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Development of Kinetic Images: When Does the Child First Represent Movement in Mental Images?

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An experiment investigated at what age children could represent movement in imagery. Five- and eight-year olds were asked whether two stimuli were the same or different in shape. The two stimuli were either presented in the same orientation or one stimulus differed from the other by clockwise rotation of 30° (0.52 rad), 60° (1.05 rad), 120° (2.09 rad), or 150° (2.62 rad). Children were instructed to visually imagine the counterclockwise rotation of one shape into the position of the other to help make the judgment. For both 5- and 8-yr olds, reaction times increased as a linear function of angular discrepancy between stimuli, indicating that both age groups represented rotation in their imagery. The findings conflict with Piaget and Inhelder's thesis that imagery representing movement first emerges when children are 7 to 8 yrs of age.

According to Piaget and Inhelder (1971), kinetic imagery, which is imagery representing movement, first emerges in the thinking of the child at the age of 7 to 8 yrs. In their view the shift from static to kinetic imagery reflects a more basic transition, that from preoperational to concrete operational thought. The following passage from *Mental Imagery in the Child* illustrates their position:

> In short, the two main periods of image development correspond to the preoperational (before 7 to 8 years) and the operational levels . . . the images of the first period remain essentially static and consequently unable to represent even the results of movements or transformations and a fortiori unable to anticipate processes not yet known. But at about 7 to 8 years a capacity for imaginal anticipation makes its first appearance, enabling the subjects to reconstitute kinetic and transformation processes, and even forsee other simple sequences (Piaget & Inhelder, 1971, p. 358).

For Piaget and Inhelder, characteristics of preoperational thought interfere with the production of kinetic imagery. Foremost among such characteristics is the preoperational child's tendency to center, or focus,

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on objects when motionless and to ignore objects when they are undergoing the movements that transport them from one stationary position to another (Piaget & Inhelder, 1971, p. 359). Even when the preoperational child does focus on the motion of objects, he tends not to comprehend that the parts of the moving object change position in a coordinated fashion (Piaget & Inhelder, 1971, p. 120). Moreover, in imaging a moving object, preoperational children may distort one or more of its properties (Piaget & Inhelder, 1971, p. 360). Finally, Piaget and Inhelder assume that the intermediate positions of an object in motion may at times be represented by a series of related images, each evoking some part of the continuous motion, and that children without operational seriation have difficulty placing each image in its proper place in the temporal sequence (Piaget & Inhelder, 1971, p. 360).

Although at first glance, several studies by Piaget and Inhelder appear to support this position (Piaget & Inhelder, 1971, Chaps. 3 & 4), closer examination renders the evidence unconvincing. For example, of the three behavioral response measures in these studies, drawing, gesturing, and choosing from prepared drawings, Piaget and Inhelder relied heavily on drawing and gesturing, two measures that seem especially vulnerable to subjective interpretation. Experimenters are likely to recognize correct responding more easily when expressed in the comparatively skillful drawing and gesturing of the older child than in the clumsier responding of the younger one, even when both children mean the same thing. In short, a performance effect may have been confused with competence. Their results would be more convincing if the choice response measure, which seems relatively free of subjective bias, had played a more central role in their research. Regardless of which measures were used, further difficulty in interpreting their results arises out of a general lack of independent tests of how well children understood what was required of them. With the kind of unusual and often abstract task instructions used by Piaget and Inhelder, young children may perform more poorly than other older ones because they fail to understand task instructions as well. Defferences in understanding may not imply differences in using imagery. Thus, once again, a potential confounding renders their results difficult to interpret. Finally there was no proper statistical handling of data, and very often the descriptions of the instructions to children and of other experimental procedures were unclear and incomplete.

The critical feature of the present study is the application of a technique developed by Shepard and his associates (Shepard & Metzler, 1971; Cooper & Shepard, 1973) for testing kinetic imagery of rotational movement. The procedure is ideal for examining Piaget and Inhelder's hypothesis because it both determines whether subjects are using kinetic imagery and quantifies the proficiency with which kinetic imagery is used. Moreover the technique avoids the weaknesses just mentioned by

(1) employing a choice response measure, (2) testing specifically how well children understand their instructions, (3) yielding statistical assessments, and (4) lending itself to clear procedural description.

