Force of symmetry in form perception

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Many objects, natural and manufactured, have at least one axis of symmetry; thus, the detection of symmetry could facilitate the detection and representation of objects. Literature is reviewed that supports the notion that humans have effective and efficient symmetry-detection ability. The question addressed in the present research is whether symmetry detection leads to biases in representations of visual forms. Two types of experimental tasks were used: a similarity-judgment task and a matching-figures task in which reaction time to find identical figures in a display was measured. Stimuli varied in degree of measured symmetry. The results of the experiments reported here indicate that nearly symmetric standard forms are judged to be more similar to, and are more confusable with, even more symmetric forms than they are with less symmetric forms. The pull toward a more symmetric form does not occur for standard forms of lower symmetry. These findings can be accounted for by a two-stage process. First, the perceiver quickly determines the presence of overall symmetry. Then, if the form is perceived as having overall symmetry, the form is assumed, sometimes incorrectly, to have symmetry at the local level as well.

Symmetry is a predominant structural factor in the real world of natural and manufactured objects. It is difficult to find an object in your office, for instance, that does not have at least one axis of mirror-image (or *bilateral*) symmetry. Your chair, your desk, and your coffee mug are probably all nearly bilaterally symmetric. Similarly, natural objects such as apples and tulips, and lions, lizards, and people are basically symmetric about an axis (see Weyl, 1955, for an analytic discussion of the preponderance of symmetry in nature; also see Gardner, 1979).

Gestalt psychologists first argued for the utility of symmetry in the detection of objects (see Koffka, 1935; Kohler, 1929). Indeed, "symmetry" was one of five basic Gestalt "principles of organization" suggested for form perception. Symmetry, like the other laws of organization (see Hochberg, 1978), was proposed to help explain how some parts of a scene are perceived to be *figure* and others *ground*. The claim was that the more symmetric a closed region, the more it tends to be seen as a figure.

The importance of bilateral symmetry as a stimulus variable has been stressed by many since the Gestalt scholars. Zusne and

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Michaels (1962), for instance, argued that it is the most important factor for determining judgments of geometricity, regularity, and familiarity of a large group of systematic distortions of a square. Barlow and Reeves (1979) proposed that symmetry may also be important for shape recognition because it helps to establish an "object-centered coordinate frame." Howard and Templeton (1966) made a similar argument: Not only does symmetry tend to be a predominant characteristic of objects, but also the axis of symmetry often helps define the proper orientation of the object. Marr and Nishihara (1978) have investigated how observers construct a general, object-centered representation of an object from a viewer-centered representation. One of the critical steps is to determine the natural coordinate system of the object. Marr and Nishihara claim that symmetry is an important clue to the natural axes of the object. Since an object is likely to be only partly symmetric from a particular vantage point, it is important to be able to infer complete symmetry from partial symmetry in constructing an object-centered representation.

A prevalent theme in perception research is that there is a discrepancy between what we should observe if our sensations were simply added together and what we actually do observe (see Hochberg, 1978). We impose structure on the world and take advantage of structure that exists. This is almost unavoidable, for as Barlow and Reeves (1979) point out it is not possible for a visual image even to be represented completely, and "any regularity such as symmetry is valuable for the very reason that it represents more of the image than an arbitrary or irregular feature" (p. 792). In effect, it is to our advantage to be able to simplify an image; it reduces both the amount of information we must collect and the amount we must store. Attneave (1954) proposed a measure of figural simplicity, based on information theory, that helps formalize the economy of symmetry: the predictability of the whole from the part. Highly predictable parts are redundant. A symmetric figure certainly contains redundant information and thus has at least one type of figural simplicity.

To summarize, two basic survival values of symmetry detection have been discussed: (a) that the world is full of symmetric objects and that fact should help us detect objects; and (b) that symmetry in an image allows it to be perceived and coded abstractly and economically.

Empirical evidence supports the notion of a very efficient and versatile symmetry-detection device. Carmody, Nodine, and Locher (1977) showed that subjects can detect symmetry with a very brief (25 ms) single fixation. Similarly, Barlow and Reeves (1979) showed that symmetry can be detected "immediately," without eye movements and conscious analysis. Even when symmetry detection is not the subject's objective, there seems to be a globally based symmetry assessment. Fox (1977) found that subjects matched symmetric forms faster than similar but asymmetric forms. Locher and Nodine (1973) recorded eye movements while subjects rated the complexity of abstract shapes. When those shapes were vertically symmetric, the subjects scanned only one side of them. Corballis (1976) concluded about Locher and Nodine's results: "Perception must therefore be fairly immediate: we may know that a shape is symmetrical before we know what else it is" (p. 77).

