Young Children's Knowledge about Visual Perception: Projective Size and Shape

Bradford H. Pillow and John H. Flavell

Stanford University

PILLOW, BRADFORD H., and FLAVELL, JOHN H. *Young Children's Knowledge about Visual Perception: Projective Size and Shape.* CHILD DEVELOPMENT, 1986, **57**, 125–135. Although recent research indicates that an increased sensitivity to visual appearances develops around 4 or 5 years of age, evidence from perceptual studies suggests that certain types of appearances, that is, projective size and shape, are not noticed or understood until at least 7. 4 experiments investigated preschool children's knowledge of the projective size–distance and projective shape–orientation relationships. In Experiment 1, 3- and 4-year-olds were asked whether an object should be moved farther or nearer in order to increase or decrease its apparent size. 4-year-olds performed significantly better than chance, but 3-year-olds did not. Experiment 2 showed that 3-year-olds are able to perceive projective size changes, indicating that although they do not fully understand the projective size–distance relationship, the necessary perceptual information is potentially available to them. In Experiment 3, 3- and 4-year-olds were asked to indicate how a circular object should be rotated to make it appear either circular or elliptical. Again, 4-year-olds performed significantly better than chance, but 3-year-olds did not. Again also, the results of Experiment 4 indicate that although 3-year-olds are not aware of the projective shape–orientation relationship, they are capable of attending to changes in projective shape. Thus, the constraints on children's knowledge of the projective size–distance and projective shape–orientation relationships seem to be at least partly cognitive rather than wholly perceptual. These results are interpreted as further evidence for the acquisition of level 2 percept knowledge during early childhood.

According to Flavell's (1974, 1978) distinction between level 1 and level 2 knowledge of visual perception, at level 1 children can infer what objects can or cannot be seen from another person's viewpoint, whereas at level 2 they also know that an object or array may present different appearances to viewers at different locations. That is, level 2 knowledge enables children to infer the nature, as well as the content, of another person's visual experience. Although the basic distinction between level 1 and level 2 knowledge is clear conceptually and has been supported by the results of a number of studies, the nature of level 2 knowledge has not been fully specified either conceptually or empirically, and the transition from level 1 to level 2 has not been investigated or explained.

The level 1–level 2 distinction has been demonstrated in a number of studies (Flavell, 1978; Flavell, Everett, Croft, & Flavell, 1981; Flavell, Shipstead, & Croft, 1978; Hughes, 1978; Hughes & Donaldson, 1979; Masangkay et al., 1974). In general, 3-year-olds are very competent at level 1 but not level 2 inferences, and level 2 knowledge is usually acquired around 4 or 5 years of age. In the earliest investigation of the level 1–level 2 distinction, Masangkay et al. (1974) assessed level 2 knowledge by asking children about the appearance of a picture from another person's point of view. While the experimenter and the child sat facing each other across a table, the experimenter placed a profile picture of a turtle horizontally between herself and the child. Then the child was asked whether the experimenter saw the turtle upside down or rightside up. Three-year-olds responded correctly on only about half of the trials, whereas 4-year-olds performed near ceiling. Using the turtle task and variants of it, Flavell et al. (1981) obtained similar results. Flavell, Flavell, Green, and Wilcox (1980) investigated another aspect of level 2 perspective-taking knowledge, namely, knowledge of the effects of an object's distance from the observer on the clarity of perception. They found that 4-year-olds were much more competent than 3-year-olds at judging that an ob-

server stationed closer to a small object would be able to see it better than an observer stationed farther away along roughly the same line of sight, and that observers stationed the same distance from the object would be able to see it equally well.

Thus far, level 2 knowledge has been defined only in a general way—that is, as an understanding of how an object's appearance differs when it is seen from different perspectives or under different circumstances. Further specification is clearly possible. Visual appearances are multifaceted; an object may have an apparent size, shape, location, color, texture, or identity, and its features may be clearly visible or difficult to discern. Thus, level 2 knowledge could include a great variety of information, ranging from specific knowledge concerning particular aspects of appearance and particular viewing conditions to more general knowledge about the nature of visual appearances. These latter might include the realizations (a) that multiple appearances may exist for a single object, (b) that appearances may be misleading, and (c) that different viewers may have different perceptual experiences of the same object or scene. The former might include knowledge about the ways that particular aspects of appearance may be affected by specific factors such as spatial transformations of the viewer-display relationship, the quality of illumination, an object's rate of movement through the visual field, the duration of its visibility, the context in which an object is seen, and the viewer's prior knowledge and expectations. This detailed information concerning the influence of viewing circumstances on visual experience may be useful for inferring the nature of another person's visual experience as well as for determining when and how an object is likely to be misperceived, by either oneself or another.

