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Mental Rotation and the Perspective Problem[1]

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Experiment I contrasts the difficulty of problems in which a child must anticipate the appearance of an array of objects that is rotated (rotation problems) to the difficulty of problems in which a child must anticipate the appearance of a fixed array to an observer who has been rotated with respect to it (perspective problems). Perspective problems are much more difficult and show a different error pattern. Experiment II contrasts standard perspective problems, in which a child must anticipate the appearance of the array to an observer whose position differs from his own, to "perspective–move" problems, in which a child must anticipate the appearance of the array from his own new position; i.e., he himself moves. The latter problems are much easier, and the error pattern is much like that for rotation problems. The mental operations involved in solving these various types of problems are discussed.

How an object or an array of objects looks to an observer depends on how the two are lined up with respect to one another. The appearance of a particular array to an observer changes as this relation is altered. That is, changes in appearance occur either if the observer remains fixed and the object rotates about its own axis, or if the object remains fixed and the observer rotates around *it*. If both the observer and object move, they can either move as a unit, preserving the relation between them, or the relation may be altered, thus changing the appearance of the array to the observer. Insofar as an array has internal axes of symmetry, a change in the relation between the observer and the array does not necessarily change its appearance.

The types of changes in the appearance of arrays which people encounter as the result of the movement of objects versus the movement of self are not necessarily equivalent. That is, a small object often occurs in a variety of positions; e.g., a toy dog may appear standing, lying down,

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or even upside down. When the observer himself moves, the set of changed relations with respect to a fixed array is, no doubt, more restricted. If he walks about, the changes in his relation to a fixed object all occur within the same horizontal plane. Of course, vertical shifts occur as well, as when the observer stands up or sits down. Less frequently, however, does he observe objects while standing on his head, or even while lying down.

The present study concerns only those changes in appearances of arrays which have to do with the relations of the parts of individual objects and of arrays of objects to the observer. Consider, for example, a series of objects involving a car, house, and tree, in that order. Given either that the array is rotated 180° or that the observer moves 180° with respect to it, that observer will see the opposite side of each individual object, and the left and right relative positions of the car and tree will reverse. We will not deal in the present study with the changes in the shapes of objects which occur with such changes in observer–array relations; for example, with the fact that a circle appears elliptical under many viewing conditions, or that a rod changes visible length depending on the angle of viewing.

Even a very young child, once he develops object permanence, can recognize objects or arrays of objects as being the same objects or arrays when his own relation to these objects is altered. Thus, in some sense, the young child knows that objects have a differing appearance when they are moved with respect to the observer, or when the observer moves with respect to them. However, the limiting conditions for recognition of objects and arrays by the young child are not known in detail. For example, while we know that a child will accept an array as being the same array under different viewing conditions, we do not know to what extent he would be willing to also accept some different array as being the same, except for his relation to it. For example, given that a child is facing the front of a house with a garage to the left and a tree to the right, he might "recognize" an array as being the same array if he faces the rear of a similar house with a garage to the left and a tree to the right.

Until well into the elementary school years, the child's knowledge of how observer–array relations affect the appearance of an array is incomplete, in the sense that he cannot anticipate the effects of changes in observer–array relations. That is, a young child is unable to predict the effects which particular changes in the observer–array relation will have on the appearance of an array. Piaget and Inhelder have done two different types of studies which demonstrate that the child has difficulty in anticipating the changes in the appearance of an array which would result from particular alterations in observer–array relations. In

The Child's Conception of Space (1956), these authors reported studies in which the child was asked to predict what a stationary array would look like to an observer who viewed it from some position other than his own. We will call such problems *perspective problems,* as did Piaget and Inhelder. More recently, in *Mental Imagery in the Child* (1970), the authors reported studies in which the child was asked to predict the outcome of rotating an object around its own axis while he remained stationary. We will call such problems *rotation problems.*

Piaget and Inhelder have not directly contrasted perspective and rotation problems, nor have they considered what relation there might be between the mental operations required to solve these two types of problems. The results of their studies show a discrepancy in the ages at which children can deal with the two types of problem. Children were unable to solve perspective problems reliably until they were 9–10 years of age, whereas they could generally solve the rotation problems by 7 or 8 years of age. One cannot fairly compare the results of Piaget and Inhelder's two series of studies, because the children were not given comparable experimental materials in the two cases. For perspective problems, children were confronted with entire scenes involving mountains and houses. For rotation problems, children were confronted with single objects and had to predict, for example, where the colored tip of a stick would appear after the stick had been flipped over. Youniss and Robertson (1970) have presented both perspective and rotation problems to the same children but they, too, used very different materials in the two cases.

It is our goal in the present study to find out more about the mental operations involved in solving rotation and perspective problems, and to evaluate the relation between the mental operations required to anticipate the outcomes of these two types of alterations in the observer–array relation. It is possible that we will find that the same mental limitations underlie the difficulties the young child has with both types of tasks — namely, a general inability to anticipate, from a particular view of an array, its other possible appearances. Alternatively, there may be genuine differences in the mental operations involved in anticipating the effects on the appearance of an array of movements of the array itself versus movements of the observer with respect to that array.