Shepard and Metzler presented college students with pairs of pictures of geometrical forms. For half of the presentations, the two forms were exactly the same, while for the remaining presentations the forms were mirror-images of each other, i.e., although the features of the two forms were identical, the positions of the features with respect to each other were left-right reversed. The subject's task was to decide whether the two forms were the same or mirror-images. What made the task interesting was that the orientations of the two forms to be compared were not always the same. The relative positions of the two in space differed by as little as 0° (0 rad) through as much as 180° (3.14 rad) of rotation.

All of the subjects claimed they first imagined the rotation of one form into the same orientation as the other to facilitate their decision. Reaction time measures corroborated the subjective reports. Specifically, the greater the difference in orientation between the two stimuli, the longer it took subjects to answer correctly. In fact, reaction time increased as a linear function of the angular difference in rotation.

In the present version of that method, children were asked whether two panda-bearlike shapes differing in orientation by a rotation about a horizontal axis were the same or different (i.e., mirror images). Subjects were instructed to visually imagine the rotation of one bear through an angle sufficient to achieve the orientation of the other in order to determine whether the two bears were congruent or incongruent. Reaction times served as the major index of whether kinetic imagery occurred or not. It was expected that if kinetic images were used by subjects, the greater the angular difference between stimuli upon presentation, the longer the arc through which mental rotation would occur, and thus, the longer the reaction time associated with a correct judgment. Thus, as in Shepard and Metzler's research, it was expected that if kinetic imagery involving object rotation occurred, a linear trend of reaction time as a function of degree of angular discrepancy between stimuli would also occur.

METHOD

Subjects

Twenty 5-yr olds and 20 8-yr olds, including an equal number of boys and girls of each age, completed the experiment. The average age was 5 yr 8.3 mo for 5-yr olds, and 8 yr 7.2 mo for 8-yr olds. All children were Caucasian, middle class students of Comsewogue Elementary School, Port Jefferson, N.Y.

Apparatus

The stimuli for the experiment consisted of bear-shaped figures [8 × 4 in. (20.3 × 10.2 cm)] with white bodies and faces, and black arms, legs, and ears. Each stood upright on its hind legs. Two, however, had their left arms raised and their right arms down, while the remaining two had their right arms raised and their left arms down.

Two bears side-by-side in front of a plywood backdrop were presented simultaneously on each trial. The bear on the child's right could be rotated in the plane parallel to the backdrop. A sliding-door which hid the stimulus array from view between trials dropped at the beginning of each trial, starting a digital timer which was read to an accuracy of 0.1 sec. The timer stopped when one of two response levers was depressed by the subject. The child sat in front of the apparatus facing the display, and the levers were situated below the display within his easy reach.

Procedure

The experimental procedure, which for each child extended over approximately 4 days with a daily experimental period of roughly 15 min. consisted of four parts: pretraining, criterion test, mental rotation training, and experimental test. The number and length of sessions varied depending on each child's class schedule and attention span. During pretraining, the child was told that when two bears had the same arms raised (both right, or both left), they should be called the "same," but when two bears had different arms raised (one left and one right), they should be called "different." Pretraining involved five trials, on the first one of which three bears were presented simultaneously and the child was instructed to point to the different one and to explain the reason for his choice. During the remaining four trials, the child was asked to determine whether two bears placed before him were the same or different. The reason for his choice was solicited, and errors were corrected. After pretraining, the child was seated in front of the apparatus for the criterion test and asked to discriminate between same and different pairs. On each trial two bears were presented simultaneously in the upright position. On one-half of the trials the bears were the same, and on one-half of the trials the bears were different. Equal numbers of same right-handed pairs, same left-handed pairs, different right-handed pairs and different left-handed pairs were displayed in random order. To indicate his response, the child pressed one of two levers, the lever on the left signifying same and the lever on the right signifying different. Criterion was responding correctly on all of the first 10 trials or on any 20 of the 24 total trials.