As an initial investigation of this conceptualization of level 2 knowledge about visual perception, the present work investigated young children's understanding of the effects of spatial transformations of the viewer-display relationship on apparent size and shape. Children's understanding of the visual consequences of such changes is of interest for at least two reasons. First, beginning with Piaget and Inhelder's (1956) three-mountains task, the ability to infer how changes in location alter the appearance of an object or array has been a traditional concern in the perspective-taking literature. Second, it is not clear when this understanding should be expected to develop. On the one hand, the classi-

fication of knowledge about spatial transformations as level 2 knowledge suggests that it may be acquired by the age of 4 or 4½, the age at which the first appearance of level 2 knowledge has been found in previous studies (Flavell, 1978, 1981; Flavell, Shipstead, & Croft, 1978; Hughes, 1978; Hughes & Donaldson, 1979; Masangkay et al., 1974). Furthermore, because the acquisition of level 2 knowledge should be facilitated by situations in which (a) differences in appearance are striking and easily perceptible, (b) the relevant changes occur along well-understood dimensions, and (c) there is a simple relationship among the apparent properties in question, relevant objective physical properties, and viewing conditions, it would seem that the effects of changes in distance or orientation on apparent size and shape might be understood relatively early. On the other hand, the natural tendency to perceive constancy rather than retinal projection (Holway & Boring, 1941), present since infancy (Bower, 1974; McKenzie, Tootell, & Day, 1980), could prevent children from noticing retinal projections or discovering their systematic relationships to distance and orientation. Moreover, the results of previous studies indicate that children may not perceive projective size or shape easily. For example, although adults can voluntarily alternate between the perception of objective and retinal size (Epstein, 1963; Gilinsky, 1955), when Piaget (1969) asked young children to match the projective size of two vertical rods by adjusting the length of one of them, children under 7 did not understand the task, as if they had no conception of projective size. In another study, Rappoport (1969) asked 5-, 7-, and 9-year-olds to make one of two equidistant triangles look farther away. The tendency to make the triangle smaller increased greatly between ages 5 and 9, with 5-year-olds responding at chance. Therefore, Rappoport's (1969) results suggest that knowledge of the projective size–distance relationship increases with age and is virtually nonexistent before age 7. Similarly, in a study of form perception, Vurpillot (1964) found that 7-year-olds did not respond differentially to objective and projective shape matching instructions. Their responses to both types of instructions tended toward shape constancy, again suggesting that younger children are not aware of retinal projection.

The present study was designed to investigate the development of preschool children's knowledge of the effects of spatial transformations of the viewer-display relationship on apparent shape and size. In Ex-

periment 1 we assessed 3- and 4-year olds' knowledge of the projective size–distance relationship by requiring them to indicate whether an object should be moved farther away or nearer in order to make it look larger or smaller to either themselves or another observer.

Experiment 1

METHOD

Subjects

The subjects were 32 nursery school children, 16 3-year-olds (mean age 3-10, range 3-7 to 4-0) and 16 4-year-olds (mean age 4-5, range 4-1 to 4-9). Seven of the 3-year-olds were female and nine were male. Six of the 4-year-olds were female and 10 were male.

Materials

Pictures.—Line drawings on 21.5 × 27.5-cm plastic transparencies were suspended at eye level 1.07 m in front of the subject. A 6.4-cm circular portion of each drawing was blank. The missing features from this region were drawn on a circular cardboard cutout attached to a vertical rod that could be placed at various distances behind the transparency. For example, one drawing was a clown without a face. The clown's face was drawn on a separate cardboard circle. When placed at the proper distance behind the transparency drawing, the cardboard circle matched the blank region of the line drawing in projective size and gave the appearance of fitting into the picture like a piece of a puzzle. The cardboard circles were of three sizes: 13 cm, 18 cm, and 21 cm in diameter.

Nonsense shapes.—Three cardboard nonsense shapes with irregular contours (approximately 21 × 25 cm) were used for an additional set of questions.

Procedure

Pretest.—To ensure that all children knew the correct meanings for "big" and "little," at the beginning of the session each child was shown two paper squares (one 5 × 5 cm and the other 23 × 23 cm) and asked which of them was big and which was little.

Picture questions.—Seated behind a 51×71-cm screen, children viewed each picture monocularly through a viewing tube (length 11.4 cm, diameter 4 cm). Only the transparency, the vertical rod with the cardboard cutout, and the plain white wall at the back of the room could be seen through the aperture. The floor, ceiling, sidewalls, and furniture could not be seen. The test trials were preceded by a demonstration in which

the child first viewed the picture with the cardboard cutout positioned so that it appeared to fit the drawing perfectly. Then the cutout was moved nearer, making it look too big for the picture, and farther away, making it look too small. While moving the cutout, the experimenter blocked the child's view of the changes in position by standing stationary in front of the viewing hole with his back to the child and moving the cutout an arm's length in the appropriate direction. This procedure prevented children from learning an association between "bigness" or "smallness" and certain directions of movement or positions in the room. Each test trial began with the cutout positioned so that it fitted the picture. After the child had agreed that the cutout fitted, the experimenter, blocking the child's view of his actions, moved it either farther away or closer to the child and asked whether it looked too big or too little. Then the experimenter asked the following question: "Now the clown's face looks too big [little] so we want to make it look little [big]. To make the clown's face look little [big] to you, should we move it this way or that way?" While offering the two choices of direction, the experimenter pointed toward the child or directly away. Children responded by pointing. No feedback, either verbal or visual, was given regarding the correctness of responses. When children indicated a direction, the cutout was not moved. Instead, the picture and cutout were replaced and a new trial began. The transparency pictures and cardboard cutouts provided a concrete, clearly visible demonstration of projective size differences and the goal of making the circular cutout appear to fit the drawing was well defined. Thus, this procedure made it possible to convey the idea of projective size and to refer to changes in projective size in a simple and direct manner. Moreover, the required response, pointing, was simple and nonverbal.

