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Perceptual alternations in stereokinesis

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Abstract. When a flat ellipse is slowly rotated in the frontoparallel plane, two different 3-D percepts can be obtained: (i) a rigid circular disc tilting back and forth in 3-D space, and (ii) an elongated egg, slanted into 3-D space, whose end parts seem to be located at different distances from the observer and describe a circular trajectory with respect to the frontal plane. Under prolonged observation, the two 3-D percepts alternate in time, separated by brief intervals in which either the rotation of a rigid flat ellipse in the frontal plane or an amoeba-like distortion of a 2-D shape can be perceived. An experiment is reported in which the sequence of perceptual alternations was investigated. Results show that the 3-D disc is mostly preceded by impressions of elastic amoeba-like deformations, whereas the 3-D egg is mostly preceded by the percept of a rotating flat ellipse. Direct transitions from egg to disc are not as frequent as transitions from disc to egg. Results are discussed in relation to Braunstein and Andersen's hypothesis that phenomena of this sort might result from the stimulation of automatic mechanisms for perceiving size change (changing—size neural channels).

1 Introduction

The human visual system shows a surprising ability to extract 3-dimensional (3-D) shape information from 2-dimensional (2-D) transformations in the image (Wallach and O'Connell 1953; Ullman 1979). When considering this ability, one is faced with the inherent mathematical ambiguity of a changing 2-D image: indeed, there are an infinite number of object transformations in 3-D space that are projectively equivalent to any given moving image on a 2-D surface. Some theorists have argued that one possible strategy for imposing 'uniqueness' upon the 3-D interpretation of moving images is to assume that the observed object is rigid (see Ullman 1984).

Recently, however, Braunstein and Andersen (1984) and Bressan and Vallortigara (1986) have presented two different counterexamples to the rigidity assumption. In both cases the demonstration involves the use of the so-called stereokinetic effect (see Musatti 1924; Piggins et al 1984; Vallortigara et al 1986). Braunstein and Andersen (1984) presented a rigid 2-D figure (the 'three-loop figure') which, when rotated in the frontal plane, is perceived as a distorting 3-D shape. Bressan and Vallortigara (1986), on the other hand, observed that a solid flat ellipse rotating in the frontal plane can be perceived either as a rigid circular disc oscillating back and forth in 3-D space (see Musatti 1924) or as an elongated egg, slanted into 3-D space, whose end parts are located at different distances from the observer and describe a circular trajectory with respect to the frontoparallel plane.

Ullman (1984) attributes the failure to perceive rigidity in stereokinetic patterns to misperception of the correct motion associated primarily with smooth contours that lack identifiable and traceable features (see also Braunstein and Andersen 1986; Ullman 1986). However, this only means that in the analysis of stereokinetic patterns one must consider the effective pattern of proximal stimulation rather than the distal stimulus. Stereokinetic effects and the classic kinetic depth effects are equivalent with respect to the pattern of retinal stimulation: in both cases the visual system is confronted with a moving image whose shape is continuously changing (see Wallach et al 1956 for similar arguments). Moreover, there is recent empirical evidence that the presence of traceable features is not a necessary condition for the human perception of structure from motion (Todd 1985). Thus, if the rigidity assumption has any psychological validity, then it must hold for stereokinetic effects as well as for kinetic depth effects. According to the rigidity assumption, there are two possibilities: either the pattern of proximal stimulation is compatible with a rigid 3-D interpretation or it is not. In the first case, the rigid 3-D interpretation will be selected and will be unique. Bressan and Vallortigara's (1986) pattern, however, demonstrates that the obtainment of rigidity does not imply the uniqueness of the 3-D perceptual interpretation. In the second case, a nonrigid 2-D interpretation will be selected. Braunstein and Andersen's (1984) pattern, however, demonstrates that a 3-D interpretation can be selected even if there is lack of rigidity.