With respect to rotation problems, recent work by Shepard and Metzler (1971) with adults suggests what mental operations may be involved in anticipating the outcome of rotating an object about its own axis. They presented their subjects with two figures and asked whether one of these figures would be identical to the other if it were simply rotated about its own axis. Shepard and Metzler found that reaction times were linearly related to the angle of separation between the two figures. They inferred from these results that people solve such problems by mentally rotating a figure continuously through space from one position to the other, a process which takes time, as if the subjects were actually rotating a *real* figure spatially into a new position in order to test directly whether it matched the other figure. We do not have comparably elegant evidence about the mental operations involved in perspective tasks. Perspective tasks might be comparable to rotation tasks, simply involving the complementary mental operation of rotating the *self* in perspective tasks as opposed to rotating the *array* in rotation tasks. The first step in answering such a question is to compare the relative difficulty and types of errors for perspective and rotation tasks using comparable materials.

EXPERIMENT I

In Expt. I different groups of subjects were presented with perspective and rotation problems which were made as identical as possible. For all experimental conditions, Ss were shown arrays which consisted of three differently colored blocks in a line. These were presented on a platform. For perspective problems, a horse faced inward to the platform and the horse and harness could rotate freely with respect to the platform. Thus, the horse was in a position to "see" the array at an equal distance from any position. For rotation problems the horse faced outward from the platform, and the horse and harness were fastened to the platform so that the apparatus could turn only as a unit. Thus, when the horse was moved together with the platform it provided an indication of the extent of rotation of the array.

Certain procedural issues arise in designing an experiment to compare the difficulty of rotation and perspective problems. One can either leave the array exposed and ask the child to *imagine* the outcome of a rotation or perspective change in the observer–array relation, or one can cover the array after the initial viewing and *actually* change the observer-array relation by rotating the array or moving the horse to its position as "observer." One *cannot* leave the array exposed and actually change the observer–array relation because, for rotation tasks, that would simply provide S with the answer. The first procedure might prove harder because S must imagine the operation as well as the appearance of the array; the second procedure might prove harder because S must hold the array in memory.

Methods and Materials

Design. To evaluate the difficulty of rotation versus perspective problems across the procedural variations described above, we used four experimental groups: two visible conditions in which S either imagined the array being rotated (RV) or imagined the horse being moved (PV), and two hidden conditions in which the array was covered and then either the array actually was rotated (RH) or the horse actually was moved (PH).

For the rotation tasks, S was asked what the array would look like if it (a) remained in place, or was rotated (b) 90°, (c)180°, or (d) 270°. For perspective tasks, S was asked what the array would look like to the horse if the horse (a) remained in place or were rotated around the platform (b) 90°, (c) 180°, or (d) 270°.

Those trials where the horse remained in place, that is, those with orientation (a) for both rotation and perspective tasks, simply required the child to select the array as it was originlly presented. Henceforth we will refer to those trials as "reproduction trials." Orientations (b), (c), and (d) for both rotation and perspective tasks require the child to anticipate the appearance of the array under changed observer–array relations. Henceforth we will refer to those trials as "anticipation trials." The reproduction trials provide a baseline against which to compare the anticipation trials. That is, the child's degree of success on reproduction trials reflects the difficulty of remembering the original array compounded with the difficulty of responding correctly; in the present experiment, to select one among four answer cards.

Each S was given 16 trials constructed in blocks of four trials. Each block of four trials included one of each of the four possible orientations (a), (b), (c), and (d). In addition, in a block of four trials each of the four color sets was used once, and two of the arrays were presented horizontally (left to right) and two vertically (front to back). For each protocol, the order of color sets was constant within each of the four blocks of trials, and each color set was presented twice in a horizontal array and twice in a vertical array.

Subjects. Subjects were 60 third-grade children and 60 fifth-grade children from a private school in an affluent New York suburb.

Apparatus. The two different platform arrangements are shown in Fig. 1. For each apparatus the platform was a 6½-in. plywood square mounted on a 1½-in. thick dowel which was 2 in. high. The five sections (1¾ in. square) were partitioned with ½-in. high strips of plywood. Each wooden horse was 6 in. high, 4½ in. long, and 1⅛ in. thick. In each apparatus the horse was attached in a slot in a 12 × 3-in. plywood harness, facing outward for the rotation equipment and inward for the perspective equipment. For the rotation apparatus, the horse and harness were fixed in place with respect to the platform so that only the entire apparatus could be rotated. For the perspective apparatus, the harness

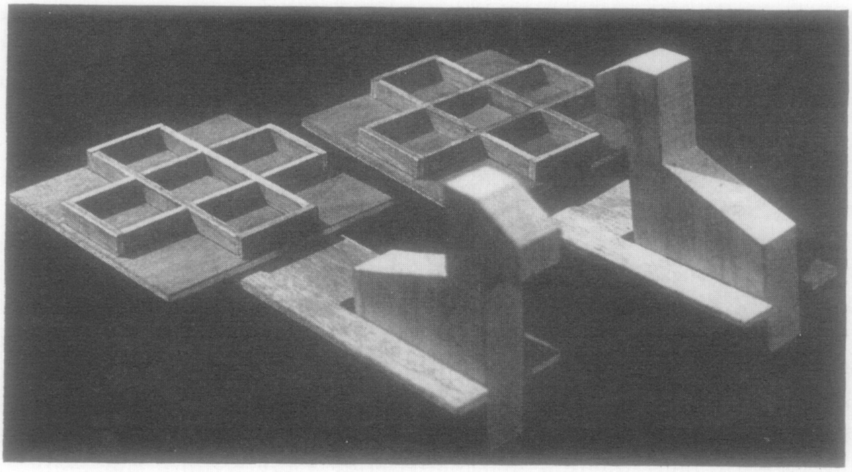

FIG. 1. The apparatus from each of the tasks in Expt. I. In the lower left is the rotation apparatus, with fixed horse and harness; in the upper right is the perspective apparatus, with movable horse and harness.

fit around the dowel of the platform loosely, and the horse and harness could rotate freely around the platform. A cover, a 6½-in. plywood piece with 1½-in. cardboard sides, could be placed over the platform so as to hide the blocks from view.

