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SUBJECTIVE CONTOURS AND APPARENT DEPTH[1]

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The phenomenal appearance of contours in the absence of abrupt stimulus gradients was first discovered by F. Schumann. Recently such contours have been produced in Julesz patterns using binocular disparity. Analysis indicates that both monocular and binocular subjective contours result from the presence of depth cues in the stimulus array.

Schumann (1904) investigated the physical parameters which affect the perception of contour. He reported that for a contour to be perceived the prerequisite was some relatively abrupt local change in brightness or color. In the course of these investigations, however, he noted that under certain favorable conditions contours could be made to appear in areas of the visual field where the physical stimulation was homogenous. As evidence of this, he presented the pattern shown in Figure 1. In the center of this pattern most observers see a white square, bounded by intermittent black and white on either side. Since the contours delineating this square are not actually present in the stimulation, these phenomena have been called "subjective contours" (Osgood, 1951).

The subjective contours in the Schumann figure are somewhat unstable. Not all observers see these contour lines, and when they are carefully fixated, they tend to disappear. Their appearance is generally enhanced when the configuration is of small visual angle. All of these factors led Schumann to conclude that subjective contours were the result of some organizational process, similar in nature to closure, which resulted in the perception of a square bounded by contours which were not physically present.

Schumann's work on subjective contours has been extended by Kanizsa (1955) who created a number of configurations which produce much more compelling contours than those in Figure 1. In addition, Kanizsa was able to demonstrate that curvilinear as well as straight contours could be produced. Some representative examples of patterns which produce subjective contours are shown in Figure 2.

When observers look at Figure 2A, which has been adapted from Kanizsa (1955), they invariably report seeing a white triangle in the center of the configuration, although no such figure physically exists. The properties of this triangle are rather interesting. In addition to being whiter than the surround, it is almost always described as a plane surface which appears to be in front of the other elements in the pattern. The triangle is apparently opaque and capable of obstructing the observer's view of the pat-

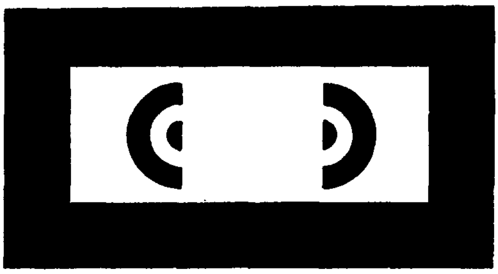

FIG. 1. The Schumann figure: A central white square is seen in this configuration, especially when the figure is of small visual angle.

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tern elements behind it. Figure 2B shows a variant in which a subjectively produced white rectangle appears in the center, while Figure 2C shows that curvilinear subjective contours are also possible. Figure 2D is the negative form of Figure 2A. It is clear that with the brightness of the lines and background reversed, the subjective triangle is still seen; only here note that it appears as blacker than the black of the background. The intriguing aspect of these figures is that large stretches of the perceived contours are not physically present, but rather are curved out of homogeneous portions of the stimulus field by the perceptual system.

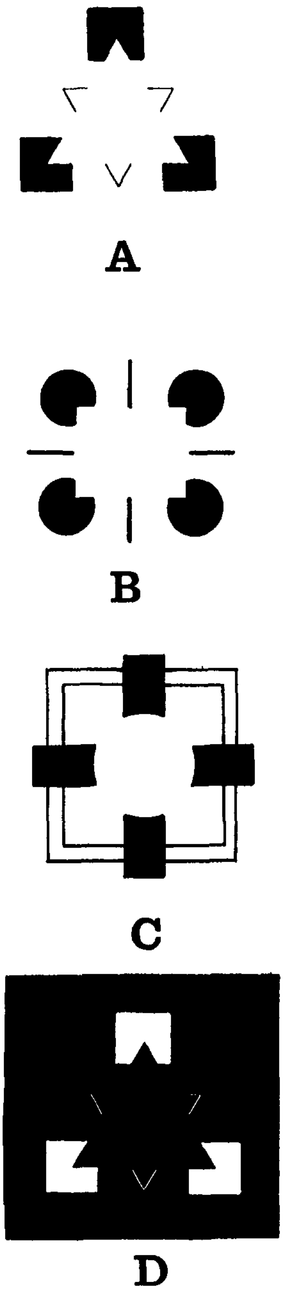

FIG. 2. Subjective contour figures adapted from Kanizsa (1955): A shows a subjective white triangle; B, a square; C illustrates that curvilinear subjective contours may be produced; and D shows a subjective contour with reversed brightness of that in A.

