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The Effect on Form Perception of Change of Orientation in the Third Dimension

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The experiments reported here concern the effect of change of orientation of figures in the third dimension on phenomenal shape. In one experiment, novel two-dimensional wire figures were first shown in one orientation in the sagittal plane, and recognition of them was then tested in an altered orientation in that plane. In another experiment, novel three-dimensional wire figures were first shown in one orientation, and recognition of them was tested following rotation about one of the three major axes of space. The guiding hypotheses were (a) form perception is the end result of a process of figural description; (b) orientation change that alters the perceived location of the top, bottom, and sides of a figure will affect this description; and (c) front–back reversal and rotations about the Y axis will not affect the description because front and back constitute the sides of a figure much as left and right do, and all figural sides are phenomenally equivalent. The findings support these hypotheses except for an unanticipated effect on recognition of 90° rotations about the Y axis. This effect was seen as a hitherto unknown example of egocentrism in perception, since the description is governed by the retinal projection resulting from the particular vantage point of the observer.

Why is it that a change of orientation of two-dimensional figures in a frontal plane has such a profound effect on phenomenal shape? Such transformations do not alter a figure's internal geometry any more than do transpositions of size or retinal locus. The general answer to this question is that it is not the retinal image transformation that is relevant but the change in the location of the regions of the figure taken to be its top, bottom, and sides. The other kinds of transpositions do not entail any such directional change. As to why change in the directions assigned to a figure by the perceptual system has a powerful effect on perceived shape, it has been suggested that the cognitive description of a figure greatly depends on which region is its top, which is its bottom, and which regions are its sides (Rock, 1973).

Phenomenal attributes such as symmetry, stability, and so forth change as a function of orientation. For example, a figure that in one orientation is symmetrical about its vertical axis will appear to be symmetrical, but when the symmetry is about an oblique or horizontal axis, it will generally not appear to be so (Corballis & Roldan, 1975; Goldmeier, 1936; Julesz, 1971; Mach, 1897;

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Rock & Leaman, 1963). Naturally a change of orientation of 45° or 90° will lead to phenomenal change because the figure will either lose its apparent symmetry or acquire it.

One might ask the further question, Why is it only (or primarily) symmetry about the axis perceived to be vertical that leads to perceived symmetry? We suggest that the explanation is tied to the fact that the left and right sides of space are descriptively equivalent regions, whereas the up and down of space are not. A thing in the real world is not a different thing by virtue of any difference in sidedness and, in fact, when approached from behind, as it were, the sides have changed places. "Left" and "right" do not characterize the world; they are ephemeral directions based on the projection of our egocentric coordinates at a given moment. This analysis may explain the well-known difficulty of children and animals in discriminating figures from their left–right (or mirror-image) reversals (Rudel & Teuber, 1963); it may also explain why left–right reversals do not look very different and do not generally lead to failure of recognition of novel figures by adults (Rock 1973). If the sides of space are phenomenally equivalent, then a left–right reversal should not lead to a change of phenomenal shape.

It is important to make clear that the effects referred to and the interpretation offered here presuppose that the observer remains naive concerning change of orientation. Thus, a rotated figure will appear different if the observer does not know it is rotated. The moment he or she knows it is, it generally becomes immediately recognizable. "Knowing" about its rotation is equivalent to assigning "top," "bottom," and "sides" appropriately rather than inappropriately. Similarly, a figure that is symmetrical about its horizontal or oblique axis will be perceived to be symmetrical once the observer knows where that axis is. Such information provides a phenomenal axis that becomes functionally equivalent to the axis that has a vertical orientation in the environment. By the same token, a novel figure that is left–right reversed with respect to the way it was first seen will appear more or less identical for adults as well as children provided attention is not drawn to what is on the left and right in both the original and later presentation. Once it is, as it ultimately must be in a discrimination test, the two versions can be discriminated. In the experiments described in this article, the subjects remain naive concerning change of orientation. It is important that this is understood so that the orientation effects studied here are not confused with those in which subjects are deliberately invited to imagine or mentally rotate an object to decide if it is the same as another object in a different orientation (e.g., Shepard & Metzler, 1971).

Others do not subscribe to the interpretation offered here concerning the equivalence of the sides of space and instead suggest that the bilateral symmetry of the organism (and, therefore, of the brain) is responsible for these facts (Corballis & Roldan, 1975; Julesz, 1971). Yet it has been demonstrated that the same tendency for symmetry to be realized only about a vertical axis occurs when the observer is no longer upright but the figure is (Rock & Leaman, 1963). It is probable that the same difficulty with left–right figure discrimination will occur even if the observer is tilted sideways away from the vertical position. This means that vertical symmetry and left–right equivalence hold even when the projection to retina and cortex is such that the sides of the figure do not fall symmetrically with respect to the sagittal axis of the brain. In other words, what seems to matter is which regions appear to be the sides of a figure, not which regions are, retinally speaking, to the left and right of a vertical retinal axis. It is true that Corballis and Roldan (1975) have found that symmetry is more readily detected when the axis of symmetry is retinally rather than environmentally vertical. In their experiment the axis of symmetry was oblique, vertical, or horizontal in the environment, and the observer viewed the figure with the head tilted to the oblique orientation. Because the subjects were instructed to decide whether a pattern was symmetrical with respect to a line axis that was drawn through it, it is not surprising that they detected symmetry when the axis of it was not vertical in the environment. However, the faster reaction time obtained when the axis was retinally vertical requires further discussion (see the General Discussion section). In any event, the hypothesis that perceived symmetry and left–right equivalence is a function of the bilateral symmetry of the organism is one that is widely held. A major purpose of the experiments reported here is to present new evidence bearing on the problem of orientation in form perception by investigating rotations in the third dimension.