There were 12 wooden blocks, 1½-in. cubes, each painted a different color. These were divided into four sets of three blocks each. On each trial a set of three blocks was arranged in a row, either horizontally or vertically, in three of the platform sections. Each row of blocks maintained a constant internal relation, in that the entire set was always reoriented as a single unit; that is, a particular set A B C always was presented with B as its center element. For each set of three blocks there were four answer cards which contained three colored patches ½ in. square. The four cards in each set were identical to one another but were arrayed in front of S in different orientations. These orientations represented the block array as it would look when viewed at 0, 90, 180, and 270° from the original position.

Procedure. S sat in front of a low square table with E seated to the right of S. A 7 × 3½ × 4-in. toy pickup truck was on the table for the instruction trials.

In the rotation conditions, S was told he would have to figure out how things look when they are turned around. He was asked to describe which part of the truck he could see now, and which parts he would see if the truck were turned to the right 90° each of three times. In those few cases in which Ss had any difficulty, feedback was given. Then the rotation apparatus was presented with the horse directly in front of S. *E* demonstrated that when the horse is turned to one of the four positions around the table, the entire platform and anything on it also turned with it. *E* said that he would put three blocks in the squares on the platform and that S would have to figure out how the blocks would look to him if the horse and platform were turned so that the horse was in a particular position around the table. *E* then placed the first block array and repeated the instructions.

For the visible rotation condition, *E* indicated one of the positions and explained that S should imagine what he would see if the horse were turned to that position; that is, what the blocks would look like to him. Then the four answer cards were placed in a row in front of S, between S and the apparatus. The order of presentation for these cards was determined by a random schedule. In the hidden rotation condition, *E* explained that the blocks would be covered, and the horse and platform moved around to a particular position. Then *E* presented the four answer cards. After S made his choice of cards, the blocks and cards were removed without feedback and the next trial was presented.

For the perspective conditions, S was told he would have to figure out how things would look from different positions. He was asked to describe which part of the truck he could see now and which parts of the truck he would see if he moved around to each of the four different sides of the table. In those few cases in which Ss had any difficulty, feedback was given. *E* then presented the perspective apparatus and demonstrated that the horse could move all around the platform, which would not itself turn, and the horse could "see" whatever was on the platform as it moved around. *E* said that he would put three blocks in the squares and that S would have to figure out what the blocks would look like to the horse if it were moved around the platform to a particular side of the apparatus. *E* emphasized that S's task was to figure out what the *horse* would see, not what he himself saw. Then *E* placed the first block array and repeated the instructions.

In the visible perspective condition, *E* indicated one of the positions and explained that S should imagine what the horse would see if it were moved to that position. Then the four answer cards were placed in front of S. In the hidden perspective condition, *E* explained that the blocks would be covered, and that then the horse would be moved to a particular position around the platform. S was told to figure out what the horse would see from there.

Results

Let us first consider the *reproduction* data with respect to rotation versus perspective conditions, visible versus hidden conditions, and grade

TABLE 1
Percentage of Errors in Experiment I

Grade level	Rotation		Perspective	
	Visible	Hidden	Visible	Hidden
		Reproduction trials[a]		
Third	18.3	25.0	11.7	28.3
Fifth	5.0	11.7	6.7	21.7
		Anticipation trials[b]		
Third	25.6	38.9	53.9	80.6
Fifth	13.9	29.4	50.0	62.2

[a] Percentage based on 60 responses, 15 *S*s per cell.
[b] Percentage based on 180 responses, 15 *S*s per cell.

level (See Table 1). All the statistical comparisons of conditions involved Mann–Whitney *U* tests. As one would expect, the overall error rate for rotation versus perspective conditions did not differ significantly for the reproduction trials (15 vs 17%). With respect to visible versus hidden conditions, the visible conditions were easier in each case than the hidden conditions (overall difference in error rate for visible versus hidden reproduction trials was not quite significant at the .05 level). With respect to grade, third graders made many more errors in all conditions than did fifth graders (overall difference in error rate for the two grades for reproduction was significant, $p < .001$). The only case in which the number of errors was not very different for the two grades was the hidden perspective condition, where the high error rate for the fifth grade was accounted for by one S who got all four problems wrong.

Under visible conditions, the reproduction tasks only require S to match the array he is looking at to the appropriate answer card. The fact that third graders had such a high error rate for this visible condition (about 15% across rotation and perspective tasks) indicates that our task, requiring S to choose among four schematic representations of four different orientations of the array, was very confusing. The greater difficulty of hidden compared with visible arrays reflects the additional problem of remembering the arrays. The memory problem, as shown by the contrast between visible and hidden conditions, remains strong for fifth graders.

