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Research Article

THREE-DIMENSIONAL BILATERAL SYMMETRY BIAS IN JUDGMENTS OF FIGURAL IDENTITY AND ORIENTATION

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Abstract—*The two experiments reported explored a bias toward symmetry in judging identity and orientation of indeterminate two-dimensional shapes Subjects viewed symmetric and asymmetric filled, random polygons and described "what each figure looks like" and its orientation Viewers almost universally interpreted the shapes as silhouettes of bilaterally symmetric three-dimensional (3-D) objects This assumption of 3-D symmetry tended to constrain perceived vantage of the identified objects such that symmetric shapes were interpreted as straight-on views, and asymmetric shapes as profile or oblique views Because most salient objects in the world are bilaterally symmetric, these findings are consistent with the view that assuming 3-D symmetry can be a robust heuristic for constraining orientation when identifying objects from indeterminate patterns*

A fundamental problem of pattern recognition is that the set of possible interpretations of a given stimulus figure can be indefinitely large The problem is multiplied when two-dimensional (2-D) figures may be taken to represent projections of three-dimensional (3-D) objects of any shape and orientation in space, as is typically the case with proximal stimuli on the retina (Hochberg, 1978) Yet people are quite good at resolving this uncertainty, typically inferring 3-D shape accurately even with the minimal outline cues given by 2-D silhouettes (Hayward, in press, Kimia, Tannenbaum, & Zucker, 1995) In attempting to achieve comparable levels of performance, most pattern-recognition models attempt to constrain stimulus indeterminacy by invoking simplifying assumptions about the structure of the stimulus set A common approach is to explicitly limit allowable object shapes orientations, or dimensionality Thus many template-matching algorithms apply only to the recognition of 2-D objects with characteristic axes of elongation that can be used to determine proper alignment (Bruce & Green, 1990) Some template models require simple 2-D shapes (typically letters) comprising line segments of a specified width (Kahan, Pavlidis, & Baird, 1987) Filter-response matching systems typically make similar assumptions in the spatial- or temporal-frequency domain (Uttal, 1975) Some models of 3-D object recognition first constrain object orientation (e g , based on elongation cues), but still can account only for objects whose shapes can be easily decomposed into a predefined set of 3-D component elements (Biederman, 1985, Marr & Nishihara, 1978)

The present article examines structural biases concerning object symmetry that humans may use to constrain stimulus indeterminacy in viewing and interpreting filled, random 2-D patterns, similar to silhouettes We first discuss the prevalence of symmetric objects and then explore how degree of figural symmetry can help establish object orientation and identity

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SYMMETRY

Symmetry is a pervasive structural characteristic of 3-D objects in the world Virtually all living organisms have at least bilateral symmetry, typically about the vertical axis Some, like trees and flowers, also have additional symmetries The few exceptions to this rule, like lobsters and sole appear odd Animals exhibit a sexual preference for more symmetric mates (Møller, 1992, Pennisi, 1995) Virtually all artifacts constructed for human use also possess an overall symmetry Symmetry confers greater balance and stability to artifacts, as well as greater compatibility with their users Although some objects, such as human faces, contain salient local asymmetries, global symmetry is typically still maintained with respect to major features such as the eyes, nose, and ears (Sackeim, Gur, & Saucy, 1978) Similarly, although symmetry may be violated in the placement of internal features (e g , a car's steering wheel, or the heart in the human body), most objects maintain symmetry with respect to major external features (e g , the car's wheels and hood, the body's limbs and head) The prevalence of symmetry as a feature of notable objects in the world may contribute to its perceptual salience