Our guiding hypothesis is that there are three directions that affect the spontaneous description of a figure, namely, top, bottom, and sides. Although it is true that what is normally perceived to be at the side in a figure is either on the observer's left or right, this is no longer the case if the head is not in an upright position but is instead tilted. This suggests that what defines sidedness is not leftness or rightness but rather the location that is perceived as midway between top and bottom. Consider a two-dimensional wire figure in a saggital plane. We perceive one region as its top and another as its bottom, and we also perceive the figure as having sides. But it is not leftness and rightness that define sidedness here; rather, one side is now nearest to and the other farthest from the observer. Consistent with the analysis outlined previously, we would predict that changes of orientation within a sagittal plane that alter the location of a figure's top, bottom, and sides will affect phenomenal shape, but changes that only exchange the location of its sides will not. Specifically, a rotation of 90° about the X axis should lead to substantial decline in recognition, whereas a rotation of 180° about the Y axis (or a front–back reversal) should not. The first experiment was designed to test this prediction.

Experiment 1: Two-Dimensional Figures Rotated in a Sagittal Plane

Method

Subjects. The final sample consisted of 36 subjects (13 males and 23 females) who were selected from the university community and paid for their participation in the experiment. Three additional subjects participated, but their data were discarded for reasons provided later.

Stimuli. Various two-dimensional novel forms were constructed of 1-mm diameter wire and painted flat black. Nine figures were used, six as experimental figures and three as control figures. Three of the experimental figures were of the open type and three were of the closed type. Seven of these were adapted from Rock (1973, see p. 136 for examples); the other two were constructed for this experiment.

Procedure. Each of these figures was mounted on a clear, 1-cm diameter Plexiglass rod supported by an optic carriage and bench. The figures were viewed against a white background and through an aperture in a white foreground so that only the black figures were visible. Exposure of the figures was controlled by a shutter mechanism wired to a timer. The figures were viewed binocularly at eye level by the subject whose head was on a chin rest at a distance of 1.25 m. At this distance the figures subtended visual angles ranging from approximately 10° to 14°.

The experimental session consisted of two series of trials, the training series and the test series. The training series served to familiarize the subject with the novel figures, whereas the test series was used to determine the effects of various changes of figural orientation on recognition.

In the training series subjects were shown each of the experimental figures for 4 sec. The figures appeared in one of two views: a frontal view, with the broadside of the figure lying in a fronto-parallel plane, and a depth view, with the broadside of the figure lying in a sagittal plane (i.e., a plane parallel to the subject's median plane). The purpose of including frontal-plane presentations in the experiment was to permit comparison of results of sagittal-plane presentations with this more traditional mode of presentation. When presented in the frontal view, the figure appeared directly in front of the subject. When presented in the depth view, the figure was moved manually left or right along the optic bench, 50 cm across the subject's field of view. The excursion was always symmetrical about the subject's median (or midsaggital) plane. The figure was moved at a steady rate and in such a manner as to allow an approximately .5-sec stationary view at either end of the excursion. The purpose of the movement was to ensure adequate perception of the figure, since a flat figure in the midsaggital plane would otherwise project to the eyes a very narrow image. Also such movement eliminates the possibility that any side of a figure would be seen exclusively as to the left or right, since it is equally often on both sides as a result of its motion.

The subject was asked to rate the aesthetic value of each figure. This was done in an attempt to ensure that the subject attended to each figure and to minimize attempts by the subject to memorize it with the aid of verbal mnemonics. We did not, of course, expect the elimination of intentional learning to interfere with either figure perception or memory formation. However, where the focus of interest is on figure perception (and ultimate figure recognizability), it would seem desirable to isolate it as much as possible from other kinds of cognitive processing. In any event, whatever the effect of our aesthetic-rating task, it would pertain to all figures equally in the training phase regardless of their orientation in the subsequent recognition test.

In the test series, subjects were shown each of nine figures for .5 sec. These included the six experimental figures presented in the training session and the three new control figures. Each experimental figure was presented in one of three possible orientations within the two viewing conditions. A figure appeared either in the same orientation as in the training trials, in a 90° rotation (about the Z axis for the frontal view and about the X axis for the depth view), or in a left–right reversed orientation for the frontal view condition and in a front–back reversed orientation for the depth view condition (Y-axis rotations). As seen by the subject, the 90° rotations were always clockwise when in the frontal view and away from the subject when in the depth view. The control figures were presented in the same orientation for all subjects; two of these figures were presented in one of the viewing conditions and one in the other. In this test series the figures presented in the depth view were not moved but were viewed in a stationary position, 25 cm to one side of the subject's midsagittal plane.

It is worth noting that in this experiment (and in Experiment 2 as well), the particular orientation of each figure selected in the training series (and also referred to as the "same" or "0" orientation in the test) was considered arbitrary. In other words we were not assuming that there was any intrinsic top, bottom, or front and back in these figures. Thus "top" or "front" would be achieved purely on the basis of directions assigned to a figure by the observer on the basis of how it was oriented in the training or test series.

For each of the test trials, the subject was instructed to indicate, by a yes–no response, whether or not the figure shown in a given trial was one shown during the training series. The subject was asked to respond immediately after the shutter closed, ending a figure's exposure. This was done to limit the possibility of mentally rotating a figure during the test trials.

Each of the six experimental figures and the three control figures was viewed once by each subject during the test series; each figure appeared in only one of the six treatment conditions. The experimental figures were presented in the same plane for both training and test trials, and for both groups of trials the order of figure presentation was randomized. For the test trials, each figure appeared in each of the six test orientations an equal number of times, and each control figure appeared an equal number of times, across subjects, in each of the two viewing conditions. The control figures were used to minimize a "yes" response bias during the test trials and to provide data concerning false positive responses to figures in the test. These control figures were similar in style and size to the experimental figures, either closed or open, so that discriminating "new" from "old" figures in the test required memory of the specific shape of the experimental figures. For the test trials, when a figure appeared in the depth view condition, the side of presentation was counterbalanced across subjects.

