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Young children's knowledge about visual perception: Lines of sight must be straight

John H. Flavell*, Frances L. Green, Carla Herrera and Eleanor R. Flavell

Department of Psychology, Jordan Hall, Stanford University, Stanford, CA 94305-2099, USA

Four studies were done to test the hypothesis that, although knowledgeable about some important facts concerning visual perception, 3-year-olds have not yet learned that lines of sight must always be straight. Subjects of 3 to 5 years of age were asked whether they (Study 1) or toy observers (Studies 2–4) would be able to see objects via looking paths that were curved rather than straight: for example, by looking through a bow-shaped hollow tube or along the curve of its outside wall. Consistent with the hypothesis, 3-year-olds gave no evidence of possessing this straight-line-of-sight rule. In contrast, 5-year-olds showed at least some command of it.

There is now considerable evidence (e.g. Astington, Harris & Olson, 1988; Wellman, 1990) that children acquire some basic knowledge about the mind during the preschool years. Part of that knowledge concerns visual perception. Research suggests that by 3 years of age children already know something about the conditions governing the visibility of objects (Flavell, 1978; Flavell, Shipstead & Croft, 1978; Hughes & Donaldson, 1979; Lempers, Flavell & Flavell, 1977; Yaniv & Shatz, 1988, 1990). They seem to realize that, in order to see an object, the observer's eye or eyes have to be (*a*) open and (*b*) facing in the general direction of the object; they also realize that (*c*) there cannot be any large vision-blocking object or screen interposed between observer and object (Flavell, 1978). A study by Hughes & Donaldson (1979) nicely illustrates this knowledge. Subjects of 3 and 4 years looked down at a table containing a small boy doll, two small walls, and two policeman dolls. The walls intersected at right angles to form a cross shape as viewed from above. The policemen were stationed at the outer ends of two adjacent walls, facing inward towards their intersection. The subjects' task was to position the boy such that he could not be seen by either policeman. Even the 3-year-olds succeeded in correctly placing the boy in the quadrant furthest from the policeman—the only location not visible to either of them.

Do young children also know that lines of sight are always straight? That is, do they understand that the visual path from an observer to a target cannot be curved but must always be straight? One would at first assume that they must understand it. Even as infants children seem able to determine approximately where another person

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is looking from looking at the person's eyes (e.g. Butterworth & Cochran, 1980). They can even do this when there is no visual target present, i.e. when the person is just staring in a certain direction (Churcher & Scaife, 1982). Infants probably do this by projecting a roughly straight line of sight outward from the person's eyes, with its direction computed from the eyes' spatial orientation. This suggests that when reading people's gazes they may operate under the tacit assumption that the looking-paths of these gazes are straight. Such understanding is also suggested by young children's sensitivity to conditions *b* and *c* above, as shown by their good performance on Hughes & Donaldson's (1979) and other Flavell (1978) visual perspective-taking tasks. Finally, they certainly could have learned from countless visual experiences in everyday life that they cannot 'bend' their looking paths over, under, or around visual barriers. For example, one would think that they must have learned from experience that they cannot see around corners without moving their heads.

However, it is still possible that 3-year-olds might possess the foregoing skills and knowledge and yet not command any explicit, general, or rule-like understanding that lines of sight are necessarily straight. For example, they may tacitly assume that lines of sight are *normally* straight without yet explicitly recognizing that they are *always* and *necessarily* straight. That is, they might tacitly expect them to be straight without yet knowing that they cannot be curved. Likewise, they may conclude that an observer's view of an object is blocked only when, as they themselves glance from observer to object, they see interposed between the two an object that is easily recognizable as a visual barrier; examples would be a wall set perpendicular to the observer's line of sight or the sharply angled corner of a building with the object located around the corner from the observer. The 3-year-olds in Hughes & Donaldson's (1979) study could have used such a procedure to solve the boy-and-policemen problem: namely, place the boy such that when you look from each policeman to the boy you see an interposed wall. On the other hand, if task conditions were such that subjects saw nothing that looked like a vision-occluding object when glancing from observer to target, they might assume that the observer could in fact see the target, even when seeing it would clearly require the observer to look along a curved rather than a straight line of sight. They might do this even while consciously aware of its curved nature, providing only that they did not construe anything they saw as being a visual barrier between observer and target.

We report four studies designed to test the hypothesis that young children lack a general rule that lines of sight must be straight and, therefore, would believe that it is possible for observers to see objects via curved looking paths, provided that there are no conspicuous interposed objects in the task display that would trigger a correct negative judgement.

Study 1

In Study 1 we asked 3-year-old and 5-year-old children to predict whether they would be able to see through a hollow tube that was progressively bent to greater degrees of curvature, as shown at the top of Fig. 1: 180° (straight), followed in succession by 140°, 90°, and 0° (candy-cane shaped). We predicted that at least the

3-year-olds would think they could see through it, except perhaps when the degree of curvature became too extreme. We then provided the children with explicit feedback that even a slightly curved tube (140°) did not afford visibility of the target and subsequently retested them for learning and transfer on the same items used in the first part of the study.

Method

Subjects. The subjects were 14 female and five male 3-year-olds (mean age = 3:5; range = 3:2 to 3:10) and 15 female and 4 male 5-year-olds (mean age = 5:2; range = 4:7 to 5:7). The children were drawn from a university laboratory preschool and were largely from upper-middle-class backgrounds. All subjects were individually tested in a single session by the same female experimenter. No subject failed to complete the procedure.