Let us now turn to the *anticipation* data (see Table 1). In contrast to the reproduction data, the overall error rate differed markedly for rotation

TABLE 2

Percentage of Egocentric vs Miscellaneous Errors on Anticipation Trials in Experiment I (N = 120 responses; 30 Ss per cell)

Degree of rotation of horse and cart	Rotation: Visible		Rotation: Hidden		Rotation: Across visible–hidden condition		Degree of rotation of horse	Perspective: Visible		Perspective: Hidden		Perspective: Across visible–hidden condition	
	Egocentric	Miscellaneous	Egocentric	Miscellaneous	Egocentric	Miscellaneous		Egocentric	Miscellaneous	Egocentric	Miscellaneous	Egocentric	Miscellaneous
90	6.7	16.7	14.2	11.7	10.4	14.2	90	46.7	4.2	51.7	15.8	49.2	10.0
180	8.3	8.3	13.3	25.8	10.8	17.1	180	49.2	3.3	60.0	15.8	54.6	9.6
270	8.3	10.8	10.0	27.5	9.2	19.2	270	45.8	6.7	55.8	14.2	50.8	10.4
Across position	7.8	11.9	12.5	21.7	10.0	16.8	Across position	47.2	4.7	55.8	15.3	51.5	10.0

versus perspective conditions (25 vs 61%; $p < .001$). Indeed, rotation tasks were significantly easier than perspective tasks at each grade level for both the visible conditions and the hidden conditions. As in reproduction trials, visible conditions were easier than hidden conditions ($p < .05$) and third graders made more errors than fifth graders ($p < .05$).

Table 2 contrasts two types of errors, egocentric and miscellaneous, for anticipation trials. The pattern of errors was parallel for grades three and five and, therefore, the results are collapsed across grade. An egocentric error was one where S chose the card which represented the array as it originally appeared to him. All other errors were designated "miscellaneous." If S's errors were distributed randomly among the three incorrect alternatives, there would have been twice as many miscellaneous as egocentric errors. That is, there were four cards, one of which was an egocentric error, and two of which were miscellaneous errors (the fourth card being the correct one).

For the rotation conditions, the ratio of egocentric to miscellaneous errors was not significantly different from the 1:2 ratio one would expect if errors were randomly distributed among the possible wrong choices. This distribution of errors was similar for both visible and hidden rotation conditions. For the perspective conditions, in sharp contrast, there was a great preponderance of egocentric as compared to miscellaneous errors. The number of egocentric errors was far greater than one would expect given a chance distribution for both visible ($p < .01$) and hidden conditions ($p < .01$). The egocentric response was particularly compelling for Ss in perspective tasks when the array was visible. That is, in the visible condition, the ratio of egocentric to miscellaneous errors was 10:1, whereas the ratio was 4:1 in the hidden condition.

Discussion

The results suggest that the mental operations involved in rotation and perspective problems are, indeed, different. Not only were the former much easier than the latter, but the pattern of errors in the two types of tasks was very different. For rotation tasks, these third- and fifth-grade Ss made no more egocentric choices than would be expected by chance. That is, they did not tend to think that the appearance of an array would remain unchanged when that array had been rotated. For perspective tasks, on the other hand, Ss had a great tendency to make egocentric choices. They responded as if the appearance of an array would remain unchanged if it was viewed from a different position.

We believe that this difference in the pattern of errors in these two different types of tasks reflects a genuine difference in the mental processes required to solve them. However, one must caution that the observed difference in error pattern might be explicable instead in terms of the differential difficulty of the two types of task; that is, it is possible that egocentricity occurs whenever a task is especially difficult. Discounting this last possibility as unlikely, we must ask whether our experiment demonstrates a general asymmetry between problems which require Ss to anticipate the outcome of a movement of an array versus a movement of an observer.

The present experiment alone cannot answer the question of whether difficulty of anticipating the appearance of an array differs depending on whether it is the array or the observer that moves. This is because the Piaget and Inhelder procedure, which we also used, is only one way to examine this question. It would be possible to have S anticipate the alteration of the appearance of an array produced by an *actual* movement of the observer rather than an *imagined* movement.

One could not have S move with respect to an *exposed* array, because this would simply give him the answer, but he could move with respect to an array which was hidden after an initial viewing. We found that a rotation task was no easier if the array was hidden and actually moved than if the array remained exposed and S imagined its movement. However, it seems, intuitively, that such a procedural difference might be important in perspective tasks, and in fact, at first glance, it even seems that it might affect the logical structure of the problem. For rotation tasks, it seems that S must simply anticipate the outcome of the movement of one of the two elements in the observer–array pair, namely, of the array itself. For perspective tasks, on the other hand, it seems that S is asked to do more than simply anticipate the outcome of the movement of one of the two elements, i.e., the observer in the observer–array pair. Since the imagined position of the observer is incongruent with S's own position with respect to the array, to ask the child to indicate the appearance of the array relative to some other observer requires him to indicate *from the vantage point of ego* (i.e., the child) how the array would appear to an observer who cannot be identified with ego. Thus, these tasks seem to involve three elements rather than two: ego, observer, and array.

A perspective task in which S actually moves would introduce no incongruity between observer and ego in perspective tasks. Before we actually analyze differences between different types of problems which require anticipation of changes in appearance, we want to obtain information about the effects of whether or not S actually moves on the difficulty and error pattern for perspective tasks. We examine this question in Expt II.