Scientific study of the perception of symmetry dates back at least to the work of Mach (1897), who first demonstrated that viewers are more sensitive to distortion of symmetry about the vertical than about the horizontal axis (the Goldmeier effect) This bias may reflect the preponderance of vertical symmetry in nature Recent experiments have confirmed and extended Mach's findings (Corballis & Roldan, 1975, Palmer & Hemenway, 1978) Gestalt psychologists placed great emphasis on symmetry, citing it as one of the fundamental perceptual principles of organization (Hochberg, 1978) Symmetry is characteristic of figures, not grounds (Attneave, 1971, Shepard, 1990) Symmetric shapes are commonly judged as simpler and more regular than nonsymmetric ones (Zusne & Michaels, 1962), and their informational redundancy may promote more efficient encoding (Attneave, 1955, Barlow & Reeves, 1979) Symmetry is a highly salient, attention-drawing figural feature (Julesz, 1971) Indeed, viewers tend to exaggerate symmetry in encoding nearly symmetric 2-D figures This bias towards symmetry has been demonstrated with a variety of figures, including polygons, dot patterns, and curves on graphs, under both perception and memory conditions (Freyd & Tversky, 1984, Schiano & Tversky, 1992, Tversky & Schiano, 1989) Symmetry is commonly assumed in completing partially occluded contours (Jenkins, 1983, Wagemans, Van Gool, Swinnen, & Horebeek, 1993). There is substantial evidence that it serves as a primary cue in determining the correspondence of successive positions in motion perception (Farrell & Shepard, 1981, McBeath, 1990).

In previous research, symmetry has characteristically been treated as a 2-D property of 2-D figures. Even when projections of common objects in varying orientations are used as stimuli, the fact that degree of figural symmetry can be used as a cue to 3-D object orientation has been largely ignored (McMullen & Farah, 1991). Such an approach does not seem to adequately acknowledge the importance and ubiquity of bilateral symmetry in people's experience of the world. The goal of the present research was to extend the investigation of 2-D symmetry toward its utility as a cue in inferring the orientation and identity of 3-D objects. We suggest that viewers may use the prominent structural characteristic of vertical symmetry to constrain the indeterminacy problem in interpreting ambiguous or indeterminate 2-D patterns. Specifically, if a projected image (or silhouette) of a vertically symmetric 3-D object appears symmetric, it implies a vantage point that cuts through the object's axis of symmetry (e.g., a "straight on" view from in front, in back, above, or below). If the image appears asymmetric, it implies a vantage point to the side or at an oblique angle with respect to the object's axis of symmetry (e.g., a side or slanted view). Thus, a bias to use degree of figural asymmetry as a cue to stimulus orientation could help constrain interpretations of the projected object and simplify the identification process. Additional orientation-related biases (e.g., toward top-up and forward-facing orientations) might serve to further constrain object identification. Thus, in the present research, we treated symmetry not only as a 2-D feature of 2-D figures, but as a cue to 3-D object orientation in depth.

In this article, we describe two experiments in which subjects viewed filled, random polygons varying in extent of vertical bilateral symmetry. We examine the influence of figural symmetry on interpretation of stimulus orientation and identity. Our hypothesis was that viewers would exhibit a bias to interpret the stimuli figures as silhouettes of 3-D symmetric objects, with symmetric polygons portraying straight-on views, and asymmetric polygons side or oblique views. We note that in preliminary investigations we examined whether demand characteristics of this task might unduly encourage subjects to interpret the stimuli as symmetric 3-D objects (Schiano, McBeath, & Chambers, 1994). We were concerned that instructing subjects to indicate the orientation of their interpretations might predispose them to describe the figures as objects with directionality. We found that subjects reliably described the figures as symmetric 3-D objects nearly 90% of the time, independent of the type of instructions (i.e., even when instructed just to "describe the figures"). In the present experiments, subjects were asked to both describe the figures and indicate orientation in order to facilitate accuracy of orientation coding. In our preliminary work, we also explored the issue of stimulus generalizability by varying complexity (number of polygon sides). Again we found a robust tendency for figures to be described as symmetric 3-D objects, independent of whether the stimuli had 9, 18, or 27 sides. In the current research, we used 18-sided stimuli, which produced a slightly more varied array of object interpretations than did the 9- and 27-sided stimuli.

EXPERIMENT 1

Method

Fifteen introductory psychology students at Stanford University participated in fulfillment of course requirements. All subjects had normal or corrected vision and were not informed of the hypotheses being tested.