The instructions to subjects were roughly as follows:

> In the experiment I am going to show you wire shapes like this one [the subject was shown a sample shape]. You will see the shapes either straight ahead or moving left or right in front of you through this shutter, which I will open and close automatically for you. When you are seeing the shapes, always keep your chin on this chin rest. All I want you to do is to look at the shape when the shutter opens and rate its aesthetic value. That is, I want you to tell me how artistically pleasing you think the shape is, and the way you do this is by using a 7-point scale [an explanation was given of how to use the scale]. I want you to look at the shape all of the time that the shutter is open, and when it closes give me your rating. Before I show you a figure I will give you a ready signal and a moment later I'll open the shutter.

Following the completion of the training series the subject was instructed as follows:

> All you have to do in this part of the experiment is tell me whether or not the shape I show you is one of the ones I showed you in the first part. You simply respond by saying "yes" or "no." I want you to respond as soon as the shutter closes. Be sure to be looking toward the shutter when I give you the ready signal because now the shape will be presented very briefly and I don't want you to miss it. If you feel like you are guessing don't worry about that, just give me your first impression about whether or not you saw the figure before.

A ready signal was given, before each figure was presented and the experimenter awaited the subject's response of "ready."

It is important to emphasize that no mention was made about the fact that the experimental figures in the test might be presented in new orientations. Every effort was made to keep the subject naive about this possibility.

An interview was held after the test trials. The purpose of the questioning was to determine whether or not the subject's recognition responses were orientation dependent per se. That is, did subjects say "no" unless a figure was in the same orientation as in the training trials even though recognition occurred? Conversely, did subjects say "yes" because they deliberately attempted to mentally rotate each figure and often succeeded? In point of fact, however, no subject reported doing the former and only three the latter. It was evident even before the interview that these three subjects were mentally rotating the test figures because they took a long time to respond and tended to recognize most of the figures. They withdrew from the study and were replaced by other subjects, bringing the total number to 36.

Results and Discussion

The results are given in Table 1 for each mode of perception (frontal plane and sagittal plane) and for each test orientation. Recognition was high when the orientation in the test was the same as in the training trials (94% for the frontal plane and 86% for the sagittal plane). These values can be contrasted with the low number of false positive responses to the new (control) figures, 2% for the frontal plane, and 17% for the sagittal plane. However, when the figure was tilted 90° in the test, recognition dropped mark-

Table 1
Recognition of Experimental and Control Figures: Experiment 1

	Plane presentation							
	Frontal				Sagittal			
	Test orientation				Test orientation			
Variable	0°	Z90°	Y180° (L–R)	New	0°	X90°	Y180° (F–B)	New
No. of yes responses ($N = 36$)	34	13	30	1[a]	31	11	28	9[a]
% of yes responses	94	36	83	2	86	31	78	17

Note. Z = Z axis; Y = Y axis; X = X axis; L–R = left–right; F–B = front–back.
[a] $n = 54$ for control figures.

edly, to 36% in the frontal plane and 31% in the sagittal plane. Each of these values represents a significant drop in recognition from the no-change, 0° baseline, $t(70) = 6.4$, $p < .01$, and $t(70) = 5.5$, $p < .01$, respectively. On the other hand, when the test orientation was reversed, there was no significant decline in recognition (83% for the left–right reversal and 78% for the front–back reversal.[1] The results for each experimental figure generally followed the trend for all figures combined.

The results for the two modes of presentation are clearly parallel; in fact, for any given test orientation, they do not differ significantly from one another. The finding that a 90° rotation in a frontal plane produces an appreciable decline in recognition simply confirms earlier findings, as does the finding that a left–right reversal in that plane has little effect on recognition (Rock, 1973). We interpreted these findings to mean that a change of figural location of top, bottom, and sides leads to a very different spontaneous figural description; whereas a change of figural location from one side to the other leads to a very similar figural description.

If the results of the sagittal plane presentations are considered, precisely the same conclusion can be drawn. Of particular importance is the equivalence of a front–back reversal to a left–right reversal. That is, just as a left–right reversal has little effect on phenomenal shape, so does front–back reversal. This supports our contention that sidedness is most generally defined as the regions that lie along the axis orthogonal to the figure's vertical axis, or, as we said previously, the regions between the figure's top and bottom. On the other hand, a 90° rotation in the sagittal plane does have a strong effect on perceived shape. Thus, the results taken together suggest that it is not depth change per se that affects recognition but change in the location of the directions assigned to a figure.

Experiment 2: Orientation Changes of Three-Dimensional Figures

In this experiment we investigated the effect of changing the orientation of three-dimensional figures. To eliminate the occlusion of the parts of a three-dimensional object that are behind other parts of it, we made use of wire figures so that the entire figure was always simultaneously visible. Interestingly, to our knowledge the fundamental question of three-dimensional visual form

[1] Because of the side-to-side motion of the figures seen in training in a sagittal plane, both left–right and right–left retinal images are produced. Therefore, if recognition was based on identity of the retinal image, the resulting high scores for the front–back test orientation would not be surprising. The retinal image in these cases would be the same in the test as one of those given in the training period. But we assume on the basis of much previous work with figures of this kind that what matters for recognition is change or nonchange of perceived orientation (Rock, 1973), and of course there is no question that such a change is present in the front–back reversal condition. In any event this problem does not arise in Experiment 2.

perception has never been directly investigated. One reason for this may be that with the typical three-dimensional solid object, only the surfaces facing the observer are visible, so that unless one is interested in the problem of mental rotation, this kind of object is not ideal for investigating form perception. Our type of figure overcame this difficulty, and facts have emerged that were hitherto unknown.

As in Experiment 1 the focus of our interest in orientation change in the third dimension led to the plan to change the orientation of our three-dimensional figures by rotating them about the X axis. Such a change would be analogous to the one investigated in Experiment 1 except that in Experiment 2 the figure was three (not two) dimensional. We decided to test for 180° rotation as well as for 90° rotation in this experiment. To isolate depth changes that in principle should entail no change in the assigned directions of top, bottom, and sides, we also included in the design rotations of 90° and 180° about the Y axis. We were predicting no effect on recognition (i.e., no decline), since we assumed that the figural description would not be a function of whether a given region was front, back, left or right, as all of these were "sides." The 180° Y-axis change is directly analogous to the front–back reversal in Experiment 1. Finally, as a control we included rotations of 90° and 180° about the Z axis. Such a change is essentially one of altering the directional location of the parts of a figure without any depth change and, as such, should yield results similar to those of orientation change in a frontal plane. In this case the three dimensionality of the figure might, by virtue of increased complexity, lower all recognition scores but should not interact with orientation change.