There were eight test trials with the pictures. On four trials (big trials) the cutout was moved away from the child, making it look little, and the child was asked how it could be made to appear big. The other four (little trials) required the child to indicate how the cutout could be made to appear little. In addition, half of the big trials and half of the little trials were "self"-trials requiring children to make judgments about their own perspective, as described above, and half of the trials were "other" trials requiring children to make judgments about another person's perspective. For the "other" trials, the experimenter sat behind the screen and viewed the pictures through the viewing tube, while the child

stood at the opposite end of the room behind the cardboard cutout. For "other" trials the question was: "Now the clown's face looks too little [big] to me. We want to make it look big [little] to me. To make the clown's face look big [little] to me, should we move it that way or that way?" While asking the question, the experimenter pointed toward and away from himself and the child. Again, children responded by pointing. Because the children stood next to the cutout, which remained stationary, they had no direct access to the experimenter's visual experience and received no verbal feedback; thus children again were prevented from learning an association between "bigness" or "smallness" and certain directions of movement or positions in the room. The sequence of "self" and "other" and "big" and "little" trials was counterbalanced, as was the order of the direction choices (pointing away from or toward the subject) in the test questions.

Nonsense shapes.—As an additional measure of children's awareness of the projective size–distance relationship, a second task was included. While standing in front of a window, the experimenter held one of the nonsense shapes approximately 1.5 m in front of the child and asked the following questions: (a) "If I put this way far away over there [pointing across the street] will it look big to you or will it look little to you?" (far question) and (b) "If I put this right up close to your eyes, will it look big to you or will it look little to you?" (close question). Far and close questions were presented in a counterbalanced sequence, and the order of the choices big or little was counterbalanced. One pair of far and close questions was asked for each of the three nonsense shapes. The first nonsense shape trial was presented immediately after the pretest. The last two were presented after

completion of the eight picture questions. Finally, to determine whether subjects who could predict projective changes also knew that objective size remains constant as projective size changes, after each of the last two far/close pairs an "objective size" question was asked: "You said that when this is far away it will look little [big]. When it's far away is it really and truly little [big], or does it just look little [big]?" The order of "really and truly" and "just look" was counterbalanced. As the wording suggests, each subject's response of big or little to the immediately preceding projective question was used as the size term in the objective question.

RESULTS AND DISCUSSION

All 32 children passed the pretest on the meanings of "big" and "little." The results for the picture questions are shown in Table 1. Whereas the 4-year-olds performed significantly better than chance on the picture questions (mean number correct = 6.81), $t(15)$ = 6.24, $p < .001$, the 3-year-olds did not (mean number correct = 4.38), $t(15) < 1$. Moreover, the 4-year-olds performed significantly better than the 3-year-olds, $t(30)$ = 3.28, $p < .01$. Performance on "self" and "other" trials did not differ, nor did performance on "big" and "little" questions, as indicated by sign tests. On the six nonsense shape questions, both 3-year-olds (mean number correct = 4.13), $t(15)$ = 3.21, $p < .01$, and 4-year-olds (mean number correct = 5.25), $t(15)$ = 6.25, $p < .001$, performed significantly better than chance; again, however, the 4-year-olds performed significantly better than the 3-year-olds, $t(30) = 2.30$, $p < .05$. Performance on far and close questions did not differ significantly by sign test. As indicated by difference scores (number correct on last four trials − number correct on first four trials), performance on the

TABLE 1

PERCENTAGE OF SUBJECTS MAKING 0–8 CORRECT RESPONSES

EXPERIMENT AND AGE	NUMBER OF QUESTIONS ANSWERED CORRECTLY								
	0	1	2	3	4	5	6	7	8
Experiment 1:									
3	6	6	6	19	19	6	19	6	13
4	0	0	0	6	13	6	0	19	56
Experiment 2:									
3	0	0	8	17	8	17	50	...	...
Experiment 3:									
3	0	0	6	19	25	25	25	0	0
4	0	0	0	0	6	31	25	13	25
Experiment 4:									
3	0	0	0	8	8	25	25	8	25

NOTE.—Number possible is 6 in Experiment 2.

last four trials did not differ significantly from performance on the first four trials for either 3-year-olds (mean difference = $-.13$), $t(15) <$ 1, or 4-year-olds (mean difference = .25), $t(15) = 1.46$, $p > .1$.

On the two objective size questions, the performance of 3-year-olds (mean number correct = 1.19) and 4-year-olds (mean number correct = 1.56) did not differ significantly, $t(30) = 1.28$, $p > .2$. These questions were intended to determine whether children who could predict projective size changes correctly also understood that these changes were apparent rather than real. Moreover, asking whether projective size changes are apparent or real made sense only if children had demonstrated an understanding of those changes. Therefore, the objective size–question performance of children who were at or near ceiling on the projective questions was compared with the performance of those who were not, collapsing across age groups. The 18 children who answered at least six of the eight picture questions correctly performed significantly better on the two objective size questions (mean number correct = 1.72) than did the 14 who answered fewer than six picture questions correctly (mean number correct = 1.07), $t(30) = 2.4$, $p < .05$. Furthermore, the probability of answering both objective size questions correctly was greater for children who correctly answered both of the immediately preceding pairs of nonsense shape questions ($p = .72$) than for children who did not answer both pairs of nonsense shape questions correctly ($p = .43$).