Stimuli consisted of twelve 18-sided random polygons (6 asymmetric and 6 symmetric), displayed with 64-by-64-pixel resolution in a computer-screen area spanning several inches. Figure 1 illus-

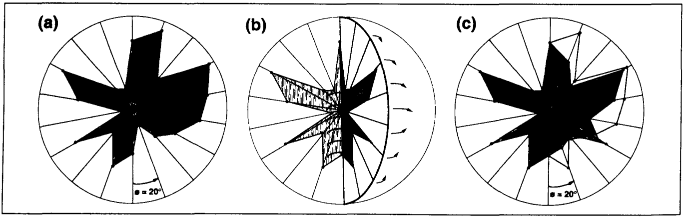

Fig. 1. Generation of the stimulus figures. For Experiment 1, asymmetric random polygons were created by connecting random-length radii at equal angular intervals and then filling the interior (a). Symmetric polygons were created by replacing the right halves of asymmetric polygons with reflections of their left halves (or vice versa) (b). In Experiment 2, three figures with intermediate degrees of imposed symmetry (25%, 50%, and 75% symmetric) were created for each asymmetric-symmetric polygon pair (0% and 100% symmetric). The intermediate figures were created by proportionally varying the lengths of radii, such that if a radial spoke was 18 units in the 0% symmetric figure and 30 units in the 100% symmetric figure, it would be 21, 24, and 27 units for the 25%, 50%, and 75% symmetric figures, respectively. Shown in (c) is a 50% symmetric figure superimposed upon its corresponding stimulus pair with 0% and 100% symmetry.

rates the method of stimulus generation Each asymmetric polygon was created by choosing random numbers between 2 and 32, which specified the lengths of radii at 18 equally spaced angular intervals around a central point Adjacent radii were connected by line segments, and the central portion was filled Symmetric stimuli were produced by replacing the left halves of asymmetric stimuli with the mirror image of the right halves (or vice versa), a vertical folding-over procedure described by Farrell and Shepard (1981) Figure 2 shows the 12 stimuli, which were presented in random order on an Amiga 2000 computer

Subjects were instructed to press a key on the computer to initiate a trial, at which point a new stimulus figure was displayed

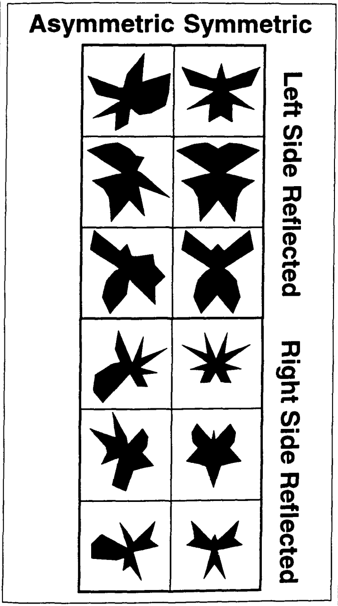

Fig. 2. Stimulus figures used in Experiment 1 (See the text for specific examples of typical and atypical responses for the two figures shown on the top row)

Subjects were told to decide what the figure looked like, decide its orientation or direction of facing, and rapidly type the interpretation The principal independent variables were percentage of descriptions that were symmetric 3-D objects and interpreted orientation Response time (RT), defined as the time elapsed between when the trial was initiated and when the first keystroke of the reply occurred, was also recorded Performance was self-paced, and the task typically lasted about 15 min

Results and Discussion

Response coding

Responses for each figure were rated by three independent judges for presence or absence of object three-dimensionality and symmetry, and for orientation, if the interpretation was of a 3-D object Judges also indicated if the interpretation was of two or more objects silhouetted together and, if so, whether this configuration of objects contained an axis of symmetry that cut through the viewer (such as mirror images of dogs looking away from each other) These rare cases, accounting for less than 1% of the trials, were classified as straight-on views in accordance with their configural orientation of symmetry The majority vote of the judges was coded as the judged orientation Following are samples of typical and atypical responses and judged orientations for the representative pair of stimuli shown in the top row of Figure 2

- *18-sided asymmetric figure* Typical Cartoon dog (side view facing right), laughing mouse (side view facing left) Atypical Distorted ax or tomahawk (side view facing right)
- *18-sided symmetric figure* Typical Fighter plane (straight-on view facing up), man in sombrero (straight-on view facing front) Atypical Tail fin of a bomb (straight-on view facing down)

