Perceived common rotary motion of ambiguous stimuli as a criterion of perceptual grouping*

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Apparent common behavior of contours with respect to a property for which each contour is ambiguous (in this case direction of rotary motion in depth) was used as a criterion of the unitary processing of the contours or "grouping." Grouping was found to decrease as a monotonic function of the difference in line orientation and, for fixed orientations, to decrease as a monotonic function of line separation. These results are tentatively attributed to the distribution of line detectors in the projection area.

One of the principal concerns of the Gestalt psychologists (Wertheimer, 1923) was the grouping of contours into perceptual units according to such stimulus properties as similarity, proximity, symmetry, and common fate. Although the notion of grouping has a certain phenomenal validity, it is difficult to define and therefore difficult to measure. Recent investigators (Beck, 1967; Olsen & Attneave, 1970) define grouping as the "segregation" of one set of contours from a background of different contours. Some index of speed of discrimination of the deviant set, for example, counting or RT, is used as a quantitative measure of grouping strength.

The following proposed operational definition of grouping may or may not be related to the above criterion. *If two or more contours always appear alike with respect to a property for which each contour is ambiguous, they constitute a perceptual unit or group.* In the present studies stimulus contours were ambiguous with respect to direction of rotary motion in depth.¹ Grouping of two contours was demonstrated if they always exhibited apparent motion in the same direction with reversals at the same time. The rationale and procedure are described in more detail below.

Apparent reversals in direction of rotary motion during rotation of a stimulus on a vertical axis can be attributed to a functional ambiguity in differential velocity cues (Graham, 1963). If this ambiguity is rendered perfect by viewing a parallel projection of the rotating stimulus, while

eliminating other cues for direction of motion, then there is an a priori probability of 0.5 for apparent motion clockwise and 0.5 for apparent motion counterclockwise at any given time. If two such rotating stimuli are viewed at once and if their directions of motion are resolved independently, it follows that the a priori probability that they will appear to rotate in the same direction at any time is also 0.5. If they *always* appear to rotate in the same direction and to reverse together, a lack of independence of the stimuli can be inferred. That is, they are processed as a unit or "grouped" for depth processing. A quantitative measure of grouping is provided by the proportion of time that the two contours rotate together. Completely independent processing of any two contours would be indicated by their apparent rotary motion in opposite directions (fragmentation) for half the time. Perfect grouping or common processing of the contours would be indicated by a complete absence of fragmentation. Intermediate degrees of grouping would be indicated by probabilities of fragmentation between 0 and 0.5. This idea was pursued in three experiments in which degree of grouping for two contours was measured as a function of two simple parameters, relative orientation and spacing, in the hope of probing some basic processes of visual form perception.

EXPERIMENT 1

Preliminary work showed that converging oblique lines (as shown in Fig. 1A) sometimes appeared to rotate in opposite directions. However, parallel oblique lines (Fig. 1B) seldom appeared to do so. This suggested that the degree to which lines are processed as a unit with respect to motion in depth may depend upon their relative orientations.

Five figures were used, each composed of two 1.5-mm rods

attached to another 1.5-mm vertical rod which formed the axis of rotation. The two rods were in the same plane and separated by 2.5 cm (1 deg of visual angle) along the vertical axis of rotation. In all five figures, the lower rod was exactly 4.4 cm in length and was oriented 15 deg from the horizontal. The upper rod orientation varied from one figure to another between plus and minus 15 deg in 7.5-deg steps and varied in length between 4.2 and 4.4 cm. (These slight variations in rod length with angle were designed to keep the ends of the upper rod always in vertical alignment with the ends of the lower rod.) The extremes are shown in Fig. 1. Each figure was rotated at a uniform rate of 30 deg/sec in a collimated light beam (achieved by placing a 9-cm-diam 1.7-diopter lens at its focal length from a point source), and each formed a sharp silhouette on a frosted glass screen. This constituted a parallel projection of the figure which was viewed by S through an aperture at a distance of 145 cm.

Each S was shown the moving silhouette of Fig. 1A and instructed to look at the center. When asked to describe it, all Ss spontaneously reported rotary motion with reversals, and all but a few Ss spontaneously reported that the two lines appeared sometimes to rotate in opposite directions. The few Ss who did not spontaneously report fragmentation were not used in any of the experiments; even though they did report fragmentation when told what to look for, E could not be certain that they really saw the effect. The total fragmentation time during 10 revolutions (120 sec) for each figure was cumulated on a clock, activated while S pressed a switch. The number of presses was recorded on a counter. Ten Ss were used and each viewed the figures in a different order.

Figure 2 shows the mean fragmentation time with standard errors for the 10 Ss as a function of the angle of the upper line. The

Fig. 1. Scale drawings of two figures used in the experiments.

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Fig. 2. Mean percent fragmentation time as a function of the angle of the upper line (lower line fixed at -15 deg).

corresponding mean number of presses is shown in parentheses beside each data point. Fragmentation time was almost zero when the upper and lower lines were parallel, increased as a monotonic function of the orientation of the upper line, and reached a level of about 0.5 (representing independent processing of the two lines) for Fig. 1A, whose lines differed most in orientation. Grouping is clearly a function of relative line orientation.

