

Shape Constancy and Polar Perspective

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The distortion of polar perspective depends on the depth of the tridimensional shape and on the observation distance. In four experiments using 54 undergraduates as subjects, we found that a compensation process which takes depth and observation distance into account corrects for such distortions. Compensation was demonstrated in experiments in which deceptive information on depth and on observation distance was provided. The result was distortions of the perceived shapes that would be expected if compensation were based on the deceptive information.

When a surface with a fixed shape is given with a slant in relation to the line of sight, the shape of its retinal image differs from the objective shape. Then if the perceived shape differs from the retinal shape in the direction of the objective shape or is in agreement with the objective shape, we speak of *shape constancy*. Hochberg (1971) discussed two explanations of such a correction for the distortion of image shapes caused by slant of the objective shape to the line of sight. One "explanation . . . is that we know what shape an object really has because of our previous experience with it" (p. 515). In other words, memory is assumed to have an influence on perceived shape (memory hypothesis). The other explanation assumes that "shape constancy depends on slant being taken into account" (p. 515) (compensation hypothesis). Although Hochberg makes no commitment to either of these explanations, an article by Wallach and Moore (1962) presented evidence that in an instance of shape constancy involving a triangular shape, constancy clearly resulted from taking slant into account.¹ That compensation operated here did not, however, mean that there can be no other causes for shape constancy, as the authors correctly noted. It does not, for instance, imply that shape constancy cannot also be based on an effect of memory, provided an orthogonal shape is involved. Epstein (1973) accepted the compensation hypothesis. He based his view on an investigation by Kaiser (1967) in which stereoscopic vision provided cues for slant. In his own research on shape constancy, Epstein also used surfaces whose slants were stereoscopically given (Epstein & Hatfield, 1978; Epstein, Hatfield, & Muise, 1977).

There is another instance of shape constancy which, in contrast to the perceptual corrections for image distortion caused by slant, has not been investigated. When tridimensional objects are viewed from a short distance, their retinal images have the configuration of polar perspective, but the distortions implicit in that configuration are not perceived. A correction takes place that raises questions resembling those connected with the

correction for the effect of slant: Is the correct shape that is perceived due to a memory of the object's shape, or does compensation operate?

A well-known fact provides a partial answer. When a wire cube, attached to a stem, is made to rotate and is observed from a short distance, its retinal image undergoes continuous deformations. Nevertheless, the cube is perceived to remain rigid. This seems to be the result of a correction for the perspective distortions of the cube's retinal image that cause the deformations. But when the observer sees the cube inverted, it appears distorted and seems to deform when it is made to rotate (von Hornbostel, 1922). This observation was not compatible with the memory hypothesis in its simplest form, and it suggested that we first put the compensation hypothesis to a test.

The degree of distortion of polar perspective is proportional to the depth of the observed shape and inversely proportional to the shape's distance from the eye. Compensation for this distortion, therefore, involves taking depth and observation distance into account, and this requires that the depth of the shape and cues for the observation distance be given. The operation of similar but simpler compensation processes, such as size and stereoscopic depth constancy, has been demonstrated in two ways: Either the cues that enable perception to compensate are eliminated and the expected loss of constancy is demonstrated (Lichten & Lurie, 1950), or deceptive cues are provided and predicted errors in perceiving are found to occur (Wallach & Zuckerman, 1963). We chose the latter method. We presented a wire cube in such a way that the distortion of its retinal image was small and was combined with cues for a short observation distance. If constancy were an effect of memory, no distortion should be perceived, because the cube shape is readily recognized. If, however, constancy took cues for observation distance into account, the perceived cube would be strongly distorted. A short observation distance normally accompanies a strong distortion, and the conjunction of a short observation distance and strong distortion results in the perception of a regular cube. But when in our planned experiment a weak distortion is to

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¹ Because the article by Wallach and Moore (1962) appeared after the next article dealing with shape constancy was submitted for publication, it is not cited in the latter and is rarely quoted in subsequent publications on this topic.

be paired with a short observation distance, the compensation process that causes a strong alteration at that distance may provide it also when the image is only a little distorted. Overcompensation may occur; a strong compensatory alteration in combination with a small distortion of the retinal projection would result in the perception of a cube that is more distorted than the retinal projection that caused it. Such a result would be a potent argument in favor of compensation.