Whereas the 3-year-olds performed essentially at chance on the picture questions but showed at least some awareness of the projective size–distance relationship on the nonsense shape task, the 4-year-olds clearly knew that objects appear smaller when farther away and larger when nearer, and those who correctly predicted projective size changes also tended to believe that these changes were apparent rather than real. Moreover, the 4-year-olds' performance did not depend on whether they were required to make judgments about their own or another person's perspective, or whether they had to make the stimuli appear larger or smaller. Thus, their understanding of the projective size–distance relationship seems to have the status of a general rule that can be applied equally well to a variety of situations. Furthermore, this knowledge seems to be acquired around 4 years of age. Therefore, the age at which children in Experiment 1 began to demonstrate clear knowledge of the projective size–distance relationship coincides with the age of transition from level 1 to level 2 knowledge found in previous studies (Flavell, 1978; Flavell et al., 1981; Flavell, Shipstead, & Croft, 1978; Masangkay et al., 1974). Despite the marked difference in the performance of 3- and 4-year-olds on the picture questions, the 3-year-olds' competence on the nonsense shape questions suggests that they may have some understanding of the projective size–distance relationship and that the acquisition of this knowledge may be gradual. Although Experiment 1 did not directly measure children's perceptual abilities, the 4-year-olds' awareness of how apparent size changes with distance implies that, contrary to Piaget's earlier findings, they must have some ability to perceive projective size; otherwise, they could not have discovered this relationship.

Experiment 2

Despite the numerous opportunities to observe the effects of distance on apparent or projective size encountered in the course of everyday experience, many of the 3-year-olds in Experiment 1 did not demonstrate an understanding of the relationship between the two. There are at least three reasons why 3-year-olds might not fully understand this relationship. First, an inability to consciously perceive projective size may prevent them from learning about its relationship to distance. In contrast, even if 3-year-olds can notice changes in projective size, they may not have discovered a systematic relationship between apparent size and distance, either because they ordinarily do not attend to projective size, despite their ability to do so, or because they give little thought to changes in projective size on those occasions when they do in fact observe them, or both. Experiment 2 investigated 3-year-olds' ability to detect changes in projective size. An inability to notice such changes could be the primary factor limiting the acquisition of knowledge about the projective size–distance relationship. However, if 3-year-olds are able to detect changes in projective size, then whatever constraints there may be on their knowledge would appear to be attentional or conceptual.

METHOD

Subjects

The subjects were 12 nursery school children (mean age 3-9, range 3-5 to 4-0). Six were male and six were female.

Materials

The materials were a spherical balloon, a bicycle tire pump, and a bicycle.

Procedure

Objective changes.—With the child watching, the experimenter gradually inflated and deflated the balloon and asked, "Does it look like the balloon is getting big or getting little?" The order of the choices "big" and "little" was counterbalanced. The purpose of this procedure was to ensure that children knew the meanings of "big" and "little" and could correctly identify and label increases and decreases in size.

Projective changes.—While the child and experimenter watched from the sidewalk, a cyclist rode a bicycle down the middle of a street, moving alternately away from and toward the child. At the beginning of each trial the experimenter pointed to the cyclist and said, "See the man on the bicycle? Watch him carefully." Then, as the cyclist rode away (away trials), the experimenter asked, "Look at the man on the bicycle. Does it look like he is getting big or getting little?" The order of the choices "big" and "little" was counterbalanced. After riding approximately 50 m, the cyclist stopped and the experimenter pointed to him and repeated the instructions. As the cyclist returned (toward trials), the experimenter again asked whether he appeared to be getting little or big. The cyclist made three round trips, so each child was asked six questions about apparent size. The balloon was inflated and deflated four times, twice at the beginning of each session and once more after each of the first two round trips by the bicycle rider, making a total of eight trials with the balloon. To make it clear that projective, rather than objective, size was being referred to, size changes were the only alternatives offered in the projective question. Therefore, because only projective size was changing, the question should make sense and elicit consistently correct responses only if interpreted as referring to projective size changes.

RESULTS AND DISCUSSION

All 12 children answered the eight balloon questions correctly, indicating that they understood the words "big" and "little" and could use them correctly to refer to changes in size. The results for the projective questions are presented in Table 1. Performance on these six questions was significantly better than chance (mean number correct = 4.83), $t(11) = 4.16$, $p < .01$, and performance on toward and away trials did not differ significantly by sign test. Though group performance was not at ceiling, these results indicate that 3-year-olds have some ability to attend to changes in projective size. Thus, although the results of Experiment 1 suggested

that 3-year-olds may not yet have a complete understanding of the projective size–distance relationship, the results of Experiment 2 suggest that the perceptual information necessary to learn about this relationship may be potentially available to them.

Experiment 3

Experiment 3 investigated children's understanding of the relationship between projective shape and orientation relative to a viewer's line of sight. The procedure was similar to that used in Experiment 1 except that subjects were required to indicate how an object should be oriented to make it appear either circular or elliptical to either themselves or another observer.

METHOD

Subjects

The subjects were 32 preschool children, 16 3-year-olds (mean age 3-9, range 3-5 to 4-0) and 16 4-year-olds (mean age 4-6, range 4-1 to 4-9). Nine of the 3-year-olds were male and seven were female. Six of the 4-year-olds were female and 10 were male.