Given that perceivers seem to detect symmetry readily and automatically, we can ask what effects this might have on the perceivers' representations of objects. Others have addressed the issue of symmetry detection itself; the basic question of interest in the present research is whether symmetry detection can lead to systematic distortions in encoding form. The prediction is that if a form is *nearly* symmetric, a perceiver might very well encode that form as more symmetric than it really is. This appears to occur in our perception of faces. We typically perceive people's faces to be symmetric, and are unaware of their asymmetry. We become aware of the asymmetry when, as is periodically done to make a point about photography, or perception, or symmetry, the separate halves of a particular person's face are duplicated by mirror image. The two resulting pictures frequently look surprisingly different. A simple two-step encoding process, consistent with the findings that symmetry detection is immediate and automatic, accounts for such systematic distortions. Suppose that first the perceiver gathers enough global information from viewing the entire form to determine the presence of overall symmetry. Corballis (1976) and Julesz (1971) have suggested mechanisms for the detection of symmetry; these cannot be more accurate than the limits of visual acuity, and are typically likely to be less accurate. If the form is perceived as symmetric, the perceiver takes advantage of that information to make inferences about those parts of the form that he or she does not bother to inspect. This seemed to occur in the Locher and Nodine study, where subjects scanned only half of a symmetric figure. Distortions may occur when, unknown to the perceiver, the form was not as symmetric as the global impression suggested. This error at the global level may lead to misapplied inferences as the local level. We use "global" and "local" in the sense recommended by Kimchi and Palmer (1982) to refer to independent properties of the geometry of shapes, to the larger figure as contrasted with the local elements. This two-step process need not, in fact, be thought of as strictly two-step, but could also be thought of as continuous and overlapping processes: The perceiver grasps overall shape and gradually fills in details, stopping at some point before all of the details are filled in.

Some mixed evidence for distortions, or normalization errors, in the direction of symmetry in *memory* for form has been presented in the past. Riley (1963) provides a review of this research. In some studies, changes in memory for visual stimuli tended to lead to more symmetric memories, and in some studies, to less. The confusion seems to be introduced by another source of memory distortion: the tendency to regularize toward specific schemata or prototypes. Often subjects remembered nonrepresentational shapes as similar to prototypical representational forms. This memory error could include a reduction in the remembered symmetry of a form, depending on the degree of symmetry in the original stimulus versus the degree of symmetry in the prototype remembered.

In the present research, we focus on systematic distortions that occur at the time of initial encoding and we avoid stimuli that have obvious representational prototypes. Our main prediction is that people sometimes distort their image of a form in the direction of symmetry. *Distortion* means nothing more than a discrepancy between physical or objective characteristics of a form and the mental representation of that form; it may be a very subtle effect. The mechanism presumably producing the distortion is one of incomplete processing. As a figure is scanned, global symmetry may be observed and represented and local violations of symmetry ignored. This is termed the "symmetry effect." We look for converging evidence for the symmetry effect in two different tasks (a) perceived *similarity* between forms (Experiments 1 and 2) and (b) *confusability* between forms as determined by reaction time (RT) in a matching-figures task (Experiment 3). We find that, as predicted, given a *standard* stimulus form, both confusability and perceived similarity will increase when the standard stimulus form is paired with a form that is more rather than less symmetric than the standard. We also confirm our prediction that this increased confusability and perceived similarity will be moderated by the overall symmetry of the standard stimulus form. As we will argue, the RT study (Experiment 3) serves to rule out possible explanations of the symmetry effect that might be proposed given the similarity data alone. Thus, the results of the three experiments, taken together, provide strong converging evidence for the symmetry effect.

EXPERIMENT 1

In Experiment 1 a similarity-judgment task was used to examine the effect of symmetry in the representation of form. On each trial, subjects were presented with a standard stimulus, of either high or low global symmetry, and two comparison stimuli. The comparison stimuli were of equal physical distance from the standard stimulus, but one comparison stimulus was more symmetric than the standard, and the other comparison stimulus was less symmetric than the standard. Subjects were asked to select which of the comparison stimuli was more similar to the standard. We predicted that subjects would be more likely to choose a more symmetric than a less symmetric alternative as most similar to a trial stimulus item, called the *standard* form, if the standard form is generally symmetric.