Perceived symmetry and orientation

The principal analyses looked at the following two relationships First, we divided the stimuli by figural symmetry (symmetric vs asymmetric figures) and determined the percentages of descriptions rated as symmetric 3-D objects Second, we considered all figures that had symmetric 3-D interpretations and determined the relationship between figural symmetry and interpreted orientation The first analysis showed that approximately 90% of the figures were interpreted as symmetric 3-D objects, the presence versus absence of figural symmetry yielded no significant difference, $F(1, 14) = 0.95$, n s The second analysis indicated that interpreted orientation was almost entirely determined by figural symmetry Of the interpretations that were symmetric 3-D objects, 98 7% of the symmetric figures were judged as straight-on views, whereas only 4 3% of the asymmetric figures were judged so, $F(1, 14) = 2{,}385.51$, $p < .0001$ Figural symmetry accounted for more than 99% of the variance in rated orientation These results are presented in Figure 3, together with those of two preliminary studies (A and B) that examined effects of instructions (Schiano et al , 1994) The instructions for Studies A and B were, respectively, "Describe what the figure looks like" and "Describe the figure and its orientation " The consistency of results across studies demonstrates the robustness of the response pattern, independent of instructions and response medium.

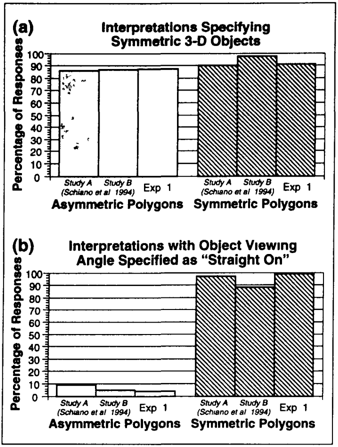

Fig. 3. Results of Experiment 1 and of two representative preliminary studies (A and B) that tested effects of instructional set (Schiano, McBeath, & Chambers, 1994). The graphs show (a) the percentage of symmetric three-dimensional (3-D) interpretations as a function of figural symmetry and (b) the percentage of interpretations seen from a straight-on vantage as a function of figural symmetry.

RTs were logarithmically transformed to normalize the data. RT to initiate a description was significantly faster for symmetric figures than for asymmetric figures (logarithmic means of 8.2 s vs. 12.0 s, respectively), $F(1, 65) = 8.01$, $p < .01$. This result is consistent with several views: that orientation alternatives are more constrained for symmetric than for asymmetric figures, that subjects perform a mental rotation or related transformation to align asymmetric figures with a straight-on view (Shepard & Metzler, 1971), or that symmetric figures' redundancy makes them simpler to process (Attneave, 1955). RTs also yielded significant differences between subjects, $F(13, 65) = 4.47$, $p < .001$, and marginal differences between the six pairs of figures, $F(5, 65) = 2.45$, $p < .05$. The effect of stimulus figure indicates some reliability for the level of difficulty subjects have in deriving interpretations for particular shapes.

These findings confirm that viewers almost universally interpret indeterminately shaped random polygons as looking like silhouettes of symmetric 3-D objects, with symmetric random figures interpreted as straight-on views and asymmetric figures as side or oblique views. In Experiment 2, we extended this inquiry to test if polygons with an intermediate degree of symmetry are, on average, interpreted to be at an orientation intermediate to the orientations of fully symmetric and fully asymmetric figures.

EXPERIMENT 2

Method

Stimuli with intermediate degrees of symmetry were created using the technique shown in Figure 1c. Intermediate symmetry polygons contained radii with lengths proportionally between the lengths in an asymmetric-symmetric stimulus pair. This allowed the creation of continua each containing figures with five levels of imposed symmetry (0%, 25%, 50%, 75%, and 100%). Figure 4 shows the five stimulus continua used. They were created from five asymmetric-symmetric polygon pairs used in Experiment 1. Five paper-and-pencil surveys that each contained one figure from each stimulus continuum were created. All five levels of imposed symmetry were represented on each survey, but no two figures on a survey were from the same continuum (to maintain independence of interpretations within a continuum). Thus, the analysis for each continuum was a between-subjects design. Subjects were instructed to describe each figure and to check off one of three boxes indicating interpreted orientation: "straight-on," "slanted," or "direct side." Each of the five surveys was completed by 30 students, resulting in a total of 30 responses for each figure and 150 responses per continuum. Subjects were again