Procedure. The stimuli were three silver-coloured flexible pieces of hollow tubing, 60.3 cm in length and 6.4 cm in diameter, sufficiently stiff that they would stay in any shape until bent by the experimenter. A small object (flower, toy bear, or toy soldier) was suspended just inside one of the ends of each tube.

The three tubes were introduced in straight-line viewing position (180°) to the subjects in the following fashion. The experimenter randomly selected one of the tubes and let the subject see that a small object was present at one of the ends. She then held the tube horizontally above the child's head, perpendicular to his/her line of vision, and asked: 'Do you think if you looked through here (she tapped the viewing end of the tube with her finger), that you'd be able to see this (object name)?' (She tapped the end with the suspended, but not currently visible, object.) Following the subject's prediction, he or she was allowed to look through the tube and was asked whether the object was seen. The experimenter then gave each subject a chance to look through the other two tubes. The purpose of this part of the procedure was to make sure the children understood the meaning of our prediction-of-seeing questions and knew that all three tubes were hollow. Three blocks of trials were then given in the following order.

Pre-feedback trials. The experimenter randomly selected one of the tubes and asked four prediction questions, in fixed order, about the visibility of the small object when the tube was held above her head, first straight (180°), then somewhat curved (140°), then more curved (90°), then bent double (0°), and finally straight (180°) again. (The degree indicated for each tube is that of the angle formed by the intersection of lines drawn perpendicular to, and into, each mouth of the tube. See Fig. 1 for the actual appearance of the successive curvatures shown to the child.) Prior to each question she called the subject's attention to the alteration of the tube by saying: 'Now I'm going to make this tube (or it) like this. Watch.' The tube was held in horizontal position above the child's head, with the ends slightly tilted upward, such that the angle of curvature, but not the suspended object, was perceptible to the child. The test question was the same throughout this block of trials: 'If you look through here (the experimenter tapped the viewing end of the tube), will you be able to see the———?' (tapping the other end). Following the fourth question only (prediction for 180°), the child was allowed to look through the tube to show that the previous alterations in the shape of the tube had not made it impossible to see through when straight.

Feedback trials. The subject was allowed to choose one of the remaining two tubes for this block of six questions. As in the previous block of trials, the experimenter began by holding the tube above the child's head in the 180° position and calling the child's attention to the alteration of the tube as she bent it to 140°. The subject was then asked to predict his/her view for 140° ('If you look through here, will you be able to see the———?'), and following this to test whether the object was visible for 140° when he or she actually looked ('Do you see the———?'). If the subject erred on the second question (i.e. said he or she could see thc object), the experimenter looked through the tube herself, gave the correct answer, and repeated the question until a correct response was obtained. The same prediction followed by feedback questions was next asked when the tube was straightened to 180°, and then once again when bent to 140°. Thus, the sequence was prediction followed by feedback, first for 140°, then for 180°, and then for 140° again. This meant that subjects predicted for 140° once before and once after

