difficulties remain. If the Poggendorff figure is drawn in its usual form (Fig. 1), then the vertical lines should appear broken and bent but do not do so. Also, Leibowitz and Toffey (1966) found that the magnitude of the Poggendorff illusion changes markedly as the figure is rotated in the fronto-parallel plane.

Houssiadas and Brown (1963) found that for certain illusions produced by lines intersecting at acute angles, including the Zöllner, Hering and Wundt illusions, the illusory effect disappears at large viewing distances. Marshall and Di Lollo (1963) found that the Hering illusion actually reverses as the viewing distance is increased. The theory under discussion cannot handle these observations. Nor can it account for the reversal of direction of the Zöllner illusion as the angle between the parallels and the cross-lines is increased from 20 deg to 70 deg, as described by Day (1965).

Parker and Newbigging (1965) reviewed several studies which had demonstrated a decrement in the Müller-Lyer illusion with repeated observations. They confirmed that a decrement does occur and found that it is greatest under conditions favoring learning. Thus any satisfactory theory must allow for a decrement in the illusion with practice. Also, Binet (1895) found that the Müller-Lyer illusion occurs when the figures shown in Fig. 2(a) and (b) are compared and so it is not sufficient to explain the illusion solely in terms of lengthening produced by the outgoing fins (Fig. 2(c)).

Any theory explaining the Poggendorff illusion of Fig. 1 should also handle the variant shown in Fig. 3. Any theory relying specifically on intersections of lines is inadequate for this reason. Similarly, a theory explaining the Müller-Lyer illusion of Fig. 2

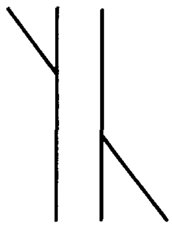

Fig. 1. The Poggendorff figure.

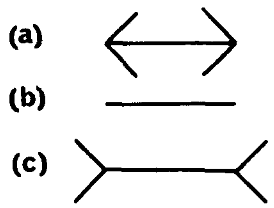

Fig. 2. The Müller-Lyer illusion occurs when (a) and (b) are compared and when (b) and (c) are compared.

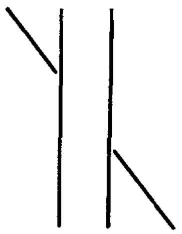

Fig. 3. The Poggendorff illusion still occurs even when the lines do not intersect.

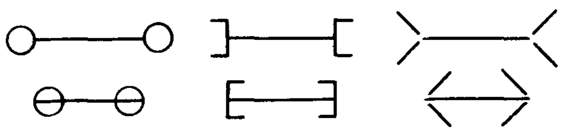

Fig. 4. Forms of the Müller-Lyer illusion not relying on intersections of lines at acute angles.

should also explain the variants (from Sanford, 1897) shown in Fig. 4. But the only intersections of lines in these figures occur at right angles and so the theory under discussion does not suffice as it relies on distortions occuring when lines actually intersect and do so at acute angles.

In summary, the theory appears inadequate at two levels. It invokes displacement and rotation of lines intersecting at an acute angle to explain geometrical illusions produced by crossing lines. But it does not satisfactorily explain why any such distortion should occur. And the occurrence of such distortion is not sufficient to account for all illusions of the type considered.

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NOTES

1. I am grateful to R. H. Day and M. Coltheart for critically reading a draft of this paper.

2. Now at the Institute of Experimental Psychology, University of Oxford.

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Reply to Cumming's criticism

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Comments are herewith presented in answer to Cumming's criticism (p. 375).

1.Cumming has misinterpreted my theory as using the interference principle. Actually it used the superposition principle. This principle applies to a slit experiment as well as to a case of image formation in the retina. Thus, it seems to me, his main objection is incorrect.

2. The vertical line in Pogendorff's illusion should, by the aberrations and diffraction accounts, appear broken. The reason that it does not so appear is that the line is too thick. This point has been discussed in the text.

3. The Pogendorff illusion occurs even though the lines may not intersect. However, it appears to me that the illusion does not occur as effectively as when the lines intersect. Furthermore, if one views the illusion at a considerable distance so that the eye cannot see that the lines do not intersect, there is no difference to the S whether the lines intersect or not. It is predicted that the illusion occurs to a lessened degree.

4. I have little doubt that diffraction and aberrations are the main causes of the illusions. However, one cannot claim that they are the only causes, a consideration that is particularly true in the Muller-Lyer illussion.

5. The effects of illumination, distance, rotation, and tilt on illusions may be important parameters, but the effects of diffraction and aberrations seem to be the controlling variables. However, I do not feel that these factors contradict the influences of the major controlling variables.