

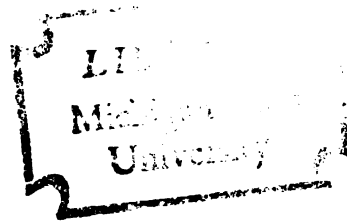


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MENTAL PICTURE INVERSION: LEFT - RIGHT  
CONFUSION AND MIRROR - IMAGING IN CHILDREN AND  
ADULTS

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ABSTRACT

MENTAL PICTURE INVERSION; LEFT-RIGHT CONFUSION AND  
MIRROR-IMAGING IN CHILDREN AND ADULTS

by

Catherine Therese Best

While preschool children can discriminate between up and down, left-right relations generally are not mastered until twelve. Major explanations for the relative difficulty with left-right are: (1) left-right differences in the environment are fewer and less salient than top-bottom differences; (2) the human nervous system may favor recognition of top-bottom cues more than left-right cues.

The purpose of this study was to evaluate the role of these factors in development of the ability to mentally invert pictures. A neural-structural model of the constitutional predisposition to confuse left-right was proposed. According to that model, there should be a prevalence of left-right mirroring errors at all ages. If underlying factors are environmental or experiential, we would expect (1) a decrease in both left-right and up-down errors with age; (2) an increase in errors as task difficulty increases. Previous studies indicate that predicting the effects of perspective change on the appearance of an array is more difficult for children than predicting the effects of rotation, and identification of upside-down pictures is more difficult than right-side-up at all ages, so these were the manipulations on task difficulty in the study.

Kindergarteners, 3<sup>rd</sup> graders, 6<sup>th</sup> graders, and college students were shown six pictures of realistic scenes, one at a time, and asked to reconstruct them with reversible felt pieces on a flannelboard. Each subject was tested with a right-side-up and an upside-down picture presentation under each of the following conditions: (1) copy: "make a picture just like this one"; (2) rotation: "show how this picture would look to you if it were upside-down"; (3) perspective: "show how this picture would look to you if you were upside-down."

As predicted, total number of errors decreased with age, and left-right errors were more frequent than top-bottom errors at all ages, although the latter effect was weak for college students. Errors increased with predicted increases in task difficulty, although the presentation effect was strong only for 3<sup>rd</sup> graders and in the perspective condition. Analysis of overall configurations of the rotation and perspective reconstructions revealed that although frequency of correct solutions increased with age, the most frequent incorrect solution at all ages was the mirror-inversion, as predicted. These findings indicate that both environmental and biological (neural-structural) factors underlie the difficulty in learning left-right relations.

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MIRROR-IMAGING IN CHILDREN AND ADULTS

by

Catherine Therese Best

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to my family and good friends,  
whose emotional support helped me throughout  
my work on this thesis.

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## INTRODUCTION

When and how do children predict the way a picture will look turned upside-down? What factors contribute to the types of errors made in such a prediction at different ages? I became interested in these questions while participating in a seminar on the development of spatial concepts. During a class presentation, an "upside-down" mural painted by some seven-year-old children was shown. Their teacher had taped a sheet of paper to the wall, with a line drawn across the top, and asked the children to draw an "upside-down picture" so that the line was the ground. The children's errors reflected deficits in skill at representing an inverted scene. For example, they often failed to make the feet of human figures touch the "ground" the teacher had drawn initially. Several trees grew in the "sky" with the roots dangling, the sun nearly touching the "ground" below them. Occasionally only parts of an object were inverted, such as the face of a clock on a building. Finally, words or letters were printed as up-down and left-right mirror-reversals, as though reversed on only one axis rather than properly rotated until upside-down.

The same children also painted a right-side-up mural. This time they had no difficulty in correctly positioning and orienting the objects in the picture.

### Spatial Ability and Past Experience

At least two lines of research indicate that the ability to imagine how something will look turned upside-down depends on the ability to mentally represent the action of rotating the object, through kinetic kinesthetic-visual imagery and/or verbal mediation. Skill in either strategy for mentally representing rotation may depend on experience in physically turning things upside-down. From their studies on the growth of spatial concepts, Piaget and Inhelder (1967) concluded that prediction of the outcome of an action is based on mental representation of the sequence of movements constituting that action. Adults generally predict the effects of a picture rotation by mentally representing the action of rotating a picture (Cooper & Shephard, 1973). When adults were asked to state whether a pair of pictures represented the same three-dimensional form or alphanumeric symbol in different orientations, their reaction times increased proportional to the angular differences between the figures. This increase in reaction time may have resulted from a mental rotation of one visual form in time and space to tell whether it matched the other. Nearly all subjects reported that they did use a mental rotation strategy, and further studies supported these self-reports. According to Cooper and Shephard, these findings show that kinetic visual imagery is the main strategy adults use to mentally rotate pictures, although this does not preclude the possibility that verbal mediation plays some role.

Piaget and Inhelder also suggested that the ability to represent a sequence of movements stems from the individual's experience with that sequence. If so, a person should be able to anticipate the outcome of actions starting from right-side-up situations better

than from upside-down situations. After all, most people spend only a small part of their time upside-down, and encounter upside-down objects much less often than right-side-up objects. For the most part, we act on objects in a right-side-up world. Piaget and Inhelder's hypothesis also predicts that mental rotation abilities increase as experience with rotation increases. Presumably such experience increases with age.

### Understanding the Effects of Rotation on Spatial Relations

There has been little research on the growth of understanding the effects of rotating an object array on spatial relations among the objects (relative positions) and on the directional features in each object (orientation). When an array is turned upside-down, both the positions and the orientations of the objects change relative to the observer. Past studies have focused mainly on the child's ability to predict the effects of rotation on the relative positions of objects rather than on their orientations.

Predicting changes in relative positions of objects in a rotated array is difficult for children, as recent studies indicate. In one test three colored beads were placed in a cardboard tube within the child's view and he was asked to name the colors of the beads in order as they would come out of the tube after it had been rotated one or more 180° turns. Before five years of age, children either repeated the original order of the beads or named the colors haphazardly. At six or seven years, the children could predict the effect of a single 180° rotation but could not generalize to trials with more beads or more turns. Only by seven or eight years could children perform correctly in all trial situations (Piaget, 1970; Charlesworth & Zahn, 1966; Charlesworth, Note 1).

There are two problems in using this test to assess children's ability to mentally represent the effects of rotation. First, age change in memory could confound the results. The children younger than seven or eight may have erred in their predictions because they forgot the original order of the beads. Second, the test only measures understanding of the effects a rotation has on the relative longitudinal positions of geometrically simple objects. Since beads are radially symmetrical, rotation does not produce noticeable changes in their orientations.

In a series of studies that partially control for the problems just noted, Piaget and Inhelder (1971) asked children to predict the positions of features on an object after it was rotated. In one study each child saw a flat square with a red line along one edge and a blue line along an adjacent edge. He then predicted where the lines would be if the square were rotated sideways ( in the picture plane-- flat on the table) through various numbers of 90° turns. In another study each child saw a flat triangle with markers superimposed on two of its angles and predicted the positions of the markers after the triangle was rotated sideways through multiples of 90° turns. The developmental stages found in these two mental imagery studies correspond with those found in the earlier tube rotation studies. However, even these later studies test only the ability to imagine the effects of rotation on the positions of simple feature markers within simple geometrical shapes. Furthermore, they do not tell us whether children understand how rotation affects the orientation of more realistic objects with implicit directionality cues.



To anticipate how an array of objects or a picture will look when turned upside-down, one must take into account the positions and orientations of the individual objects in the array or picture, not only in the vertical (top-bottom) dimension, but also in the horizontal (left-right) and depth (front-back) dimensions. The positions and orientations of objects in an inverted three-dimensional array depend on how the inversion was done--whether by turning the array sideways in the picture plane, or by flipping the top toward oneself in the depth plane to reverse the array along the horizontal axis. One cannot see a picture that is turned upside-down along its horizontal axis in the depth plane, so we need be concerned here only with the effects of inverting a picture by turning it in the picture plane. That operation will retain the depth relationships among objects in the picture but will reverse positions and orientations within both the vertical and the horizontal dimensions. Thus, objects in front in the right-side-up picture will still be in front relative to the observer, and objects facing him will remain facing him. But objects on top when the picture was right-side-up will now be on the bottom. Likewise, objects on the left before will now be on the right, and orientations of objects will be reversed left to right as well as top to bottom.