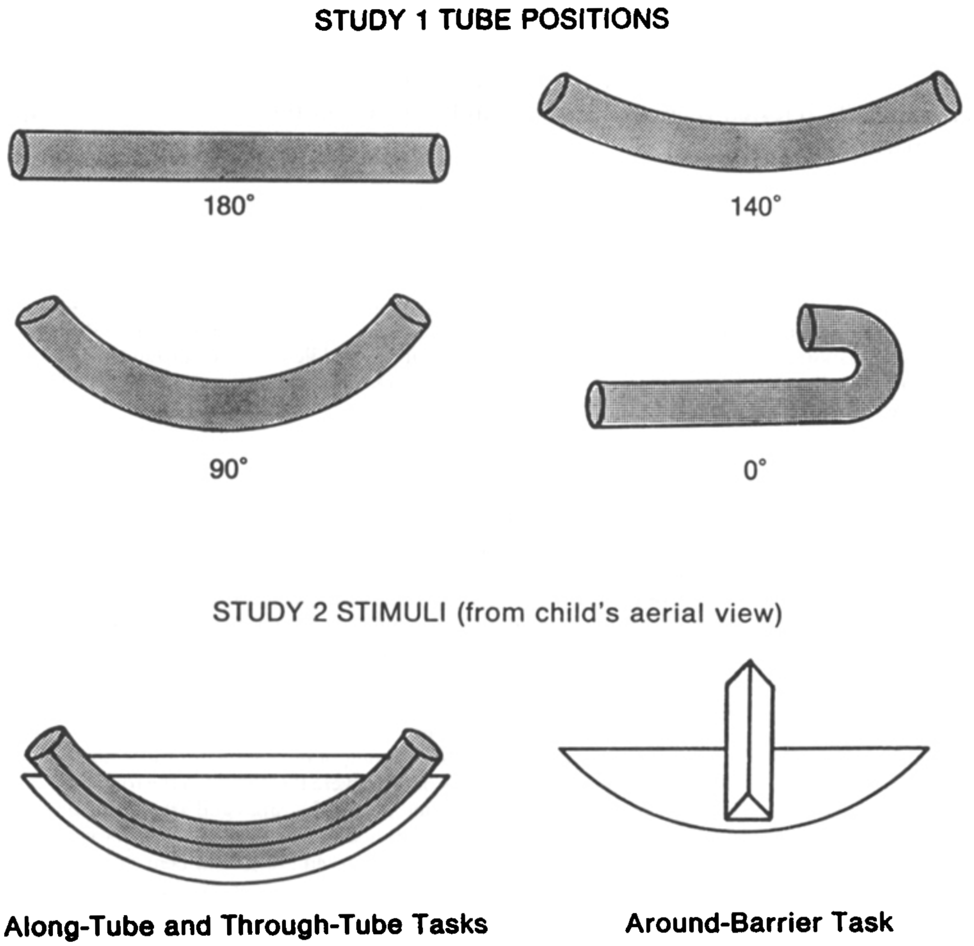

Figure 1. *Stimulus displays used in Studies 1 and 2.*

experiencing an inability to see the object at that degree of curvature, and had a total of two such feedback experiences before making predictions on the post-feedback trials.

Post-feedback trials. The experimenter said: 'Let's try it again with a different toy' (the third tube), and repeated the order of questioning and viewing positions given in the first block of trials, i.e. 140°, 90°, 0°, and 180°. Feedback was not given following these final four prediction trials.

Results and discussion

As would be expected, subjects in both age groups usually predicted correctly that they would be able to see the object through straight (180°) tubes. Of more interest was the accuracy of their predictions when the tubes were not straight. Percentages of subjects in each age group correctly predicting that they could not see the object on these trials are shown in Table 1. A 2 (age) × 3 (degree of curvature) analysis of variance carried out on the three pre-feedback prediction trials revealed significant

Table 1. Percentage of subjects in each age group correctly predicting non-visibility through tubes of various curvatures in Study 1

Age	Trials							
	Pre-feedback			Feedback Before	Feedback After	Post-feedback		
	140°	90°	0°	140°	140°	140°	90°	0°
3	16	26	32	16	26	21	32	32
5	47	47	68	26	79	84	84	89

main effects for age (F (1,36) = 5.06, $p < .05$) and degree of curvature (F (2,72) = 4.20, $p < .05$) with no significant interaction. *Post hoc* Tukey tests indicated ($p < .05$) that the 0° task was easier than both the 140° and 90° tasks. On the feedback trials, t tests showed that the 5-year-olds performed significantly better on the second, subsequent-to-feedback 140° trial than the 3-year-olds did. They also performed significantly better on this second trial than they themselves had done on the first, prior-to-feedback 140° trial, whereas the 3-year-olds showed no such improvement. On the post-feedback trials, the same 2 × 3 ANOVA yielded a significant effect for age only (F (1,36) = 23.91, $p < .001$). Related t tests indicated that the 5-year-olds also performed significantly better on the post-feedback trials than on the pre-feedback trials of the 140° and 90° tasks, but not the 0° task; the 3-year-olds showed no such significant pre-to-post improvement on any of these three tasks.

These results suggest the following picture of each group's performance across this series of eight trials. Most 3-year-olds initially assumed that they could see through the tube no matter how extreme its curvature. For example, 13 of the 19 predicted that they could see the object even when the tube was bent double on the pre-feedback (0°) task. Seventeen subjects erred on at least one of the three pre-feedback trials. Moreover, they did not appear to learn anything from two subsequent experiences, during the feedback trials, of not being able to see the object even when the degree of tube curvature was slight (140°): again, 13 of them were incorrect on the post-feedback 0° task. Although the 5-year-olds performed better than the 3-year-olds prior to feedback, their level of performance was not very high in absolute terms (26–68 per cent correct). Eleven of these older subjects erred on at least one of the three pre-feedback trials. However, a single feedback trial sufficed to teach most of them that they could not see through curved tubes: percentages correct following that first feedback trial ranged from 79 to 89 per cent. Taken all together, the results of this study clearly provide strong preliminary support for the hypothesis that young children do not understand that lines of sight must be straight.

Study 2

The data from Study 1 suggested that, prior to explicit training to the contrary, even young 5-year-olds may accept the possibility of seeing along curvilinear looking paths, and that 3-year-olds accept it even after training. However, it is possible that the experimental procedures and materials used in that study may have masked underlying competencies in any or all of the following ways: (*a*) the subjects probably had had little prior experience looking through tubes (especially bent ones); (*b*) a hollow tube 'affords' (à la Gibson) and invites looking and seeing through; (*c*) when presented with the first non-straight tube the subjects had just had the experience of being able to see through three straight tubes, thereby perhaps engendering a tendency to say 'yes' to subsequent questions; (*d*) questions about their own seeing abilities may stimulate overly optimistic 'I can do it' responses; and (*e*) the conditional format of the question '*If* you look through here, *will* you be able to see the X?' may have been problematical for some of the younger children.

Study 2 was intended to be a better assessment of 3-year-olds' and 5-year-olds' explicit untutored understanding that one cannot see along curvilinear visual trajectories. Several changes were made. We used a 90° curve in three different tasks. While looking directly down at the appropriate stimulus display (similar to the reader's view of Fig. 1), the children were asked whether one doll character (O) could see another doll character (X): (*a*) 'by looking through a curvy tube'; (*b*) 'by looking along a curvy line' (along the outside wall or perimeter of the tube); and (*c*) 'by looking along a curvy line' (around a barrier set midway between O and X and at right angles to a line between O and X). We added a question at the end about looking along a right-angle, L-shaped path (around the sharp corner formed by two sides of a box) that we predicted even the youngest children would answer correctly. We also predicted that the around-barrier task would prove easier than the other two curved trajectories, despite its having the same 90° curvature, because of the salience of the barrier as a visual obstacle. The stimulus displays for tasks *a*–*c* are depicted at the bottom of Fig. 1. Curved and straight lines highlighting the curvature were drawn in on the stimulus displays, as shown.