Method

Subjects. The final sample consisted of 28 students from the university community (11 males and 17 females) who volunteered to participate in the experiment. Three additional subjects participated, but their data were discarded for reasons stated below.

Stimuli. Three-dimensional novel figures were constructed of 2.5-mm diameter wire, roughly half of which were "open" and half "closed." These figures varied in size from one another, and the dimensions of the three axes of each figure also varied. These latter values ranged from about 5 cm to 18 cm. The average dimension across figures and axes was approximately 9 cm. Two of the figures are shown in Figures 1 and 2 with front, bottom, and side views. They were coated with luminous paint and mounted centrally in metal cube frames by threads. Neither the threads nor the frames were visible when the figures were viewed in the dark under ultraviolet illumination. The cube frames made it possible to alter the orientation of a figure as desired simply by rotating the cubes appropriately. Twenty-one such figures were constructed, 7 of which were seen in the training and test session of the experiment and 14 of which were seen only in the test.

Procedure. To view the figures the subject stood with his or her head positioned by a chin rest and looked through a shutter aperture. The center of the figure was at eye level and straight ahead in the midsagittal plane, 50 cm from the subject. At this distance the average dimension of 9 cm of the figures subtended approximately 10° of visual angle. It was important that the figures were close enough to the observer to ensure that its depth would be veridically perceived, presumably via the combined cues of accommodation, convergence, and stereopsis. Exposure of the figures was controlled by a shutter mechanism wired to a timer.

The experimental session consisted of two series of trials, the training and test series. In the training series the subject viewed each of the seven test figures for a period of 4 sec. The subject was asked to rate the aesthetic value of each figure.

In the test series the subject viewed each of 21 figures for a period of 1 sec. These figures included the 7 experimental figures and the 14 new or control figures. The inclusion of the many new figures in the test was a further measure designed to prevent subjects from realizing that the experimental figures might be presented in altered orientations. The subjects would not be expecting many figures to be familiar and hence would be less likely to engage in processes such as mental rotation. The new figures were similar in style and size to the experimental figures but different in specific shape. Given the relative complexity of the three-dimensional figures used in this experiment, the discrimination of the "old" from the "new" figures in the test was expected to be relatively difficult. Each experimental figure was presented in one of seven possible orientations, which may be specified relative to the training-trial orientation. These orientations were 0°, X90°, X180°, Y90°, Y180°, Z90°, and Z180°. For the 0° orientation condition, the figure was presented in the same orientation as in the training session. For the remaining six orientations, the figure was rotated either 90° or 180° about the X, Y, or Z axis. The new, control figures were presented in the same orientation for all subjects.

After each of the test trials, the subject was instructed to indicate, by a yes or no response, whether or not the figure had also appeared in the training trials. The subject was asked to respond immediately after the shutter closed, ending the figure's exposure. This was done to eliminate or minimize any tendency to mentally rotate the figure.

Each of the 7 experimental figures and 14 new figures was viewed once by each subject during the test series;

each test figure appeared in only one of the 7 orientation conditions. For all subjects combined, each figure appeared in each of the orientation conditions an equal number of times.

The instructions to subjects were essentially the same as those used in Experiment 1, with the following minor differences: Instead of the word *shape*, the word *object* was used to refer to the figures that were shown, and no reference to moving figures was made, since in this experiment the figures did not move in the training session.

An interview followed the test trials. As in Experiment 1, the purpose of the questioning was to determine whether or not the subject had remained naive concerning the fact that the experimental figures were often being presented in the test in altered orientations. We specifically asked subjects if they said "yes" only if a figure appeared in the same orientation as in the training period, even though it was recognized, or if they said "yes" only after realizing it was disoriented.

The experiment described here was a repetition of a preliminary experiment using the same number of subjects. The only differences in the preliminary experiment from the one described here were as follows: Instead of luminous figures seen in the dark, the figures were silver colored and seen against a white background; they were attached at the bottom to a clip that was not visible, and the position of the figure in relation to the clip was varied appropriately in the test; a few figures were different from those used in the main experiment; the exposure period in the test was .5 sec rather than 1.0 sec; only 2 new figures rather than 14 were used with the 7 experimental figures in the test; the figures were presented to the left or right of the midsagittal plane rather than straight ahead in the training phase but were equally often on the same or a different side in the test. The preliminary experiment was performed in another laboratory by a different experimenter.

Results and Discussion

Three subjects were disqualified on the basis of the outcome of the interview because they developed an expectation that the figures might be in new orientations in the test. The remaining subjects were naive about orientation change. The results are given in Table 2 in terms of the number of recognitions for each test orientation for all figures and all subjects combined. As in Experiment 1, the results for each experimental figure generally followed the trend of the results for all figures combined. Recognition in the no-change or 0° condition was quite good (82%) if one bears in mind the greater complexity of these three-dimensional figures and the fact that the majority of figures in the test were new. The number of false recognitions of these new figures was 22%.

We consider first the effect of rotation about the Z axis, since there was no change of depth. These test conditions are of least interest in this experiment. The 90° test rotation resulted in a sharp drop in recognition—to 46%—which is significantly lower than is recognition in the 0° or no-change condition, $t(54) = 3.16$, $p < .01$. The 180° test rotation also resulted in a drop in recognition but not as great as for 90° (i.e., 57%). This decline is also significant, $t(54) = 2.2$, $p < .025$, one-tailed.. Thus, the trend is similar to what we might expect for two-dimensional figures rotated into these orientations in a frontal plane (Rock, 1973).