Mentally inverting a picture thus can be seen as a complex task involving at least three different types of spatial ability: recognition of the orientation and identity of inverted objects; coordination of perspectives in order to predict how things will look either in a different position or from a different position; and differentiation between top and bottom, front and back, and left and right.

### Recognition of Inverted Faces and Figures

Since inverting a display of objects with directional cues reverses the objects' orientations as well as relative positions, it is important to know how much attention children pay to orientation cues in objects and scenes. In particular, we want to know how recognition of a figure's identity is affected by a change in its orientation.

Early studies of form perception and picture recognition suggested that children below about five or six years of age are insensitive to changes in orientation of objects and figures (Koffka, 1924; Stern, 1930). In one such study children first were shown line drawings of two standard forms, a diamond and a spoon with the bowl end down, and then were asked to indicate each time they saw one of those forms among drawings of a variety of objects, including diamonds and spoons, in various orientations. Children younger than five or six tended to point out all the spoons and diamonds, whatever their orientations, while the older children restricted their choices to diamonds and spoons in the same orientations as the standards (Rice, 1930). However, the author's interpretation that the younger children were insensitive to orientation changes is questionable. The instructions failed to state that orientation as well as shape was important and therefore may have been ambiguous for the younger subjects (see Harris & Allen, 1974; Harris & Schaller, 1974).

Later studies showed that children do respond to orientation cues. Children can detect orientation differences among identical forms (Wohlwill & Weiner, 1964). Also, changing the orientation

of a picture can affect recognition of it, especially for younger children. In one test, children under eight years referred to fewer actions and fewer functional relationships among picture elements in describing upside-down pictures than right-side-up pictures. Older children used the same amount and type of description regardless of picture orientation (Hunton, 1955).

More recently, the finding that recognition is reduced for inverted pictures has been extended. Adults make more errors and take longer to identify inverted than right-side-up words and figures (Rock, 1974). And individual faces are more difficult for both adults and children to identify when inverted than when right-side-up (e.g., Bradshaw & Wallace, 1971; Brooks & Goldstein, 1963). In all cases the stimuli were still easily recognized as words and faces. Inversion simply made it more difficult to identify a particular word or face. These findings agree with the suggestion made earlier that because of different experience with right-side-up and upside-down, people should be able to anticipate the outcomes of actions better in the former than in the latter situation. For the same reason, it should be easier to predict the effects of inverting a right-side-up picture than the effects of inverting an upside-down picture.

#### Coordination of Perspectives

To predict how a picture will look turned upside-down, one must be able to imagine it in a different position. This may be accomplished either by mentally turning the picture upside-down while remaining right-side-up oneself, or by mentally turning oneself upside-down

while the picture remains right-side-up with respect to gravity. The first method involves imagined movement of the object, while the other involves imagined movement of the observer. Though both methods yield the same retinal image of the object, they are not necessarily psychologically equivalent. The ability to imagine movement of an observer with respect to an array has been measured in coordination of perspectives tests. In these tests the subject is usually asked to imagine how the array would look to someone else, in a different position than his own with respect to the array. This may not be psychologically equivalent to asking the subject how the array would appear to him if he changed his own position.

In their coordination of perspectives test, Piaget and Inhelder (1967) asked children to predict the appearance of a model of three differently colored mountains to a doll placed at various points around the model. The children made their predictions of the doll's view either by choosing from photographs or by constructing the scene with colored cutouts of the mountains. Children under seven years indicated that, whatever the doll's positions, she saw the scene as they saw it. By seven or eight years the children showed that they knew the doll's view was different from their own, but were unable to predict changes in the relationships among the mountains in the left-right and front-back dimensions simultaneously. Only at nine or ten were they able to coordinate perspectives by correctly predicting changes in both spatial dimensions relative to the doll's viewpoint. Errors at all ages were predominantly left-right rather than front-back errors.

As already mentioned, asking what a scene will look like after a change in observer position is not necessarily psychologically equivalent to asking what it will look like after a change in the scene's position. The former is defined as a coordination of perspectives problem, the latter as a rotation problem. To identify the psychological difference between the two, third- and fifth-graders were asked rotation and perspective change questions about the order of a row of colored blocks in a toy horsecart (Huttenlocher & Presson, 1973). This cart was mounted on a turntable for the rotation tasks, and had a detachable horse that could be positioned anywhere around the cart for the perspectives task. The children erred more in predicting the order of blocks seen by the horse in the perspective change condition than in predicting the order of blocks after a cart rotation. Third-graders made more mistakes overall than fifth-graders. Children at both ages erred more often on the tasks in making predictions about the array when it was hidden beneath a cloth than when it was visible, indicating that task difficulty increases when the original array must be remembered.

That children make more errors in the perspectives change than the rotation task indicates differences in their mental representations of the two actions, and may reflect their greater difficulty in mentally representing a change in observer position than a change in position of the array. Huttenlocher and Presson (1973) suggest two other possible sources of the performance difference: (1) it may be that although children realize another person's viewpoint differs from their own, they have difficulty representing it because they have trouble "lining up" their viewpoint with another; (2) there

was a fixed outside reference point (the horse) which bore a constant relationship to the array in the orientation task but not the perspective task, so that the subjects may have used a regenerative strategy to solve the rotation problem. A second experiment by Huttenlocher and Presson (1973) supports the contention that difficulty in representing another's viewpoint is the cause of the performance difference between the rotation and perspective change tasks used in their earlier experiment. Fourth-grade children found it easier to predict how the hidden horsecart array would look to them after an actual change in their position than after an imagined change in their position. A fixed outside reference point (the horse) aided task solution when the subject actually changed position but not when he had to imagine a change in position. The second study clarified the role of actual versus imagined change in the subject's position and of a fixed outside reference point in perspective change tasks. However, since there may be other factors underlying the performance differences between rotation and perspective change tasks, and it was never demonstrated that a fixed outside referent did aid solution of the rotation task in the first experiment, it still is not clear that there are differences in the subject's mental representations of a change in position of an array and a change in his position with respect to that array.

The most direct determination of differences in mental representations of the two actions would be the comparison of responses to a mental rotation problem with the responses to an equivalent perspective change problem in which the subject imagines a change in his own position relative to the array rather than a change in

someone else's position. A performance difference between these tasks, either in frequency or type of error, would indicate that the two actions are mentally represented differently. On the other hand, a lack of difference between the tasks would demonstrate no differences in mental representations of the two actions involved. Such a lack of differences would suggest, however, that difficulty in representing another's viewpoint underlay performance differences found in earlier comparisons of rotation and traditional coordination of perspectives tasks.

There may be an experiential basis for either a difference in the mental representations of the two actions or a difficulty in representing a perspective change task. Whichever of these proves to better explain the performance difference between rotation and perspective change tests found in earlier studies, both tests require knowledge of spatial relationships for adequate performance. One must be able to identify relationships among objects in the horizontal, vertical, and depth dimensions whether predicting the effects of turning a picture upside-down or predicting how a picture would look if one were upside-down oneself.

#### Learning Spatial Relationships: the Problem with Left and Right

It was mentioned earlier that children err more in representing left-right than front-back relationships among objects when solving coordination of perspectives problems (Piaget & Inhelder, 1967). In general, left-right discrimination lags behind up-down and front-back discrimination. Most children do not distinguish left and right until the early elementary school years, although they learned to discriminate up and down (Benton, 1959; Harris, 1973; Huttenlocher,

1967a) and front and back (Harris & Strommen, 1973) during their preschool years. Piaget (1928) reported three stages in the learning of left-right relations. Until eight years of age, children consider left and right only from their own viewpoint. Between eight and 11 years they are able to distinguish left from right according to another person's viewpoint. Finally, at 11 or 12 they realize that left and right may be considered from the viewpoint of objects themselves. Simple discrimination questions about left and right are answered earlier and with fewer mistakes than are questions about the relativity of left and right in regard to the middle object in a three-object array. This may help account for the stages in learning left-right. The problem with learning left-right is an imperfect mastery of the basic discrimination rather than an imperfect mastery of relational concepts in general (Harris, 1973). In fact, since left and right seem to present particular problems for children compared with other spatial dimensions, Piaget appears to have erred in choosing to study understanding of left and right as a measure of the development of general logic and relational concepts.