Materials

A cardboard box with a 21.5 × 27.5-cm rectangular opening on one side and a 4-cm circular opening on its top was used as a viewer. Plastic transparencies with line drawings could be placed over the vertical opening on the side or they could be placed on a horizontal frame that fit into the box near its top. This arrangement permitted an observer either to look into the box from the side or down into it from the top. The line drawings depicted animals whose bodies were represented either with an empty circle or an empty ellipse. Inside the box (and below the horizontal picture frame) there was a horizontal rod to which a cardboard circle (diameter, 9 cm) was attached. The projective image of the circle could be made to appear either circular or elliptical by rotating this rod. All of the circles had patterning on them except for a plain black circle that was used for a demonstration, and the inside of the box was well illuminated. Consequently, the circle's tilt was easily visible. The transparency drawings were positioned so that the projective image of the cardboard circle inside the box could be made to fit the boundaries of the circular or elliptical region in the drawing when viewed from the proper location. For example, one drawing was a horse with an elliptical body. When a brown circle was tilted at the proper angle it appeared to fit into the picture, representing the horse's body.

Procedure

Pretest.—To ensure that all children knew the correct meanings of "fat" and "thin," at the beginning of the session each child was shown a cardboard circle and a cardboard ellipse and asked which of them was fat and which was thin. Next, to ascertain that children understood the words "standing up" and "lying down," each child was shown a pair of pencils, one vertical and the other horizontal. The child was asked which pencil was standing up and which was lying down.

Picture questions.—Children viewed each picture monocularly through a viewing tube either from in front of the box or from the top of the box, depending on whether the picture was attached to the front of the box (front question) or placed in the horizontal frame (top question). The test trials were preceded by a demonstration trial. First the child viewed a picture of an elliptical animal with the circle positioned so that it appeared to fit the drawing perfectly. Then, the circle was rotated to make it appear too "fat" (circular) to fit the picture, and rotated again to make it appear too "thin" (narrow ellipse). While rotating the circle, the experimenter blocked the child's view of these changes by placing a hand in front of the viewing tube. This procedure prevented children from learning an association between circular or elliptical projective shape and specific directions of rotation or specific orientations within the box. Moreover, projective shape was dissociated from the circle's position in the box (vertical vs. horizontal) by using two viewing positions, front and top, separated by a 90° angle. When viewed from above, a circle in a nearly horizontal position would appear more or less circular, but when viewed from the front of the box, a circle in this position would appear elliptical. However, the opposite would be true when the circle was rotated toward a vertical position. Each test trial began with the circle positioned so that it appeared either too circular or too elliptical to fit the picture. The child was asked whether it looked too fat or too thin. Then the experimenter asked the following question: "Now the horse's body looks too fat [thin] so we want to make it look thin [fat]. To make the horse's body look thin [fat] to you, should we make it stand up like this [holding a finger upright] or lie down like this [holding a finger horizontally]?" No feedback, either verbal or visual, was given concerning the correctness of responses. When children made their responses, the circle was not rotated. Instead, the picture and circle were replaced and a new trial began. There were eight test trials. On four trials children were asked how the circle could be made to appear

"thin" (elliptical) and on the other four they were required to indicate how it could be made to appear "fat" (circular). In addition, half of the trials required children to make judgments about their own perspective, and half of the trials required judgments concerning another person's perspective. For these "other" trials, the child sat next to the box while the experimenter viewed the picture. The question for the "other" trials was, "Now the horse's body looks too fat [thin] to me, so we want to make it look thin [fat] to me. To make the horse's body look thin [fat] to me, should we make it stand up like this [holding finger upright] or lie down like this [holding finger horizontally]?" The picture was placed horizontally and viewed from above on half of the trials and attached vertically and viewed from in front on the other half. The order of "fat" and "thin," "self" and "other," and "front" and "top" trials was counterbalanced, as was the order of the choices "stand up" and "lie down" in the test question. Finally, there were two "objective shape" questions, one following each of the last two "thin" trials for each child. The question was: "You said if we make this lie down [stand up] it will look thin. When we make it lie down [stand up], is it really and truly thin, or does it just look thin?" The order of the choices "really and truly" and "just look" was counterbalanced. The child's choice of stand up or lie down for the immediately preceding picture question was used in the objective shape question.

RESULTS AND DISCUSSION

All 32 children passed both the pretest on the meanings of "fat" and "thin" and the pretest on the meanings of "stand up" and "lie down." The results for the picture questions are shown in Table 1. Whereas the 4-year-olds performed significantly better than chance on the picture questions (mean number correct = 6.19), $t(15) = 6.37$, $p < .001$, the 3-year-olds did not (mean number correct = 4.44), $t(15) = 1.35$, $p > .05$. Moreover, the 4-year-olds performed significantly better than the 3-year-olds, $t(30) = 5.40$, $p < .001$. Performance on "self" and "other" trials did not differ significantly for either age group, nor did performance on "front" and "top" trials, or performance on "fat" and "thin" questions, as indicated by sign tests. Performance on the last four trials did not differ significantly from performance on the first four trials for either 3-year-olds (mean difference = $-.63$), $t(15) = 1.50$, $p > .05$, or 4-year-olds (mean difference = $-.25$), $t(15) = 1.16$, $p > .2$. On the two objective shape questions the performance of 3-year-olds (mean number correct = .81) and 4-year-olds (mean number correct = 1.31) did

not differ significantly, $t(30) = 1.85$, $p > .05$. For further analysis of performance on these questions the responses of children who performed near ceiling on the picture questions were compared with the responses of those who did not, collapsing across age groups. The 14 children who answered at least six of the eight questions correctly performed significantly better on the two objective shape questions (mean number correct = 1.5) than did the 18 who answered fewer than six picture questions correctly (mean number correct = .72), $t(30) = 3.0$, $p < .01$. Furthermore, the probability of answering both objective shape questions correctly was greater for children who correctly answered the two picture questions immediately preceding the objective shape questions ($p = .67$) than for children who did not answer both of these picture questions correctly ($p = .25$).