Virtually all observers see the subjective contours in these configurations. Knowledge of the fact that there is no triangle physically present in Figure 2A does not seem to lessen the strength of the percept, and the contour remains visible even with careful fixation. As in the case of Figure 1, figures of small visual angle tend to produce an enhanced effect.

The phenomenon of apparent contour has never been convincingly explained. Kanizsa (1955) reiterates a Gestalt position and refers to subjective contours as unusually strong examples of closure or figure-ground organization. His position is close to Schumann's. This same theoretical stand was also taken by Rubin (1921).

Binocular Disparity and Subjective Contour

Julesz (1964) presented a stimulus array which produced a very compelling subjective contour in the absence of an abrupt change in brightness. Using computer matrices of randomly generated dots, he created a sensory environment devoid of all depth and familiarity cues except retinal disparity. Stereoscopic presentation of identical dot matrices results in the perception of a simple two-dimensional display of dots on a homogeneous background. If the dots are small enough or slightly blurred, the perception is of a homogeneous textured field. If, however, these displays are altered by shifting the location of all dots in a central submatrix one column laterally, the percept immediately changes. If, for instance, the dots in a square central area seen by the left eye are shifted one column to the right, the observer now reports that this central square region is seen in depth. It is now localized as being closer to the observer than the background. In addition to this depth effect, the observer notes that this region is bounded by subjective contours which appear to be localized between the rows and columns of dots. As White (1962) pointed out, these contours are clearly subjective in nature and do not require the usual stimulus correlates associated with the perception of contours. Closing either eye results in an immediate loss of the impression of depth and a disappearance of the contour.

Under optimal conditions, these contours are very impressive and are indistinguishable from those produced by sharp stimulus gradients. Shipley (1965) has shown that even in blurred or out-of-focus configurations, the sharp subjective contour still accompanies the perception of the central form in depth.

Lawson and Gulick (1967) extended the analysis of subjective contours seen in these patterns. They presented stimulus arrays in which the disparity cue produced subjective edges bounding large homogeneous areas of the field. They have shown that the important feature of the stimulus display is not simply retinal disparity, for in some cases they were able to produce arrays which resulted in the perception of a group of dots seen in depth, not bounded by any contours, but rather form disparity. Form disparity is defined here as that pair of disparate views that would result if an opaque form were physically present in the visual field and were differentially obstructing parts of the background matrix which were seen by the two eyes. A striking example of this is found in the work of Kaufman (1964) and Kaufman and Pitblado (1965), who were able to show that even when the elements presented to the two eyes were quite different in nature (i.e., were rows and columns of different letters), the effect of disparity was the perception of a target in depth, bounded by subjectively seen contours. Lawson and Gulick (1967) observed that in the absence of the perception of depth they found no subjective contours.

The question which immediately springs to mind is whether the subjective contours visible in these stereograms are due to the operation of the same general mechanism as are the monocularly visible contours in Figure 2. One hint that such might be the case comes from the phenomenal reports by observers when looking at these monocular stimuli. The subjective contours in Figure 2 almost always are seen as bounding an opaque figure which is *in front of* the other pattern elements. This perception of relative depth is quite strong, as may be anecdotally illustrated by the fact that one observer, while viewing a pattern similar to Figure 2A, accused the experimenter of cutting a triangle out of a piece of white paper, different than the background, and pasting it onto the stimulus card. If the important aspect of the stimulus display is the displacement of one part of the array in depth, then one ought to be able to demonstrate the ability of other depth cues to produce the perception of subjective contours.

Shading and Subjective Contours

One such depth cue which has long been known to produce subjective planes varying in apparent distance from the background is the cue of shading (Brunswik, 1935). Figure 3 shows a stimulus configuration which utilizes this cue. In this figure the word FEET is clearly seen in white letters which stand out from the background. It is difficult to believe, when looking at this figure, that about 50% of each letter is not present in the stimulation. Most observers report the perception of white letters, whiter than the background, with the contours defining the letters faintly visible. These contours are subjective contours in the same way that the contours in Figure 2 were. The boundaries defining the edge between the white of the raised plane of the letters and the white of the background are subjectively created from homogeneous stretches of the stimulation. That this phenomenon is due to the

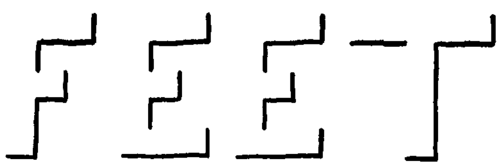

FIG. 3. Subjective contours produced by shading cues.

presence of the depth cues and not simply to the presence of these particular lines in the field is shown in Figure 4.