METHOD

Subjects

Participants were 92 Stanford University undergraduates who received course credit in introductory psychology. The experiment took each subject about 5 min to complete. Subjects were run in large groups and completed a number of other unrelated experiments to fill a 1-hr session.

Stimuli

Drawings of 16 standard stimuli were prepared; all were simple, closed, abstract polygons that could be described as rectangles with protruding or intruding "limbs." Examples appear at the top of Figure 1. Overall symmetry of the standard stimulus was manipulated by the alignment of the limbs, or protrusions. The eight high overall symmetry standards had aligned limbs, and the eight low overall symmetry standards had misaligned limbs. All 16 standard forms departed from symmetry in that for one pair of limbs, one protrusion was longer than its pair. Symmetry of the comparison stimuli was manipulated by altering the length of one of the unequal protrusions. To construct the more symmetric alternative, the shorter limb was increased (or the longer limb decreased) a small amount; to construct the less symmetric alternative, the shorter limb was decreased (or the longer limb increased) by the same amount. The differences between the standard and each of its alternatives were controlled for degree of physical variation and counterbalanced for type of physical variation.

The stimuli were subjected to a metric analysis using the formula of Zimmer (1983) for degree of symmetry which produces symmetry values between 0 (asymmetric, or random) and 1 (perfectly symmetric).[1] Applying this formula for the high overall symmetry figures, we found that the mean symmetry values were .923 for the standard forms, .962 for the symmetric

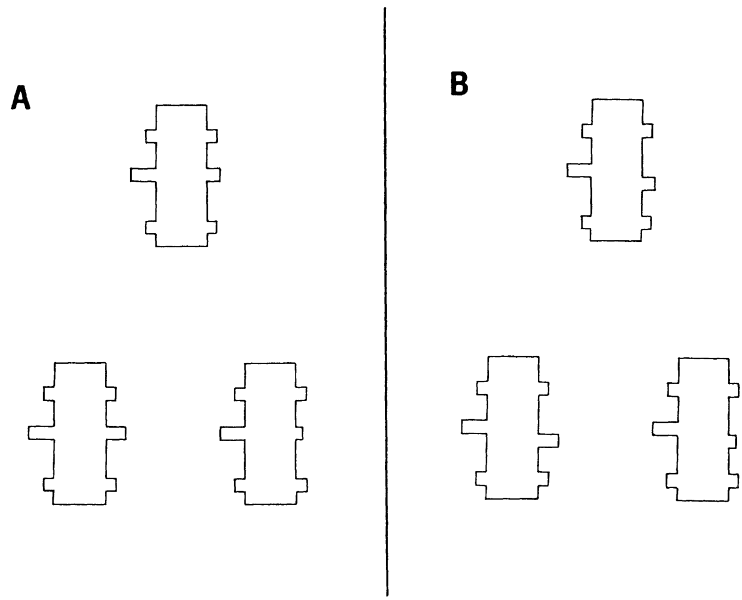

Figure 1. Example sheets of stimuli administered in Experiments 1 and 2: Panel A, Standard form (high overall symmetry condition) on top, and more symmetric and less symmetric alternatives on lower left and right; Panel B, Standard form (low overall symmetry condition) on top, and more symmetric and less symmetric alternatives on lower left and right

alternatives, and .896 for the asymmetric alternatives. For the corresponding low overall symmetry figures, we computed .857, .886, and .831.

Booklets

Each standard stimulus appeared at the top of an 8½ × 11-in. (22 × 28-cm) sheet of paper. The two comparison stimuli appeared side-by-side at the bottom (see Figure 1). The position of the more symmetric comparison stimulus was counterbalanced across stimuli. The 16 stimulus pages were randomized for each subject booklet, with an instruction page at the top.

Procedure

Subjects were instructed to look through all 16 pages before making any similarity choices. The cover sheet directed participants to select the comparison stimulus that seemed more similar to the standard and to indicate that choice by marking an "X" under the selected drawing. Then, they were asked to write down a similarity rating (from 1, least similar, to 10, exactly alike) below each alternative. The entire task took about 5 min.

RESULTS

As expected, subjects gave higher similarity ratings to the alternatives they picked as more similar. Of the alternatives, 80% received a similarity judgment of 8 or more, indicating that subjects perceived both alternatives to be similar to the standard. Percentages of symmetric alternative choices were calculated for each subject, one for high overall symmetry forms and one for low. The null hypothesis, that subjects had no preference for the symmetric alternative or that they were responding randomly, is that 50% of similarity choices were in favor of the symmetric alternative. A contrast score was then formed for each subject for use in a one sample *t*-test to confirm the interaction hypothesis.