The child who passed the criterion test was given the experimental test which was substantially like the criterion test except that the bear on his left remained upright, and the bear on his right appeared in one of five orientations: upright (0° 0 rad rotation) or in 30° (0.52 rad), 60° (1.05 rad), 120° (2.09 rad), or 150° (2.62 rad) clockwise rotation from upright. Each child was given 60 trials (12/orientation condition), randomly ordered with the following restrictions: (1) that each orientation precede every other an equal number of times, (2) that a given orientation condition never be presented consecutively, (3) that same or different pairs never be presented more than four times consecutively, and (4) that single and double alternation sequences of same and different pairs be limited to three consecutive alternations.

At the beginning of the experimental test, children were given mental rotation training involving seven trials with sets of unaligned bears. After responding on the first trial, the child observed the experimenter manually rotate the bear on the right to upright in order to check whether the two bears matched and whether the child had been correct. On the next three practice trials, the child was allowed to manually turn the right-hand bear to upright before making the required same–different judgment. On the final three practice trials, which were just like the subsequent test trials, the child was asked to mentally rotate the right-hand bear to upright before responding, with words to the effect, "Now you turn this bear (pointing to the bear on the child's right) to where he will be standing like this one (pointing to the bear on the child's left) in your mind. Don't use your hands."

During the experimental test, children were instructed to answer both quickly and accurately in the following way:

> I want you to try very hard to give the *right* answer. When you are right I will know and mark it down. If you are right enough you will get a prize at the end. As soon as you know the right answer hit the lever like this or like this. Don't waste time and don't wait. It is important to answer as *fast* as you can. I have a clock here and I will know how quickly you answer. You cannot win a prize if you do not answer fast enough.

The intertrial interval was approximately 20 sec. During the period between test trials, children were reminded to answer correctly and to work quickly. Moreover, the phrase "OK" or "Good" followed correct trials, and the phrase "Be careful" followed incorrect trials. After the experiment was completed, all children who participated received a small prize. Children were randomly assigned to one of two female experimenters.

Measures

Reaction times and errors were recorded.

Design

The basic design included five rotations (0° [0 rad], 30° [0.52 rad], 60° [1.05 rad], 120° [2.09 rad], 150° [2.62 rad]), two ages (5 and 8) × two sexes × same–different × two experimenters. Both rotations and same–different were within-subject factors, while age, sex, and experimenters were between-subject factors.

RESULTS

Of the initial 47 children who started the experiment, three 5-yr olds were excluded during testing for inattention, and three more 5-yr olds were excluded because they failed the criterion test. One 8-yr old was excluded because of erratic performance. Thus, the performances of 20 5-yr olds and 20 8-yr olds, including an equal number of boys and girls of each age, were analyzed.

0° (0 rad) Rotation

Since no kinetic imagery of rotation was expected for stimuli in identical orientations, data collected at 0° (0 rad) rotation were analyzed separately. A one-way analysis of variance on reaction times for correct responses yielded a significant difference between age groups ($F(1,38) = 45.6, p < .01$) indicating that 5-yr olds took longer to respond when no mental rotation was required. The reaction time means were 2.80 sec for 5-yr olds and 1.56 sec for 8-yr olds. There was no evidence of an association between age and making at least one error versus making no errors ($\chi^2(1) = 2.13$, $p \leq .05$). Only three 5-yr olds made any errors, while seven 8-yr olds made at least one error at 0° rotation. The results at 0° rotation are excluded from remaining analyses to avoid introducing any temporal interval which would be constant whenever rotation occurred, but which differed from the temporal interval for no rotation at 0° (0 rad) discrepancy.

Reaction Time for Rotated Stimuli

Despite apparent violations of the assumptions of normality and homogeneity of variance for reaction times, a five-way (sex × age × experimenter × same–different × rotations) analysis of variance distinguishing linear and residual nonlinear components of effects involving rotation was performed on reaction times for correct responses. The effects significant with $p < .05$ were: age ($F(1,32) = 30.7$, $p < .01$); the linear component of rotations ($F(1,32) = 31.8$ $p < .01$); the interaction of the linear component of rotations × age ($F(1.32) = 5.7$); and the nonlinear residual component of rotations × sex × same–different ($F(2,64) = 4.8$).