We began the session by calling the subjects' attention to the different visual appearances of a curved vs. straight line. Next we introduced the toy figure O who could look at things but not move from a 'chair', and made sure the subjects knew that the O could see, but not touch, an object held at a distance. The experimental task was then defined by introducing a second toy figure, X, who liked to play hiding games, and by asking the subject to decide whether or not O could see X from various hiding positions. Prior to each of the three critical test trials (*a*–*c* above) we gave the subjects two experiences in ascertaining whether or not O could see X, one involving a clearly impossible looking path (correct answer = no), and the other involving a straight-line looking path (correct answer = yes). For example, on one 'no' warm-up trial the looking path traced by the experimenter went up, over, and behind the O's head to the X situated behind a wall to the rear of O. On the 'yes' warm-up trial paired with this experience, a straight-line looking path was traced from the O to the X who was only partially obscured by a small flower. We confirmed the correctness of the subjects' responses on these warm-up trials and corrected any mistakes before proceeding to the test questions. A major purpose of these warm-up trials was to show the children that observers cannot always see things along suggested looking paths—that it is all right to say 'no' to some 'Can O see X?' questions. Thus, there were six warm-up trials, two preceding each test trial; three curvilinear test trials (through tube, along tube, and around barrier), administered in counterbalanced order; and one right-angle test trial given at the end. Children failing two or more warm-up trials (six 3-year-olds) were not retained as subjects in the study. Thus, all subjects had experience saying both 'yes' and 'no' to proffered looking paths prior to the test questions. Passing the warm-up trials ensured that just prior to the test questions subjects were neither attributing magical visual powers to the O nor confusing physical locomotion with vision along the proffered paths. A few probes, to be subsequently described, concluded the session.

Method

Subjects. The subjects were 10 female and eight male 3-year-olds (mean age = 3:7; range = 3:3 to 3:11) and nine female and nine male 5-year-olds (mean age = 5:1, range 4:10 to 5:7). The subjects were drawn from the same preschool described in Study 1, but tested by a different female experimenter. None of the subjects had participated in the first study. All subjects were tested individually in a single session.

Procedure. Pretraining and task introduction. First the experimenter demonstrated the difference between a 'curvy' line and a 'straight' line. Two Playmobil toy figures served as the O and the X in the hiding game. The O was presented to the child in a sitting position and attached by two rubber bands to a cardboard 'chair' to emphasize a lack of physical mobility throughout the study. Seated, the O was 4 cm tall. The experimenter said 'Our game today is about how we can see things. Here is a little doll named Jack. Let's pretend he is a real little child and that he can see with his eyes just the way we can. Jack is a very little boy and is too young to walk around. His mother has fastened him down in a child's seat so he won't fall out. But he likes to look at things'. The experimenter then positioned Jack in front of the subject such that they shared the same line of vision and held a small block approximately 51 cm in front of them. She asked 'Can Jack see this block right now? That's right (or actually), he *can* see it. We are pretending he can see with his eyes just the way we do. Can Jack touch this block right now? That's right (or actually), he *can't* touch the block because he is fastened to his child's seat. He can't move from his seat in this game. He can only look at things with his eyes'. (Two subjects erred on the see question, and three subjects erred on the touch question.) Next, the X, never affixed to a chair, was introduced: 'Here is Suzy, Jack's sister. These children like to play a hiding game. Suzy thinks it is a whole lot of fun to try to hide so her brother can't see her. In our game today I'll show you some places where Suzy is trying to hide and you decide whether or not Jack can see her'.

Materials. The display for the through-tube and along-tube tasks was affixed to a large sheet of white cardboard placed on the floor of the testing room. This display consisted of one of the tubes from Study 1 taped permanently to the cardboard in an approximately 90° curvature (see bottom of Fig. 1). Along the middle of the top of the tube a piece of blue yarn was taped to indicate the curvature of the looking path within the tube. A pen-drawn straight purple line connected the ends of the tube. On test trials, the tube looked like a shallow U from the seated subject's aerial viewing position mid-way between O and X. For use in the along-tube task, this same display had a curved green line drawn along the outer wall of the tube, the one nearest the child. This curve's end points were connected by a straight orange line that was partially interrupted by the placement of the tube, as shown in Fig. 1. The stimulus display for the around-barrier task was another large piece of white cardboard with a curved green line drawn on it that was identical to the curved path through the tube. Its end points were joined by a straight orange line. A cardboard wall (6 cm thick at its base, 8 cm tall, and 36 cm long) bisected the straight line but did not interrupt the curve (see Fig. 1). For both the around-barrier and along-tube tasks the subjects could see that the eye lines and body positions of both dolls were oriented toward the curved rather than the straight-line paths. On the through-tube task, however, the O and X were placed just inside the ends of the tube and were therefore not visible to the subject.