The results are very clear. The interaction between alternative and degree of overall symmetry was highly statistically significant, $t(91) = 15.03$, $p < .001$, and the-magnitude of the effect was very large. Separate tests were performed on the two levels of overall symmetry to determine, in each case, if the percentage of choices for the symmetric or less symmetric alternative was different from chance (50%). As predicted, stimuli with a high degree of overall symmetry showed a very large symmetry effect. In the high overall symmetry conditions, 73.5% of the choices favored the symmetric alternative, $t(91) = 13.38$, $p < .001$. In the low overall symmetry condition, only 43.5% of the choices favored the symmetric alternative, $t(91) = 3.40$, $p < .005$.

DISCUSSION

The main finding of Experiment 1 is the predicted, but unexpectedly powerful, interaction between degree of overall symmetry and type of alternative. We interpret the effect of symmetry as evidence for distortion in the perception of these forms. That is, we argue that the symmetric alternative appeared to be more similar to the standard form because the subject's representation of the standard form was distorted to be more symmetric than it really was. This occurred only when the form was symmetric enough to be globally coded as symmetric, that is, in the high overall symmetry conditions.

The strength of the effect of degree of overall symmetry in the interaction found in Experiment 1 is intriguing. It is as if forms with a low degree of overall symmetry were not treated as symmetric forms at all. One question that emerges is whether subjects responded so differently in high and low degree of overall symmetry conditions only because of a contrast effect within the experiment. Experiment 2 attempts to control for this potential experimental artifact by using a between subjects study instead of a within subjects study for this factor.

EXPERIMENT 2

The data from Experiment 1 leave open the question of what caused the interaction effect involving degree of overall symmetry: Was it due to the within-subjects design? Did subjects respond to the high and low degree of overall symmetry conditions differently because they were influenced by the contrast between them? Or is there something in each stimulus alone that determines whether there will be a tendency toward picking the symmetric alternative?

In Experiment 2, one group of subjects received only stimuli from the high overall symmetry condition, and another group received only stimuli from the low overall symmetry condition. This design should eliminate the possibility that intraexperimental contrast caused the interaction between degree of overall symmetry and alternative type in the first experiment.

METHOD

For participation in this study, 32 Stanford undergraduates received course credit in introductory psychology. Experimental procedures of Experiment 2 were almost the same as those for Experiment 1. The only difference was that the 16 pages of stimuli from Experiment 1 were divided into two groups of 8. Thus each subject in Experiment 2 had to make only eight similarity decisions. Half of the subjects received booklets with high overall symmetry standard forms. All other experimental factors were still within subjects. Booklets were distributed to subjects randomly, and, as before, the order of sheets of stimuli in each booklet was randomized for each subject.

RESULTS

Results of Experiment 2 replicated those of Experiment 1. The critical question, whether the interaction between alternative and degree of overall symmetry would be found in a *between*-subjects study, was answered clearly. A two sample t-test was used to test the interaction hypothesis, and the results were as predicted, $t(30) = 6.89$, $p < .001$. Separate tests were performed on each of the two groups of subjects to determine, in each case, if the percentage of choices for the symmetric or less symmetric alternative was different from chance (50%). In the high overall symmetry group, the symmetric alternative was preferred 75% of the time, $t(15) = 5.67$, $p < .001$, whereas in the low overall symmetry group the symmetric alternative was preferred only 34% of the time, $t(15) = 4.03$, $p < .005$. These proportions are consistent with those from Experiment 1.

DISCUSSION

Experiments 1 and 2 demonstrate that perceived similarity can be influenced by manipulating the degree of symmetry of a form and its alternatives. Specifically, a form that is nearly symmetric was judged more similar to an alternative form that is even more symmetric than to one that is less symmetric. However, a form that is not so nearly symmetric was judged more similar to an alternative that is less symmetric than to one that is more symmetric. Because this interaction was found when subjects judged the entire set of stimuli as well as when subjects judged only the high overall symmetry subset or only the low overall symmetry subset of stimuli, it cannot be attributed to a range effect within a particular set of stimuli.

The main results of these experiments are consistent with our initial hypothesis that subjects exaggerate the symmetry of a form if the form can lead to a global perception of symmetry. However, the generality of these results is potentially limited by the nature of the similarity task. Similarity decisions, after all, are subjective; there is no right answer. Moreover, this was not a speeded task. The symmetry effect is that local asymmetry is ignored when global symmetry is present and perceived. If the symmetry effect occurs in the processing of a stimulus that leads to a representation of it, then the symmetry effect should also be apparent in a speeded forced-choice task in which the incorrect alternative is either more or less symmetric than the correct alternative. The next experiment is just such a task.