Many environmental factors may make left-right discriminations more difficult than up-down or front-back. There are numerous intrinsic cues in most objects and figures that aid up-down discrimination (Harris & Schaller, 1971; Schaller & Harris, 1975; Harris, Note 2) and front-back discrimination (Harris & Strommen, 1973; Harris, Note 2), but few, if any intrinsic left-right cues. There also is a greater opportunity to practice up-down and front-back than left-right, probably because of differences in their operational



significance (Harris, Note 2). Often things are unusable when turned upside-down, but their usefulness is not reduced nearly so much by reversing them left to right. In explaining children's more numerous left-right than top-bottom errors in their coordination of perspectives task, Piaget and Inhelder (1967) argued that a child becomes aware of the difference between front and back because of differences in his actions on front and back. Foreground and background are different distances from him, so the child performs different actions on objects that are in the foreground than those in the background. However, left and right are more difficult to discriminate because they are equidistant from the child. His actions on objects to the left are not much different from those on objects to the right.

Since up-down cues in the environment are more salient and frequent than left-right cues, one would be more likely to attend to the top-bottom than the left-right reversals in positions and orientations of objects than the left-right reversals in positions and orientations of objects that occur when a picture is inverted. Thus people would make fewer top-bottom than left-right errors when asked to predict what a picture will look like turned upside-down, although both errors should decrease as age and experience increase. If environmental factors are the sole cause of left-right difficulty regardless of age or task difficulty, we would expect left-right errors to be haphazard, as though the subject were failing to note left-right cues.

There is much evidence that environmental factors are not necessarily the only basis for left-right confusion. Structural or

biological factors may play a part, too. The human nervous system may be wired more specifically for recognition of the top-bottom than the left-right cues present in objects (Rudel & Teuber, 1963; Sutherland, 1957). Because our nervous system is more nearly symmetrical left to right than top to bottom or front to back, we may be less able to distinguish left from right than top from bottom or front from back (Corballis & Beale, 1970).

Left-right mirror-image problems with certain tasks may be traceable to these factors. When children below seven years are asked to copy the gestures of a person facing them, they more often mirror than transpose the gestures. That is, they will touch their left leg when the experimenter facing them touches his right (Benton, 1959). In fact, if an unobtrusive measure is used to elicit gesturing, for instance when the experimenter says, "there is something on your face" while pointing to his own right or left cheek, even college students mirror rather than transpose the gesture. However, the object of an action is apparently more susceptible to mirroring than the agent of the action. The college student more reliably cheek-mirrored than hand-mirrored, presumably because the cheek is the object of the action while the hand is the agent (Harris, Note 3).

Mirror-image problems also emerge in tasks requiring discrimination among figure orientations. Left-right mirror-images of simple figures or oblique lines are more difficult to discriminate than equivalent up-down mirror-images for children (Rudel & Teuber, 1963; Sekuler & Rosenblith, 1964; Podell, Note 4), adults (Sekuler & Houlihan, 1968), and octopuses (Sutherland, 1957). Such pairs of

figures are more difficult to discriminate in either dimension when the pair members are in mirror-image rather than aligned positions (Huttenlocher, 1967a, b; Kershner, 1971). Yet even when left-right and top-bottom mirror-image pairs are both presented in mirror-image positions, the left-right discrimination is still more difficult than the top-bottom one, both for children (Chapman, Note 5) and adults (Sekuler & Houlihan, 1968). Furthermore, in a study of memory for a pattern on a pegboard, children made many symmetrical (mirror-image) left-right errors but no symmetrical top-bottom errors (Emerson, 1931). Research on perception of form orientation suggests that of mirror-images in all possible orientations, and left-right mirror-image is especially appealing to humans, whatever the reason. In one study, when asked to make a variety of nonrepresentational two-dimensional forms "upright," subjects of all ages turned them so that the axis of symmetry was vertical, making left-right mirror-images. The only exception was a form resembling the letter 'C' (Schaller & Harris, 1975).

The mirror-image problems just described have often been invoked as evidence that neural-structural factors underlie left-right difficulties (e.g., Benton, 1959; Harris, Notes 2 & 3). The theory that left-right difficulties are caused by greater left-right than top-bottom body and nervous system symmetry (Corballis & Beale, 1970) does not completely explain the left-right mirror-image problem. A model that would adequately explain the problem and also predict the effects of structural factors in a mental picture inversion task would have to include an outline of the specific neural structures involved.

Since the concern is with neural-structural effects on visual information processing, the brain would be the major structure involved, particularly the visual cortex. The brain hemispheres, including the visual areas, are nearly symmetrical left to right, but not top to bottom. Neurophysiological studies indicate that there are no direct neural connections **between** the primary visual areas of the hemispheres. The corpus callosum connects only mirror-image points of the visual association cortex (Crosby, Humphrey & Lauer, 1967; Myers, 1960; Sperry, 1962), although evidence from research with the monkey and the cat suggest that there may be some nonmirror-image connections (Crosby, Humphrey & Lauer, 1967). There is no electrical discharge from the visual association areas back to the primary visual areas (Bonin, Garol & McCulloch, 1948, cited in Downer, 1962). Information about visual input that is transferred callosally therefore is partially processed rather than raw sensory data. The transferred information is already modified by the other input to the association areas, and some clarity is lost in the transfer (Downer, 1962; Myers, 1962). Interconnections of visual mechanisms within a hemisphere are more potent or efficient in information transfer than are interhemispheric connections (Mishkin, 1962).

When someone fixates on the center of a visual target, that part of the target in the left visual field is projected to his right hemisphere, and the part in the right field to his left hemisphere (Crosby, Humphrey & Lauer, 1967; Kimura, 1973). Even if one visually inspects the entire target, more of the information in each visual hemifield reaches the respective contralateral than ipsilateral

hemisphere. Since interhemispheric visual connections are mainly between left-right mirror-image points, while intrahemispheric top-bottom connections are not between mirror-image points and are at the same time more effective, integration of information about each lateral half of the target will be better than integration of information between the lateral halves, and mirror confusions of the lateral halves of the visual field common. Thus more left-right than top-bottom mirror-image problems would be expected. It may be that we are able to overcome left-right mirroring tendencies only because of some left-right nervous system asymmetries (Tschirgi, 1958, cited in Scheibel & Scheibel, 1962), including proposed asymmetrical connections between some left-right points in the visual association areas of the hemispheres (Sperry, 1962).

Support has already been described for the following predictions about left-right mirroring tendencies derived from the neural-structural model just outlined: (1) the visual processing system should confuse left-right more than top-bottom mirror-image pairs of figures; (2) in pattern memory tasks there should be more left-right than top-bottom mirror-image errors; (3) the easiest imitative response to a gesture seen in one visual hemifield should be a gesture with the ipsilateral limb, since most sensory-motor as well as visual field connections are to the contralateral side of the body [thus the hemisphere contralateral to the field in which the gesture was seen would be activated, which would activate the limb contralateral to it, or ipsilateral to the gesture (Kinsbourne, 1973)]. Predictions could also be made from the proposed model about the effects of structural factors in a mental picture inversion task. It should be easier

to mentally reverse the top-bottom poles in each lateral half of the picture than to mentally reverse the two lateral halves and thus the left-right poles. Therefore the easiest response of the visual processing system to mental picture inversion instructions would be a mirror-inversion, with top and bottom reversed and left and right mirrored from the original pattern.