Figure 4A shows a letter H created in the same manner as the letters in Figure 3. Here the shading provides a monocular depth cue sufficient to create an apparent plane displaced forward in space, and the contours which bound it are visible. Figure 4B contains the same lines as Figure 4A, except that they have been rearranged so that the shading cues are inconsistent. Thus, a variety of "impossible figure" with locally consistent and globally inconsistent depth has been created, such as the figures explored by Hochberg (1968). Most observers report that Figure 4B is much harder to see as separate from the background, and the subjective contours are never very clear or stable. They tend to spontaneously appear and disappear. As one observer put it, the subjective contours of Figure 4B lack the "reality" of the contours of Figure 4A.

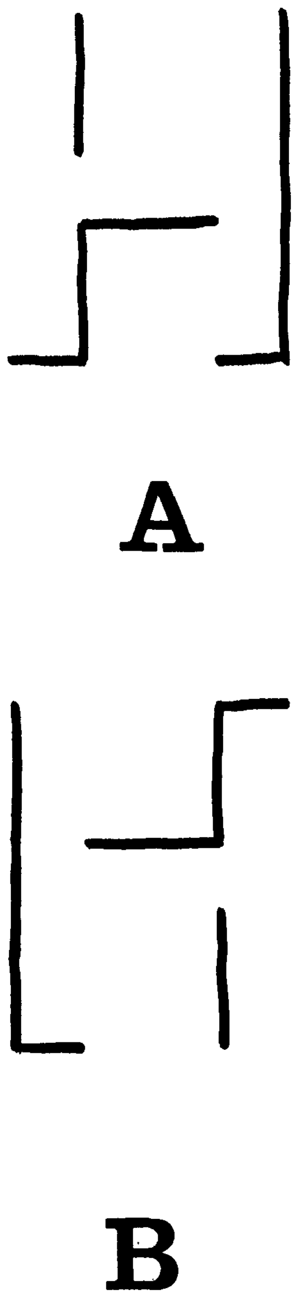

FIG. 4. A subjectively contoured letter H produced by shading cues (A). The same shading lines, arranged to produce inconsistent cues, produce an unstable subjective contour (B).

The perceptual creation of three-dimensional planes out of a two-dimensional array of elements is not a new phenomenon. Hochberg and Brooks (1960) have shown that when a complex two-dimensional figure is presented to observers, they very frequently "simplify it" by coding it as a three-dimensional figure. Thus the meaningless, asymetrical jumble of two-dimensional lines in Figure 4A is more compactly coded as a single three-dimensional letter H. The main difference between these figures and the Kopferman cube figures used by Hochberg and Brooks is that in these configurations the subject not only renders the percept into one of tridimensionality, but supplies the missing edges to make the stimulus apparently complete.

Interposition as a Cue for Subjective Contour

Now return to the stimuli presented in Figure 2. Since it has already been shown that a monocular depth cue, namely shading, can act in the same fashion that the binocular disparity cue does to form planes and contours out of homogeneous stimulus regions, a new way of looking at these subjective contour configurations has emerged. Given the fact that the triangle in Figure 2A is clearly seen in front of the other elements, let us look for the relevant depth cues which cause this displacement and the corresponding creation of the subjective edges. The depth cue becomes quite apparent when the observer's descriptions of the figure are recalled. It was described as a white triangle *in front of* an inverted black outline triangle, with its corners *resting on* three black squares. The depth cue involved in this pattern is therefore probably interposition. If there were an opaque white triangle overlying a black outline triangle and three black squares, the same retinal pattern would be produced, except, of course, for the existence of contours and apparent brightness or color differences in the field. Thus the observer creates the surface indicated by the depth cues and edges it with subjectively created contours to bound it. Interposition cues can also be found in the remaining patterns in Figure 2. Figure 2B is easily seen as a white rectangle interposed in front of the intersection of two black lines, its corners resting on four black circles, and Figure 2C is seen as a white circle resting on the intersection of two heavier black bars. Figure 2D provides the same interposition cues as are found in Figure 2A, except that the brightnesses are reversed, such that the interposition cues indicate that the figure which must be present is a black triangle.