EXPERIMENT 3

Experiments 1 and 2 demonstrated that a symmetry effect can be found in similarity decisions. We argue that this effect occurs because of systematic perceptual distortions in the direction of making a globally symmetric form more symmetric. Our goal in Experiment 3 is to be able to say something about the locus of the symmetry effect. We chose a matching-figures RT task for Experiment 3. As in the first two experiments, subjects saw a standard form and two alternatives. Now, however, one of the alternatives was actually the same as the standard, and the subject's task was to find the correct alternative as rapidly and accurately as possible. The standard stimulus was of either high or low overall symmetry, and the incorrect alternative was either more or less symmetric than the standard. According to the symmetry effect, for stimuli of high global symmetry, the more symmetric alternative should be more confusable than the less symmetric alternative, and therefore yield longer latencies.

The present experiment differed from the first in two additional ways. First, we broadened the stimulus base by including four basic shape groups instead of one. In addition to basically rectangular shapes (like buildings), we also included a set of stimuli that were broader at the base and narrower at the top (like histograms or mountains), a set of stimuli that were broader near the top than at the base (like trees or people), and finally, a set of paired stimuli (like two birds, two houses, or two land masses). Second, we had independent judges determine the overall symmetry of this expanded stimulus base, and used the judges' ratings as well as the symmetry metric in our predictions. The ratings validated our assumption that the four form types had different average degrees of overall symmetry.

METHOD

Subjects

Participants were 16 Stanford undergraduates who received course credit in introductory psychology. Subjects were run individually in an experimental session of about 45 min.

Stimuli

There were 64 unique stimuli of four types of 16 each: "rectangles," "histograms," "bases," and "pairs." One rationale for using these four form types was that they were based on forms in the world where the detection of symmetry might be useful. Rectangular forms, similar in overall shape to buildings or furniture, were like those used in Experiments 1 and 2. Histograms were modeled after the statistical data presentation of that name. Base forms were constructed so that they seemed to have a canonical orientation, that is, there was a base, as with trees and people. Pairs were actually two simple, very similar grouped figures, like two land masses on a map. Figure 2 shows examples of the four form types.

The alternatives, one more symmetric and one less symmetric, were generated much as they were for Experiments 1 and 2 for three of the four form types: rectangles, bases, and histograms. Portions of the figures were

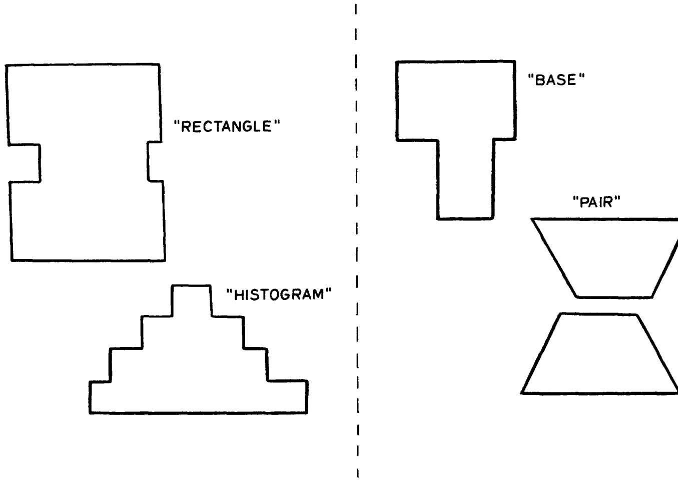

Figure 2. Examples from the four types of standard forms for Experiment 3. “Rectangle” and “histogram” are considered high overall symmetry, and “base” and “pair” are considered low overall symmetry

increased or decreased (and this was counterbalanced) to make the figure more symmetric. The reverse transformation was applied to make the less symmetric alternative. Another type of transformation used (on about 30% of the forms) was to move the position of a portion of the figure. This did not affect the size of the form, and again the inverse transformation was applied to the less symmetric alternative. The manipulation of symmetry for the fourth form type, pairs, was somewhat different. These stimulus alternatives varied in the degree to which each “half” of the pair was aligned with the other half. Thus, one member of the pair was moved to be more aligned to create the more symmetric alternative. The inverse transformation was applied to make the less symmetric alternative.

As in Experiments 1 and 2, the symmetric alternatives for all form types were not absolutely symmetric, just more symmetric than the standard.