A mirror-inversion response probably would not result from specific experience with seeing mirror-inversions after rotating most pictures until upside-down. To invert a picture printed on only one side of a page, one must rotate it in the picture plane--flipping the top over in the depth plane will only show the blank back of the page. Rotation in the picture plane will reverse both the left-right and the top-bottom poles of an asymmetrical picture. Therefore, a mental rotation of the picture that produced a mirror-inversion could not be based on experience in seeing mirror-inversions after inverting asymmetrical pictures. Experience may play some part in mirror-inversion responses, however. If top-bottom is a more salient dimensions than left-right, as has been suggested, people would be more likely to attend to top-bottom than left-right reversals that occur in a picture inversion, and experience may have negative carryover in a mental inversion task.

Ability to inhibit the mirroring tendency should increase with age. The cortex, which plays an important role in the inhibition of responses (Brackbill, 1971), matures and grows more effective with age. Neurophysiological research with animals indicates that experience and environmental influences modify biological effects on behavior by affecting the connections and response properties of

cortical cells (see review by Kolata, 1975; Roseweig, Bennett & Diamond, 1972). Thus, experience with inverting pictures and objects, as well as experience with left-right relations in general, should affect the connections in the visual processing system and strengthen the older individual's ability to inhibit mirroring tendencies. In addition, studies on language acquisition indicate that the self-regulatory function of language, or the ability to use one's language to inhibit one's own behavior, increases with age. This is tied to changes in the functioning of the central nervous system (e.g., Luria, 1959, in Oldfield & Marshall, 1968).

#### Experimental Hypotheses and Tests

A simple test was devised to measure children's ability to mentally invert pictures. College students and children from the pivotal ages for the three developmental stages in learning left-right (Piaget, 1928) were asked to predict how pictures of asymmetrical scenes would look after a rotation or perspective change. In the rotation condition subjects predicted how the picture would look to them if it were turned upside-down; in the perspective change (or "self-rotation") condition they predicted how the picture would look to them if they themselves were upside-down. On the assumption that children and adults have had more experience turning things upside-down than being upside-down themselves, more errors were expected in the perspective change than in the rotation condition. Recent evidence supports this prediction in part (Huttenlocher & Presson, 1973). On the further assumption that children and adults have had more experience with right-side-up than upside-down pictures, subjects also were asked to make predictions about pictures presented

upside-down. More errors were expected in this condition than when pictures were presented right-side-up.

At all ages and in all conditions and picture presentations, left-right errors were expected to exceed top-bottom errors as a result of both environmental and biological factors. Mirror-inversion responses to the mental picture inversion tasks would reflect biological-structural limitations on learning left-right. If biological-structural factors are at least in part responsible for difficulties with left and right, the mirror-inversion should be the most common erroneous solution in mental picture inversion tests at all ages. However, correct solutions should increase with age as people gain both in experience relevant to the tasks and in ability to inhibit left-right mirroring tendencies.

Two control pretests were given to determine whether the subjects, especially the children, could detect orientation cues and note the left-right positions of objects in the pictures. In one, each subject was asked to fit the smallest picture part from each of the standard pictures used in the mental inversion tests inside its own outline on a flannelboard. These outlines were drawn in various orientations to measure the ability to detect orientation cues as well as to recognize figure outlines. In the second pretest, subjects were asked to make copies of two pictures of natural scenes, like those used in the inversion tests. One picture was presented right-side-up and the other upside-down. This test provided a measure of the subjects' ability to note orientations and relative positions of the objects within the pictures, and skill in matching those orientations and positions.



## METHOD

### Subjects

Twenty-four subjects (12 males, 12 females) from each of the following age groups were tested: kindergarten (mean age = 6.0 years, third grade (mean age = 9.2 years), sixth grade (mean age = 12.2 years), and college (mean age = 21.2 years). The children were enrolled at Dimondale Elementary School in Dimondale, Michigan. The college students were enrolled at Michigan State University, and were either volunteers from an experimental psychology laboratory class or introductory psychology students offered grade credit for participation.

### Apparatus

The test materials were: a flannelboard with outlines of six small directionally-featured (asymmetrical) objects in various orientations and corresponding reversible felt pieces for the subject to fit inside the outlines; six pictures of asymmetrical realistic scenes made of felt pieces. These six pictures are referred to as the standards. Each of the six felt pictures had four corresponding reversible felt pieces to use in constructing flannelboard pictures. These four pieces are marked in each of the six standards shown in Figure 1. Each piece contains obvious left-right and top-bottom directional cues. Although some pieces (e.g., chair, table) represent three-dimensional objects that are symmetrical

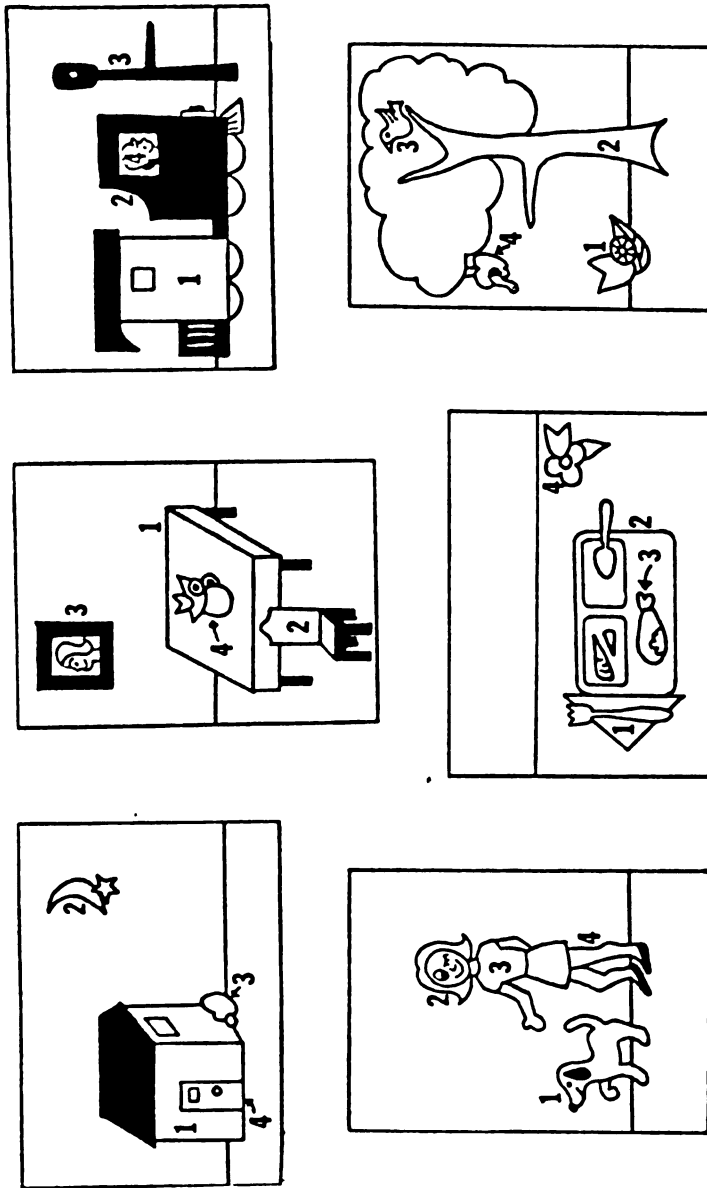


Figure 1 -- The six picture standards shown to each subject

from some viewpoints, the felt pieces were cut so as to be asymmetrical in a two-dimensional representation (as if the objects were viewed off-center). All pieces were reversible so that the subjects could use the mirror-image of any given object and therefore could make left-right orientation errors independently of top-bottom errors. Blank white flannelboards the same size as the standards were the background on which the subjects stuck the reversible felt pieces to construct the pictures.