The slope of the least-squares line relating rotations to reaction time

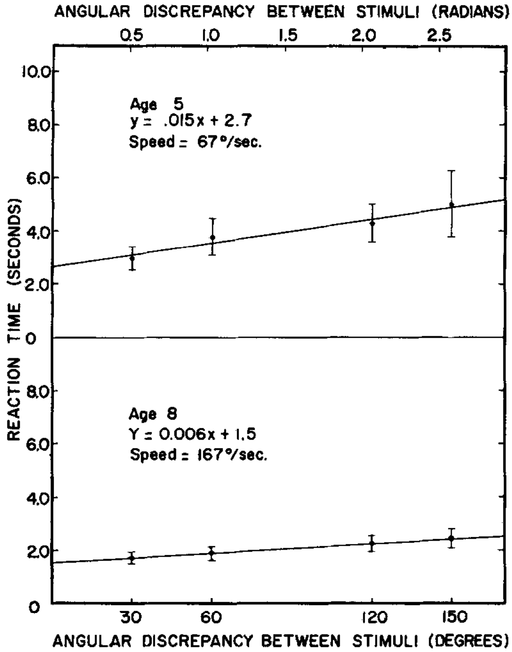

FIG. 1. Reaction time means and least-squares fits of the means for 5- and 8-yr olds as a function of angular discrepancy between stimuli. (The 95% confidence limits about each mean have been based on the *t* distribution. The slopes are given in units of [degrees/sec]$^{-1}$.)

was .006 for 8-yr olds and .015 for 5-yr olds. The 95% confidence interval was $.004 \leqslant \beta \leqslant .008$ for 8-yr olds and $.008 \leqslant \beta \leqslant .022$ for 5-yr olds. The correspondence of these fitted lines to the mean of individual reaction time means at each rotation is shown for the two age groups in Figure 1. This figure also suggests the accuracy with which these fitted lines can predict the mean reaction times reported above for 0° (0 rad) rotation. Estimates of the speed of mental rotation based on the slope suggest that the 5-yr olds mentally rotate at the rate of 67° (1.17 rad)/sec and 8-yr olds at approximately 167° (2.81 rad)/sec.

Inasmuch as the assumptions of normality and homogeneity of variance were not met in the foregoing analyses involving reaction time scores, a second set of distribution-free analyses was based on slopes of individual subject's least-squares lines. Within each age group, a Sign Test indicated that the median of the individual's slopes differed from zero ($p < .001$, two-tailed). The median for 8-yr olds was .005 with a 95% confidence interval based on the Sign Test of $.004 \leqslant \beta \leqslant .009$ (i.e., null hypothesis for median β, which the Sign Test would reject with $p < .05$, two-tailed). The median for 5-yr olds was .0105 with a 95% confidence interval of $.0086 \leq \beta \leq .015$. For 5-yr olds, fitted linear slopes ranged between .004 and .081; for 8-yr olds fitted linear slopes ranged between .001 and .014. A Mann–Whitney Test showed that the 5-yr olds' slopes differed significantly from the 8-yr olds' ($p < .001$, two-tailed).

Errors for Rotated Stimuli

Five-year olds responded incorrectly on an average of 11.1% of trials with individual error rates over all conditions except 0° (0 rad) rotation ranging from 0 to 25%. Eight-year olds responded incorrectly on an average of 5.9% of the trials with individual error rates over all conditions except 0° (0 rad) rotation ranging from 0 to 18%. Table 1 suggests that errors were not equally distributed among angles for either age group. A two-way (age × rotations) analysis of variance on the 2 arcsin $(X_{ijk})^{1/2}$ transformed proportions of errors (Winer, 1962) yielded significant effects for age ($F(1,38) = 5.5$, $p < .05$) and rotations ($F(3,114) = 14.1$, $p < 0.1$), but no significant age × rotation interaction ($F(3,114) = 0.7$, $p > .20$). The mean reaction times for incorrect responses for 5-yr olds and 8-yr olds also appear to increase with angular discrepancy between stimuli in Table 1.