Symmetry ratings

The four form types were classified according to degree of overall symmetry by asking 30 more introductory psychology students to rate four randomly selected examples of each form type for degree of symmetry. The resulting order of those judgments was, from high to low symmetry: rectangles, histograms, bases, and finally pairs. The difference between the ratings of rectangles and histograms versus bases and pairs was statistically significant, $t(29) = 2.89, p < .01$. We therefore made two groups from the four types based on the judges’ classifications of overall symmetry. Thus, rectangle and histogram trials were considered high degree of overall symmetry conditions, and base and pair trials were considered low degree of overall symmetry conditions. Figure 2 shows examples of the four form types in their symmetry order. We also applied the symmetry metric used in Experiment 1 for all 64 forms. We found for the standard forms of rectangles, histograms, bases, and pairs, that the symmetry values were .918, .910, .805, and .802, respectively. The ordering by degree of symmetry achieved from this metric measure of symmetry is the same as the ordering given by the judges, and the absolute values of high and low overall symmetric standards are comparable to those in Experiments 1 and 2.

Form-matching task

Stimuli were presented on a Megatek 5000 graphics screen, controlled by a Data General Nova computer. The computer was programmed to display stimuli by lighting up specific grid points on the graphics screen; thus the presentation was light on black.

In each trial, a fixation point was illuminated for 1 s, followed by the experimental stimuli and subject's response. Stimuli for each trial were three figures arranged on the screen in the same format as stimuli were arranged on paper in Experiments 1 and 2. That is, centered on the upper half of the screen was a standard figure and in the lower left- and right-hand corners, respectively, were two alternative figures. Figure 3 illustrates the presentation. The subject's task was to determine which of the two alternatives was exactly the same as the standard figure. Responses were indicated by pressing one of two keys (one on the left and one on the right of a key press box). Subjects were instructed to press the left key if the alternative they chose was on the left-hand corner of the screen and to press the right key if they had picked the right-hand alternative. The position of the correct alternative was randomized for each trial, block, and subject. The response and RT were recorded by the computer. After the subject pressed a key, the next trial was initiated.

The experiment was run in four blocks. Subjects had three short breaks between blocks. The order of the four blocks was randomized over subjects. Each block had 64 experimental trials that were randomized for each block and each subject. In all, each subject had 256 trials generated from 128 stimuli forms (a combination of 64 unique stimuli forms and those same 64 forms rotated 90° so as to be horizontally aligned to the screen) with two types of incorrect alternatives (more symmetric or less symmetric). The subjects were directed to respond as quickly as possible without sacrificing accuracy.

RESULTS

The error rate for Experiment 3 was 12.5%. Errors appeared to be distributed approximately equally across conditions; an analysis of variance was used to test for systematic error effects and none were found. Only reaction times of correct choices entered subsequent data analyses.

The 256 reaction times collected per subject were reduced to mean

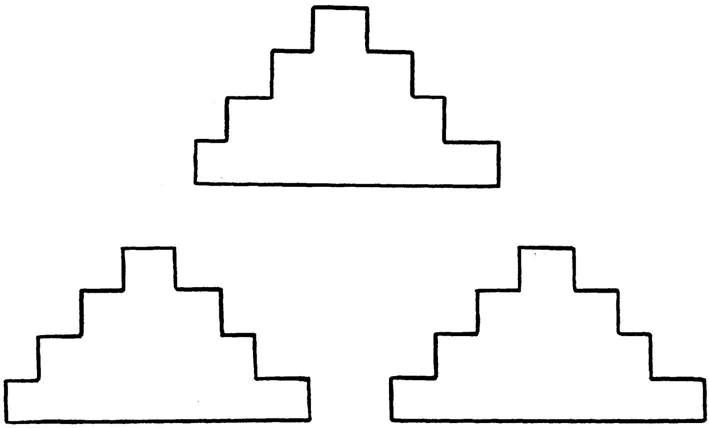

Figure 3. Facsimile of the computer screen presentation of stimuli in Experiment 3. Standard form on top, correct alternative on lower left, and an incorrect alternative on lower right (in this example the incorrect alternative is a more symmetric alternative)