Braunstein and Andersen (1984) argue that percepts of this kind result from the stimulation of automatic processes for perceiving size change, and that these processes are not subject to a general rigidity assumption. They suggest that distortions of the figures during rotation in the frontal plane may result from stimulation of changing-size filters that, in turn, feed a motion-in-depth stage (for psychophysical and neurophysiological evidence see Regan and Beverley 1978; Regan and Cynader 1979). Assuming that this hypothesis is correct, an interesting question arises when two different 3-D percepts can be obtained with the same rotating pattern, as in the stereokinetic effect described by Bressan and Vallortigara (1986). Can the visual system directly shift from one 3-D interpretation to the other, or does each 3-D percept require activation of the changing-size channel in order to be selected? The question is accessible to an empirical test. Bressan and Vallortigara (1986) have observed that, after they have been achieved, the 3-D percepts alternate in time, separated by brief intervals in which subjects report seeing either a 2-D distorting figure [an "amoeba-like pattern", in Musatti's (1924) terms] or the simple rotation of a flat rigid ellipse. Theoretically, each 3-D percept might be randomly preceded either by the other 3-D percept or by one 2-D percept. However, if selection of a 3-D percept requires, as input, an output from the changing-size channel, then one can expect an orderly sequence of impressions: namely, a significant tendency to report each 3-D percept directly *after* a distorting 2-D percept, with no or few direct shifts from one 3-D percept to the other 3-D percept.

2 Method

2.1 *Subjects*

Thirteen university students served as subjects. They had some previous experience in viewing stereokinetic phenomena, but were naive as regards the aim and theoretical implications of the experiment.

2.2 *Apparatus and procedure*

The pattern consisted of a white cardboard ellipse (9 cm major axis, 6 cm minor axis) placed in the centre of a black turntable. The figure, whose luminance was $\sim 2.06 \times 10^{-2}$ cd m^{-2}, was rotated at a speed of 8 rev min^{-1} in the frontoparallel plane. Viewing distance was 1.75 m from the seated observer. Subjects were asked to observe the rotating stimulus monocularly as steadily as possible and to give a continuous report of what they saw, using four verbal labels previously agreed upon (disc, egg, ellipse, amoeba). The experimenter measured with a chronometer the duration of the various percepts and the sequence of their occurrence. Each individual session lasted 15 min.

3 Results

Percentages of the times in which any given percept preceded each of the two 3-D percepts are shown in figure 1. As can be seen, overall the disc was introduced twice as often by amoeba-like deformations than by the egg, and only occasionally by the flat ellipse. As for the egg, however, the results are curiously different: this 3-D percept was, in fact, frequently preceded by the impression of a flat ellipse. Also, quite a number of direct transitions from the disc to the egg were recorded. The egg was seldom preceded by the amoeba-like deformations.

Considering only transitions from 2-D to 3-D percepts (see figures 2a and 2b), there was a significant tendency to report deformations before the disc ($\chi_1^2 = 9.30$, $p < 0.01$) and the ellipse before the egg ($\chi_1^2 = 3.76$, $p < 0.05$). Direct transitions between the two 3-D percepts (see figure 2c) occurred more frequently from the disc to the egg than from the egg to the disc ($\chi_1^2 = 5.33$, $p < 0.05$). 3-D percepts lasted about twice as long as 2-D percepts (on average, 24 s versus 13 s) and the four alternative percepts appeared approximately an equal number of times (on average twelve times each during the 15 min session).