Warm-up trials. The ordering of the test trials was counterbalanced across subjects, with each trial preceded by a particular pair of warm-up trials, one involving a clearly possible looking path, the other a clearly impossible looking path. The two warm-up trials were given in randomized order. The question for each warm-up trial was as follows: 'Suzy is trying to hide from Jack right here. Can Jack see Suzy by looking along this way?' (The experimenter traced with her finger along the looking path from O to X.) Following the subject's response, the experimenter said, 'That's right (or actually), Jack *can* (*can't*) see Suzy'. The clearly impossible looking paths traced were always curvilinear and barrier related. The clearly possible ones included inadequate barriers behind which X was clearly visible. An example of each was given in the introduction to this study. The two figures remained visible to the subjects on both kinds of trials. To be correct on an impossible trial, therefore, subjects had to assert that Jack could not see Suzy even though they themselves could see her.

Test trials. On each test trial, the O and the X were placed on the stimulus display and the subject was asked: 'Suzy is trying to hide from Jack here. Can Jack see Suzy by looking along a curvy line (through a curvy tube) like this?' (The experimenter traced the curve with her finger.) Unlike in the warm-up trials, the looking paths were explicitly identified as 'curvy' and no feedback was given following a test question.

Following a subject's third test trial, he or she was asked whether the X could be seen along a right-angle visual path. The O was positioned at the end of one of the long sides of a flat rectangular box 26 cm wide, 38 cm long, and 6 cm tall, and the X placed at the end of the far short side, diagonally opposite. The experimenter asked: 'Can Jack see Suzy by looking along this way?' and traced a right-angle path from O to X.

Probe and feedback. Following the fourth test question, the experimenter repositioned O and X for the along-tube task and said: 'I think you said that Jack could (could not) see Suzy by looking along this curvy line like this. Why can (can't) Jack see Suzy by looking along a curvy line like this?' Next, the subject was positioned behind the O at approximately the same eye-level and asked whether he or she could see Suzy by looking along the curved line. Some of the subjects tried to look through the tube as well at this time. The child was returned to his or her mid-line aerial viewing position and the along-tube and through-tube tasks were readministered, in that order. The purpose of readminstering the through-tube task was to test for the ability to generalize from the recent experience of inability to see along a curved line in the along-tube task. However, given that some of the subjects had also just experienced an inability to see through the tube, the data we report may overestimate subjects' capabilities.

Results and discussion

Table 2 shows the percentages of subjects in each age group correctly judging that O could not see X in each viewing condition. A 2 (age) × 4 (viewing condition) analysis of variance performed on these data showed significant main effects for age (F $(1,34) = 5.73$, $p < .02$) and viewing condition (F $(3,102) = 12.20$, $p < .001$) with no significant interaction. Of the 18 subjects at each age level, 15 3-year-olds and eight 5-year-olds erred on at least one of these four tasks. In contrast, eight 3-year-olds and 14 5-year olds responded correctly to at least three of them; when they missed only one, it was almost always the through-tube task. *Post-hoc* Tukey tests showed the following significant effects ($p < .01$) between viewing conditions: right-angle task easier than through-tube and along-tube tasks, and around-barrier task easier than through-tube task. We also did an additional 2 × 2 ANOVA combining the two conditions we had predicted would be easier (right-angle and around-barrier) and the two we had predicted would be harder (through-tube and along-tube). This analysis yielded significant main effects for age (F $(1,34) = 5.73$, $p < .02$) and viewing condition (F $(1,34) = 31.12$, $p < .001$) and a significant age by condition interaction, (F $(1,34) = 4.77$, $p < .04$). *Post hoc* Tukey tests showed that the 5-year-olds performed significantly better than the 3-year-olds in the harder (tube) conditions only, and that the 3-year-olds performed significantly better in the easier conditions than in the harder ones.

Table 2. Percentage of subjects in each age group correctly predicting non-visibility in different viewing conditions in Study 2

	Viewing condition			
Age	Through tube	Along tube	Around barrier	Right angle
3	28	39	67	89
5	61	78	83	94

Of the seven 3-year-olds who had correctly indicated that O could not see X on the along-tube task, only three (43 per cent) alluded to the impossibility of seeing along curved lines or to the necessity of seeing along straight ones when asked to say why during the subsequent probe and feedback period. The comparable figures for the 5-year-olds were 14 and 11 (79 per cent). Also, during that probe and feedback period, 78 and 100 per cent of the 3- and 5-year-olds, respectively, judged correctly that O could not see X along the tube after having just experienced their own inability to do so a moment before ($t\,(34) = 2.20, p < .05$). A moment later, 44 per cent of the 3-year-olds vs. 77 per cent of the 5-year-olds judged correctly that O could not see X through the tube either, when the through-tube task was readministered ($t\,(34) = 1.71, p < .10$). Both groups performed significantly ($p < .05$, by t tests) worse on this readministered through-tube task than on the readministered along-tube task immediately preceding it.