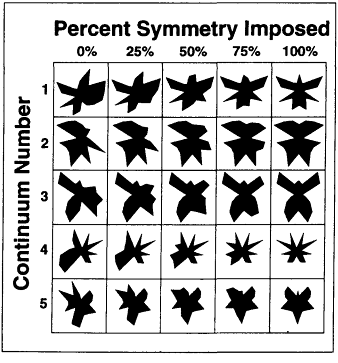

Fig. 4. Stimulus figures used in Experiment 2. Each of the five sets of figures varied along a five-step continuum of imposed figural symmetry. Each subject described one figure from each of the five stimulus continua. (See the text for specific examples of typical and atypical responses for Continuum 1.)

introductory psychology students at Stanford University, had normal or corrected vision, and were unaware of the hypotheses being tested.

Results and Discussion

Following are samples of typical and atypical responses for the five stimuli in Continuum 1, shown on the top row of Figure 4. Descriptions generally specified side or slanted views for asymmetric shapes, and increasingly specified a straight-on view as figural symmetry increased.

- *0% symmetric figure.* Typical: Cartoon dog (side view facing right), pelican with mouth open (slanted view facing left). Atypical: Witch on broom (side view facing left).
- *25% symmetric figure.* Typical: Barking dog (side view facing right), flying bird (slanted view facing right). Atypical: Map of Russia (straight-on view facing front).
- *50% symmetric figure.* Typical: Bird about to land (slanted view facing right), head with hat (slanted view facing right). Atypical: Deformed star (straight-on view facing front).
- *75% symmetric figure.* Typical: Large bird with stretched wings (straight-on view facing front), man in sombrero (slanted view facing front). Atypical: Finned torpedo (slanted view facing down).
- *100% symmetric figure.* Typical: Man with sombrero (straight-on view facing front), flying airplane (straight-on view facing up). Atypical: Eagle with wings spread sitting on the roof of a house (straight-on view facing front).

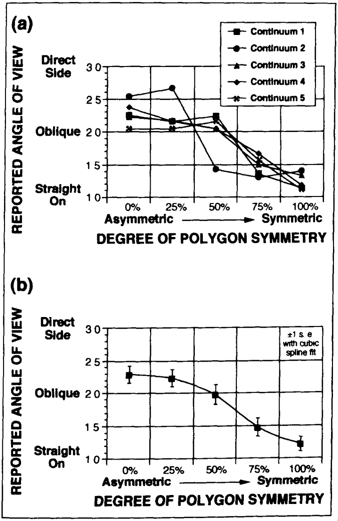

Fig. 5. Results of Experiment 2. Interpreted orientation (reported angle of view) is plotted as a function of figural symmetry for (a) each of the five continua and (b) all continua combined.

Responses in general were very similar to those found previously. Once again, virtually all interpretations were symmetric 3-D objects. Figure 5a shows the interpreted orientations for individual continua. As predicted, degree of imposed symmetry in a figure was a highly significant indicator of interpreted orientation: linear trend, $F(1, 748) = 225.29$, $p < .0001$. Figures with intermediate degrees of symmetry tended to be interpreted to be at intermediate orientations. Differences between the continua were not significant, $F(4, 748) = 0.65$; the interaction between imposed symmetry and continuum was marginally significant, $F(16, 748) = 2.97$, $p < .01$, and disappeared if Continuum 2 was not included. Figure 5b shows the data from all continua combined with the best fitting cubic spline curve. The apparent nonlinear S-shaped falloff may indicate a tendency to interpret objects to be aligned more with viewer-centered axes than is specified by imposed degree of figural symmetry. Alternatively, it may merely indicate that the method of imposing stimulus symmetry produced continua with nonlinear increments in perceived symmetry. In any case, the overall pattern of results indicates that extent of figural symmetry is highly predictive of interpreted orientation.