The pattern of results in Experiment 3 was very similar to the findings in Experiment 1. The 3-year-olds performed near chance, but the 4-year-olds demonstrated a clear understanding of the relationship between an object's projective shape and its orientation relative to an observer's line of sight. They could correctly indicate how the orientation of an object should be changed to make it appear either more circular or more elliptical, and this understanding was not limited to the familiar horizontal line of sight; that is, they performed equally well when asked questions about a vertical (downward) line of sight. Thus, the 4-year-olds understood that projective shape is a function of the object's orientation relative to the viewer's line of sight rather than a function of its orientation relative to the horizontal plane. They also understood that these changes were apparent rather than real. Moreover, the 4-year-olds' performance did not depend on whether they were required to make judgments about their own or another person's perspective, or whether they had to make the stimuli appear circular or elliptical. Therefore, their understanding of projective shape appears to be sufficiently general to allow them to solve problems equally well in a variety of situations. Furthermore, this ability seems to be acquired by the age of 4 or 4½, the same age that children in Experiment 1 began to show clear understanding of the projective size–distance relationship. Although Experiment 3 did not directly measure children's perceptual abilities, the 4-year-olds' understanding of the relationship between orientation and projective shape implies that children of this age must possess some ability to perceive projective shape, contrary to Vurpillot's (1964) earlier findings.

Experiment 4

Experiment 4 investigated 3-year-olds' ability to detect changes in projective shape. An inability to notice such changes may be the primary factor limiting the acquisition of knowledge about the relationship between projective shape and orientation. If they are able to detect changes in projective shape, then the constraints on their knowledge would appear to be at least partly cognitive.

METHOD

Subjects

The subjects were 12 nursery school children (mean age 3-8, range 3-5 to 3-11). Six were female and six were male.

Materials

The materials were two plates with different patterns (diameter 23 cm), a thin children's book (20 × 20 cm), a paper folder (23 × 30 cm), and a picture of a worm. The worm picture was made by superimposing a piece of blue paper with the outline of a worm cut out of it over an orange piece of paper with the worm's eye drawn on it. The blue paper was cut in half horizontally so that the worm's width could be varied by adjusting the distance between the halves of the outline.

Procedure

Objective changes.—The child watched as the experimenter gradually separated the two halves of the worm's outline, making the worm fatter, and then gradually moved them closer together, making the worm thinner. Each time the worm's width changed, the child was asked whether it was getting fat or thin. The order of the choices "fat" and "thin" was counterbalanced. The purpose of this procedure was to ensure that children understood the terms "fat" and "thin" and could use them to label changes in shape. There were four trials at the beginning of each session (two fat and two thin) and two more halfway through the test procedure.

Projective changes.—The child and experimenter sat about 2 m apart, facing each other. The experimenter held up an object— one of the plates, the book, or the folder—and slowly rotated it. While the object was being rotated, the experimenter asked "Look at this. Does it look like it's getting fat or getting thin?" There were eight trials, four each with circular stimuli and with rectangular stimuli. The order of the choices "fat" and "thin" was counterbalanced. On half of the trials the object's projective image grew wider and on half of the trials it grew narrower. As was the case in Experiment 2, the alternatives in the pro-

jective question were chosen so that the question would make sense only if interpreted as referring to projective, rather than objective, shape.

RESULTS AND DISCUSSION

All 12 children answered the objective change questions with the worm correctly, indicating that they understood the words "fat" and "thin" and could use them to refer to changes in shape. Results for the projective changes questions are presented in Table 1. Performance on the eight projective shape questions was significantly better than chance (mean number correct = 5.92), $t(11) = 3.92$, $p < .01$. Performance on "fat" and "thin" trials did not differ significantly, nor did performance with vertical and horizontal rotation, as shown by sign tests. Though group performance was not at ceiling, these results indicate that 3-year-olds have some ability to perceive changes in projective shape. Although, as suggested by the results of Experiment 3, many 3-year-olds may not yet have discovered the systematic relationship between projective shape and orientation, the results of Experiment 4 suggest that the perceptual information necessary to learn about this relationship may be potentially available to them.

General Discussion

Contrary to the previous findings that children under the age of 7 years are unaware of projective phenomena in vision (Piaget, 1969; Vurpillot, 1964), the results of this study suggest that children begin to notice changes in projective size and shape, and to understand the visual consequences for projective size and shape of certain spatial transformations of the viewer-display relationship, during the preschool years. Considering that the natural tendency to perceive constancy should render changes in apparent size subtle and difficult to notice in most ordinary circumstances, the discovery of the projective size–distance and projective shape–orientation relationships by children as young as 4 years seems particularly striking. At least two factors may have contributed to the discrepancy between the present results and those of previous studies. First, because real size and shape are most salient, children may tend to interpret projective size or shape-matching instructions as referring to real size and shape, whereas the forced-choice questions used in the present study may be less ambiguous because requiring subjects to indicate a direction of change should eliminate real size or shape as a possible choice. Second, the transparency drawings may have

helped to convey the notions of projective size and shape more clearly than they were conveyed in previous studies. As the level 2 classification would suggest, knowledge of both the projective size–distance relationship and the projective shape–orientation relationship is acquired during the fourth year. Thus, the age at which this knowledge first appears coincides with the age of transition from level 1 to level 2 found in previous studies (Flavell, 1978; Flavell et al., 1981; Flavell, Shipstead, & Croft, 1978; Hughes, 1978; Hughes & Donaldson, 1979; Masangkay et al., 1974). Moreover, 4-year-olds' understanding of the visual effects of changes in distance or orientation is not limited to specific situations, such as making judgments about their own perspective or about familiar points of view. Instead, their knowledge is general and abstract enough to allow them to solve a variety of problems, including those that require taking another person's visual perspective.