Since the proportion of errors increased as the angular discrepancy between stimuli increased, it seemed likely that correct guesses included in the preceding analysis might also increase with angular discrepancy. Thus, the linear relationship of reaction times for correct responses to angular discrepancy might be due, at least in part, to an increase in the frequency and reaction times of guesses with increases in angular discrepancy between stimuli. In order to estimate the mean reaction times for all correct responses which were not based on guessing (RT not guess),

TABLE 1
PERCENTAGE AND MEAN REACTION TIME FOR ERRORS AT EACH ROTATION FOR EACH AGE

	Angular separation between stimuli			
	30° (0.52 rad)	60° (1.05 rad)	120° (2.09 rad)	150° (2.62 rad)
5-yr olds				
Percentage of error	5.4	5.4	13.3	20.4
Mean reaction time for errors (sec)	3.2	4.4	3.7	4.3
8-yr olds				
Percentage of error	2.5	2.5	6.7	12.1
Mean reaction time for errors (sec)	1.4	1.6	1.9	3.0

TABLE 2
ESTIMATED AND OBSERVED REACTION TIME MEANS (IN SECONDS) FOR EACH ROTATION AT EACH AGE

	Angular separation between stimuli			
	30° (0.52 rad)	60° (1.05 rad)	120° (2.09 rad)	150° (2.62 rad)
5-yr olds				
Estimated reaction time means	3.0	3.8	4.4	5.2
Observed reaction time means	3.0	3.8	4.3	5.0
8-yr olds				
Estimated reaction time means	1.7	1.9	2.2	2.3
Observed reaction time means	1.7	1.9	2.2	2.4

the following two equations were used for each group at each rotation condition:

$$P \text{ error} \cdot RT \text{ error} + P \text{ correct} \cdot RT \text{ correct} = RT, \tag{1}$$

$$P \text{ guess} \cdot RT \text{ guess} + P \text{ not guess} \cdot RT \text{ not guess} = RT. \tag{2}$$

All terms in Equation 1 are empirically known. In Equation 2, P guess, *RT* guess, and *P* not guess must be estimated in order to solve for *RT* not guess. It was assumed that all errors resulted from guessing; then since any guess had a 50% chance of being correct, *P* guess $= 2 \cdot P$ error, and *P* not guess $= 1 - 2 \cdot P$ error. Further, it was assumed that the mean reaction times associated with guessing correctly and incorrectly were equal, and therefore *RT* guess = *RT* error.[1]

The analysis yielded estimated reaction time means for correct non-guessing responses which differed very little from the original means for correct responses. These results, which appear in Table 2, strongly suggest that removing the presumed effects of guessing from reaction times will not disturb the relationship between times for correct responses and the angular discrepancy between stimuli.

DISCUSSION

The present study was designed to test whether 5-yr olds have the ability to produce kinetic imagery. Since Piaget and Inhelder (1971) suggest that kinetic imagery emerges first at approximately 7 to 8 yrs of age, a comparison was made between the performances of 5- and 8-yr olds on a task requiring the production of kinetic images of object rota-

[1] This procedure was suggested by Dr. Mary Ann Fisher of the University of Maryland, Baltimore County.

tion. The results indicate that 5-yr olds, like 8-yr olds, use kinetic imagery.

The experimental procedures adopted in the present study are similar to those employed in studying the kinetic imagery of adults (Cooper & Shepard, 1973, Shepard & Metzler, 1971. Shepard and Metzler found that their subjects both reported using kinetic imagery representing object rotation and produced corroborating reaction times which increased linearly as a function of the angular separation between stimuli. In the present study, 8-yr-old subjects, considered capable of kinetic imagery by Piaget and Inhelder (1971), also produced reaction times increasing linearly as a function of angular separation between stimuli. Thus, the fact that the reaction time scores produced by 5-yr olds also showed a significant linear relationship suggests that their imagery is like that of adult and 8-yr-old subjects. The linear trend in reaction time scores of adult, 8-yr-old, and 5-yr-old subjects is parsimoniously accounted for by the process which Shepard and Metzler's adult subjects reported using, namely imagery representing object rotation.