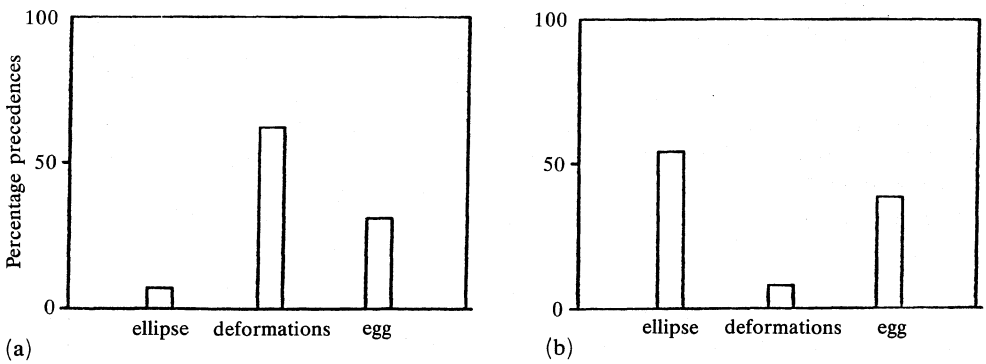

Figure 1. Percentages of the number of times in which any given percept preceded (a) the disc or (b) the egg.

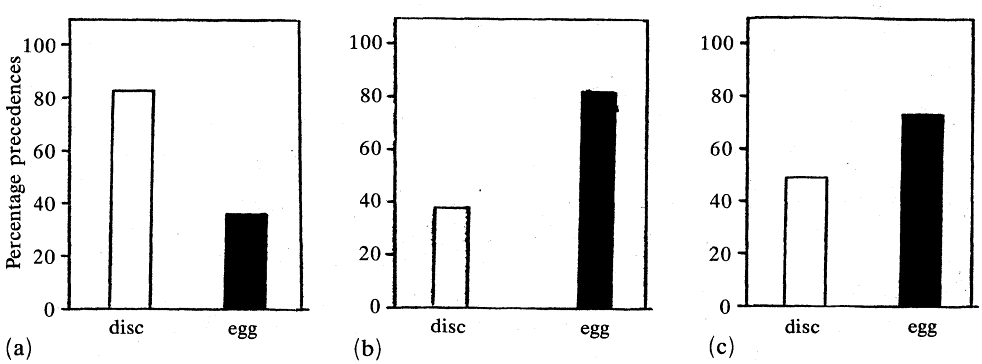

Figure 2. Percentages of the number of times in which (a) deformations preceded the disc and the egg, (b) the ellipse preceded the disc and the egg, and (c) each 3-D percept preceded the disc or the egg.

4 Discussion

A straightforward interpretation of our results is difficult. A fairly regular sequence of impressions seem to occur as far as the disc is concerned: this percept is, in fact, mostly preceded by apparent elastic deformations. This fits in well with Braunstein and

Andersen's (1984) hypothesis: amoeba-like distortions—which are probably, for the disc, analogous to the expansion/contraction impressions that occur with rotating spirals—stimulate changing-size neural channels which, in turn, activate a motion-in-depth stage. Results for the second 3-D percept, however, appear rather disturbing. The egg is preceded, roughly to the same extent, by the other 3-D percept (the disc) and by the 2-D ellipse. Transitions from the amoeba-like deformations to the egg are quite infrequent. It seems that the percept that comes before the egg is mostly that of a rigid shape (either 2-D or 3-D), and that direct transitions between the two 3-D percepts occur preferably in one direction, ie from the disc to the egg, and not the other way round.

Since the attainment of the 3-D egg appears to be independent of impressions of elastic deformations, a tentative hypothesis might be that the mechanisms producing the egg are different to those producing the tilting disc. It is unclear, however, what sort of mechanisms these might be. One might remark that, under reduced lighting conditions, seeing a rotating ellipse as a 2-D figure or as a 3-D object is rather a matter of cognitive-like interpretation. The crucial point, however, is that the egg does not appear located in the frontal plane, but has a considerable slant ($\sim 45-60°$ with respect to the frontal plane) and moves in 3-D space, tracing a fairly complex trajectory. When it first appears to a naive observer, it looks like a completely new and unexpected object (see Bressan and Vallortigara 1986). Moreover, it is virtually impossible to see the slanted egg when the pattern is stationary.

Braunstein and Andersen (1984) observed that it is likely that stereokinetic effects are multifactorially determined. In fact, our results suggest that the model based on changing-size filters may account only in part for the depth effects obtained with curvilinear patterns, and that other factors are probably involved.

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