The test condition of 90° rotation about the X axis is analogous to the 90° rotation in the sagittal plane in Experiment 1. In the present experiment, however, we found an even greater drop in recognition—to 21%—which in fact is the lowest value of all test conditions and is not significantly different from the value of 22% derived from presentation of new figures in the test. In other words, for the 90° X-axis change there was essentially no recognition at all. Although we predicted a marked decline in recognition in this condition because of the change in the figural regions that became top, bottom, and sides, we now believe that the actual result achieved has an additional cause. The results of 180° rotation around the X axis yielded a decline in recognition to 61%, which is of borderline significance, $t(54) = 1.84$, $p < .05$ (one-tailed), and clearly one that was much less than for the 90° rotation, $t(54) = 3.3$, $p < .01$.

But the result that was not at all anticipated and in fact was contrary to the prediction based on the presumption of equivalence of left–right sides with front–back sides was the significant decline in recognition for the 90° rotation about the Y axis to a value of 43%, $t(54) = 3.4$, $p < .01$. On the other hand, the result of the 180° rotation about the Y axis was anticipated. There was no decline in recognition at all here, since 86% of the subjects correctly identified the test figure. Thus, these results parallel those of front–back reversal of a two-dimensional figure in Experiment 1.

The results of the preliminary experiment are also given in Table 2. They closely par-

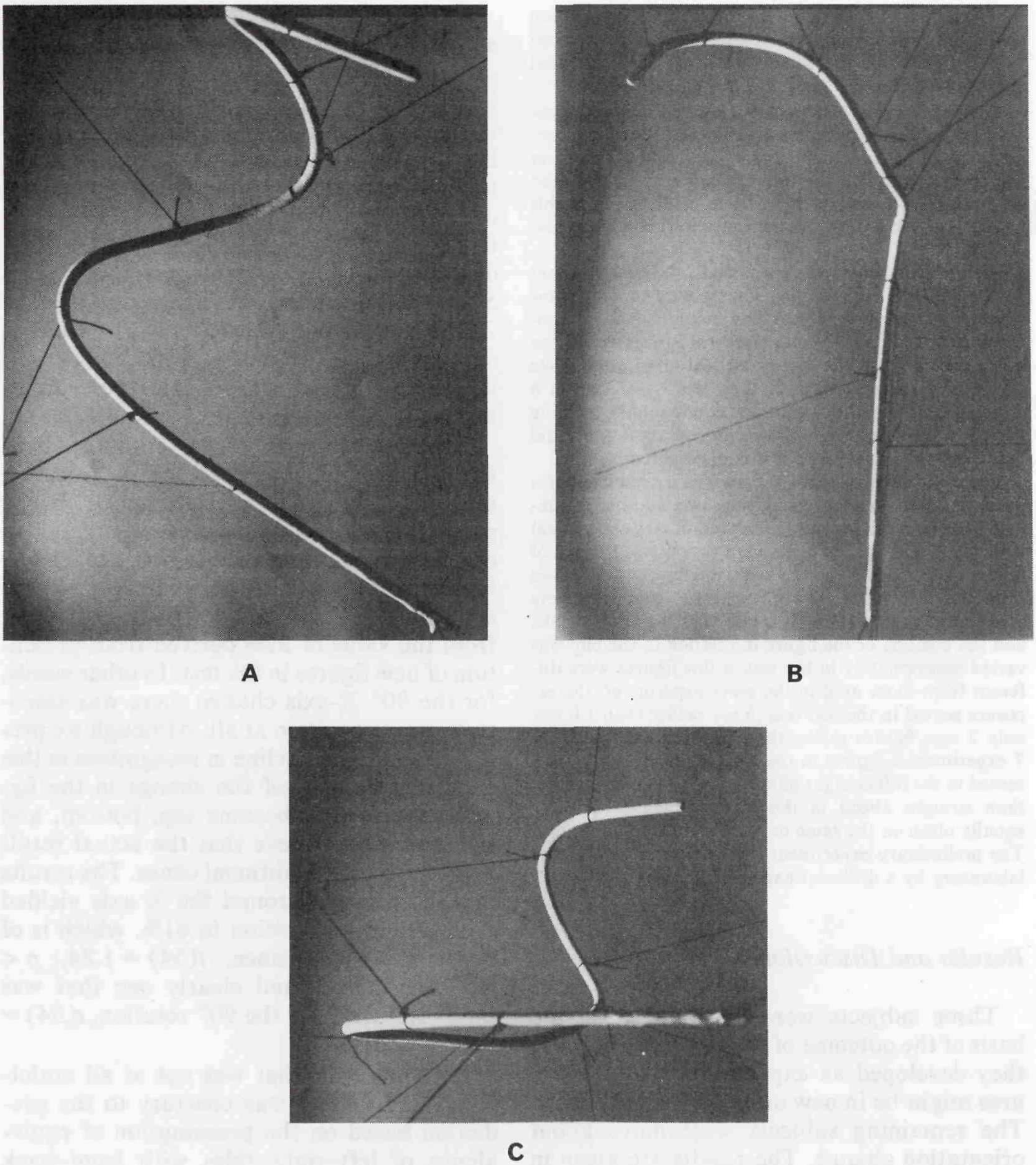

Figure 1. An open figure used in Experiment 1. (A = front view; B = side view; C = bottom view. This figure was luminous and seen in the dark so that the threads shown here were not visible.)

allel those of the main experiment with respect to the major trends outlined above.