GENERAL DISCUSSION

In two experiments, viewers were asked to describe filled, random 2-D shapes that were either vertically symmetric or asymmetric. In the vast majority of cases, the viewers interpreted both kinds of stimuli as silhouettes of 3-D, bilaterally symmetric common objects. Symmetric figures were interpreted as objects aligned with the viewer and asymmetric figures as objects oriented obliquely or facing to the side. These results are consistent with the use of symmetry as a cue to constrain object orientation and identification. Given that so many of the objects that people perceive and interact with are bilaterally symmetric or nearly so, the assumption of 3-D bilateral symmetry can serve as a simple yet powerful pattern-recognition heuristic, effectively constraining possible interpretations of dimensionality, orientation, and shape.

Previous research on symmetry perception has focused primarily on recognition and classification of 2-D features in 2-D figures. That research has shown that viewers rapidly detect symmetry, especially bilateral symmetry (Barlow & Reeves, 1979), and that they exhibit a bias to impose symmetry so that nearly symmetric figures are encoded as more symmetric than the originals (Freyd & Tversky, 1984; Schiano & Tversky, 1992; Tversky & Schiano, 1989). The present findings suggest that the same principles extend to 3-D pattern recognition. Viewers appear to rapidly detect implied 3-D symmetries and to impose symmetry in their

3-D interpretations of 2-D figures. Earlier research has shown that figural symmetry is an effective cue for distinguishing figure from ground because figures are more likely to be symmetric than are backgrounds (Attneave, 1971; Shepard, 1990). The present work extends this reasoning to three dimensions as well, suggesting that *3-D objects are more likely to be interpreted as symmetric than are backgrounds.* The assumption of symmetry gives clues not just to figurality, but also to 3-D orientation and identity.

The assumption of symmetry has ecological validity. There is little cost to incorrectly classifying most truly asymmetric objects, such as rocks, but substantial potential benefits to correctly classifying most genuinely symmetric or nearly symmetric objects, including life forms and many human artifacts. For many such objects, symmetry reliably indicates important orientation information such as the direction they are facing and are most likely to move, or the direction indicative of aerodynamic stability (McBeath, 1990; McBeath, Morikawa, & Kaiser, 1992). The assumption of symmetry also simplifies object recognition and representation. Computationally, symmetric figures are easier to encode and require less storage space (Attneave, 1955; Julesz, 1971). Once the orientation of a symmetric figure is determined, only half of it needs to be scanned and encoded. Indeed, there is evidence that scanning of symmetric figures is shortcut in this way (Locher & Nodine, 1973). Thus, the assumption of 3-D bilateral symmetry can facilitate object representation in addition to object identification.

In the present studies, viewers assumed 3-D bilateral symmetry not just for symmetric and nearly symmetric figures, but for asymmetric ones as well. Yet identifying the asymmetric figures took more time. One interpretation is that viewers may mentally transform asymmetric shapes in search of a plausible vantage for a compatible symmetric 3-D object. Results suggestive of mental transformations in object identification have been found for objects rotated in the picture plane (Jolicoeur, 1985; McMullen & Farah, 1991), but the case of rotation about an object's vertical axis of symmetry has not been studied. Common symmetric objects are readily recognized when shown at oblique perspectives. In fact, the best perspective for recognizing a common object from a set of similar objects is an oblique or side perspective, possibly because it captures more of the distinguishing features of the objects (Palmer, Rosch, & Chase, 1981). Our findings are consistent with viewers effectively performing a rotational transformation in which, on average, extent of mental rotation in depth is inversely proportional to degree of figural symmetry.

SYMMETRY-SEEKING ALGORITHM

Substantial research has investigated the problem of deducing 3-D structure from a 2-D image when motion or stereo disparity information is limited or unavailable (Marr, 1982; Marr & Nishihara, 1978). One approach is to assume that silhouetted edge *contours continue smoothly into the third dimension,* yielding an effective extrapolation of surfaces across silhouetted locations of 3-D space (Burbeck & Pizer, 1995; Terzopoulos, Witkin, & Kass, 1987). This 3-D extrapolation is analogous to the 2-D extrapolation of line segments that occurs in viewing 2-D subjective contours (Kanizsa, 1979). A concave edge on a silhouette typically indicates the presence of a surface that maintains concavity as it curves in depth toward or away from the viewer. Similarly, a convex edge typically indicates a surface that maintains convexity as it curves toward or away from the viewer. Reliance on this *heuristic of edge-contour continuation would always lead to interpretations* that have volume as well as bilateral symmetry (i.e., with a reflection through the picture plane). Such a "symmetry-seeking" algorithm has been demonstrated in computer enhancement applications to create 3-D structures from 2-D images (Terzopoulos et al., 1987).