### Procedure

Subjects were tested individually in a room with two experimenters present. Each subject stood behind an easel 3 ft. (.91 m.) from a wall on which a 3 ft. x 4 ft. (.91 m. x 1.22 m.) white posterboard had been taped. At the easel the subject reconstructed felt and flannelboard pictures according to instructions for each test. Each subject was given two pretests (A and B) and the two experimental tests (Rotation and Perspective). Pretest B and the two experimental tests are the tests on which statistical analyses are based, and are referred to as the three flannelboard conditions, or the 'Conditions' factor, in analyses. In each condition two standards were presented on the posterboard, one right-side-up, the other upside-down ('Presentation' factor), so that the subject constructed two flannelboard pictures per condition.

Pretest A. The flannelboard with the six outlined figures was clipped to the easel and the subject was given the corresponding six felt pieces. The instructions were: "I want you to match some felt pieces to the outlines on this flannelboard. You can use either side of each felt piece (here the experimenter showed both

sides of several pieces). Make the pieces stick to the flannelboard so they fit exactly (or, to the younger subjects, "just the right way...") inside their own outlines. Do this as fast as you can, but make sure to do it correctly."

This pretest was a measure of the subjects' ability to note orientation cues in the smallest felt pieces used in the standards. Since all subjects did this quite easily, with the exception of one kindergarten girl who improperly oriented one of her pieces, analysis of this pretest will not be reported. The ease of the task indicates that even the youngest subjects could detect orientation cues in representations of small objects and match them with their outlines.

Pretest B (copy condition). One of the six felt pictures described earlier (see Figure 1) was attached to the center of the posterboard on the wall. The subject was then given a blank white flannelboard and told, "Make a picture just like the one up here, exactly the way this one is." The four felt pieces corresponding to the standard displayed were placed in a box on a table next to the easel. Each piece was named as it was put in the box, and the subject was shown that either side of each piece could be used in constructing his picture.

In this condition and the two experimental test conditions, the standard was left on the posterboard for the subject to refer to while making his copy, so that age differences in memory would not be confounded with age differences in the ability to perform the tasks. When the subject had completed his flannelboard picture it was taken from the easel and a new standard was attached to the

posterboard. This time the standard was shown upside-down. The subject was given the materials needed to copy this picture, and received the same instructions as before.

Test R (rotation condition). Another of the standards was attached to the posterboard and the subject was given the materials to make a flannelboard picture of it. The instructions were: "Imagine (or, to the younger subjects, "think of...") how this picture would look to you if it were turned upside-down. Make a picture to show how this one would look if it were turned upside-down." When the subject completed his reconstruction, it was removed from the easel. A new standard was hung on the posterboard and new materials were given. The Rotation instructions were repeated.

Test P (perspective condition). The format of Test R was followed, with a change only in instructions. These were: "Imagine (or, to younger subjects, "think of...") how this picture would look to you if you were upside-down, like hanging by your knees from a tree, and looking back at it. Show me how this picture would look to you if you were upside-down." The experimenter determined whether the subject understood what was meant by being upside-down and, if necessary, first let him look upside-down at something other than the standard by placing his head between his knees.

The pretests were always given in the order A, B followed by the two experimental tests. The test orders R, P and P, R were counterbalanced. A modified Latin Square design was used to counterbalance order of presentation of the six standards so that within each age x sex x condition order group each picture appeared once

in each of the six condition x presentation tasks. Subjects for each age x sex group were preassigned to these picture orders and condition orders.

## RESULTS

### Analysis of Orientation Errors

The final positions and orientations of the felt pieces in each of the six flannelboard picture reconstructions for each subject were traced after testing. The tracings for each condition and presentation were scored for orientation errors in the left-right and top-bottom dimensions separately (this was possible because the felt pieces were reversible) by comparison with the appropriately oriented standard. The scores for orientation error analysis were the number of errors per picture in each of the two spatial dimensions ('Error Dimension' factor). Since there were four felt pieces per picture, the maximum number of errors per picture in either dimension was four.

Table 1 shows the means of the two dimensions of orientation errors (left-right and top-bottom) for each Age x Sex group under each Condition and Presentation. A 4 x 2 x 3 x 2 analysis of variance (ANOVA) was performed on the average of the two Error Dimensions, with Age and Sex as the between-groups factors and Condition and Presentation as repeated measures within subjects. The results of this analysis are presented in Table 2.

All main effects except Sex were significant (all  $p$ s  $\leq .001$ ). The effect of Age ( $F(3,88) = 18.3$ ,  $p < .001$ ) is illustrated in Figure 2.

Table 1 --- Mean Number of Errors per Error Dimension in the Three Picture Reconstruction Conditions.

| Condition:                                             | Pre-test B     |                | Test R         |                | Test P         |                |             |
|--------------------------------------------------------|----------------|----------------|----------------|----------------|----------------|----------------|-------------|
|                                                        | right-side-up  | upside-down    | right-side-up  | upside-down    | right-side-up  | upside-down    |             |
| Presenta-<br>tion:                                     | left-<br>right | top-<br>bottom | left-<br>right | top-<br>bottom | left-<br>right | top-<br>bottom |             |
| Error<br>Dimension:                                    | left-<br>right | top-<br>bottom | left-<br>right | top-<br>bottom | left-<br>right | top-<br>bottom |             |
| <u>Group<sup>a</sup>:</u><br><u>Males<sup>b</sup>:</u> | K              | 1.000 .333     | 1.500 .750     | 2.333 1.833    | 1.833 2.083    | 2.750 1.417    | 2.250 1.917 |
|                                                        | 3              | .083 .167      | .750 .750      | 1.833 .667     | 2.250 .667     | 2.283 1.000    | 1.667 2.500 |
|                                                        | 6              | .583 .167      | .667 .500      | 1.417 .333     | 1.250 .333     | 1.667 .417     | 2.000 1.917 |
|                                                        | C              | .000 .000      | .083 .000      | .417 .250      | .750 .333      | .750 .667      | 1.000 .750  |
| <u>Females:</u>                                        | K              | .833 .333      | .833 .167      | 2.417 1.417    | 2.750 1.167    | 3.167 2.417    | 2.500 2.917 |
|                                                        | 3              | .417 .167      | 1.000 .167     | 1.667 .333     | 2.500 .833     | 1.583 .583     | 3.000 1.917 |
|                                                        | 6              | .083 .250      | .500 .167      | 1.667 1.000    | 1.667 .500     | 2.167 .417     | 2.083 1.167 |
|                                                        | C              | .083 .083      | .000 .000      | 1.000 .083     | .583 .250      | .917 1.667     | 1.750 1.667 |

a.  $\bar{n}=12$ , in each age x sex group

b. K=kindergarten, 3=3rd grade, 6=6th grade, C=college



Table 2 -- Summary of the Analysis of Variance on Mean Number of Errors for the Two Error Dimensions in the Three Picture Reconstruction Conditions.

| Source                                    | SS      | df   | MS     | F     | P    |
|-------------------------------------------|---------|------|--------|-------|------|
| Grand Mean                                | 1404.50 | 1    | --     | --    | --   |
| Total                                     | 2507.50 | 1151 | --     | --    | --   |
| Sex                                       | 1.68    | 1    | 1.68   | .45   | NS   |
| Age                                       | 203.68  | 3    | 67.89  | 18.38 | .001 |
| Sex x Age                                 | 3.86    | 3    | 1.29   | .09   | NS   |
| Ss (Sex x Age)                            | 325.11  | 88   | --     | --    | --   |
| Condition                                 | 348.02  | 2    | 174.01 | 76.20 | .001 |
| Sex x Condition                           | 8.97    | 2    | 4.49   | 1.96  | NS   |
| Age x Condition                           | 21.01   | 6    | 3.50   | 1.53  | NS   |
| Sex x Age x Condition                     | 16.78   | 6    | 2.79   | 1.22  | NS   |
| Ss x Conditions (Sex x Age)               | 401.89  | 176  | --     | --    | --   |
| Presentation                              | 15.59   | 1    | 15.59  | 16.99 | .001 |
| Sex x Presentation                        | .03     | 1    | .03    | .03   | NS   |
| Age x Presentation                        | 12.54   | 3    | 4.18   | 4.55  | .01  |
| Sex x Age x Presentation                  | 4.65    | 3    | 1.55   | 1.69  | NS   |
| Ss x Presentation (Sex x Age)             | 80.69   | 88   | --     | --    | --   |
| Condition x Presentation                  | 6.33    | 2    | 3.16   | 2.04  | NS   |
| Sex x Condition x Presentation            | 2.29    | 2    | 1.14   | 1.69  | NS   |
| Age x Condition x Presentation            | 5.76    | 6    | .96    | .62   | NS   |
| Sex x Age x Condition x Presentation      | 7.33    | 6    | 1.22   | .79   | NS   |
| Ss x Condition x Presentation (Sex x Age) | 272.31  | 176  | --     | --    | --   |
| Error Dimension                           | 92.25   | 1    | 92.25  | 75.02 | .001 |
| Sex x Error Dimension                     | 1.84    | 1    | 1.84   | 1.49  | NS   |
| Age x Error Dimension                     | 19.26   | 3    | 6.42   | 5.22  | .005 |
| Sex x Age x Error Dimension               | 2.59    | 3    | .86    | .70   | NS   |
| Ss x Error Dimension (Sex x Age)          | 108.22  | 88   | --     | --    | --   |

