The development of sensitivity to cast and attached shadows in pictures as information for the direction of the source of illumination

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The development of the perception of cast and attached shadows as information in pictures for the direction of the light source was studied with children in kindergarten, third and sixth grades, and adults in college. Subjects viewed photographs of objects under four different positions of illumination, with either cast or attached shadows alone, or with both present. Error in angular displacement from the correct position of the light source was 76.5° for kindergarten children, 40.5° for those in the third grade, 34.9° for those in the sixth, and 18.0° for college students. Neither position of light nor type of object affected performance. Results are discussed in the context of a developmental hypothesis of changing interpretation of the relations between pictorial and nonpictorial space from childhood to adolescence.

Gibson (1950) argued that attached shadows provide information for the true shape of objects in depth. He hypothesized that for any given visual field, the order of projected light and shade could function as information for shape in depth, such that if the order "light-shadowed" yields a perception of protuberance, then the order "shadowed-lighted" anywhere in the same field will yield a perception of indentation. Pictures also can provide such ordered shadow information for shapes in depth as Gibson and others have argued extensively. (Gibson, 1972; Hagen, 1974; Kennedy, 1974). The only hypothetical constraint on the functioning of such information Gibson gave is as follows: "the order of shading is a stimulus for depth . . . , *only in relation to the orientation of the observer to his total visual world* or, more specifically, his orientation to the direction of the illumination" (Gibson, 1972, p. 98).

With some qualifications, it may be assumed that in the ordinary terrestrial environment, light comes from above. Hence, an observer may rely on such an assumption in the ordinary case to interpret ordered shadow information. It is possible, however, as Gibson notes, to experimentally change the direction of the source of illumination without the observer's knowledge and reverse the direction of his perceptions of shapes in depth. This effect depends

on the absence of adequate texture information and is similar to the effect of inverting a picture also lacking texture gradients.

Benson and Yonas (1973) in an investigation of such picture inversions made an important observation about perception of the direction of the source of illumination in pictures. They found that adults assumed the source of illumination to be at the top of a picture regardless of the orientation of the picture itself and responded accordingly to the shadow information, while young children responded lawfully only when the picture was placed vertically. In other words, children appear to assume that the light in a picture comes from above their heads regardless of information to the contrary within the picture itself. In Benson and Yonas's study, for distinguishing convexity from concavity, the mean percentage of errors was only 14.6% for the 3-year-old children when the pictures were oriented vertically and 49.3% when the pictures were oriented horizontally. These data argue for the presence of a developmental change in the ability to treat the representation of space within the picture as an organized whole, discontinuous with the external extrapictorial environment. It follows from Gibson's formulation of the nature of shadow information that the perception of such information in pictures depends on treatment of the pictorial space as a separate whole and on the correct localization of the source of illumination within that whole. Accordingly, an experiment was designed to test for developmental change in the treatment of pictorial shadow information. The experiment investigated the development of the ability to use shadows as information for the direction of the source of illumination within the pictorial space itself.

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METHOD

Subjects

The subjects were children in kindergarten, third grade and sixth grade from a local public school, and adults in an introductory psychology course. There were 35 subjects at each grade level. Approximately half the subjects were male and half female at each grade.

Stimuli

A cylinder and a pentagon, each 10.2 cm high, were constructed out of heavy white paper and photographed against a gray background with the light source at four different positions, 0°, 45°, 135°, and 180°. Each time, the light source was 22.9 cm above the background surface and 34.3 cm away from the center of the base of the object. The camera was a 35-mm single-lens reflex Nikon with a 50-mm lens mounted 25.4 cm above the background surface at a distance of 50.8 cm from the center of the base of the object. Three types of pictures were created from these photographs: (1) pictures in which both cast and attached shadows were present (the original photographs); (2) pictures with only cast shadows depicted; and (3) pictures in which only attached shadows remained. The pictures with cast shadows alone were created by replacing the white object image with an identical line drawing lacking attached shadows. The pictures with attached shadows alone were created by placing the object image removed above against a plain black background. (see Figure 1). Thus, 24 pictures were created, 12 of the cylinder and 12 of the pentagon, with the three types of shadowing depicted for each of the four positions of the light source. Each picture was 16.5 × 10.4 cm with an object image 7.6 cm high.