The results of Study 2 seem largely consistent with those of Study 1. Consider first the performance of the younger children. As in Study 1, most 3-year-old subjects showed no evidence of understanding that lines of sight have to be straight. They showed some recognition that O would be unable to see X only when there was a prominent barrier set squarely between O and X as in the around-barrier task, or when O's looking path had to make an abrupt 90° turn around a corner as in the right-angle task. Without these salient and prototypical obstructions, which they may have learned to recognize as specific obstacles to seeing from numerous visual experiences in everyday life, they freely accepted curved lines of sight. Indeed, more than half of the 3-year-olds continued to accept curved lines of sight (through the tube) even after having just experienced their own inability to see along them (along the tube), just as in Study 1. One could reasonably have concluded from Study 1 alone that children of this age would only accept curved looking paths that strongly tempt acceptance, such as the passage through a curved hollow tube. This conclusion is contradicted by the results of Study 2, however, because in that study 3-year-old subjects did not perform significantly better on an along-tube task than on a through-tube task involving a looking path of identical curvature; the same was true of 5-year-olds. We conclude that, if through-tube tasks do underestimate young children's understanding of this fact about vision, they do not underestimate it by much. The pretraining, the warm-up trials, the presence of drawn-in straight and curved lines in the task displays, the instructions, and the feedback trial at the end—all of these task features should have made it easy for subjects possessing even the most implicit straight-line-of-sight rule to use it in Study 2. The finding that 3-year-olds did not use it suggests that they did not possess it.

In contrast, the majority of the 5-year-olds did show evidence of possessing something akin to this rule, at some level of accessibility. Under the favourable task conditions of Study 2, many responded correctly on the critical through-tube and along-tube tasks. They also frequently referred explicitly to the curvature of O's looking path as an obstacle to O's seeing X when justifying correct responses to the along-tube task. Examples are: 'Because people can't see in curvy lines unless their eyes can stick out and around'; 'Because his eyes can only see straight'; 'Because, see, eyes don't curve along things, they are looking straight'.

Studies 3 and 4

The data from Studies 1 and 2 strongly suggest that most 3-year-olds have not yet acquired an explicit rule that lines of sight must be straight. However, it is possible that the methods used in these studies underestimated children's knowledge of that rule. For example, in Study 2 the experimenter explicitly identified each proposed looking route as 'curvy' and asked the subjects whether it was possible to see along that route. Her purpose in doing so was to help the children by calling explicit attention to its curved nature. It is conceivable, however, that this procedure may instead have had the opposite effect of suggesting that it was indeed possible to see along at least some curved paths. Although it obviously did not very often lead them to accept the curved route presented in the around-barrier task, it may have done so on the harder along-tube and through-tube tasks.

Studies 3 and 4 were carried out both to check this possibility and to provide additional evidence regarding young children's understanding of the straight-line rule. Three considerations led us to use looking paths that went through tubes. First, tubes visually define the looking path for the child, thereby making it easy for the experimenter to communicate the task without manually tracing the path or verbally describing its straight or curved shape. Second, in Study 2 looking paths through tubes did not prove to be significantly harder than looking paths along the outside of tubes. Third, we wanted a task that the subject could not solve merely by seeing an obvious visual obstacle interposed between toy perceiver and target. Rather, we wanted one that would require the knowledge that perceivers cannot see along curved looking paths.

In Study 3, after brief pretraining, 3- and 4-year-old-subjects were presented with a stimulus display of four hollow tubes. Three of the tubes were placed such that open ends were equidistant from and aimed directly at a small toy zebra: one tube was straight, one was bent to approximately 90° of curvature as in Study 2, and one was bent into a circular coil with the two open ends extending past each other. The open end of the fourth tube (a straight tube) was aimed away from the target toward the other straight tube. Thus, only the first-mentioned of the four tubes afforded visibility of the target. Playmobil toy figures, strapped to chairs, were placed in the opposite ends of each of the four tubes and subjects were asked which figures could see the zebra and which could not. Tubes not spontaneously categorized by the subjects were queried individually. We expected the subjects to be largely correct on the two straight-line tubes and the circular tube. We expected it would be possible for subjects to succeed on the circular tube task through mere visual inspection of the stimulus display rather than explicit rule knowledge. Given the severity of the curve and the proximity of the bend to the eyes of the toy observer, the tube wall of the display presents a barrier-like obstacle to seeing. However, if subjects failed to possess the explicit rule that line-of-sight cannot be curved they might say vision was possible through the 90° tube, as in the previous studies. Although we were basically interested in the performance of the 3-year-olds we also tested 4-year-olds, reasoning that if we found similar results with older children better able to deal with the complexities of the task, we would have greater confidence in the 3-year-old data. Finally, a fourth study was conducted with 4-year-old subjects using much of the same procedure but only asking yes-no questions about the visibility afforded by each of the four tubes.

Method

Subjects. Study 3 subjects were six female and 12 male 3-year-olds (mean age = 4:7, range 3:5 to 3:11) and nine female and nine male 4-year-olds (mean age = 4:5, range 4:0 to 4:10). The subjects were drawn from the same preschool described in Study 1. Four additional subjects (three 3-year-olds and one 4-year-old) were excluded from the experiment. Three of these subjects denied that any of the toy perceivers could see the target, and a fourth child refused to answer the questions. All subjects were tested individually in a single session by the same female experimenter in Study 2. A second experimenter recorded responses.