Table 2(continued)

| Source                                          | SS     | df  | MS   | F    | P    |
|-------------------------------------------------|--------|-----|------|------|------|
| Condition x Error Dimension                     | 18.30  | 2   | 9.15 | 7.42 | .001 |
| Sex x Condition x Error Dimension               | 1.84   | 2   | .92  | .74  | NS   |
| Age x Condition x Error Dimension               | 13.47  | 6   | 2.25 | 1.82 | NS   |
| Sex x Age x Condition x Error Dimension         | 14.61  | 6   | 2.43 | 1.97 | NS   |
| Ss x Condition x Error Dimension (Sex x Age)    | 217.11 | 176 | --   | --   | --   |
| Presentation x Error Dimension                  | 1.68   | 1   | 1.68 | 1.61 | NS   |
| Sex x Presentation x Error Dimension            | 4.01   | 1   | 4.01 | 3.85 | NS   |
| Age x Presentation x Error Dimension            | 2.19   | 3   | .73  | .70  | NS   |
| Sex x Age x Presentation x Error Dimension      | 2.58   | 3   | .86  | .82  | NS   |
| Ss x Presentation x Error Dimension (Sex x Age) | 91.69  | 88  | --   | --   | --   |

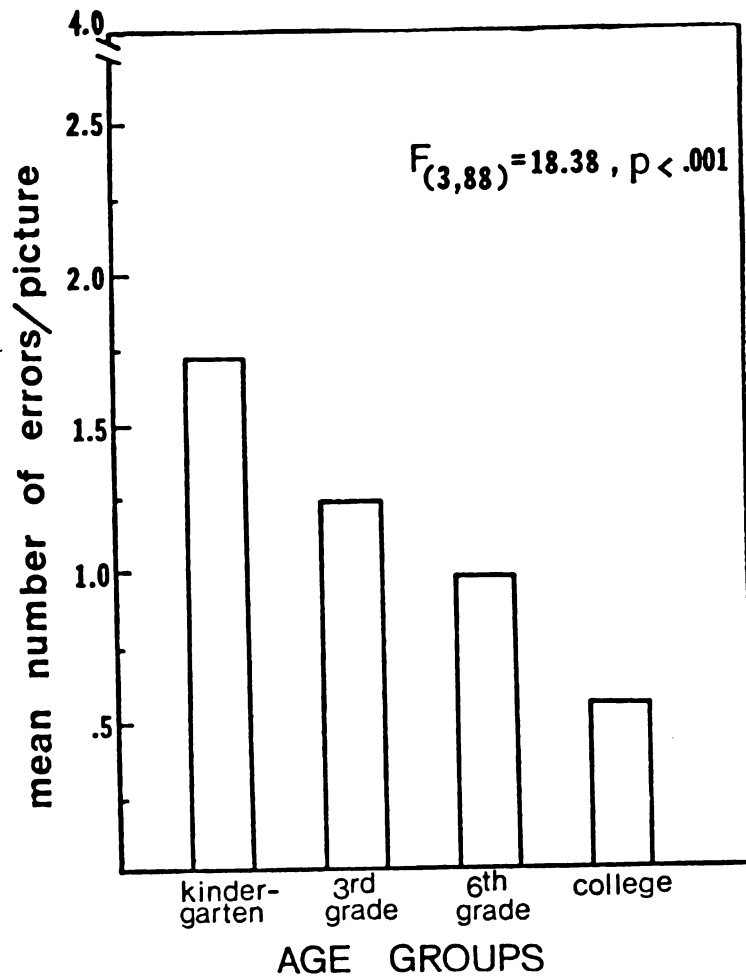


Figure 2 -- Mean number of orientation errors per picture for each age group, over all conditions and presentations (ANOVA main effect for Age)

As predicted, orientation errors in both dimensions declined with age. The Condition effect ( $F(2,176) = 76.2, p < .001$ ) is shown in Figure 3. The predicted order of task difficulty was supported: the Copy Condition proved to be the easiest (fewest orientation errors), the Rotation Condition somewhat harder, and the Perspective Condition the most difficult. As Figure 4 illustrates, subjects made more errors in their reconstructions when the standard was presented upside-down than when presented right-side-up (Presentation effect:  $F(1,88) = 16.99, p < .001$ ). This Presentation effect supports the hypothesis that it is more difficult to perform a mental operation on an upside-down than a right-side-up picture. The Error Dimension effect ( $F(1,88) = 75.0, p < .001$ ) is depicted in Figure 5. As predicted, subjects made more left-right than top-bottom errors.

These main effects, however, are qualified by several significant interactions. The Age x Presentation interaction ( $F(3,88) = 4.6, p < .01$ ) is shown in Figure 6. The Presentation effect described earlier was produced mainly by third graders (Presentation effect for third grade:  $F(1,88) = 4.34, p < .05$ ); the effect failed to reach significance for the other age groups, each of which did equally well or poorly regardless of upside-down or right-side-up presentation (all  $F$ 's(1,88)  $\leq .61$ , all  $p$ s  $\geq .10$ ). The kindergarteners did worst overall, erring about 50% of the time. Orientation in which the standards were presented therefore may not have affected their scores because the two experimental conditions were so difficult for them--a 'ceiling' effect. Conversely, it may be that sixth graders and college students were not affected by Presentation because the tasks were fairly easy for them--a 'floor' effect.

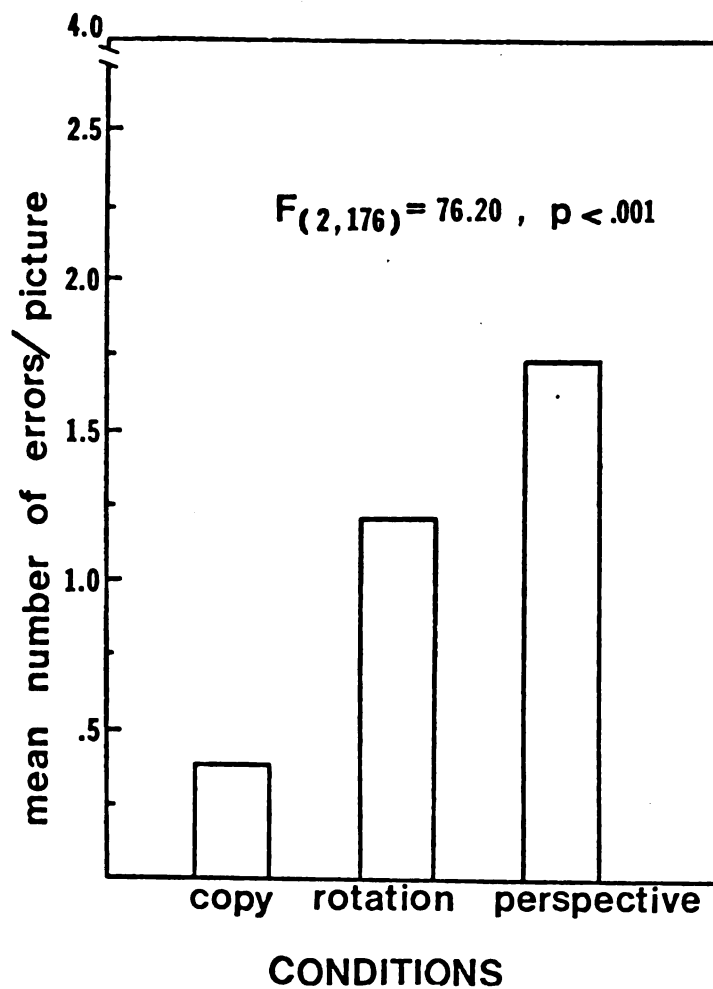


Figure 3 -- Mean number of orientation errors per picture for each condition, over all ages and presentations (ANOVA main effect for Condition)

