Notes and Comment

Animated subjective contours

DRAKE R. BRADLEY and KJUNGJA LEE
Bates College, Lewiston, Maine

Although a number of theorists have emphasized the role of depth cues in generating or facilitating the perception of subjective contours (Coren, 1972; Gregory & Harris, 1974; Harris & Gregory, 1973; Julesz & Frisby, 1975; Lawson, Cowan, Gibbs, & Whitmore, 1974; Whitmore, Lawson, & Korzora, 1976), no one has investigated what effect, if any, kinetic depth information has on these phenomena. Consider Figure 1, a "minimum" configuration for producing subjective contours (Kanizsa, 1955). While most observers see subjective contours in this figure, the contours are weak and somewhat tenuous. We asked the following question: What would happen if the subjective triangle were rotated using animation techniques? It was anticipated that rotation of the dots at the vertices of the subjective triangle, as well as the gaps in the black outline triangle, would enhance the clarity and strength of the subjective contours.

The animated sequence was prepared by photographing, frame by frame, successive versions of a black outline triangle and three dots, starting with the configuration shown in Figure 1. Each successive frame presented the dots and gaps rotated 6 deg clockwise from their positions in the previous frame, as illustrated in Figure 2 for the first four frames of the animated sequence. Hence, a single 360-deg rotation of the subjective triangle required the presentation of 60 discrete patterns in succession. Because of symmetry, only 20 different figures were actually needed to accomplish this: 1 corresponding to Figure 1, 18 for the intermediate orientations to either side of Figure 1, and 1 for when the two triangles had the same orientation. The latter pattern consisted of just the three dots, since the subjective contour triangle completely "masks" the black outline triangle in this case. In making the animated film, a series of frames was made of Figure 1 prior to commencing rotation in order to provide a stationary figure for comparison. At the slowest speed of projection used, the resulting film provided 1 min of exposure to the stationary figure and 3 min to the rotating figure.

The animated film was projected by an Elmo Super 8 movie projector (Model K-100SM) with vari-

Figure 1. A "minimum" subjective contour figure introduced by Gaetano Kanizsa (1955).

able speed (5-24 fps), reverse, and stop-action capability. The projector was located at the back of a medium-sized classroom, and the image was projected onto a large screen suspended from the ceiling. At the distance used for projection, the sides of the subjective and black outline triangles were 84.8 cm long. The projection speed employed was approximately 9 frames/sec, so that the subjective triangle completed one rotation in about 6.7 sec (for the moving version). Consequently, each individual frame corresponding to a particular orientation of the 60 possible orientations was exposed for .11 sec. This resulted in the impression of a continuously rotating figure.

Thirty-seven college undergraduates viewed both the stationary and moving subjective contours for 1 min each. Approximately half the group viewed the stationary figure first, followed by the moving figure; the other half viewed them in the reverse order. Following exposure, each student indicated on a previously distributed data sheet which condition, stationary or rotating, generated the strongest subjective contours. They also recorded any impressions they had about the appearance of the subjective triangle while it was rotating.

The results indicated that 35 of the 37 students experienced the subjective contours to be stronger when in motion ($p < .0001$ by the binomial test). In addition, 25.7% of the students reported that the sides of the rotating subjective triangle appeared bowed inward. We have since investigated this effect further, and have found that it becomes much more pronounced at higher rates of rotation. This distortion in shape provides another instance in which

The authors' mailing address is: Department of Psychology, Bates College, Lewiston, Maine 04240.

Figure 2. The first four frames from the animated sequence: the black outline triangle remains stationary while the dots and gaps rotate 6 deg clockwise each frame. A rotating subjective triangle is perceived, and, at sufficiently high rates of rotation, the "sides" of the triangle appear bowed inward. When the dots are omitted from the animated sequence, the rotating gaps still convey sufficient kinetic information for the subjective triangle to be perceived, although the "corners" appear rounded.

subjective contours behave similarly to real contours: it has been long known that geometric figures (e.g., ellipses, squares) distort when subjected to rotation (see Fineman, 1981, p. 55). In the present case, it would be difficult to attribute such distortions to spatiotemporal interactions of contours at the retinal level, because there are no contours to interact (excluding the stationary outline triangle). Consequently, shape distortions in moving subjective contours may call into question peripheral physiological theories used to explain similar distortions in real contours.

We would like to close by introducing a new "minimum" subjective contour figure which exists only when kinetic depth information is provided. If the dots are deleted from Figure 1, the subjective contours disappear for most observers. In fact, this version of the figure has been used to demonstrate that

gestalt closure is not a sufficient condition for producing subjective contours (Coren, 1972, Figure 8b). However, if the gaps in the sides of the triangle are subjected to rotation, a subjective contour figure can be seen. We prepared an animated film of just this case, following the procedures reviewed above except that the dots were omitted from the individual figures used to produce the animated sequence. We have shown this film to a large number of observers, and nearly all report being able to see a rotating subjective triangle. Unlike the case described above, however, the corners of the subjective triangle appear rounded. Interestingly, the observers insist that they can still see the subjective triangle even when it is completely aligned with the black outline triangle. In the previous case, this situation was represented by just the three dots, but in the present case it is represented by a blank frame (since the

dots have been omitted). Apparently, the kinetic depth information provided by the immediately preceding and following frames in the film is sufficient to sustain the perception of subjective contours in the complete absence of a stimulus. In all likelihood, this represents an irreducible lower limit in the design of "minimum" figures required to produce subjective contours.

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