To achieve this combination of a short observation distance with a retinal projection showing little distortion, the cube's projection had to be made independent of the observation distance. This was done by having the subject view the projection of a cube on a translucent screen. A small light source illuminated the screen from the rear, and a wire cube, located between the screen and the light source and so close to the screen that it almost touched it, cast a shadow that was observed by the subject from the other side of the screen. A finite distance between the light source and the screen resulted in the shadow of the cube having the configuration of polar perspective, and the degree of perspective distortion varied with the distance of the light source from the screen.² The distance of the subject from the screen could be varied, but this had no effect on the distortion in the cube projection that was the same on the retina as on the screen.

Two conditions were used. The experimental condition was arranged in accordance with the scheme just described: The distance between the light source and the screen was large so that the shadow of the cube was only slightly distorted, but the observation distance was short so that a real cube at that distance would have been given with strong distortions. In the control condition the two distances were such that the arrangement simulated the conditions that a real cube would have provided. The distance of the light source was chosen so that the distortions of the shadow of the cube were in accord with the same short observation distance that was employed in the experimental condition.

Because compensation for the distortion of polar perspective involves taking observation distance into account, we saw to it that all possible cues for the distance between the subject's eyes and the screen on which the shadow of the cube was visible were provided: The subject observed binocularly. A cloth with a large pattern of squares was placed on the surface of the table in front of the screen and adjacent to it. Because the subject looked obliquely down on it, the pattern was given with perspective distortion. Wallach, Moore, and Davidson (1963) found that such an arrangement served as an additional distance cue (p. 199), and this technique was used again by O'Leary and Wallach (1980). Finally, we made use of the fact that image sizes of familiar objects serve as potent distance cues (Wallach, Frey, & Bode, 1972, Experiment 5; see also O'Leary & Wallach, 1980). A dollar bill was fastened on the screen below the shadow of the cube.

Compensation for the distortion of polar perspective also involves taking the depth of the tridimensional shape into account, and information about the shape's depth was needed. Because stereoscopic vision, which ordinarily provides the requisite information, was absent from our manner of presentation, we made use of the kinetic depth effect. The cube whose shadow the subject observed was slowly turned back and forth through a small angle.

The subject had the task to compare the shape of the cube in the experimental and the control condition and to tell which version looked more cubelike and had more nearly rectangular corners. The following arrangement enabled the experimenter to change rapidly between the experimental and the control condition. The distant light source was in a fixed position and remained lit throughout the experiment. The near light source was mounted at the end of a horizontal arm that could be swung through an angle of 90° so that the source was either in its proper position or was moved out of the way. A black shield was attached in back to the near source so that it blocked the light from the distant source from reaching the screen when the near source was in position.

Experiment 1

Method

Subjects. Twelve undergraduate students were paid for serving as subjects.

Equipment. A translucent screen 70 cm wide and 48 cm high stood on a table that was covered with a cloth with a pattern of 7.5-cm squares that were parallel to the edge of the table. The screen was placed away from the edge so that an area of the pattern 28 cm wide and running the width of the screen was visible to the subject. The lowest 12 cm of the screen were covered with black cardboard. A dollar bill was fastened in the center of this black area. A shielded 7.5-W bulb illuminated the square pattern and the dollar bill.

The two light sources consisted of C-2R 6.2-V bulbs encased in boxes that allowed light to escape only on one side. The boxes were painted black inside. The filaments of these bulbs had a diameter of 3 mm, small enough for the wires of the cubes to cast sharp shadows. The current for the bulbs was supplied by variable transformers, making it possible to dim the bulb that was nearer to the screen to the point where the two bulbs provided equal screen illuminations.

Two wire cubes of different size were used, one with an edge of 22.8 cm and a smaller one with an edge of 11.5 cm. Each cube was in the diamond position. The stem that supported it was attached to the midpoint of one of the edge wires so that it formed an angle of 135° with each of the two adjacent cube faces. With the stem in vertical orientation, the two vertical faces of the cube formed diamonds. The two light sources were 97.1 cm and 314.4 cm from the screen. When the large cube was turned so that its two vertical faces were parallel to the screen, the ratio of the size of the shadow of the smaller face to the size of the shadow of the larger face was .93 when the far light source cast the shadow. This "distortion ratio" was .79 when the near light source was used. For the smaller cube the corresponding distortion ratios of .96 and .89 were thus less different from each other. The subject viewed all cube shadows with the head in a headrest from a distance of 97 cm.