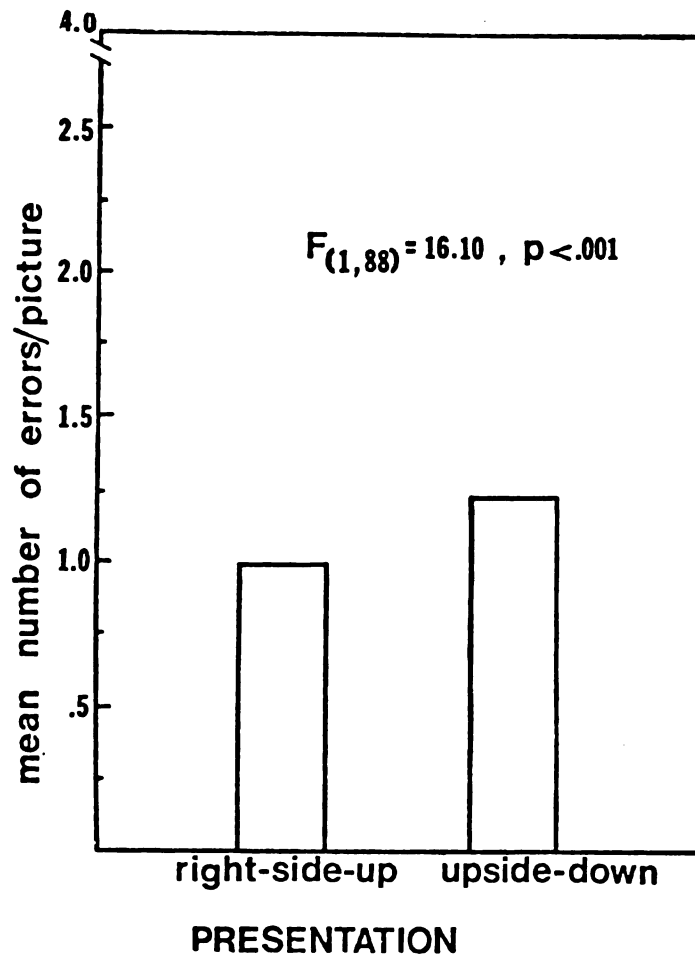


Figure 4 -- Mean number of orientation errors per picture for each presentation, over ages and over conditions (ANOVA main effect for Presentation)

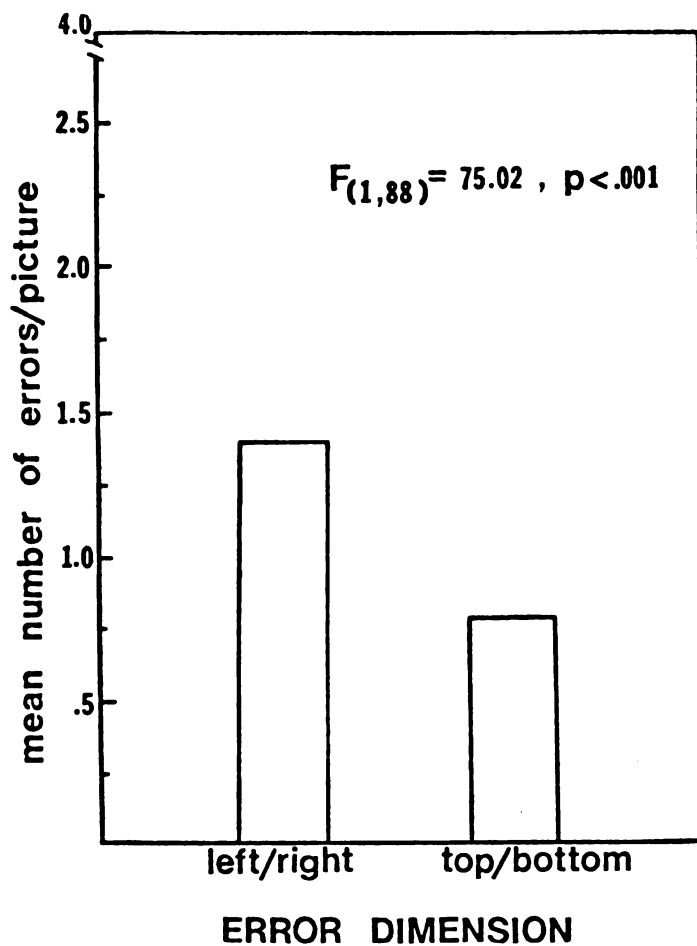


Figure 5 -- Mean number of errors per picture in each error dimension, over all ages, presentations and conditions (ANOVA main effect for Error Dimension)

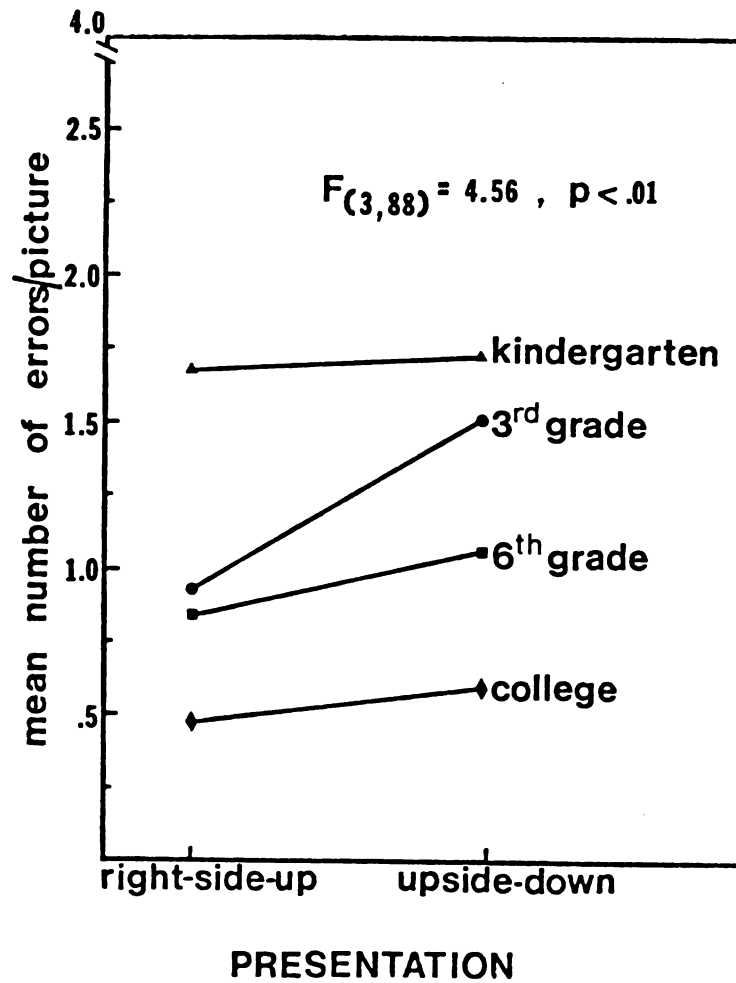


Figure 6 -- Mean number of orientation errors per picture for each presentation in each age group, over all conditions (ANOVA Age x Presentation interaction)



Why Presentation affected third graders alone is not clear. The tasks were of moderate difficulty for them and so there may have been more "room" for error in the upside-down relative to the right-side-up presentations. If the tasks had been made more difficult for the sixth graders and college students, or easier for kindergarteners, it seems likely that the Presentation effect would have been significant for them.