A very interesting demonstration of the presence of depth cues in these configurations is shown in Figure 5. This figure is a variant of Figure 2A where a circle on the apparent triangle and one beside it on the background have been placed. Now if a cue for depth is present, then a situation arises where two stimuli both subtend the same visual angle, but one is seen as apparently closer than the other. If the depth cue is strong enough to evoke the operation of the constancy scaling mechanism, then the circle on the apparently closer plane (the triangle) should be seen as smaller than the circle on the apparently more distant plane (the background). A copy of this figure was presented to 12 subjects. Each subject was required to judge which of the two circles appeared larger, using a forced-choice technique. Eleven of the 12 reported that the circle on the subjective triangle appeared smaller than the one outside it ($p < .01$, sign test). These results seem to indicate not only the presence of the interposition cue in these configurations, but the fact that they are relatively strong. It should be clear that this demonstration is lacking in a control group, since the effect might also be due to configurational properties. Simply adding a real contour does not suffice as a control, since then both the interposition cues for depth and configurational properties would still be present. Removing the interposition cues on the other hand, drastically changes the configuration. Suffice it to say that accompanied with the reported depth difference between the subjectively seen contour and the background, these results are clearly in accord with the hypothesis that depth cues are present in configurations which produce subjective contours.

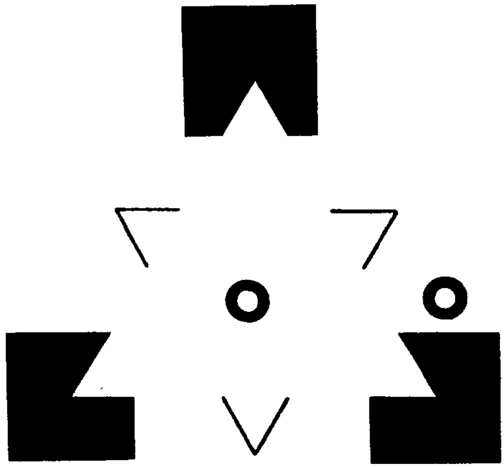

FIG. 5. Both circles subtend the same visual angle; however, the apparent depth difference produces an apparent size difference.

Figure 6 is an example of how the explicit use of the interposition cue can result in the perception of subjective contours. This figure has been adopted from one presented by Matthaei (1929). When shown this figure, the immediate response of most observers is that they are seeing a word which is *partially blocked by a white strip which has been overlayed.* In fact the principle guiding the construction of this figure was to simply remove those portions of the display which would not be seen if such an opaque strip were physically present.

FIG. 6. A subjective contour produced by interposition cues.

Texture and Perspective

If the author's analysis is correct, and it is the presence of depth cues which are constant with the presence of forms or planes at various depths, then almost any monocular depth cue could be utilized to produce the perception of subjective contours. The only prerequisite is that cues be strong enough so that the configuration is seen as tridimensional rather than as bidimensional. This has been done for a number of these cues, and Figure 7 presents a combination of texture and perspective cues which demonstrates the effect very clearly. This configuration is patterned after the stimuli presented by Gibson (1950). The general impression produced by this figure is that of two planes differing in relative depth. The plane in the upper part of the figure is perceived as more distant than the plane in the lower half of the figure. There is apparently a sharp drop or a cliff separating these two planes. The contour delineating the edge of the cliff is clearly seen. It is visible as a sort of whitish line. This light line is, of course, not present in the physical stimulation. As in the previous stimuli, it bounds the edge between two planes seen at different depths.

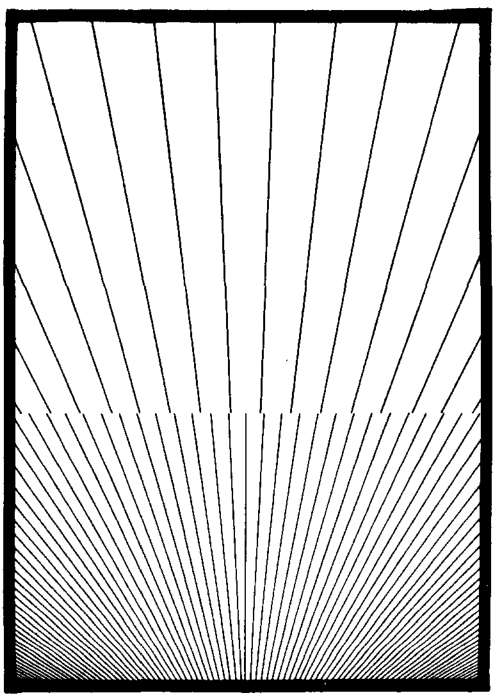

FIG. 7. A subjective contour produced by texture and perspective cues (after Gibson 1950).