A cube stem was mounted on the slow shaft of a reversible motor, and the cube was turned alternately clockwise and counterclockwise through an angle of 25° at a rate of 5 s per cycle. At the midpoint of its oscillation, the vertical faces of the cube formed an angle of 45° with the screen. The cube was also slightly slanted, its shaft forming an angle of 6° with the screen.

Procedure. The subject was told that he or she would be shown two figures in succession and "was to judge whether one is a better cube shape," based on rectangularity and equality of surface sizes. One of the shadows was shown, and the experimenter checked whether the subject

² The senior author believes that James J. Gibson used such an arrangement to control the degree of polar perspective, but he was unable to locate Gibson's report.

Table 1
*Distances of the Eyes From the Screen and Distances
 Commensurate With the Shadows With a
 Distortion Ratio of .93*

Distance of source	Distortion ratio	Cube sizes (in cm)		
		22.8 ^a	11.5 ^b	5.2 ^c
Near	.79	97.1	49.0	22.2
Far	.93	314.4	158.6	71.7

^a *N* = 18. ^b *N* = 15. ^c *N* = 15.

saw the larger edges as near and the smaller as far. The experimenter pointed to an edge and asked the subject whether that edge was "closest." If it was not, the subject was taught to invert the figure. All subjects were instructed not to make the comparison of the figures when that edge was not in front. Actually, inversions of the cubes were rare, because the distortion of polar perspective operates as a cue for near and far (Braunstein, 1966) and therefore favors the version that is in agreement with the given perspective distortion. To enable the subject to make a comparison, the experimenter alternately interposed the near light source and pushed it out of the way. This was done as often as the subject requested. Six of the subjects first made the comparison for the larger cube and then for the smaller cube, and for the other six this order was reversed.

Results

All 12 subjects judged the shadow of the larger cube the better shaped cube when its shadow had the .79 distortion ratio that was commensurate with the 97-cm observation distance. By comparison, the other shadow, which represented the cube with less distortion—the distortion ratio was .93—looked more distorted. Only 9 of the 12 subjects gave this report for the smaller cube. Two subjects reported the less distorted shadow as the better shaped cube, and one saw no difference.

In this experiment, cube size was not the only variable. The difference between the distortion ratios was greater for the large cube than for the smaller cube. The latter variable was eliminated in our next experiment.

Experiment 2

Method

Subjects. Eighteen undergraduate students, paid for serving as subjects, participated.

Stimuli. A third, still smaller cube was added. Its edge measured 5.2 cm. For each of the three cubes the distances of the two light sources from the screen were chosen so that each pair of shadows had the same two distortion ratios, namely, .79 and .93. The six distances were found empirically: The light sources were gradually shifted to where they produced shadows of the proper proportions. The distance of the subject's eyes from the screen was also different for each pair of cube shadows. These distances are listed in the top row of Table 1. They were selected so that real cubes located at the screen would have caused retinal projections with distortion ratios of .79.

Procedure. There were six orders in which the three cubes could be presented. Thus, each group of 3 subjects saw the shadows of the cubes in the same order. In all other respects the procedure was the same as in Experiment 1.

Results

The results of the comparisons of the shadows of the same cube resembled those of Experiment 1. (See Table 1.) In 48 out of 54 comparisons the shadows that represented the cubes with less distortion because they were formed by the more distant light source were judged more distorted. This result is in agreement with our proposition that a compensation process operates here and takes the short observation distance into account. This interpretation is supported by the result of our next experiment.

Experiment 3

Shape constancy can be conceived to compensate for the distortion of polar perspective by expanding in the perceived shape those parts of the retinal projection that correspond to the more distant parts of the observed tridimensional shape relative to the near parts. Because the distortion of the retinal image becomes greater as the observation distance becomes shorter, compensation requires that this expanding of the more distant parts is greater when the observation distance is shorter. Because our subjects observed the less distorted shadows from a distance shorter than that distortion would warrant, the expanding of the more distant parts should be larger than what would be needed to compensate for the given distortion. As a result the more distant parts should, in that case, appear larger than the nearer parts, and parallel edges occupying the depth dimension should appear to diverge. In other words, the distortions of the perceived cube should be the reverse of the distortions of polar perspective. We repeated part of Experiment 1 to obtain evidence that the distortion indeed took that form.