Procedure

The pictures were mounted vertically with L-shaped hardware and placed one at a time centrally under a flat canopy, 20 × 25 cm, painted blue and designated as the "sky." The canopy 22.9 cm above the bottom edge of the pictures, the same height as the light source used during the initial photography. The subjects were instructed to move a small cardboard "sun" to the correct position in the sky for the shadow information depicted in the stimuli. The sun was anchored at a fixed distance from the canopy center around which it rotated. The distance from the sun to the base of the depicted object was the same as the distance from the original light source to the solid objects (34.3 cm). Thus, subjects were restricted to errors of angular orientation, since errors in height and distance of the sun were eliminated by the design. The subjects were first given time to practice moving the sun around the sky. The first picture was then centrally positioned and the subject was told, "Look very carefully at this picture. Can you show me where the sun should be for this picture? Where was the sun when I made this picture? Move the sun to the right place in the sky for this picture." No mention of shadows was made at this time. The subjects were similarly instructed for each of the 24 pictures, which were presented in a different random order to each subject. An angular grid was drawn on the canopy so that subjects could be scored for magnitude of error by degree of displacement from the correct location. To this end, the subjects were always required to place the sun directly on one line of the grid or precisely on the harsh mark between two lines. Initial placement of the sun for each trial was always at 90°.

The week following testing, the subjects were split into two groups, a training and no-training group. For the training group, 20 of the 35 subjects at each grade level, a combination training/demonstration session was held with the solid cylinder and pentagon and a small lamp. The subjects in this training group were instructed to move the lamp around each of the objects investigating the relation between shadow pattern and the orientation of the light source. The demonstration was terminated when the subject verbalized the law of opposites for light and shadow for both cast and attached shadows at five different positions

of the light source. Following the demonstration, the subjects were again tested with the rerandomized pictorial stimuli. The 15 subjects in the no-training group were simply retested after 1 week's interval.

RESULTS

A six-way analysis of variance was performed on the extent of angular displacement from the correct sun location. On any single trial, a subject could receive an error score from 0 to 16. Zero represents

Figure 1. Photographs of a cylinder taken with the light source at 0°: left, attached plus cast shadows; center, cast shadow alone; right, attached shadow alone.

Table 1
Mean Error for Each Age Group as Scored
and in Angular Degrees

	Mean Error	SD	Mean Error (Deg)	SD (Deg)
Kindergarten	6.8	5.1	76.5	57.4
Third	3.6	3.8	40.5	42.8
Sixth	3.1	4.1	34.9	46.1
College	1.6	1.8	18.0	12.3

correct placement of the sun, and 16, a position 180° away. Thus, an error score of 8 corresponds to a 90° error, 4 to 45° error, etc. This transposition from angular deviation to error scores was made simply to facilitate scoring. The six factors were Training (present-absent), Grade (kindergarten, third, sixth, and college), Pre- and Posttest, Object (cylinder-pentagon), Position of light (0°, 45°, 135°, 180°), and Shadow (attached, cast, both). The main effect for the presence and absence of training was not significant. The main effect for grade was significant, $F(3,129) = 32.6$, $p < .001$. Duncan's multiple range test indicated that all grade levels differed significantly from each other at least at $p < .05$ except the third and sixth grades (see Table 1). The main effect for Pretest/Posttest was significant, $F(1,129) = 33.1$, $p < .001$. Errors decreased significantly on the posttest. Neither the main effect for Object nor the main effect for Position was significant. The main effect for Shadow was significant, $F(2,258) = 7.9$, $p < .01$. Duncan post hoc comparisons indicated that while there was a general improvement from attached shadows alone to cast alone to both together, the only difference between means to reach significance was that between attached shadows alone and both together, $p < .05$.

Three two-way interactions were significant. Training by Pretest/Posttest was significant at $p < .001$ [$F(1,129) = 21.9$]. Performance improved only slightly and nonsignificantly for the no-training groups from the pretest to the posttest, showing only a small practice effect. The groups with training, however, improved significantly, as indicated by Duncan's a posteriori test, $p < .05$, showing the effect of practice plus training. The two-way interaction of Age by Position also reached significance, $F(9,387) = 2.99$, $p < .01$. As can be seen in Figure 2, both sixth grade children and college students made smaller angular errors when the light source was at either 0° or 180°. For children in kindergarten, these positions were the most difficult, often producing 180° errors. Third grade children appeared to be in transition between the confusion generated by these positions for the younger children and the facilitation generated for the older subjects (see Figure 2).