A second possible reason for the differences in difficulty between rotation and perspective tasks in Expt I resulted from a variation in procedure; for the rotation tasks the presence of the horse provided a fixed outside point with respect to the array. The reason we affixed the horse in the rotation tasks was to designate to S the extent to which the array was being rotated. However, the fact that the horse maintained a constant relation to the array in the rotation tasks makes it possible for S to use a strategy which would not otherwise be available, and surely was not available to an S in the perspective tasks. We will call this strategy a regenerative strategy. Rather than using a mental rotation strategy which involves tracking the trajectory of the items as these change relative to ego, as we described above, S could, instead, simply use the final position of the horse to determine the appearance of the array. That is, whenever an outside point maintains a fixed relation to an array, one need not consider the rotation process at all, because the final position of the fixed point provides sufficient information to generate the layout of the array.

We would tentatively argue that such a regenerative strategy is not used. The reason is the following: In hidden rotation tasks, we rotated the horse and array to the position from which S's judgment was to be made, but for visible rotation tasks S only had to imagine the equipment being rotated. If S's strategy were to determine the layout of the array by regenerating it from its position relative to the horse, we would expect this strategy to be easier to apply when the horse is actually in its final position. Instead, the visible rotation condition with the final position of the horse imagined was the easiest. Such a comparison is not completely fair since the hidden rotation condition in which the horse was actually moved required S to remember the array, whereas the visible condition did not. Still, the results suggest that being given the horse in final position was not very important to success in problem solving. Because of the tentative nature of this argument, however, we will vary whether or not there is a fixed outside point for perspective tasks in Expt II.

EXPERIMENT II

As we have pointed out, one characteristic of the perspective task as opposed to the rotation task is that, for the former, there is an incongruence between the position of the imagined observer and that of ego; i.e., the child himself. Experiment II involves two different sorts of perspective problems, for each of which the array was hidden after an initial viewing by S. One was the standard perspective task in which S had to imagine taking the position of the observer. In the other perspective task, S actually moved his position to that of the observer after the initial viewing of the array; we call this task the *perspective–move tasks*. This perspective–move task was the same as the standard procedure in that S was shown the initial array in the same way, and in that S indicated his answer by showing what the array would look like from a particular new position. However, since S moved to the new position from which he was to anticipate what the array would look like if it were uncovered, this type of task did not require him to take the vantage point of an observer who is separate from ego. In this sense, the present variation of the perspective task renders it more equivalent to a rotation task.

The other characteristic of perspective as opposed to rotation tasks was the absence, for the former, of a fixed outside point which bore a constant relation to the block array. Experiment II introduced a fixed outside point for half the Ss in each of the two perspective conditions; thus, there was a total of four experimental groups: + and − move conditions with + and − fixed outside point conditions. If S did use a regenerative strategy, which, as we pointed out above, we doubt, it would seem that the fixed point should affect task difficulty chiefly in the + move condition. That is, in these tasks, it seems clear that S *could* use the final position of the horse to regenerate the array. It is less obvious that the fixed outside point could be used this way in the − move condition. That is, one could not directly regenerate the array from the final position of the horse, because its final position is not given but must be anticipated. For S to anticipate the final position of the horse while he remains stationary is itself a standard perspective problem (with respect to the horse).

Shantz and Watson (1971) did a study in which the child moved around a hidden array and was given the task of predicting how that array would look from his new position. The array they used consisted of a house, a tree, and a street light. The authors used a training procedure to teach S the relative positions of the three objects while he remained in place. The training involved the use of a covering lid which had nine doors in a 3×3 grid. S was shown the array, which was then covered, and he was asked to point to the doors under which the particular objects were located. After each choice, *E* placed a marker on that door. The child then lifted the doors to check his choices and afterward was shown the entire array again. The procedure was repeated up to five times until the child could respond correctly. S then moved 180° around the covered apparatus and was asked to indicate under which doors the objects were located. Several such trials were given.

Unfortunately, a child's success in carrying out the Shantz and Watson task does not insure that he can *predict* the positions of hidden objects when he moves his position relative to these objects. S might rather have remembered which particular doors he opened on the training trials, and, in fact, he could continue to gaze at these doors as he changed his position. Thus, this study does not provide us with evidence we seek about the child's ability to anticipate the appearance of a fixed array when the observer changes his position with respect to it. Insofar as S remembered which doors he had opened, there was no necessity to anticipate the appearance of the array at all.

One of the procedures which Piaget and Inhelder used involved changes in the child's position in visible perspective tasks. A child who made egocentric errors was then placed in the position of the imagined observer. In this new position, it was easier for the child to *reconstruct* the original appearance of the array than to *predict* its appearance from some *new* position in which he had never viewed it. While this procedure had the child move his position, it again does not provide us with the information we seek as to whether the child can predict the appearance of an array if the incongruence between his own position and that of an imagined observer is removed.

We have introduced a change of procedure for Expt II with respect to the mode of indicating the appearance of the array. The four answer cards from which S had to choose in Expt I were hard to discriminate from one another, as indicated by the high error rate on reproduction trials even when the array was visible.

Methods and Materials

Design. Four experimental groups were given hidden perspective tasks under different conditions. The two variables were (a) whether S remained fixed in one position or moved to the appropriate position around the apparatus, and (b) whether or not there was a fixed outside point, i.e., the horse. Thus, the four experimental groups were as follows: two perspective–move tasks in which S moved (1) with horse present (+M +H) and (2) with horse absent (+M −H), and two standard perspective tasks in which S did not move (3) with horse present (−M +H) and (4) with horse absent (−M −H).