Two shadows of the large cube were formed with light source distances that differed slightly more than the ones used previously. The two distortion ratios were .94 and .78, and the distance between the subject's eyes and the screen was 90 cm. As before, the two shadows were shown successively. All 15 subjects who participated saw the more distorted shadow, the one with the .78 distortion ratio, as the better shaped cube. Once this judgment had been obtained, the less distorted shadow was shown again and the subject was asked in what respect this figure seemed less cubic. Of the 15 subjects, 7 reported that the receding edges were not parallel but seemed to diverge going into depth. Two subjects said that the angles were not 90°. When they were questioned about whether the receding lines were parallel, they reported that they seemed to diverge going into depth. Five subjects reported spontaneously that the back surfaces were too big. Only 1 subject's description did not clearly indicate that she saw a distortion that was the reverse of the distortion of polar perspective. In other words, 14 of the 15 subjects described a distortion where the more distant parts were larger than the nearer parts. This made it clear that the greater apparent distortion of the less distorted shadow was caused by a compensation that resulted from the deceptive distance information.

Experiment 4

As has been mentioned before, the distortion of polar perspective also depends on the depth of the tridimensional shape.

Therefore, compensation for that distortion implies that the depth of the tridimensional shape be taken into account. Our last experiment was designed to show that the compensation process indeed operates in this manner. Again, the method of deceptive cues was employed. An actual wire cube was viewed through a mirror arrangement that altered retinal disparity by altering the distance between the vantage points of the two eyes. (See Figure 1 in Wallach, Moore, & Davidson, 1963.) When we found that an instrument that increased the effective interocular distance enhanced disparity at a suitably short observation distance to the point where fusion was lost, we decided to use an instrument that decreased the effective interocular distance. The diminished disparities with which a tridimensional shape is given when it is viewed through such an instrument should result in a diminished compensation for the distortion of the retinal projection of the tridimensional shape. Because the distortion of polar perspective is proportional to the depth of the object, diminished depth normally results in less distortion, and less compensation is required. Such a diminished compensation would produce a perceived shape that is not fully corrected for the distortion of polar perspective in the retinal projection of the shape, and the more distant parts of the shape should look smaller than nearer parts. (The instrument changes only disparities; the distortion ratio in the shape's retinal projection is not altered.)

Method

Subjects. Twelve undergraduate students were paid for serving as subjects. They had been selected for good stereoscopic vision.

Equipment. Two identical wire cubes, the smallest of the three whose shadows had been used in Experiment 2 and a duplicate, served as target objects. Both were oriented in such a way that their two diamond faces formed an angle of 10° with the subject's frontal plane. One was viewed directly and the other through the instrument. The latter consisted of a row of four first-surface mirrors (2.8×2.4 cm) that were vertically mounted on vertical stems. The subject's eyes looked into the two outer (ocular) mirrors, whose centers were 6.5 cm apart. These mirrors were in fixed position, forming angles of 45° with the subject's frontal plane. The objective mirrors were placed symmetrically between the ocular mirrors, with their reflecting surfaces approximately parallel to and facing them. The optical distance between an ocular and the neighboring objective mirror was 1.5 cm. Therefore, the instrument diminished the effective interocular distance by 3.0 cm. Each objective mirror could be turned about its vertical axis, making it possible for an experimenter to adjust the instrument so that the target object was viewed through the instrument with the same convergence of the eyes as in direct viewing.

The target cubes were mounted on vertical stems and placed on a line parallel to the table edge, 22 cm apart. The subject saw the cube on the left through the instrument, which was mounted above the edge of the table. To the right was a headrest, which the subject used when he or she viewed the other cube directly. The observation distances were the same for both cubes, namely, 36 cm. Each cube was enclosed by tall vertical panels of white cardboard that prevented the subject from seeing it except through an oblong opening in the front panel. One opening was next to the mirror instrument and the other directly in front of the headrest. Illumination of the rear panel against which the black wire cubes were visible was from light fixtures at the ceiling.