Although children are not able to demonstrate a complete understanding of the relationships between projective size and distance or projective shape and orientation until approximately the age of 4, 3-year-olds seem to have some ability to attend to changes in projective size and shape. Thus, the necessary perceptual information may be available to children before they construct these relationships. Perhaps 3-year-olds' knowledge is constrained by an inability to conceptualize variations in one dimension as a function of variations in another. According to Piaget (1970), between the ages of 4 and 6 years children begin to develop a logic consisting of functions of the form $y = (f)x$ that allows them to discover dependency relationships and covariations. A number of other theorists (Case, 1984; Fischer, 1980; Fischer & Pipp, 1984; Halford, 1982; Siegler, 1981) have also hypothesized the development of similar capacities at this age. For example, Fischer (1980) has proposed that at the age of 4 or 5 children develop the ability to relate covarying entities to each other, and Siegler (1981) has suggested that children do not begin to conceive of dependency relationships in terms of consistent rules before the age of 4. In the case of projective size or shape, an object's appearance is a product of its objective properties and the prevailing viewing conditions (e.g., distance from the observer). Hence, discovering the projective size–distance and projective shape–orientation relationships may require, at least in part, an ability to relate changes on covarying dimensions to each other. However, because the present tasks could be solved by conceptualizing the relevant dimensions as attributes with two

values (e.g., big and little) rather than as continuous dimensions, the understanding of covariation evidenced by our subjects may be very rudimentary. More generally, progressing from level 1 to level 2 may involve acquiring information about visual appearances, constant objective properties, and viewing circumstances, and discovering systematic relationships by coordinating observations of the three. The finding that prior to the acquisition of level 2 knowledge, children can notice changes in appearance without having systematic understanding of them is consistent with this view of the transition from level 1 to level 2.

Given that 4-year-olds demonstrated a clear understanding of the projective size–distance and projective shape–orientation relationships, a further question concerns the exact nature of the knowledge or abilities they used to solve the perspective problems in this study. Salatas and Flavell (1976) have distinguished between level 2 rules and computational procedures. As they and others (Flavell, Flavell, Green, & Wilcox, 1981; Flavell, Omanson, & Latham, 1978) have shown, in some cases it is possible to infer how an object appears from another viewpoint or would appear if moved relative to the observer, either by applying knowledge of perspective rules or by using computational procedures (e.g., mental rotation). Because the relationship between projective size and distance can be summarized by the simple rule that projective size decreases as distance increases and vice versa, projective size problems probably are solved by rule use. However, the projective shape–orientation relationship is more difficult to encode in a simple rule. Inferring how a complex object looks from various positions around the object seems to lend itself to computational procedures rather than rule use because rules relating different views of the object would be numerous and complex. Moreover, Marmor (1975) found evidence that 5-year-olds represent rotation in their imagery and that their kinetic imagery is similar to that of 8-year-olds and adults, suggesting that the present subjects could have used such processes. On the other hand, easier shape-orientation problems employing simple stimuli and not requiring precise computation might be soluble by rule use. For example, knowing that more of a surface is visible when it is perpendicular to the line of sight than when it is parallel or nearly parallel to the line of sight might be enough to solve the problems used in Experiment 3. Unfortunately, the data provide no hints as to how children in the present study solved these problems. The two strategies seem

equally likely, and children may have differed in their preferred strategy.

Taken together with the results of previous studies, the results of the present investigation suggest that young children possess rich and detailed knowledge concerning the nature of visual experience. Knowledge of visual perception is an important acquisition not only because of its relevance to visual perspective taking but also because it may be related to understanding the concept of appearance and the distinction between appearance and reality (Flavell et al., 1983), as well as to the ability to assess another person's knowledge state. Cognitive perspective-taking studies (e.g., Marvin et al., 1976; Mossler et al., 1976; Wimmer & Perner, 1983) indicate that both the ability to infer what another person does and does not know and the understanding that others may have false beliefs increase around the age of four. In many situations, in order to know what objects or events another person has knowledge of, it is necessary to be aware of what that person has seen. Similarly, awareness of the nature of someone else's perceptual experience of an object or event often may be necessary for making inferences about how that person is likely to construe that object or event. In other words, level 2 perceptual perspective-taking abilities may contribute to the ability to infer what another person knows or believes about the nature, as contrasted with the existence or occurrence, of objects or events. In addition, level 2 perspective knowledge may facilitate the realization that one's own beliefs may be based upon misleading perceptual experiences, and therefore may differ from objective reality, as well as from the beliefs of others. Recent evidence (Flavell, Green, & Flavell, in preparation) indicates that level 2 perspective-taking ability is highly correlated with understanding of the appearance-reality distinction. Moreover, knowledge about visual perception is of interest because there is a great deal that young children might come to know about visual experience. As described earlier, many aspects of the appearance of objects or scenes can vary besides projective size and shape, and many factors other than spatial transformation of the viewer-display relationship can affect visual experience. Consequently, the extent of children's knowledge in this domain and the manner in which it develops seem worthy of further investigation.