In the (+M) conditions the child either remained in place (for reproduction trials), or actually moved 90, 180, or 270° clockwise around the table. Then he indicated what the covered blocks would look like to him, if he could actually see them. In the (−M) conditions, the child always remained in place, but was asked to imagine what the covered blocks would look like if he moved 90, 180, or 270°. In the (+H) conditions, the horse was always nearest S and faced him. In the (−H) conditions, the other apparatus which involved only the platform was used. Each S was given 16 trials. Each protocol was constructed in blocks of four trials with the same constraints as in the previous experiment.

Subjects. Subjects were 88 fourth-grade children from a public school in an affluent New York suburb.

Apparatus. Two versions of the apparatus were used. One was identical to the rotation apparatus described in the first experiment with a fixed horse and harness attached to the platform. The other apparatus was just the platform of the equipment without any horse or harness. The same cover was used to hide the block arrays from view as in Expt I.

The same 12 wooden blocks were used as in Expt I. Again, they were divided into four sets of three blocks each, and each set maintained a constant internal relation whenever presented. Rather than using the schematic answer cards from Expt I, a set of answer boards was employed in Expt II, each of which was a 3-in. plywood square on which three ½-in. colored cubes were glued. Each answer board was a model of one of the sets of blocks as it would look when presented on the platform. The answer board could easily be turned to indicate how the blocks on the platform would look from any position.

Procedure. S sat in front of low square table with *E* seated to the right of S. A 7 × 3½ × 4-in. toy pickup truck was on the table for the instruction trials. A 2-in. toy pickup truck, similar to the larger one, was also used.

S was told he would have to figure out how things looked from different positions. He was asked to describe what part of the truck he saw. *E* showed how the small model might be used to represent what S saw when looking at the big truck by placing the small truck parallel to the larger truck and facing the same direction. Then S moved 90° clockwise to the next side of the table, and *E* asked him to describe what part of the truck he now saw. Again *E* used the small truck to represent what S saw when looking at the larger truck by placing it parallel to that larger truck. This process was repeated at 180 and 270° from the original position.

Then S returned to the original position and *E* explained that S could sit in one spot and play the same game without actually moving, by imagining moving around the table looking at the big truck and then using the small truck to show what the big truck would look like from the different positions. *E* showed S with the little truck what the big truck would look like if S were in each one of the four positions around the table. S was asked to verify each of *E*'s small truck placements. If S did not agree, he was asked to move to that location and describe what part of the truck was visible, and then to return to the original position to check the small truck's placement. All Ss in all groups received the entire instructions.

Next, *E* presented the appropriate test apparatus and said that he would place three blocks on the platform, and that *S* should look carefully to see just how the blocks looked because *E* would then cover the blocks.

In the perspective–move conditions (+M), *E* told *S* that after the blocks were covered *S* would move to one of the four positions around the table and use a model to show how the blocks look if the cover were removed, just as *S* had earlier used the little truck to show what the big truck looked like as he moved around the table. Then *E* placed the first block array and repeated the instructions.

In the standard perspective conditions (−M), *E* told *S* that after the blocks were covered he would have to imagine what the blocks would look like if he were to move to one of the four positions around the table, just as earlier, *S* had, without moving, used the little truck to show what the big truck looked like from positions around the table. Then *E* placed the first block array and repeated the task instructions.

Results

The percentages of errors in *reproduction* of the original array for the four conditions were +M +H 4.5%, +M −H 4.5%, −M +H 8.0%, and −M −H 9.1%. The difference in errors between +M and −M conditions was not significant.

The results for *anticipation* trials are presented in Table 3. The + and − move conditions were significantly different in difficulty; that is, the +M conditions were much easier than the −M conditions ($p < .001$). Even treating the groups with and without a fixed outside point separately, movement made the tasks significantly easier ($p < .01$ in each case).

The presence of the horse had only a small but, nevertheless, significant effect on overall task difficulty ($p < .04$). The effect of the horse was significant for the + move condition taken separately ($p < .025$) but not, as we had predicted, for the − move condition taken separately ($.05 < p < .10$).

Let us now consider the effects of movement and the presence of the horse on the pattern of egocentric versus miscellaneous errors. When *S* remained stationary, the pattern of errors in the present experiment was similar to that in the hidden perspective conditions in Expt I. That is, the ratio of egocentric to miscellaneous errors in the − move condition was approximately 3:1. This was, of course, vastly different from the chance ratio of egocentric to miscellaneous errors which would have been 1:2. When *S* moved, on the other hand, the numbers of egocentric and miscellaneous errors were about equal and indeed were not significantly different from the chance 1:2 ratio. With respect to the horse, for both

TABLE 3
Percentage of Egocentric vs Miscellaneous Errors on Anticipation Trials in Experiment II (N = 88 Responses, 22 *S*s per Cell)

Position of *S* when responding	*S* moves (+M)						Imagined position of *S* for response	*S* doesn't move (−M)					
	With fixed outside point (+H)		Without fixed outside point (−H)		Across +H and −H conditions			With fixed outside point (+H)		Without fixed outside point (−H)		Across +H and −H conditions	
	Egocentric	Miscellaneous	Egocentric	Miscellaneous	Egocentric	Miscellaneous		Egocentric	Miscellaneous	Egocentric	Miscellaneous	Egocentric	Miscellaneous
90	4.5	2.3	4.5	5.7	4.5	4.0	90	15.9	6.8	20.5	11.4	18.2	9.1
180	8.0	1.1	8.0	8.0	8.0	4.5	180	43.2	1.1	42.0	9.1	42.6	5.1
270	5.7	8.0	5.7	10.2	5.7	9.1	270	15.9	11.4	23.9	13.6	19.9	12.5
Across position	6.1	3.8	6.1	8.0	6.1	5.9	Across position	25.0	6.4	28.8	11.4	26.9	8.9

+M and −M conditions, the +H groups had half as many miscellaneous errors as the −H groups, while the overall amount of egocentric errors was unchanged.