General Discussion

Little more needs to be said about the results of the Z-axis test orientations of Experiment 2. Except for the fact that three-dimensional figures were used, these conditions have the same theoretical implications as those in which a two-dimensional figure is rotated in a frontal plane. Phenomenal shape is affected by the altered assignment of directions. That a 90° change would have as much of an effect as, if not a greater effect than, a 180° change not only makes sense

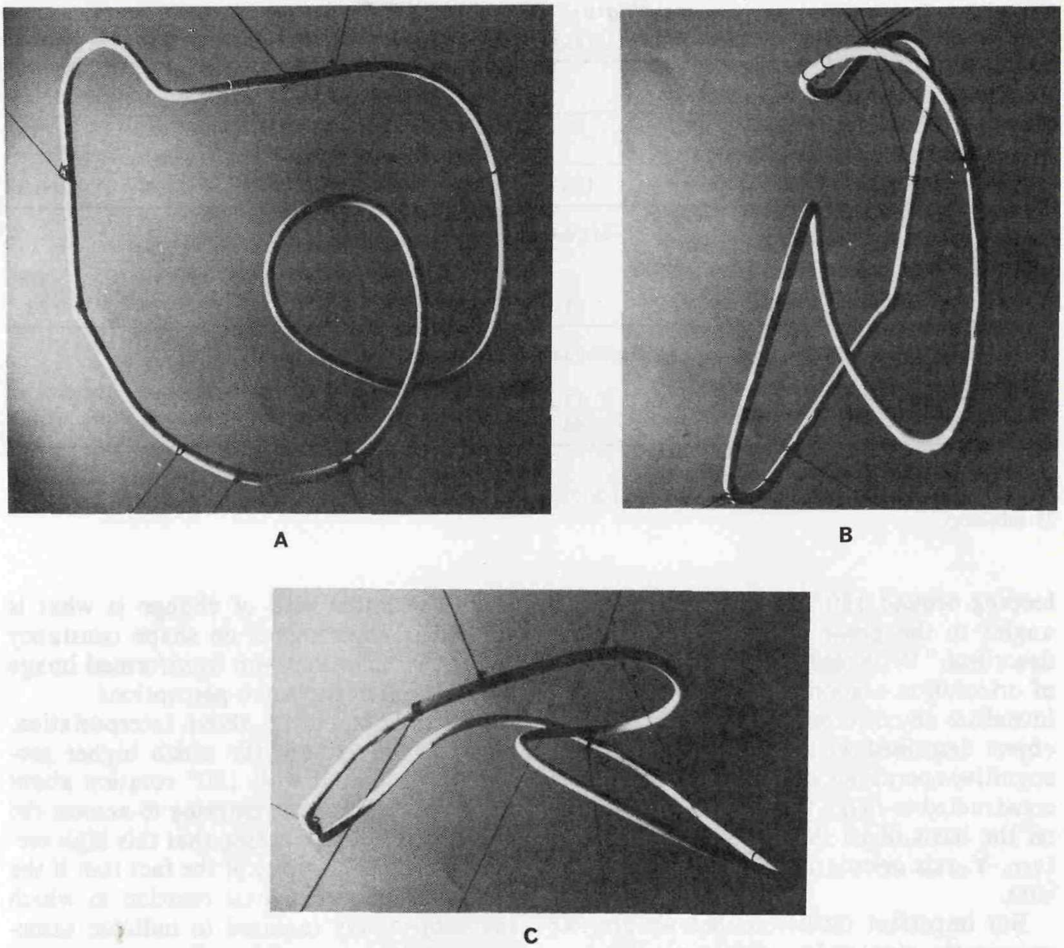

Figure 2. A closed figure used in Experiment 1. (A = front view; B = side view; C = bottom view. This figure was luminous and seen in the dark so that the threads shown here were not visible.)

theoretically but parallels findings with two-dimensional figures (Rock, 1973). Everything depends on the structure of the particular figure. For example, for a square, a 45° rotation produces a maximum change; for a vertically symmetrical figure, a 90° rotation does so, since at 180° the very salient characteristic of symmetry reemerges. One must be careful not to confuse this kind of result with that of an experiment that asks a different question about degree of orientation change. That is, if one does not alter the regions of a figure interpreted as top, bottom, and sides but does alter the retinal-image orientation of the figures (as in viewing from differently tilted head positions certain kinds of complex material that remain upright), then the greater the retinal disorientation, the greater the difficulty of recognition (Rock, 1973).

As already noted, the unanticipated result of Experiment 2 was the significant drop in recognition for the Y90° test orientation. We had expected that the description of the three-dimensional figure would remain much the same because there was no change in its top and bottom and only an exchange in the location of its sides, from left–right to front–back and vice versa. As already stated, we had expected that such changes in side locations would be irrelevant as far as phenomenal shape is concerned. Thus, for example, one might describe one of our figures as "a vertical stem curving as it rises, then

Table 2
Recognition of Experimental and Control Figures: Experiment 2

Variable	0°	X 90°	X 180°	Y 90°	Y 180°	Z 90°	Z 180°	New
Main experiment								
No. of yes responses (N = 28)	23	6	17	12	24	13	16	86[a]
% of yes responses	82	21	61	43	86	46	57	22
Preliminary experiment								
No. of yes responses (N = 28)	25	7	13	13	25	13	12	5[b]
% of yes responses	89	25	46	46	89	46	43	9

Note. X = X axis; Y = Y axis; Z = Z axis. Test orientation: X, Y, Z.
[a] n = 392 for control figures (14 figures/subject × 28 subjects). [b] n = 56 for control figures (2 figures/subject × 28 subjects).

looping around 180°, then turning at right angles to the plane of the figure thus far described." With such a description, changes of orientation around the Y axis should not introduce any difference. In other words the object described would be the same. If the cognitive operations were those of a machine constructed to make this kind of description on the basis of its three-dimensional structure, Y-axis orientation should not be relevant.

But imperfect machines that we are, we apparently give undue weight to the very different retinal projection that occurs as a function of the Y-axis orientation. Figures 1 and 2 illustrate this difference for two figures (the front, A, vs. the side, B, views). If recognition was solely a function of the retinal image, there would obviously be few if any correct identifications of the side view if the front view had been seen previously.

Although the figure is perceived as three dimensional, that perception is governed to a great degree by the retinal projection resulting from the observer's vantage point. With three-dimensional figures, unlike two-dimensional ones, there can be a great qualitative change in this projection such that different projections have very little if any similarity to one another. With two-dimensional figures such change in projection can result at most in a quantitative transformation, for example a compression along one axis. The latter kind of change is what is studied in experiments on shape constancy where, by definition, the transformed image leads to much the same perception.