The two-way interaction of Age by Shadow was also significant, $F(6,258) = 7.4$, $p < .01$. All grade

levels except the youngest showed the general pattern of performance suggested by the main effect for Shadow, that is, best performance in the presence of both attached and cast shadows, diminished performance with cast shadows alone, and the poorest performance when attached shadows alone were depicted. Kindergarten children were equally poor with attached shadows alone and with cast and attached together and somewhat better when cast shadows alone were depicted. However, since none of the kindergarten means significantly differed from each other, and the youngest children in general were highly variable, it is extremely unlikely that their pattern of results is indicative of anything other than equally poor understanding of all three types of depicted shadow.

Only one three-way interaction reached significance. Training by Grade by Pre-/posttest was significant at $p < .05$ [$F(3,129) = 3.14$]. All grade levels except college showed the pattern of results indicated by the two-way interaction of Training by Pre-/posttest, that is, a slight practice effect from pretest to posttest for the no-training groups and a significant pretest to posttest decrease in error for the training groups. College level subjects, however, showed slight and equivalent decreases in error from pre- to posttest for both training and no-training groups. Since the mean error for college posttest was only .3, or approximately 12°, in the no-training group, there was room for very little improvement through the addition of training, and indeed there was none. Preliminary analysis indicated no effects of sex or order of presentation of the pictures.

DISCUSSION

Gibson, as noted above, has argued that the successful perception of ordered shadow information in both the ordinary world and in pictures depends

Figure 2. Mean error score in degrees by position of light source for the four grade levels tested.

on the correct localization of the source of illumination. Piaget and Inhelder (1967) found that what they have termed the coordination of perspectives with respect to shadow, light source, and observer is accomplished by the age of 7 or 8 years with real objects. Correct prediction of the shape of the shadow projection of complex objects, however, is not acquired until 10 to 12 years of age. Since the shadow information for direction of the source of illumination is presumably the same in pictures as in the ordinary environment, it follows that successful utilization of such information in pictures should also be accomplished by 7 or 8 years. This is true unless, as noted by Benson and Yonas, the young child is incapable of separating the visual space within the picture from the external nonpictorial space. The data of the present study strongly support their inability to do so. The mean error in angular displacement from the correct orientation of the light source was 76.5° for children in kindergarten, 40.5° for children in third grade, 34.9° for those in sixth grade, and 18.0° at the college level. It is also true that the younger the subject, the greater the variability, and, as noted above, the youngest children often displaced the light source by as much as 180° . It should be noted, however, that no grade level appeared to make judgments completely independent of the information within the picture space itself as did the children in Benson and Yonas' study. The youngest children in the present study, however, were approximately 2 years older than the children observed by Benson and Yonas. These findings are suggestive of a developmental change in the ability to separate internal pictorial space from the nonpictorial surround. In support of such a developmental change, Cooper (Note 1) found, in a study of the development of the ability to compensate for perspective distortion in pictures viewed obliquely, that 3-year-old children respond when viewing pictures as if the projections on their retinas come from real objects fixed in nonpictorial space and not from self-contained representations of those objects fixed in pictured space. Similarly, it has been argued by Pirenne (1970) and by Hagen (1976) that pictures provide observers with a very unusual duality of conflicting information: information for the space within the picture and information for the picture as a representational vehicle, a flat object like any other object. The coordination of these types of information is essential for success-

ful picture perception, since ordinary picture observation almost never takes place at the geometrically correct center of projection. Thus all perspective relations within pictures, including shadows, are necessarily distorted in ordinary viewing. If the information carried by these relations is to be effective despite such distortions, then it must be treated by the observer in context of the pictorial space as a self-contained whole. The observer must learn to use information for the picture as an ordinary object as a signal to attend to within-picture spatial information discontinuous with the ordinary environment. A picture functions as a window between the two environments *only* when the observer is at the correct station point. All other station points require a more complex perceptual process, usually termed a process of compensation for oblique view. Work investigating the limits and development of the ability to so compensate has already begun (Hagen, 1976; Perkins, 1973; Pirenne, 1970; Cooper, Note 1) but the integration of shadow perception within this framework has yet to take a place.

REFERENCE NOTE

1. Cooper, R. *The development of recursion in pictorial perception*. Paper given at Conference on Picture Perception, Center for Research in Human Learning: University of Minnesota, July 1975.

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