EXPERIMENT 2

In all figures used in this experiment, the two lines were oriented 15 deg from the horizontal in opposite directions (as in Fig. 1A). The figures differed only in the separation of the lines along the vertical axis. Method and procedure were as for Experiment 1, and 16 new Ss were used. Mean fragmentation time as a function of line separation for the 16 Ss is shown in Fig. 3 (unbroken line). Fragmentation time increased as a function of line separation, reaching an asymptote at a level of about 0.5 for Fig. 1A (separation 1 deg).

EXPERIMENT 3

In all figures of this experiment, the two lines were parallel and oriented 15 deg from the horizontal (as in Fig. 1B). They differed in the separation of the upper and lower lines along the vertical axis. Method and procedure were as for Experiments 1 and 2, and 14 new Ss were used. Results are shown by the dotted line in Fig. 3. They show that even the parallel lines were processed with a considerable degree of independence when sufficiently separated (by 3.75 cm or 1.5 deg of visual angle).

DISCUSSION

Relative line orientation and line proximity are critical interacting variables determining whether common or independent processing of direction of rotary motion occurs under conditions of ambiguity. These determinants suggest the Gestalt grouping principles of similarity and proximity. However, in Experiments 1 and 2 similarities of the lines other than orientation (length and thickness) did not elicit grouping for Fig. 1A. Neither did symmetry appear to cause grouping; in fact, the symmetric figure (1A) showed the greatest fragmentation. A related point is the lack of any tendency to respond to Fig. 1A as a linear perspective. Of course, when the figure is closed by vertical lines at the sides this does occur and the figure appears to oscillate like an Ames window during rotary motion.

Beck (1967) reported that an orientation difference between two sets of stimuli facilitated grouping according to the discrimination criterion described in the introduction. However, Olsen & Attneave (1970) found that an even more potent variable producing segregation of two sets of stimuli was Cartesian vs oblique orientation, which does not have a direct parallel in the present results.² At the present stage, the relationship between the grouping criterion involving the discrimination of stimuli and the present criterion involving unitary processing with respect to ambiguous spatial position is not clear. It would seem that the grouping variations found in the present studies could be more plausibly accounted for by organization of stimulus input at the projection level,³ as Beck proposed for his results, than by conceptual processes occurring later in the system. Theories of form perception involving descriptors (Olsen & Attneave, 1970), schemata (Vernon, 1952), or information analysis [for example, the minimum complexity principle proposed by Attneave (1954), Hochberg & McAlister (1953), and Hochberg (1964)⁴] can explain the kinetic depth effect as observed for each line of the present stimuli, but without excessive complications cannot account for the importance of orientation and spacing compared to other variables in determining grouping of the lines and especially not the monotonic functions relating these variables to degree of grouping.

This tentative ascription of the present results to the projection level of processing is supported by the striking similarity between the variables found here to determine perceptual organization of contours and the variables determining

organization of complex line detector cells in the projection area (striate cortex) of the monkey (Hubel & Wiesel, 1968). These cells are grouped in Area 17 directly according to the retinal proximity and similarity in orientation of their receptive fields, variables which directly parallel the spacing⁵ and orientation determinants of *perceptual* grouping found in the present studies. Therefore, it could be the case that the degree to which two lines are processed as a single unit at some higher level in the system is influenced by the proximity and overlap of the cells responding to these lines at the projection level.

In explaining the present results this way, it is not meant to imply that all grouping is determined at the projection level. There is a possibility that contours not grouped on the basis of output from the projection areas could be grouped later according to stored schemata, descriptors, or information processing rules. For example, the grouping produced by closing Fig. 1A by vertical lines at the sides may well reflect processes of this kind rather than projection processes.

Development of a less crude physiological model, which would necessarily deal with the sampling of large numbers of receptive fields, would be premature without further investigation of the grouping variables already considered (especially their interaction) and new variables suggested by other properties of receptive fields known to be related to cell clustering in Area 17. These investigations are currently being pursued.

Even if the physiological explanation does not withstand further investigation, the technique described here should be useful in that it is a very direct measure of unitary vs independent processing of contours.

Fig. 3. Mean percent fragmentation time as a function of line separation for convergent lines (open circles) and parallel lines (filled circles). $N = 16$, $N = 14$, respectively.

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NOTES

1. Stationary ambiguous figures could in principle have been used, but the depth response they elicit is far less compelling than the depth response to moving figures, especially if the figures are very simple.
2. Figure 1 shows that the single condition in the present studies for which one line was in a horizontal orientation did not show an especially high degree of fragmentation.
3. In Sutherland's (1968) terms, the present results seem better accounted for by

the "processor" rather than by the "store."

4. In his analysis of the Penrose "impossible" figures, Hochberg himself (1968) casts doubt on the universality of the law of minimally complex resolutions in perception.

5. It is interesting to note that the angular separation of parallel lines for which fragmentation strongly increases (1.5 deg) is of the same order of magnitude as receptive field sizes for complex cells in the monkey striate cortex (Hubel & Wiesel, 1968, p. 221). A quantitative comparison of the required orientation difference between lines for independent processing of motion direction with the orientation range of receptive fields of individual complex cells would be difficult because of complications arising from the interaction between orientations and spacing and the fact that retinal line orientations change during rotation of a figure with an increasing, then decreasing, difference in orientation of converging lines as the figure moves from the frontal plane to the sagittal plane.

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