Procedure. Pretraining and task introduction. As in Study 2, the subjects were first acquainted with two different lines, one of which was curved and the other straight. The hollow tubes, placed elsewhere in the room on the floor in a preset display, were described as before as hollow and empty and then the experimenter introduced the game: 'The game today is about how we see things with our eyes. Here are four children (Playmobil figures strapped to seats via rubber bands) who like to look at things. They are fastened down to chairs so they can't walk around in our game. But in our game they can look at things with their eyes, just like we can. Can they walk around in this game? That's right/actually, they *can't* walk around in this game. Can they look at things with their eyes in this game? That's right/actually, in our game they *can* see things with their eyes just the way we do'. Using three different toy animals, the experimenter then selected one of the toy perceivers and gave in randomized order three control trials with an animal positioned directly in front of the observer, behind his head, and directly behind a cardboard barrier. The questions to the subject were 'Can he see the X right now or not?' Feedback was given after each trial and in those instances where an error was made (four 3-year-olds and two 4-year-olds made at least one error) the question was re-asked. All subjects initially incorrect were correct when the questions were posed a second time and no subject had to be excluded from the study. The reason for giving these control trials was to give the subjects experience of saying both yes and no to different viewing conditions and to ensure that they entered into the spirit of the game, allowing the possibility for the toy perceiver to 'see' under normal viewing conditions. The control trials were concluded by the experimenter saying 'Sometimes these children *can* see things from where they are sitting and sometimes they *can not*'. The experimenter and the subject then moved to the preset display of tubes where the subject was seated and, as in Study 2, given an aerial view of the display.

Materials. The four tubes previously described were displayed in two different spatial arrangements, with half of the subjects in each group receiving one arrangement and half the other. These different arrangements turned out to have no discernible effect on performance. The 'correct' straight tube (the one through which a toy perceiver could see the target), the circular tube, and the 90° tube were all directed toward a small toy zebra (5 cm tall and 6 cm long) approximately 10 cm away from the end of each tube. The 'wrong' straight tube was placed perpendicular to the side of the correct straight tube with its open end 5 cm away from it. The circular tube was bent such that when a toy perceiver was placed inside one end of the tube, he faced in the direction of the zebra.

Test trial. Each subject was presented with one of the stimulus displays. For half the 3-year-old subjects and all the 4-year-old subjects, probe questions were asked at the end of the task about each of their responses to the four tubes. The experimenter positioned the zebra in the display and asked the subject to watch as she placed a toy observer in the opposite end of each tube such that each observer was no longer visible to the child. The experimenter then reminded the subject a second time where each observer was sitting and said 'From where they are sitting, some of them *can* see the zebra and some of them *can not* see the zebra'. Next, in fixed order, the experimenter asked 'Which ones *can* see the zebra from where they are sitting?' 'Which ones *can not* see the zebra from where they are sitting?' 'If a child did not spontaneously categorize a viewing position, the experimenter asked: 'How about this one (points)? From where he is sitting, can he see the zebra or not?' Thirty-three per cent of the 72 responses to tubes had to be individually queried in this way for 3-year-olds and 14 per cent for 4-year-olds. Across all subjects, the correct straight tube had to be queried five times, the wrong straight tube 10 times, the circular tube six times, and the 90° tube 10 times. In the probe period, subjects were first asked about their response to the 90° tube, then the tubes identified as not affording visibility, and then the tubes identified as affording visibility. The probe question was 'How come this one *can* (*can not*) see the zebra from where he is sitting?' No child in the study claimed that all tubes afforded visibility and no child was inconsistent in identifying the same tube as one that did and did not afford visibility. As previously noted, three subjects claiming no observer could see the zebra were excluded from the study.

Study 4, conducted with 12 4-year-olds (mean age = 4:5), was very similar to the above procedure. However, the subjects were not told that some of the viewers could see the target and some could not. Instead, these subjects were simply asked about each viewing position in turn: 'From where he is sitting (points) can he see the zebra or not?' These subjects were given two tasks, one with each spatial arrangement of the tube positions. Their responses were queried at the end of the procedure. Four additional subjects were excluded from Study 4: three denied that anyone could see the target and one failed the control tasks. The reasons for conducting Study 4 were twofold: (1) we wished to make the task as easy as possible for subjects by questioning them about only one tube at a time; (2) we wanted to ensure that the wording of the question in Study 3 ('which ones *can* see the zebra . . . ?') had not strongly suggested that more than one of the four tubes afforded visibility. Had subjects performed considerably better in Study 4 than Study 3, then one might argue that either the Study 3 procedures were flawed or the task was too complex even for 4-year-old subjects.

Results and discussion

Table 3 shows the percentages of 3- and 4-year-olds correctly predicting visibility or non-visibility through each tube in the two studies. Table 3 shows the percentages for predictions made either spontaneously or following the experimenter's follow-up query; the percentages are very similar if only the spontaneous predictions are included. A 2 (age) × 4 (tube) analysis of variance performed on the Study 3 data showed a significant main effect for tube (F (3,102) = 18.51, $p < .001$) a near-significant main effect for age (F (1,34) = 3.83, $p < .06$) and no significant interaction. *Post hoc* Tukey tests showed that the children predicted significantly ($p < .01$) less accurately on the 90° tube than on each of the other three. The results of Study 4 were very similar. A simple analysis of variance performed on the Study 4 data also yielded a significant effect for tube (F (3,33) = 5.47, $p < .004$) with *post hoc* tests again showing significantly ($p < .05$) more incorrect predictions on the 90° tube.

Table 3. Percentage of subjects in each age group correctly predicting visibility–non-visibility through different tubes in Studies 3 and 4

Study	Age	Tube			
		Correct straight	Wrong straight	Coil	90°
3	3	78	83	83	22
	4	100	94	78	39
4	4	92	96	75	50

Note. The target could be seen through the correct straight tube (visibility) but not through the other three tubes (non-visibility).