For − move conditions especially, the 180° position was clearly hardest, as has been reported in earlier studies by both Piaget and Inhelder (1956) and Flavell (1968). However, we found no such difference for the three different positions for + move conditions, nor did we find such a difference for the standard perspective task in Expt I.

Discussion

Experiment II was designed to determine whether either of two procedural differences between rotation tasks and standard perspective tasks might be critical in determining why the latter were so much more difficult and led to such a different pattern of errors than the former. One factor which we varied in the four different perspective tasks in Expt II was whether or not a fixed outside point was present. The other factor we varied was whether *S* remained stationary or moved to the new viewing position.

With respect to the fixed outside point, we pointed out in our discussion of *S*'s strategy on rotation problems that, with a fixed point, it would be possible for *S* to anticipate the appearance of the array by regenerating its relation to that fixed point. Experiment II shows clearly that the presence of the fixed point cannot explain why standard perspective tasks are harder than the rotation tasks. First of all, in those perspective tasks in which *S* did not move, the horse did not significantly affect problem difficulty. Secondly, whether or not the horse was present, movement had a profound effect on both task difficulty and error pattern for perspective problems. Thus, one can reject the notion that rotation and perspective-move tasks are easier than standard perspective tasks because, for the former, *S* can use a regenerative strategy.

Even though the presence of the horse was a minor factor, it did significantly affect task difficulty. It is not completely clear why. Perhaps a regenerative strategy was occasionally used. Alternatively, the horse may have served as an extra cue, possibly as an aid in remembering the original array itself. As we noted above, the horse affected the pattern of errors in Expt II in both + and − M groups, by halving the percentage of miscellaneous errors, while the percentage of egocentric errors remained virtually unchanged. Egocentric errors, one might argue, are of a conceptual nature and, thus, are unaffected by the horse, whereas the miscellaneous errors are more likely to result from forgetting the original array and, thus, might be decreased if the horse aids in retaining the initial array.

The critical factor which affected both task difficulty and error pattern was whether or not S moved to the position from which the appearance of the array was to be judged. This experiment shows that the problem of anticipating the appearance of an array when the *observer shifts position* is not necessarily different in kind and more difficult than that of anticipating its appearance when the *array shifts position*. The critical factor contributing to the observed difference in difficulty and error pattern between rotation and perspective tasks, and between different types of perspective tasks, is whether or not there is an incongruence between observer and ego.

DISCUSSION AND CONCLUSIONS

The most sensible hypothesis about how people solve rotation problems, it seems to us, is that they use the type of mental rotation process described by Shepard and Metzler; that is, they mentally rotate the array from its initial to its final position, continuously tracking the relation between their own bodies and the parts of the array. This hypothesis is certainly consistent with the introspections of adults,[3] who report that they imagine how the array would appear as they mentally rotate it in space. They report a continuous conscious experience of the appearance of the array.

We hypothesize that the reason perspective–move tasks are similar in difficulty and error pattern to rotation tasks is that their solution involves analogous mental processes; namely, that for perspective–move tasks, S continuously tracks the relation between his own moving body and the parts of the fixed array. For perspective–move tasks, as for rotation tasks, adults report that they imagine how the array would appear at all times as their relation to it changes; that is, they report a continuous conscious experience of the appearance of the array.

Some adults doing such problems report that they track only one of the elements in the array as their relation to it changes. Obviously there can be such variations on a tracking strategy which include some elements of a regenerative strategy. As S's position changes relative to the array, he can focus his attention on his relation to just one of the elements in the array, tracking his position relative to that single element. After figuring out his final relation to that element of the array, he could then regenerate the remainder as if that element were a fixed outside point. It is not possible, from the present experiments, to differentiate a strategy of mentally rotating the entire array from that of mentally rotating part of the array and regenerating the remainder.

[3] We have obtained introspections from approximately a dozen adults and are currently in the process of obtaining systematic data on adult strategies.

Adults, who are able to solve standard perspective problems, believe that they follow a very different strategy than for rotation or perspective-move tasks, a claim which is supported by the difference in difficulty and error pattern on these problems for children, as well as by the great effort even adults report in obtaining answers. They report a two-stage process, as opposed to the single continuous mental process in which one imagines "seeing" the original array gradually change its appearance. The first stage is to consider the relation between the imagined viewer and the array. This is only a first step which is not directly accompained by a knowledge of how the array *appears*. There are two reported alternatives for the second stage in obtaining answers. The most common claim which adults make about how they then determine the appearance of the array is that they rotate the entire observer–array pair until the imagined observer becomes recoupled with ego. At that point, they claim that they know how the array *appears*. The other claim one occasionally hears is that for these problems the appearance of the array is never experienced, but rather is *inferred* from the relation between the array and the imagined observer; e.g., "the red block is to the horse's left and the green one to the his right, so he must see the array like so."