Procedure. The subject was given outside calipers and asked to use them to give estimates of the depth of the wire forms and of the length of a near edge and of a far edge of each. Half the subjects gave the three estimates, first viewing a cube directly and then observing through the

Table 2
Mean Estimates (in cm) of Depth and Length of Edges for 5.2-cm Wire Cubes Viewed Directly or With Diminished Disparity

Estimation dimension	Direct view		Diminished disparity	
	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>
Depth	5.30	.63	4.45	.65
Near edge	5.31	.40	5.32	.46
Far edge	5.36	.51	4.99	.56

instrument; for the others this order was reversed. Of the three estimates, the one for depth was always given first, followed by the estimates for the edges, with order varied. After all six estimates had been made, they were repeated in the same order. The averages of two identical estimates became scores. With an observation distance of 36 cm, the cubes had a distortion ratio of .865. This rather large distance was chosen to ensure that subjects saw all cube edges fused. Because our mostly female subjects had an average interocular distance of 6 cm, the instrument reduced it to one half, and the cube seen through the instrument was, on the average, given with only half its real disparity. An orthogonal wire form of corresponding depth would have had a distortion ratio of .930.

Results

The mean depth and length estimates for the directly viewed cube and for the shape perceived when the cube was viewed through the disparity-reducing instrument are listed in Table 2. The mean estimates in the first column of Table 2 show that, in direct view, our subjects perceived a cube, and the good agreement between the mean estimates and the actual measurements of the cube demonstrates the soundness of our estimation method.

When in the experimental condition the cube was viewed through the instrument, the estimates for the length of the edges show the predicted distortion of the perceived shape; the more distant edges appeared shorter. The difference of 0.33 cm was significantly different from the corresponding difference in the directly viewed cube, $t(11) = 5.034, p < .001$.

When the cube was viewed through the instrument, the distortion ratio of the perceived shape derived from the mean length estimates of the far and near edges was $4.99/5.32 = .938$. This value can be compared with the distortion ratio of .930 of an orthogonal wire form of the diminished depth that corresponds to the diminished disparity produced by the instrument. The fit of .938 with .930 suggests that the diminished disparities were fully taken into account in the compensation process that deals with polar perspective. Again, it appears that a correction for the distortion of polar perspective can be caused by compensation, because we were able to show that deceptive sensory information was effective.

This conclusion is not contradicted by the mean depth estimate of 4.45 cm obtained in the experimental condition, even though that estimate is much larger than the depth of about 2.7 cm, which is to be expected if the perceived depth of the shape that is seen in place of the cube were fully dependent on the diminished disparity. This discrepancy is not unique; there are several instances where a parameter that operates in a compen-

sation process is not also fully effective in perceptual experience. Kaufman and Rock (1962), for example, showed that the relatively large size of the horizon moon results from cues for a larger observation distance. Nevertheless, the horizon moon appears to be nearer than the elevated moon.

Discussion

We have demonstrated that the correction for the distortions of polar perspective can be achieved by a compensation process that takes both the depth of the target object and its distance from the eyes into account. This is only the second known instance of a process that compensates for the effect of proximal stimulation on more than one parameter. It had been known that the process that compensates for the stimulation provided by the relative displacement between head and environment during head movements requires two inputs. Compensation here is not only based on proprioception that provides independent information about head movements, but it also takes observation distance into account (Hay & Sawyer, 1969; Wallach, Yablick, & Smith, 1972).

Under certain circumstances, little or no correction for the distortion of polar perspective seems to take place. Hagen and Elliott (1976) experimented with a series of drawings of seven tridimensional wire shapes. Each shape was represented by five drawings that rendered it with different degrees of distortion of polar perspective, including a version executed in parallel perspective. Subjects had to rate the 35 drawings for natural and realistic look. A strong tendency to prefer the least distorted representations of the shapes was found. This happened even in an experiment where the subject's eye was at the proper station point for each drawing, that is, where the viewing distances corresponded to the degrees of distortion. Whether the nearly absent correction for the distortions of polar perspective, which these findings imply, is an aspect of a special pictorial perception remains to be seen.

The demonstration that a compensation process operates when perceptual correction for the distortions of polar perspective takes place does not preclude familiarity from also operating in bringing about such corrections. This may particularly be the case in connection with orthogonal shapes. To be sure, our method of using deceptive cues for observation distance or for depth brought compensation and familiarity into conflict with each other. Our results, however, show only that under the conditions we used, compensation is more effective than familiarity. They do not mean that, in general, compensation is more potent than familiarity. With their vertical faces in the diamond position, our cubes were given as projections that were not like frequently occurring projections of orthogonal shapes and may

not have been very effective in bringing memories into play that then would cause the perception of orthogonal shapes. That may have been the reason why compensation prevailed.

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