References

Bower, T. G. R. (1974). *Development in infancy*. San Francisco: W. H. Freeman.

Case, R. (1984). The process of stage transition: A neo-Piagetian view. In R. J. Sternberg (Ed.), *Mechanisms of cognitive development* (pp. 19–44). New York: W. H. Freeman.

Epstein, W. (1963). The influences of assumed size on apparent distance. *American Journal of Psychology, 76,* 257–265.

Fischer, K. W. (1980). A theory of cognitive development: The control and construction of hierarchies of skills. *Psychological Review, 87,* 447–531.

Fischer, K. W., & Pipp, S. L. (1984). Processes of cognitive development: Optimal level and skill acquisition. In R. J. Sternberg (Ed.), *Mechanisms of cognitive development* (pp. 45–80). New York: W. H. Freeman.

Flavell, J. H. (1974). The development of inferences about others. In T. Mischel (Ed.), *Understanding other persons* (pp. 66–116). Oxford: Blackwell.

Flavell, J. H. (1978). The development of knowledge about visual perception. In C. B. Keasey (Ed.), *Nebraska symposium on motivation* (pp. 43–76). Lincoln: University of Nebraska Press.

Flavell, J. H., Green, F. L., & Flavell, E. R. (In preparation). The development of knowledge about the appearance-reality distinction.

Flavell, J. H., Everett, B. A., Croft, K., & Flavell, E. R. (1981). Young children's knowledge about visual perception: Further evidence for the Level 1–Level 2 distinction. *Developmental Psychology, 17,* 99–103.

Flavell, J. H., Flavell, E. R., & Green, F. L. (1983). Development of the appearance-reality distinction. *Cognitive Psychology, 15,* 95–120.

Flavell, J. H., Flavell, E. R., Green, F. L., & Wilcox, S. A. (1980). Young children's knowledge about visual perception: Effects of observer's distance from target on perceptual clarity of target. *Developmental Psychology, 16,* 10–12.

Flavell, J. H., Flavell, E. R., Green, F. L., & Wilcox, S. A. (1981). The development of three spatial perspective-taking rules. *Child Development, 52,* 356–358.

Flavell, J. H., Omanson, R. C., & Latham, C. (1978). Solving spatial perspective-taking problems by rule versus computation: A developmental study. *Developmental Psychology, 14,* 462–473.

Flavell, J. H., Shipstead, S. G., & Croft, K. (1978). Young children's knowledge about visual perception: Hiding objects from others. *Child Development, 49,* 1208–1211.

Gilinsky, A. S. (1955). The effect of attitude upon the perception of size. *American Journal of Psychology, 68,* 173–192.

Halford, G. S. (1982). *The development of thought.* Hillsdale, NJ: Erlbaum.

Holway, A. F., & Boring, E. G. (1941). Determinants of apparent visual size with distance variant. *American Journal of Psychology, 54,* 21–37.

Hughes, M. (1978). Selecting pictures of another person's view. *British Journal of Educational Psychology, 48,* 210–219.

Hughes, M., & Donaldson, M. (1979). The use of hiding games for studying the coordination of viewpoints. *Educational Review, 31,* 133–140.

Marmor, G. S. (1975). Development of kinetic images: When does the child first represent movement in mental images? *Cognitive Psychology, 7,* 548–559.

Marvin, R. S., Greenberg, M. T., & Mossler, D. G. (1976). The early development of conceptual perspective taking: Distinguishing among multiple perspectives. *Child Development, 47,* 511–514.

Masangkay, Z. S., McClusky, K. A., McIntyre, C. W., Sims-Knight, J., Vaughn, B. E., & Flavell, J. H. (1974). The early development of inferences about the visual percepts of others. *Child Development, 45,* 357–366.

McKenzie, B. E., Tootell, H. E., & Day, R. H. (1980). Development of visual size constancy during the 1st year of human infancy. *Developmental Psychology, 16,* 163–174.

Mossler, D. G., Marvin, R. S., & Greenberg, M. T. (1976). Conceptual perspective taking in 2- to 6-year-old children. *Developmental Psychology, 12,* 85–86.

Piaget, J. (1969). *The mechanisms of perception.* New York: Basic.

Piaget, J. (1970). *Genetic epistemology.* New York: Norton.

Piaget, J., & Inhelder, B. (1956). *The child's conception of space.* London: Routledge & Kegan Paul.

Rappoport, J. L. (1969). Size-constancy in children measured by a functional size-discrimination task. *Journal of Experimental Child Psychology, 7,* 366–373.

Salatas, H., & Flavell, J. H. (1976). Perspective-taking: The development of two components of knowledge. *Child Development, 47,* 103–109.

Siegler, R. S. (1981) Developmental sequences within and between concepts. *Monographs of the Society for Research in Child Development, 46*(3, Serial No. 189).

Vurpillot, E. (1964). Perception et représentation dans la constance de la forme. *Année Psychologique, 64,* 61–82.

Wimmer, H., & Perner, J. (1983). Beliefs about beliefs: Representation and constraining function of wrong beliefs in young children's understanding of deception. *Cognition, 13,* 103–128.