In the light of the above interpretation, how can we explain the much higher recognition achieved with 180° rotation about the Y axis? Before attempting to answer the question it is worth noting that this high recognition occurs in spite of the fact that if the task were one of mental rotation in which the subject was required to indicate sameness or difference with respect to a nonrotated comparison figure, performance would undoubtedly be poorer for 180° than for 90° rotations (Shepard & Metzer, 1971), the very opposite of our result. In that case the subject would have to rotate the figure mentally to be sure of sameness or difference, whereas in our experiment the subject is responding on the basis of a spontaneous impression of similarity. This emphasizes the importance once again of being clear that our experiments concern the spontaneous description observers make of our figures without knowledge of change of orientation or without an attempt to rotate them mentally.

There are two possible explanations of the finding about 180° rotation. One is that there is a greater equivalence of front with back and left with right than there is of front or back with left or right. Thus, in rotating a figure by 180° about the Y axis, what had been in front is now in back (and vice versa) and what had been to the left is now to the right (and vice versa), whereas for 90° rotations, what had been in front or back is now to the side (and vice versa). The other explanation is that the retinal projection of our wire figures for 180° Y-axis rotation is essentially a left–right reversal of that image. When this image is incorporated into a three-dimensional description, it yields a percept similar to that which was achieved for the 0° orientation.

The effect of change of retinal projection can also explain one of the results concerning the X-axis rotations. The 90° X-axis rotation led to the greatest drop in recognition of all conditions tested. In fact it led to what is essentially no recognition at all. Part of the explanation is, of course, the phenomenal change brought about by the newly assigned directions. But on the basis of the Z-axis 90° change, which should yield precisely the same kind of effect, one might expect this to lead to a decline in recognition to roughly a 45% level, not to a level only half of that percentage. There is, however, an interesting difference between an X- and Z-axis rotation of 90°: The Z change does not alter the retinal projection of the figure at all (except for its orientation), whereas the X change does alter it very much. Comparison of Figure 1A with 1C or of Figure 2A with 2C provides an illustration of such an X-axis change of 90° for two figures. One might say that there are two causes for phenomenal difference in the case of X90° test orientation: (a) The top, bottom, and side directions are assigned to different parts of the figure, thus changing its description and (b) the retinal projection is totally different, thus leading to a different figural description on this basis.

The X180° test orientation does not lead to a different retinal projection as far as internal geometry is concerned, only to an inverted retinal image. Therefore only the first cause listed previously would be relevant. The significantly higher recognition achieved in this case (61%) is thus understandable and, moreover, the closeness of this result to that of the Z180° test orientation (57%) is what we should expect. The only difference between these two conditions of 180° change—apart from a depth change in the X but not in the Z axis, which we know from the Y180° condition is not itself a relevant factor—is that for Z, the retinal image entails a left–right reversal along with its inversion, and for X it does not.

The powerful effect of change of retinal projection obtained in the Y90° and X90° conditions of Experiment 2 calls for further discussion. It seems necessary to conclude that there is a cognitive description based on the retinal projection. Thus, for example, the front retinal projection shown in Figure 1A would lead to a description somewhat like the script capital letter $\mathcal{E}$, whereas the side projection (Figure 1B), would lead to a description somewhat like the number 7. (This is not to imply that such description is based on approximations of the image to familiar objects or categories; it is simply easier to make our point using such examples.) The bottom projection of that figure would lead to a still different description, among other reasons because in this case part of the figure overlaps other parts of it. To be sure, these descriptions include the third dimension of the figure as seen from the observer's vantage point. But the three-dimensional percept is dominated by the specific retinal projection.

At the same time, the figure can be and probably is described in terms of its objective properties, independent of the retinal projection of the moment. Yet the first kind of description apparently carries enough weight to lead to an overall impression of shape that will vary from projection to projection. This first kind of description might be called an egocentric one, based as it is on the vantage point of the observer vis-à-vis the figure, whereas the second kind of description is essentially objective, based as it is on the internal relationship of the parts of the figure to one another. If this analysis is correct, it suggests a hitherto unrecognized egocentrism in perception.

Some theoretical speculation that seeks to relate these findings to the more general effects of orientation on form perception may be warranted here. Consider the situation where a tilted observer views a figure that remains in its upright orientation in the environment. With no information or set to the contrary, the observer will correctly assign directions to the figure on the basis of visual and gravitational information. Therefore, according to what was said earlier, despite the abnormal retinal orientation of the figure's image, there should be no change in the description of the figure, and it should be readily recognized.

However, what was left out of the discussion is the fact that even under these conditions, it is difficult to perceive correctly certain kinds of stimulus material as, for example, cursive writing or pictures of faces. To explain this fact it was suggested that a process of correction is required in which the perceptual system first analyzes the image on the basis of its given retinal orientation (Rock, 1973). The absolute retinal coordinates apparently establish a primitive, egocentric top, bottom, and sides, but these must be superseded by a different set of such directions, the objectively correct ones, when, as in the example under discussion, other information indicates that these are not aligned with the retinally given ones. This step entails some process of mental rotation and, for relatively simple figures, is normally easily achieved. For certain complex material, however, the correction process is not entirely successful, so that the retinal orientation continues to play a role in how the figure is perceived. Therefore, with change of orientation in a frontal plane, there are often also two figural descriptions to reckon with, one based directly on the retinal image that is thus egocentric and one based on the directions assigned to the figure.

We can extend this analysis to the problem of figural symmetry. If the tilted observer views a figure that is symmetrical about an axis that is vertical in the environment, the figure will, as noted earlier, appear symmetrical. But we can conjecture that this percept is achieved only by a correction process of discounting the asymmetrical projection of the image with respect to the vertical retinal orientation. Conversely, if the figure is tilted so as to be symmetrical about that vertical retinal axis (i.e., egocentrically symmetrical), it ordinarily will not appear to be symmetrical. This means that the system passes over or rejects the symmetry that is present in a primitive form by virtue of the retinal symmetry and ends up not perceiving the figure as symmetrical! However, if the axis of symmetry is established by a set, or instructions, or a line drawn through the figure, and if a sensitive test such as reaction time is employed, then it may be the case that the detection of symmetry will be superior when the axis is vertical on the retina. For now no process of correction entailing mental rotation is required. This may explain the findings of Corballis and Roldan (1975) referred to earlier. But assuming this analysis is correct, it does not as such support the hypothesis that phenomenal symmetry is based on the bilateral symmetry of the brain. Rather, symmetry about a retinally vertical axis leads to perceived symmetry—under the conditions described above—because of the primitively given egocentric direction of verticality. Thus, in another investigation, Corballis and Roldan (1974) demonstrated a rapid detection of symmetry when their patterns were flashed entirely within a single retinal half-field, so that the primary projection to the brain was entirely to one hemisphere.