RT scores in each of four cells (high vs. low overall symmetry of standard × more symmetric vs. less symmetric alternative). An analysis of variance was used to test for the predicted interaction. The predicted interaction between type of alternative and degree of overall symmetry is large and highly significant, $F(1, 15) = 17.80$, $p < .001$. Separate tests were performed on the two levels of overall symmetry to determine, in each case, if the reaction times differed when the symmetric versus less symmetric alternatives were present. The mean time to pick the correct alternative in a symmetric condition with a high degree of overall symmetry was 599 ms longer than in a high overall symmetry, less symmetric condition, $t(15) = 3.69$, $p < .005$. Thus, in the high overall symmetry condition, a symmetric alternative lengthens the response time, presumably because the symmetric alternative is more confusable with the standard form than is the less symmetric alternative. The opposite effect was obtained when the correct alternative had low overall symmetry; then, the more symmetric alternative yielded reaction times that were 382 ms shorter than the less symmetric alternative, $t(15) = 2.11, p < .10$. These effects are represented graphically in Figure 4.

DISCUSSION

In Experiment 3, RT was measured while subjects selected a standard form from one of two alternatives. One of the alternatives was correct, and the other either more or less symmetric than the stan-

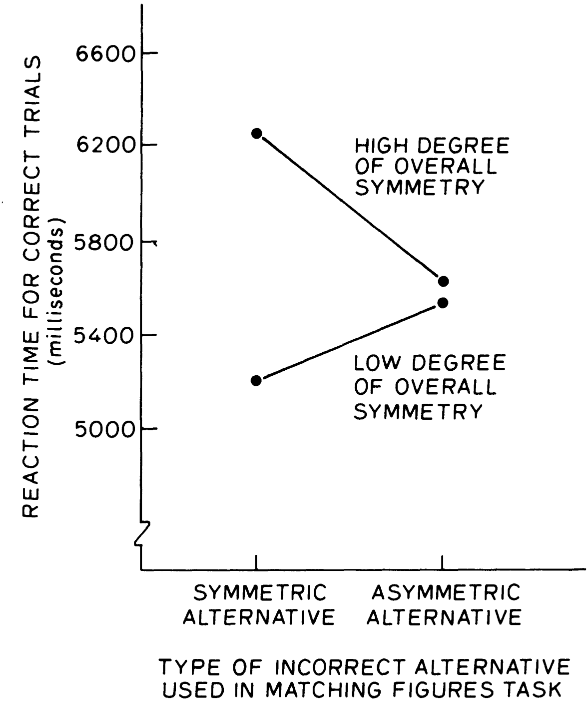

Figure 4. Results from Experiment 3

dard. When the standard form was globally symmetric, correct latencies were longer in the presence of the more symmetric alternative, whereas when the standard form was not globally symmetric, correct latencies were shorter in the presence of the more symmetric alternative. Thus, the symmetry effect has been demonstrated in speed of processing to detect a correct alternative as well as in judgments of similarity. Furthermore, the results of the symmetry metric applied to the stimuli from all experiments converge on a critical value for degree of symmetry above which the form is perceived as having overall symmetry.

GENERAL DISCUSSION

The main results from all three experiments provide converging evidence for the force of symmetry in form perception. Our hypothesis was that forms with near symmetry would be "distorted" by perceivers in the direction of symmetry. The mechanism producing the distortion lies, we proposed, in the perceptual scanning processes that establish representations of forms. There is a bias to detect global symmetry, presumably because of its utility in segregating figures from ground and in forming economical representations of stimuli. Because scanning of forms is rarely, if ever, complete, local departures from symmetry may never be noticed and never be represented. This yields representations that are more symmetric than the forms they represent. We found (Experiments 1 and 2) that the perceived similarity of a form to an alternative form is influenced by the symmetry of those forms. A nearly symmetric standard form is judged more similar to an even more symmetric alternative than to a less symmetric alternative. This is not true of forms that have a low degree of overall symmetry. High and low overall symmetry was validated by a metric that compared the contours of the forms. This result was obtained from subjects viewing both high overall symmetry stimuli and low overall symmetry simuli as well as from subjects viewing only high symmetry or low symmetry forms. Finally, we have shown (Experiment 3) that a nearly symmetric form is apparently more confusable with an even more symmetric form than with a less symmetric form. And again this is not true for forms that are not very symmetric. Thus, the symmetry effect is robust over different visual forms and over different perceptual tasks.

One alternative explanation that might be suggested is a response-bias hypothesis. Are the subjects picking the more symmetric alternative and finding the symmetric incorrect alternative hard to reject because these alternatives are preferred irrespective of the task (and without the presence of the standard figure)? It seems unlikely, because the preference for the symmetric alternative exists only in high overall symmetry conditions. Indeed, in low overall symmetry conditions the asymmetric alternative was preferred. A rather complicated response-bias story would have to be constructed to explain this discrepancy in which the alternative was preferred.