When viewers interpret indeterminately shaped figures as silhouettes of symmetric 3-D objects, a symmetry-seeking strategy may be used to help judge stimulus orientation (Vetter & Poggio, 1994). Viewers may effectively "match up" opposite-sided appendages in determining possible orientations of 3-D bilateral symmetry that could produce the observed silhouette (Braunstein, 1971). The favored interpretation of orientation would result from the smallest rotation from a top-up frontal plane that allows undistorted symmetry. Once favored orientation is determined, the set of possible object shapes becomes highly constrained, greatly simplifying the task of identification.

The present research did not specifically test viewers' rules for determining object identity and orientation, but the interpretations that viewers provided are consistent with a symmetry-seeking approach similar to the following:

1. Assume a bilaterally symmetric 3-D object (or object set).
2. Begin search by favoring object interpretations with a vertical plane of symmetry (and perhaps other, related orientation constraints, e.g., that "top is up").
3. Scan the figure for possible matching appendages (i.e., shape protuberances that approximate rotated or mirror images of each other).

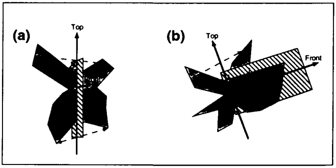

Fig. 6. Typical interpreted axes of symmetry. Viewers typically interpret the polygons as silhouettes of objects that have a near-vertical axis of symmetry. They appear to scan the figures for possible matching appendages that can produce object symmetry through lateral rotation. Two figures are shown in gray with dotted arrows indicating typical interpreted matching appendages and hatched surfaces indicating resultant planes of symmetry. (a) Largely symmetric figures result in planes of symmetry nearly perpendicular to the picture plane. (b) Largely asymmetric figures result in planes of symmetry nearly parallel to the picture plane.

4 Consider orientations that deviate more and more from the initial straight-on view Once a satisfactory symmetry match is achieved, constrain the interpreted plane of symmetry to contain the bisector points between matched appendage pairs

5 Assume smooth continuation of convex and concave silhouette edges forward and backward into depth

6 Assume flattening in depth to the extent required so that smooth continuation of appendage surfaces does not occlude visible background at concave contours

Figure 6 shows some illustrative examples

Taken together, our findings suggest that the visual system may have evolved to exploit the salience and pervasiveness of vertical bilateral symmetry by effectively employing a symmetry-seeking heuristic to constrain the stimulus indeterminacy problem in interpreting object orientation and identity

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REFERENCES

Attneave F (1955) Symmetry information and memory for patterns *American Journal of Psychology 68*, 209-222

Attneave F (1971) Multistability in perception *Scientific American, 225*(10) 62-71

Barlow H B & Reeves B C (1979) The versatility and absolute efficiency of detecting mirror symmetry in random dot displays *Vision Research 19* 783-793

Biederman I (1985) Human image understanding Recent research and a theory *Computer Vision, Graphics & Image Processing 32* 29-73

Braunstein M L (1971) Perception of rotation in figures with rectangular and trapezoidal features *Journal of Experimental Psychology 91*(1) 25-29

Bruce V & Green P R (1990) *Visual perception physiology psychology and ecology* (2nd ed) London Erlbaum

Burbeck C A & Pizer S M (1995) Object representation by cores Identifying and representing primitive spatial regions *Vision Research 35*, 1917-1930

Corballis M C & Roldan, C E (1975) Detection of symmetry as a function of angular orientation *Journal of Experimental Psychology Human Perception and Performance, 1* 221-230

Farrell, J E, & Shepard R N (1981) Shape orientation and apparent rotational motion *Journal of Experimental Psychology Human Perception and Performance 7*, 477-486

Freyd, J & Tversky B (1984) Force of symmetry in form perception *American Journal of Psychology 97*, 109-126