Some of the responses to the probe questions suggested that the children making them did explicitly believe that curved looking paths are possible. The following examples are justifications by 4-year-olds for their judgement that the observer could see the target through the 90° tube: (1) 'Because the tube goes curved and he can see all the way through to the zebra'; (2) 'Because it goes from there and it's curvy'; (3) ' 'Cause this (tube) is turned around this way'. As in Study 2, there were also justifications of correct responses that testified to the opposite belief, e.g. 'It can't see bended', 'He can only see to here, until the curvy part', and 'No, because it's curvy'. Thus, the results of Studies 3 and 4 are consistent with those of Studies 1 and 2 in suggesting that young preschoolers tend to be unaware of the fact that one cannot see along a curved looking path.

General discussion

We conclude by briefly discussing the questions of what develops in this area, when, and how. As to what and when, these and previous studies suggest that by the age of 3 years or so children are normally aware that to see something an observer's eye(s) must be (*a*) open and (*b*) aimed in the general direction of the visual target. For example, in the Studies 2–4 warm-up trials, 3-year-old subjects realized that an observer could not see something located behind him or her while facing straight ahead. They also will usually infer that (*c*) an observer cannot see the target if they detect a conspicuous and familiar visual barrier interposed between observer and target, such as the walls used in the Hughes & Donaldson (1979) task, and those employed in our around-barrier and right-angle tasks in Study 2 and in our warm-up or control tasks in Studies 2–4. However, children of this age do not yet seem to have acquired what might be considered a refinement or elaboration of knowledge *b* and *c*, namely, that (*d*) an observer not only normally, but always and necessarily, sees targets via straight-line looking paths. Because they lack knowledge *d*, they will tend to accept curved looking paths—sometimes even very curved ones—whenever they do not detect a visual barrier.

It may seem surprising that even 3-year-olds would lack such an obvious generalization about the visual process, but there may be good reasons for the lack. One possible reason is that information about eyes open, direction of gaze, and visual obstacles is more perceptually and cognitively salient for young children than information about eye line. For example, when young children fail to see object A because object B is in the way, it seems much more likely that they would be consciously aware that B is a visual obstacle than that their looking path could not bend around it. Awareness of obstacles requires only attending to *what* is seen, an earlier, Level 1 type of cognition in Flavell's analysis of the development of percept knowledge (e.g. Flavell, 1978). In contrast, awareness of eye line would seem to require attending to *how* the seeing is accomplished, a presumably later-developing, more Level-2-like type of cognition that focuses on perceptual process rather than perceptual product. Another factor that might retard children's awareness that one *cannot* bend one's looking path is their awareness that one *can* change its direction. That is, perhaps young children may confuse looking around a curve that bends right or left with simply looking to the right or left. Similarly, they may also confuse it with seeing things to the right or left without changing fixation, i.e. in peripheral vision.

Our data suggest that by about 5 years of age children seem to have acquired some command of a straight-line looking path rule, and can access and use it, at least under facilitative task conditions. Further research would be needed to uncover any subsequent development that may occur here. One would think that the people who understand the rule best would be those who understand why it is valid: namely, because seeing an object occurs when light travelling on a straight-line path from the object enters the eye. However, it is uncertain whether even most adults possess this model of the visual process; surely most children do not (Guesne, 1985, p. 29).

How might this rule be acquired? We can think of two developments that might contribute to its acquisition. The first is a general increase with age in children's awareness of perceptual processes and experiences. The growth of a Level 2 understanding of perception beginning around 4 or 5 years of age is part of this development. This increased awareness should make it more possible for children to notice what they can and cannot do visually. The second might be the development of a more explicit concept of a straight line (Piaget, 1956). Perhaps it is only after children acquire such a concept, bringing with it the ability spontaneously to notice and reflect on the straightness vs. non-straightness of lines, that they become able to induce the rule from the visual evidence. Prior to that, they may only be able to use their visual experience to form generalizations of a more global sort, such as knowledge *a*, *b*, and *c*. Consistent with this possibility is evidence by Piaget (1956) and others (Estes, 1956; Lovell, 1959) that children acquire several abilities involving straight lines during the preschool and early elementary school years. An early one is the ability to discriminate straight and curved lines when copying geometric figures, e.g. to include only straight lines when drawing a square or a rectangle. A later one is the ability to imagine and construct a straight line, as when asked to align a set of objects so that they form one. It is possible, therefore, that an increasing sensitivity to perceptual phenomena coupled with an increasing sensitivity to straightness vs. non-straightness of lines helps children acquire an explicit understanding that lines of sight must always be straight.

Further research is needed to find out when children acquire explicit knowledge of other basic facts and phenomena concerning vision. For example, when do they become consciously aware that we sometimes see things poorly rather than well, and aware of some of the conditions under which vision is indistinct or blurred (e.g. objects seen only in peripheral vision, at a great distance, in poor illumination, etc.)? There is some evidence on this question (Flavell, Flavell, Green & Wilcox, 1980; Yaniv & Shatz, 1988) but not much. Similarly, when do they understand explicitly that we sometimes do not immediately detect visual targets that are 'right in plain sight' because they require visual search, e.g. embedded figures or objects that otherwise blend with their backgrounds? The child has to realize in these cases that conditions *a*, *b*, and *c* are necessary but not sufficient for good seeing, i.e. that there can be obstacles to good visibility other than closed or wrongly oriented eyes and interposed objects.

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