How might we explain the converse of the symmetry effect, that subjects judged forms of low overall symmetry to be more similar to an even less symmetric alternative than to an equidistant, more symmetric alternative? Although this trend appeared in all three experiments, it was not quite significant on its own in Experiment 3. One intriguing way to explain this effect is the complement to the explanation we gave of the symmetry effect: that representations of stimuli of low global symmetry get distorted in the direction of even greater asymmetry. However, we are hesitant to draw this conclusion because none of the stimuli used in the experiment were very asymmetric relative to, say, random polygons. A simpler explanation of the "asymmetry effect," as it might be called, is consistent with the "symmetry effect" explanation we have proposed in this paper: If the more symmetric alternative in the low overall symmetry condition is perceived globally as symmetric but the low overall symmetry standard form and the less symmetric alternative are not perceived as globally symmetric, then the perceived similarity and confusability of the more symmetric alternative with the standard should be lowered relative to the perceived similarity and confusability of the less symmetric alternative with the standard.

Our account of the symmetry effect asserts that the representations of the forms are distorted, depending on their perceived symmetry. Another way to explain the effect would be to assume no symmetry-dependent distortions of form, but instead to attribute the effect to symmetry-dependent distortions in the perceived similarity relations between the forms. To explain the data, a "distorted metric" account would have to maintain that, for physically equal distances, departures from high overall or near symmetry have less weight than departures from low overall or far symmetry. However, such an account runs counter to typical psychophysical scaling effects, where near departures are typically weighted more than equal-sized far departures.

A more complex version of this interpretation appears to be compatible with our data. Representation of stimuli is presumed to be veridical with respect to symmetry, but similarity judgments tend to go toward symmetry for high global symmetry standards and away from symmetry for low global symmetry standards. Accordingly, the RT data follow this pattern because highly similar foils are known to retard comparisons. Although this explanation preserves the integrity of the stimulus, it offers no explanation of why similarity goes with symmetry for high global symmetry standards and against symmetry for low global symmetry standards. Moreover, Locher and Nodine (1973) showed that subjects scanned only one side of a symmetric figure, giving support to the mechanism proposed for producing distorted representations, namely, a bias to detect symmetry and incomplete processing of stimuli. This phenomenon is consistent with the two-step encoding model described in the introduction of this paper: First, a subject uses *global* information to detect symmetry, and then, if symmetry is detected, the subject uses that knowledge to make inferences about parts of the form not scanned carefully at the *local* level. Given this model, clearly a mistaken symmetry detection at the global level could lead to inferential errors at the local level.

We have presented evidence that symmetry detection leads to a biased representation of form. As we argued at the beginning of this paper, there are two good reasons for symmetry detection: one is that objects can be detected via symmetry; the other is that symmetry is an economical organizational factor. Thus we are dealing with a fundamental question in psychology: How do humans structure their perceptions of the world? What rules do they use to reduce the amount of information they will attempt to collect? And how do their mental representations of the world differ systematically from objective reality? The research paradigm we have employed is similarly a basic research strategy used in psychology: If there is a generally useful rule, then we must be able to find cases where it leads us to errors because the situation is exceptional. Thus, can we fool people into applying symmetry information when it is somewhat misleading? It seems we can; it seems that symmetry exerts a force on the human perceptual and representational system.

Notes

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[1]The symmetry metric of Zimmer (1983) was developed for measuring the symmetry of contours, and it uses a simple algorithm when the stimuli are nearly bilaterally symmetric and the axis of symmetry is obvious (as is true with all of the stimuli used in the studies here). First the figure is mapped onto a grid such that any deviations from symmetry are at least as large as one square grid. Then one picks an endpoint of the figure and starts a downward search along the axis of symmetry looking for violations of symmetry. When mismatches are detected, one continues the downward search looking for better solutions (thus misalignments can be considered less destructive to symmetry than unequal lengths of parts). The metric takes into account the amount of mismatch between opposing parts of the figure (the proportion of areas on each side) and the amount of shift or misalignment (proportion of parallel vs. orthogonal shift). The final value of symmetry is achieved by summing all the values of symmetry for each grid point orthogonal to the axis of symmetry and then dividing by the number of such grid points. When there is no mismatch at a single grid point, the value of symmetry is 1; when there is a mismatch, the value is determined by the amount of proportional mismatch in area multiplied by the amount of proportional mismatch in shift (rendering a value between 0 and 1). Thus the final index of summetry is between 0 and 1.

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