Hayward W G (in press) Effects of outline shape in object recognition *Journal of Experimental Psychology Human Perception and Performance*

Hochberg J E (1978) *Perception*. Englewood Cliffs NJ Prentice-Hall

Jenkins B (1983) Component process in the perception of bilaterally symmetric dot patterns *Perception & Psychophysics 34* 433-440

Jolicoeur P (1985) The time to name disoriented natural objects *Memory & Cognition, 13* 289-303

Julesz, B (1971) *Foundations of cyclopean perception* New York University Press

Kahan S Pavlidis T & Baird H S (1987) On the recognition of printed characters of any font and size *IEEE Transactions on Pattern Analysis and Machine Intelligence PAMI 9* 274-288

Kanizsa G (1979) *Organization in vision Essays in Gestalt perception*. New York Praeger

Kimia, B B Tannenbaum A R & Zucker S W (1995) Shapes shocks and deformations I The components of shape and the reaction-diffusion space *International Journal of Computer Vision, 15*(3) 189-224

Locher P & Nodine C (1973) Influence of stimulus symmetry on visual scanning patterns *Perception & Psychophysics, 13* 408-412

Mach E (1897) *The analysis of sensations* Chicago Open Court

Marr D (1982) *Vision. A computational investigation into the human representation and processing of visual information* San Francisco W F Freeman

Marr D & Nishihara H K (1978) Representation and recognition of the spatial organisation of three-dimensional shapes *Proceedings of the Royal Society of London B 200* 269-294

McBeath M K (1990 April) *The effect of object shape on the path of apparent motion* Paper presented at the annual meeting of the Western Psychological Association Los Angeles

McBeath M K Morikawa K & Kaiser M (1992) Perceptual bias for forward facing motion *Psychological Science 3* 362-367

McMullen P A & Farah M J (1991) Viewer-centered and object-centered representations in the recognition of naturalistic line drawings *Psychological Science 2* 275-277

Møller A P (1992) Female swallow preference for symmetrical male sexual ornaments *Nature, 357* 238-240

Palmer S & Hemenway K (1978) Orientation and symmetry Effects of multiple rotational and near symmetries *Journal of Experimental Psychology Human Perception and Performance 4* 691-702

Palmer S Rosch E & Chase P (1981) Canonical perspective and the perception of objects In J Long & A Baddeley (Eds) *Attention and performance IX* (pp 135-151) Hillsdale NJ Erlbaum

Pennisi E (1995) Not simple symmetry Does it really matter if the right ear is bigger than the left? *Science News 147*(3) 46-47

Sackeim H A Gur R C & Saucy M D (1978) Emotions are expressed more intensely on the left side of the face *Science 202* 434-436

Schiano D J McBeath M & Chambers K (1994 November) *Orientation constraining heuristics for interpreting figures as 3 D objects* Paper presented at the annual meeting of the Psychonomic Society St Louis MO

Schiano D J & Tversky B (1992) Structure and strategy in encoding simplified graphs *Memory & Cognition 20*(1) 12-20

Shepard R N (1990) *Mind sights Original visual illusions ambiguities, and other anomalies with a commentary on the play of mind in perception and art* New York W H Freeman

Shepard, R N & Metzler J (1971) Mental rotation of three-dimensional objects *Science, 171*, 701-703

Terzopoulos D Witkin A & Kass M (1987) Symmetry seeking models and 3D object reconstruction *International Journal of Computer Vision 1*, 211-221

Tversky B & Schiano D J (1989) Perceptual and conceptual factors in distortions in memory for graphs and maps *Journal of Experimental Psychology General, 118* 387-398

Uttal W R (1975) *An autocorrelation theory of form detection* Hillsdale NJ Erlbaum

Vetter T & Poggio T (1994) Symmetric 3D objects are an easy case for 2D object recognition *Spatial Vision, 8* 443-453

Wagemans J Van Gool L Swinnen V & Horebeek J V (1993) Higher-order structure in regularity detection *Vision Research, 33* 1067-1088

Zusne L & Michaels K M (1962) Geometricity of visual form *Perceptual and Motor Skills 14* 147-154

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