Closure as an Explanatory Mechanism

At the outset it was noted that the most frequently offered explanation for subjective contours is that they are an example of the Gestalt principle of closure (Kanizsa, 1935; Lawson & Gulick, 1967; Pastore, 1971; Rubin, 1921; Schumann, 1904). It is interesting to compare these effects which are being ascribed to the effects of depth cues with the perceptual effect generally called closure. Figure 8A is a configuration which utilizes interposition cues to produce the perception of a white triangle with its corners resting on three black circles. The phenomenological impression is that this triangle is in front of the background and the other pattern elements, and that it is bounded by contours which are faintly visible to the observer. Figure 8B is a typical figure which is associated with the phenomena of closure. This figure is easily perceptually completed and recognized by the observer as a triangle. The percept which results from this configuration is quite different from that of 8A. The figure does not lie in front of the plane and the figure is still seen as being incomplete. Most importantly, this figure is not bounded by subjective contours which clearly set it off from the background. It is thus clear that by degrading the stimulus in such a way that the relative depth cues are not readily available then closure alone is not sufficient to produce the perception of subjective contours. Figure 8B is also interesting in that it clarifies a major criterion for the perception of the subjective contour. Discussions with Julian Hochberg have suggested that a depth cue be defined as some aspect of a configuration which can be read as consistent with a given spatial arrangement of objects at different relative distances. To the extent, then, that there is no evoked perception of objects differing in relative depth in Figure 8B, there are no depth cues in this pattern. However, since the definition of a depth cue includes any configurational change which may result from objects in depth relative to each other, then there are potential depth cues in Figure 8B. Any time there is a discontinuous black line on a white ground, the discontinuity may be caused by an interposed white figure. Thus if one looks at Figure 8B and imagines that it is a complete black outline triangle, then one can begin to configure a white object interposed in front of it. This figure may either be an amorphous white cloud or, more spectacularly, an inverted white subjective triangle. Such an inverted triangle is not generally seen, although when alerted to its presence an observer may be able to make out its form. This illustrates that the mere presence of potential depth cues in an array is not sufficient to evoke the perception of a subjective contour. The reason for its appearance in some situations and not in others is sug-

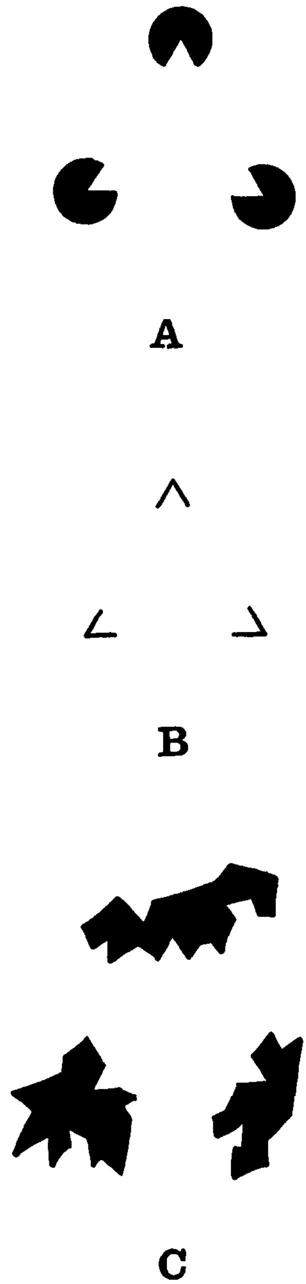

FIG. 8. A subjective contour produced by interposition (A). A typical closure configuration which produces no subjective contour (B). Although corner elements are still present, this configuration generally yields no subjective contours (C).