Every 5-yr old tested produced reaction times which were successfully fitted by a positive linear slope. Further, all 5-yr olds performed well above chance guessing and, in fact, no 5-yr old averaged more than 25% error on a task where chance would yield error rates of approximately 50%. Thus, it cannot be argued that the linear trend or the high level of success for 5-yr olds as a group stems from the performance of a subset of advanced children. Estimates of the speed of mental rotation suggest that 5-yr olds mentally rotate at the rate of approximately 67° (1.17 rad)/sec, and 8-yr olds at approximately 167° (2.81 rad)/sec. Speed estimates for adults on a similar, but far from identical, task indicate speeds varying from 164 (2.86 rad) to 800° (14.0 rad)/sec (Cooper & Shepard, 1973). Comparison suggests the 8-yr olds mentally rotate as quickly as some adults.

However, two studies undertaken by Piaget and Inhelder (1971) suggest an alternative explanation for at least a portion of the present findings. If the child imagined what the mobile stimulus would look like after rotation into the orientation of the upright stimulus without imagining the rotation itself he could achieve the low error rates found in the present study. In one study (Piaget & Inhelder, 1971, pp. 135–144) Piaget and Inhelder found that 5-yr olds could not properly draw the trajectory of a beaded rod in rotation, but could accurately portray the beginning and end states of the rotation. Similarly in a second study (Piaget & Inhelder, 1971, pp. 65–73), some 4- and 5-yr olds successfully drew the initial and final positions of a pivoting rod, but could not draw its trajectory. Piaget and Inhelder concluded that 5-yr olds could, at least sometimes, imaginally represent the outcome of a rotation without being able to imaginally represent the movement itself (Piaget & Inhelder, 1971, p. 83, p. 137). Thus it might be claimed that the 5-yr olds in the present study in fact produced the final position of the mobile stimulus necessary to solve the experimental problem, but did not imagine the rotation itself. This interpretation is inadequate, however, because it does not account for the linear relationship between reaction time and angular separation between stimuli.

Alternatively, it would be possible for the subject to solve the problem using a strategy based on imagining change in his own orientation. Presented with two bears, the subject might: (1) mentally rotate himself around a vertical axis to place himself in the position of the upright bear, (2) imagine raising the same arm as that bear, (3) mentally rotate himself around a horizontal axis into the position of the other bear, (4) determine whether or not he can imitate the second bear with the same arm raised, (5) if so, he decides that the two bears are the same. Application of such a strategy seems unlikely, however, in light of recent research by Huttenlocher and Presson (1973) which suggests that, at least for 8-yr olds, problems which require children to imagine a change in their orientation are more difficult than problems which require them to imagine the rotation of an object in space. In short, it seems improbable that children of 5 and 8 yrs would deliberately employ a more difficult solution strategy when they were essentially instructed to solve the problem by rotation.

Of the three interpretations discussed, that following Shepard and Metzler (1971) provides the most complete explanation. It clearly conflicts with Piaget and Inhelder's thesis that kinetic imagery first emerges at 7 to 8 yrs of age. The source of the disagreement may perhaps be found among several experimental differences between the present study and Piaget and Inhelder's research.

One possibility follows from Flavell's distinction between the evocability (the ability to sense the relevance of a certain solution procedure) and the utilizability (the ability, once having sensed the solution procedure-to-problem fit, to employ the solution procedure effectively) of a cognitive strategy (Flavell, 1971). A major difference between Piaget and Inhelder's studies and the present one is that in the latter, each child was specifically instructed to use kinetic imagery of rotation to solve the experimental problem, while no solution instructions were provided by Piaget and Inhelder. Thus, it seems possible that one component of kinetic imagery, namely utilizability, was observed in the present study, and another, evocability, was observed by Piaget and Inhelder. Alternatively cultural and educational differences between Swiss and American children may have contributed to the discrepancy between findings. But perhaps a more convincing hypothesis stems from the fact that the main evidence for kinetic imagery in the present study is based on reaction time scores, while that in Piaget and Inhelder's research is based on analysis of the character and quality of errors. Consideration should be given to which measure best indicates use of kinetic imagery. With these several possible sources of disagreement between the present study and the work of Piaget and Inhelder (1971), a specific understanding of the reason for the conflicting results awaits further research.

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