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Notes and Comment

Rubber rhomboids: Nonrigid interpretation of a rigid structure moving

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Computational research on the interpretation of changing images has emphasized elegant methods based on a rigidity postulate (e.g., Ullman, 1983). However, the empirical value of this approach is unclear. This note reports a new illusion, the rubber rhomboid illusion, which highlights some reasons for doubt. When a rigid but nonrectangular parallelepiped rotates slowly about a vertical axis, and is viewed from a distance, it appears nonrigid.

The main features of the effect were demonstrated as follows. A single wire-frame parallelepiped was used. The angles at one (arbitrary) vertex were 65°, 75°, and 125°. Both edges flanking the 65° angle measured 6.3 cm, and the remaining edge measured 12.5 cm. The long edge was roughly horizontal, and the faces with 75° angles were about 25° from the vertical. The object was rotated about a vertical axis at either 1.5 or 12 rpm, and viewed from about 4.5 m. Binocular viewing was used to minimize reversals in depth.

Twenty-two naive subjects observed the object. Half saw fast rotation followed by slow; half saw the reverse. During each period they rated the strengths of six effects by circling one of five responses. The effects were: reversals in direction of rotation, apparent expansion or contraction, change in apparent orientation relative to the vertical, impressions that edges met at right angles in some but not all parts of the cycle (projectively, not all edges could have met at right angles throughout the cycle), impressions of change in overall shape, and uncertainty about the object's actual shape. The responses were "no," "possibly," "weak effect," "moderate effect," and "strong effect." These were scored as 0-4, respectively, for analysis. Average ratings are shown in Table 1.

Apparent reversals were clearly less salient than any form of continuous change. Eight sign tests were carried out to confirm the trend, each comparing reversal ratings at a given speed with ratings for one type of continuous change at the same speed. All comparisons were significant, with $p < .05$.

Two key conclusions can be drawn from these comparisons: (1) Reversals are not a major feature of the illusion, in contrast to most cases in which researchers fail to see a possible rigid interpretation; (2) Using reversal ratings as a baseline, one can conclude that all of the probed continuous changes did occur at both speeds. The specific changes probed—in angles, in tilt, and in linear dimensions—were those that would follow from imposing a rectangular interpretation wherever possible. Interpretation based on other considerations could lead to some of these effects, but no obvious alternative would produce all of them. Hence, the general kinds of change that occur provide prima facie evidence that a bias toward rectangular interpretation underlies the illusion.

Table 1
Average Ratings of Effects Experienced During Rotation

	Apparent Reversals	Changes in Apparent: Shape	Tilt	Size	Angles	Doubt About Shape
Fast Rotation	.72	2.4	2.4	2.1	2.5	2
Slow Rotation	1.7	3.4	2.9	3.6	3.6	1.7

The table also suggests that slow rotation produced higher ratings of nonveridical change. Sign tests showed that slow rotation gave significantly higher ratings of change ($p < .05$) in apparent shape, volume, and angle. Differences in apparent reversals and change in tilt were nonsignificant. The trend here bears out a conclusion that is reasonable and consistent with other evidence (e.g., Borjesson, 1971; Braden, 1978; Mulholland, 1956): high rates of change favor interpretations consistent with rigidity. Note, however, that despite this, effects suggesting rectangular, rather than rigid, interpretation persist even at a rate of change that appears quite fast by ecological standards—faster, for instance, than the change produced by walking past objects much more than a meter away.

Additional evidence reverses the natural expectation that as rigidity-based interpretation becomes more influential at higher speeds, percepts will become more veridical. Between the viewings considered so far, the subjects inspected the stimulus object at close quarters. They rated the fit between what they saw and the judgment they had formed during long-range viewing, on three counts: Was the object more flattened than had been expected? Was it less rectangular than had been expected? Had the object's true shape been much misjudged? Response format was the same as before, as was the scoring.

At this stage, half of the subjects had seen the object rotating at 1.5 rpm, half at 12 rpm. The former group rated their initial impressions more accurate on all counts. This emerged as a main effect in an analysis of variance [$F(1,20) = 4.314$, $p < .051\%$]. This coheres with the assessments that are shown in the last column of Table 1: Those who had seen the object rotating slowly were more confident about its true shape before close inspection and were less surprised by close inspection.

These effects suggest two underlying factors.

The first is the bias toward rectangular interpretation, which is suggested by the observed changes. Work with

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other parallelepipeds (Smyth, 1978) confirms the key prediction that truly rectangular structures should show little nonrigidity, although it also raises a complication. Relatively rigid impressions also occur when nonrectangular objects rotate about axes aligned with their long diagonals. This suggests that the bias underlying perceived nonrigidity involves imposing a natural axis structure, rather than rectangularity per se, although the two will often coincide.

Watching the object suggests that a second factor may explain the accuracy of judgments following slow rotation. At certain stages in rotation, significant lines lie at right angles to the line of sight, so that for all intents and purposes the key parameters can be observed directly. Slow rotation gives time to register these parameters, and therefore to judge the object's true shape with confidence and accuracy.

The main interest in the illusion lies in its relation to the larger issue of whether vision generally separates stability of shape (which in the limit equals rigidity) from other expectations about form. Here two points bear comment.

Empirically, the illusion argues against the view that percepts incompatible with rigidity are localized exceptions to a rule of rigidity-based interpretation. Most simply, it broadens the range of counterexamples. In addition, it lacks features that make well-known cases easy to regard as exceptions. The Ames trapezoid and its variants tend to offer small numbers of points, many or all of them coplanar, and so are problematic for rigidity-based schemes. In Mach's reversed-card illusion, in the deforming cubes of Sperling, Pavel, Cohen, Landy, and Schwartz (1983), and so far as one can judge in Green's (1961) nonrigid displays, Necker-like reversal occurs and could be seen as preempting rigidity-based interpretation. Hence, it is suggestive to find nonrigid interpretation in a case that seems quite different from any of these, and in which neither problem arises.

Theoretically, the natural hypotheses about the effect suggest an interesting alternative to classical uses of rigidity. The use of parameters from key views depends implicitly on rigidity (since the parameters might change over time in a nonrigid structure). The implication is that visual exploitation of rigidity may be mediated and simplified by attention to other significant types of regularity, since only once one has a grasp of structure can one establish what are the key parameters and which views specify them. This kind of interaction makes considerable intuitive sense, and may (at least in human vision) work better than more direct uses of rigidity postulate.

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