Even among sophisticated adults, there is some tendency to pick an array which is identical to the original (i.e., to make an egocentric choice), yet say, "but seen from here," pointing to the position of the imagined viewer. An adult, however, knows that this is not an adequate answer, and that another step is necessary. A child sometimes makes such egocentric choices accompained by a gestural indication that he is aware that the horse is viewing the array from a different position, and that something more than a simple egocentric response is called for. However, unlike an adult, if one presses the child as to whether the egocentric response indicates "just what the horse would see," the child continues to insist that it does, rather than carrying out the operation of determining what the horse would see.

The adult is apt to attribute his difficulty with these problems to the necessity of choosing as the answer a display of blocks which "contradicts" the present actual appearance of the array to himself. One might hypothesize that this apparent contradiction is the source of the difficulty of standard perspective problems. That is, S solves these problems momentarily but then becomes confused when he looks at the array or remembers how it appeared. The possibility that this factor might underlie children's difficulty with standard perspective tasks may have been what led Flavell (1968) to introduce a procedural variation in which S turned away from the original array to indicate his answers. This procedural variation did not, in fact, decrease the difficulty of such problems. Furthermore, we have evidence from the visible rotation task in Expt I that a contradiction between the appearance of the array and the display S must choose is not necessarily a source of difficulty; these problems were the easiest of all.

If we tentatively accept the notion that standard perspective problems are solved via a two-stage strategy, as outlined above, one wants to know whether the difference between this strategy and that used for rotation and perspective–move problems derives from a difference in the logical requirements of these tasks. We hypothesized in the discussion of Expt I that perhaps the standard perspective task is inherently more complex because of the necessity of uncoupling the role of ego from that of observer. Rotation and perspective–move tasks seem to involve only the two elements of observer and array, whereas the standard perspective task seems to involve the three elements: observer, ego, and array.

A closer look at these problems has led us to conclude that, logically speaking, the different types do not differ in terms of the number of elements involved or in the number of spatial operations in which these elements are involved. That is, for all types of problems, S must determine the appearance of the array on the basis of (a) information about the initial appearance of the array which results from his particular relation to it, and (b) information about the extent to which the moving element changes position. Rotation problems do differ from perspective problems in terms of whether the observer or the array is the moving element. These different types of element do serve asymmetrical roles in the processing of the appearance of arrays in the sense that the observer is the element which registers the array, whereas the array is the element which is registered. This difference in role is reflected in the path of each element's movement. Thus, the observer transverses a circular path around the stationary array in order to view it from different angles, whereas the array rotates about its own axis so it can be viewed from different angles by the stationary observer.

Perhaps because of the asymmetrical roles of observer and array, S treats them differently in those cases where the movement of elements is *imagined* rather than *actual* in a manner which creates the strong impression that there is an extra element in the standard perspective task. That is, when the array remains stationary and S must anticipate how it would look if it were rotated, he imagines the array to move from its starting to its final position. He does not treat the array as if it involved two separate elements, one consisting of the array in its initial position and the other consisting of the array in the final position. Rather, he treats it as the *same* array at two points in time. On the other hand, when the observer remains stationary and must anticipate what the array would look like if *he* moved, he treats the observer as two separate elements, himself (ego) and imagined observer, rather than as the same observer at two points in time. This is equally true whether one asks S to imagine himself to be moving, or one actually uses some other viewer like the horse.

There does not seem to be any *logical* reason why S should not solve standard perspective problems using a strategy analogous to that which he uses in perspective–move problems; namely, why he should not track the changing appearance of an array to an imaginary observer who is experienced as moving from the position of ego to some other point. If S has a continuous experience of the changing appearance of a hidden array when he *actually* moves to a new position, it is not obvious why he should not be able to experience its changing appearance in an analogous fashion when he *imagines* moving to a new position. No additional information logically relevant to solving the problem is available to an S who actually moves.

The reason people use a different strategy for standard perspective problems than for perspective–move or rotation problems, we would argue, is because of a psychological restriction of mental imagination, whereby judgments of appearance are made in terms of ego's present position. There is no parallel restriction of mental imagination with respect to the array. S can imagine the *array* in some other position than its present one, but he cannot imagine *himself* in some other position than his present one. This restriction of mental imagination to ego's spatial position at a particular point in time is a form of egocentrism which, in one sense, is characteristic of adults as well as children. That is, while an adult is able to solve standard perspective problems, he typically seems to do so by using a strategy in which he refers the array to his own present position, rather than a strategy in which he imagines himself to be moving from place to place through time.

In summary, the present experiments compared the child's difficulty in anticipating how changes in the observer–array relation affected the appearance of an array under varying experimental conditions. We found an asymmetry between the mental processes involved when S must *imagine* the movement of the observer versus that of the array. When the observer's movement is to be imagined, children make large numbers of egocentric errors, and even adults find the problem difficult. The reason, we have argued, is that both children and adults judge the appearance of an array from their own present positions. Thus, problems which involve an imagined observer entail extra steps, because S mentally reunites the imagined observer with himself in order to judge how the array would appear to that imagined observer. The child's inability to solve such problems does not result from an "egocentric" approach unique to childhood which, in general, restricts his ability to anticipate changes in appearance. It results, rather, from a specific inability to reunite the imagined observer, with his particular relation to the array, to one's own present position.

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