We believe a parallel analysis can be made of the effect of rotation of a three-dimensional figure about the Y axis. In principle, the specific retinal projection should be superseded by a description based on both the directions assigned to the figure (which are unchanged) and the objective relations of the parts of the figure to one another. However, we can assume that there is a primitive description based on the specific character of the retinal projection. Given the complexity of our wire figures, it is likely that this description is not easily passed over in favor of the more objective description. It is even likely that if the information is given as to precisely how the figure has been rotated about its vertical axis, there still would be a difficulty in achieving the objective description that would make recognition possible. Even if recognition succeeded under such conditions, the perception would undoubtedly remain different from that of the figure in the original orientation. If these conjectures are correct, the effect would be very similar to that of the inadequate perception of complex two-dimensional figures when their retinal orientation is abnormal despite knowledge of their true orientation.

There is one other finding in both experiments reported here, the importance of which transcends the particular focus of this investigation. As can be seen from the results of all conditions where the up-down-sides orientation of a figure in the environment is changed (e.g., Experiment 1, 90° frontal plane and 90° sagittal plane conditions; Experiment 2, X180°, Z90°, and Z180°), although recognition declines, it is higher than the proportion of "yes" responses made to the new figures introduced in the test. In four of these five cases the difference is significant at beyond the .01 level.

In previous work on orientation change in a frontal plane this question was not adequately tested and the theoretical issue not resolved (Rock, 1973, pp. 36–41). It was not adequately tested because a baseline of recognition was not established by including new figures in the test. The question of interest here is why *any* recognition should occur when orientation is changed, since presumably the description, based as it must be on orientation, would be so different. One might think that the phenomenal change created by orientation change would be as great as that created by geometrical difference. Among the possible answers previously suggested are the following: The experimental figure is stylistically the same in any orientation and different from new test figures introduced; the figure has its own intrinsic axis of orientation so that phenomenally it may not be tilted even when it is physically; the subject mentally rotates either the training or test figure, thus establishing directions other than those intended by the experiment. Since we believe the design of the present experiments in all likelihood eliminated all of these possibilities, we are left with an unsolved problem. The obvious answer is that despite the profundity of the effect of a new figural orientation on its cognitive description, there remains some core description that is faithful to the internal geometry of the figure and that is orientation free. Thus our disoriented test figures will still look more similar to the subjects than our new test figures, despite the general stylistic similarity of these to each other. An alternative answer is that despite our intentions and despite the reports of the subjects in the interview to the contrary, some mental rotation did occur in the test. If so, it would to that extent obviously undo the effect of physical orientation change. This particular problem therefore warrants further investigation.

A brief summary of the major findings and conclusions of this study may be helpful: Altering the up-down-sides orientation of a two-dimensional figure in a sagittal plane viewed by observers naive about such change has the same powerful effect on its phenomenal shape as does altering the orientation of such a figure in a frontal plane (Experiment 1). A similar effect holds true for three-dimensional figures that are rotated about their X axes into different orientations (Experiment 2). On the other hand, alterations of orientation of two-dimensional figures within the sagittal plane that only entail front–back reversal (Experiment 1) or of three-dimensional figures that only entail such reversal (Experiment 2, Y180° test orientation) has no effect on phenomenal shape. These findings support the interpretation that the sides of figures are defined in terms of their location between top and bottom rather than in terms of left and right directions.

Altering the orientation of a three-dimensional figure about its Z axis has essentially the same effect and the same explanation as altering the orientation of a two-dimensional figure about this axis in a frontal plane (Experiment 2).

Altering the orientation of a three-dimensional figure by 90° about the Y axis in Experiment 2 was expected to have little effect on phenomenal shape because there is no change of top–bottom attribution and because there is only an exchange in the location of sides from front or back to left or right (and vice versa). However this change did have an appreciable effect on recognition. It was suggested that the explanation of this effect is based on the great qualitative change in the retinal projection of such a figure in this condition. That projection leads to an egocentrically based figural description very different from the original one and is sufficiently salient to dominate the overall impression, despite another description that occurs based purely on the objective structure of the figure. This is an important new finding about form perception and shape constancy not previously known because of the relatively simple objects typically used in such experiments. The very low recognition that occurred for the 90° X-axis transformation in Experiment 2 can be explained along similar lines. That is, in addition to change of directional attribution, there is in this case also a qualitatively very different retinal projection. The high recognition for the 180° change of orientation about this axis can be understood in terms of the fact that the retinal projection is here unchanged (except for left–right reversal).

In our view then, depth transformations will only affect form perception if they alter a figure's perceived directions or if they yield a qualitatively different retinal projection (not merely a foreshortened projection as with a two-dimensional figure).

The effect of a qualitatively different retinal projection of three-dimensional figures on form perception is analogous to the effect of altered retinal orientation of two-dimensional figures rotated in a frontal plane. For here, too, recognition may fail under certain conditions, despite an effort to describe the figure on the basis of its correctly perceived coordinate environmental directions. Thus in both cases there would seem to be a description based directly on the retinal image, despite an effort toward a further description based on the objective characteristics of the figure.

Finally, it would appear that all those orientation changes that do entail new attribution of figural directions, although certainly lowering recognition significantly by virtue of the altered figural description achieved, do not eliminate recognition entirely. It was tentatively suggested that this fact may be based on some component of the overall figural description that is orientation free, that is, based solely on the figure's internal geometry, whether two or three dimensional.

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