gested from the work of Kopfermann (1930) and Hochberg and Brooks (1960), who showed that complex two-dimensional line figures were seen as tridimensional if such a percept resulted in a simpler overall organization. Thus Figure 8A is simplified from a meaningless pattern of irregular forms into an arrangement in depth of four simple symmetrical forms. Figure 8B can be simplified into a triangular organization without the necessity of rendering the percept into depth. Hochberg (1970) has shown several convincing demonstrations of the effect of expectation on perceptual organization based on the utilization of local and global depth cues. Thus in Figure 8B, once the observer is alerted to the presence of the depth cues and the possibility of an object in depth, the perceptual organization may change in such a manner as to allow for the perception of the subjective contours. Figure 8C is another form of the same figure and makes a similar point. Here the corner elements are still present and we also have the black masses associated with Figure 8A. If subjects are shown this figure, they usually describe three black nonsense figures (more or less meaningful according to their personal styles). The spontaneous report of a white triangle which is invariably obtained in Figure 8A is missing. By reducing the regularity of the forms at the corners of the subjective figure, the likelihood that the configuration will be perceptually simplified by assuming a white triangle interposed in front of the background has been reduced. It is interesting to note that when the white triangle is pointed out in Figure 8C, many observers report that it is faintly visible, as are the subjective contours bounding it.

Conclusions

These demonstrations may be summarized then by indicating that all of the figures which have been presented that contain subjective contours are seen as associated with apparent surfaces or planes that are in depth relative to the remainder of the array. These planes are perceptually created on the depth cues present in the stimulus. Since every plane must have an edge, the bounding contour is supplied by the perceptual system. This contour thus segregates the homogeneous stimulation into discrete units, one comprising the plane in depth and the other, the background stimulation. The edges of the plane are subjective contours, since there is no discontinuity in physical stimulation at the locus where they are seen in space. In this way a chaotic collection of complex two-dimensional elements has been simplified into a simple and easily coded three-dimensional array of meaningful or symmetrical elements. Thus, a subjective contour is simply the edge of a subjective plane, and a subjective plane is a surface which ought to be present on the basis of the available depth cues, but is not except in the mind of the perceiver.

REFERENCES

BRUNSWIK, E. *Experimentelle psychologie in demonstrationen.* Vienna: Springer, 1935.

GIBSON, J. J. *The perception of the visual world.* Boston: Houghton Mifflin, 1950.

HOCHBERG, J. In the mind's eye. In R. N. Haber (Ed.), *Contemporary theory and research in visual perception.* New York: Holt, Rinehart & Winston, 1968.

HOCHBERG, J. Attention, organization, and consciousness. In D. I. Mostofsky (Ed.), *Attention: Contemporary theory and analysis.* New York: Appleton-Century-Crofts, 1970.

HOCHBERG, J., & BROOKS, V. The psychophysics of form: Reversible-perspective drawings of spatial objects. *American Journal of Psychology,* 1960, **73**, 337–354.

JULESZ, B. Binocular depth perception without familiarity cues. *Science,* 1964, **145**, 356–362.

KANIZSA, G. Marzini quasi-percettivi in campi con stimolazione omogenea. *Rivista di psicologia,* 1955, **49**, 7–30.

KAUFMAN, L. On the nature of binocular disparity. *American Journal of Psychology,* 1964, **77**, 393–402.

KAUFMAN, L., & PITBLADO, C. Further observations on the nature of effective binocular disparities. *American Journal of Psychology,* 1965, **78**, 379–391.

KOPFERMANN, H. Psychologische Untersuchungen über die wirkung Zweidimensionälar Darstellungen korperlicher Gebilde. *Psychologische Forschung,* 1930, **13**, 293–364.

LAWSON, R. B., & GULICK, W. L. Stereopsis and anomalous contour. *Vision Research,* 1967, **7**, 271–297.

MATTHAEI, R. *Das Gestalt problem.* Munich: Bergmann, 1929.
OSGOOD, C. E. *Method and theory in experimental psychology.* New York: Oxford University Press, 1951.
PASTORE, N. *Selective history of theories of visual perception 1650–1950.* New York: Oxford University Press, 1971.
RUBIN, E. *Visuell wahrgenommene figuren.* Copenhagen: Gyldendal, 1921.
SCHUMANN, F. Einige Beobachtungen über die Zusammenfassung von Gesichtseindrücken zu Einheiten. *Psychologische Studien,* 1904, **1**, 1–32.
SHIPLEY, T. Visual contours in homogeneous space. *Science,* 1965, **150**, 348–350.
WHITE, B. W. Stimulus-conditions affecting a recently discovered stereoscopic effect. *American Journal of Psychology,* 1962, **75**, 411–420.

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