As can be seen in Figure 7, the Error Dimension effect was modified by a significant Age x Error Dimension interaction ( $F(3,88) = 5.2, p < .005$ ). Subjects overall made more left-right than top-bottom orientation errors. The ratio of the former to the latter was large only for children [Error Dimension effect in each of the younger age groups: all  $F$ 's(1,88)  $\geq 5.0$ , all  $p$ 's  $\leq .05$ ] and low for college students ( $F(1,88) = .17, p > .10$ , NS) probably because they made few errors overall (approximately 10%). The individual simple effects  $F$  tests as well as the slopes of the lines in Figure 7 indicate that this interaction would not have been significant if the college data had not been included. Left-right remained a more difficult dimension than top-bottom at all ages, although the difference in difficulty for these dimensions was nonsignificant for the oldest subjects. However, individual variation did exist in the college sample. Among those college students who erred, left-right errors were more common than top-bottom, indicating that if the tasks had been made more difficult for them (e.g., by putting a short time limit on task completion) the college students would have erred significantly more often in the left-right relative to the top-bottom dimension.

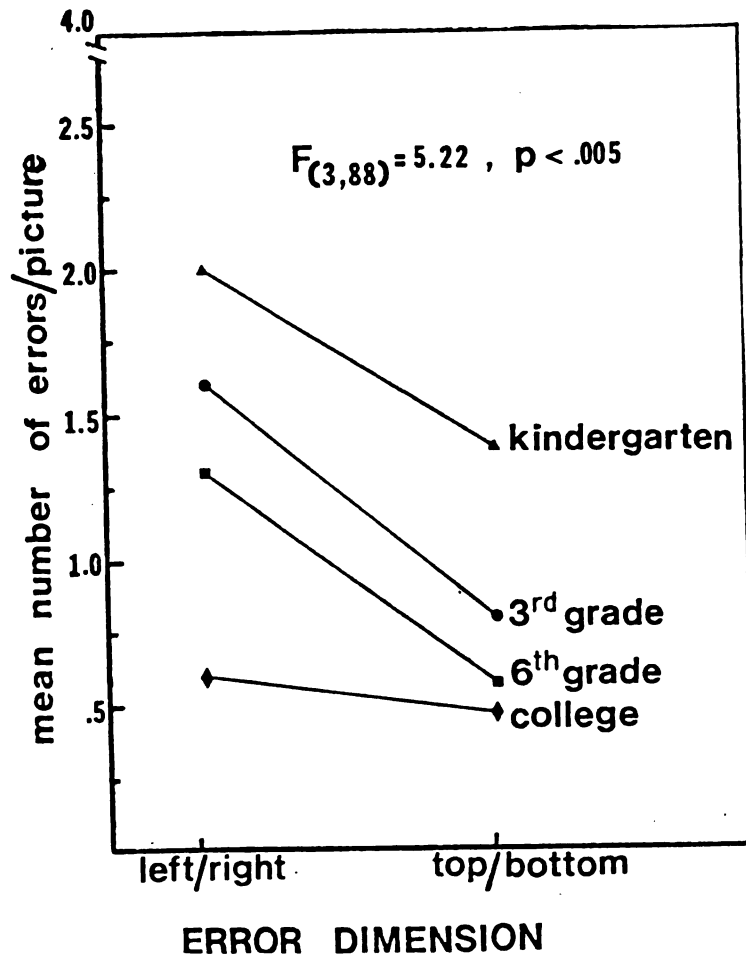


Figure 7 -- Mean number of orientation errors per picture in both error dimensions in each age group, over all conditions (ANOVA Age x Error Dimension interaction)

The Error Dimension effect was further qualified by a significant Condition x Error Dimension interaction ( $F(3,88) = 5.2, p < .005$ ) illustrated in Figure 8. The ratio of left-right to top-bottom errors was greater in the two more difficult conditions, Rotation and Perspective, than in the Copy Condition, which produced few errors. This finding agrees with the prediction that the relative difficulty of left-right to top-bottom would be greater for more difficulty tasks. The error ratio was significant in the Rotation Condition ( $F(1,88) = 5.38, p < .05$ ), and marginally in the Perspective Condition ( $F(1,88) = 2.82, p < .10$ ), which were the two most difficult conditions. Although the slopes of the lines for those two conditions appear different in Figure 8, the difference was not quite significant ( $t' = 1.58, .10 > p > .05$ ). The lack of Error Dimension effect in the Copy Condition ( $F(1,88) = .74, p > .10$ ) is probably the result of a 'floor' effect. The Error Dimension effect may have been stronger in the Copy Condition had it been more difficult (e.g., a memory task).

The interaction just described was further qualified by a Condition x Presentation x Error Dimension interaction ( $F(2,176) = 6.2, p < .005$ ; see Figure 9). Although over all Conditions right-side-up presentation of the standard evoked fewer orientation errors in reconstructions than upside-down presentation, and left-right errors were more frequent than top-bottom errors over all presentations and conditions, the Error Dimension effect failed to reach significance in the Perspective Condition when the standard was presented upside-down ( $F(1,88) = .342, p > .10, NS$ ). The ratios of left-right to top-bottom errors in the two Presentations for the Perspective

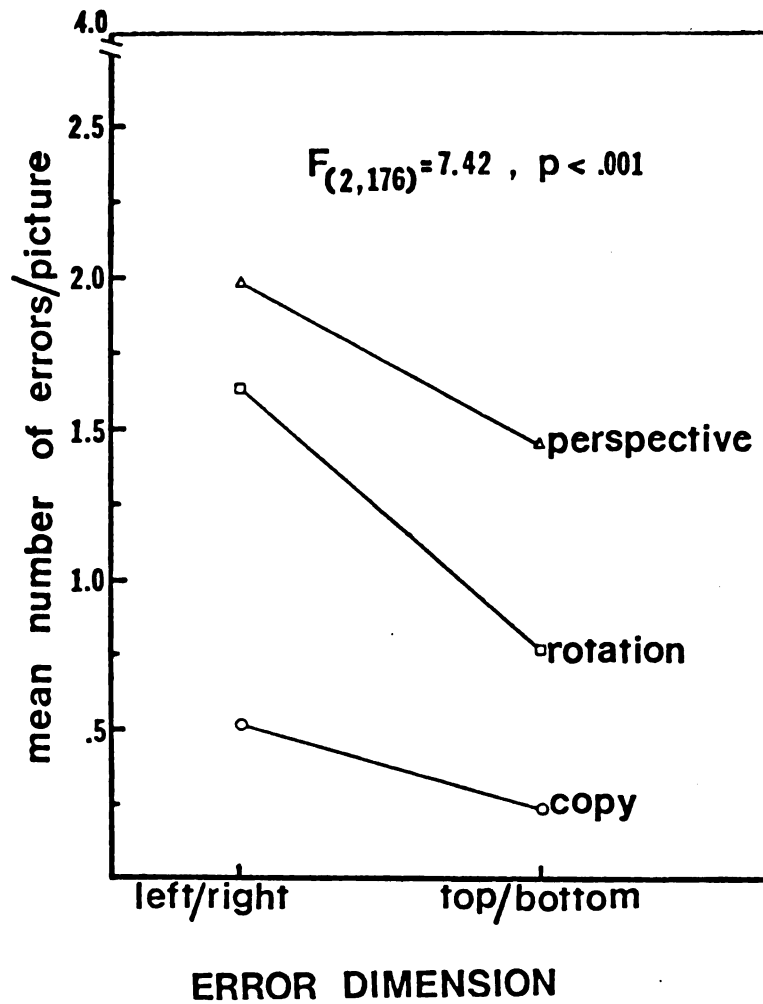


Figure 8 -- Mean number of orientation errors per picture in both error dimensions in each condition, over all ages and presentations (ANOVA Condition x Error Dimension interaction)

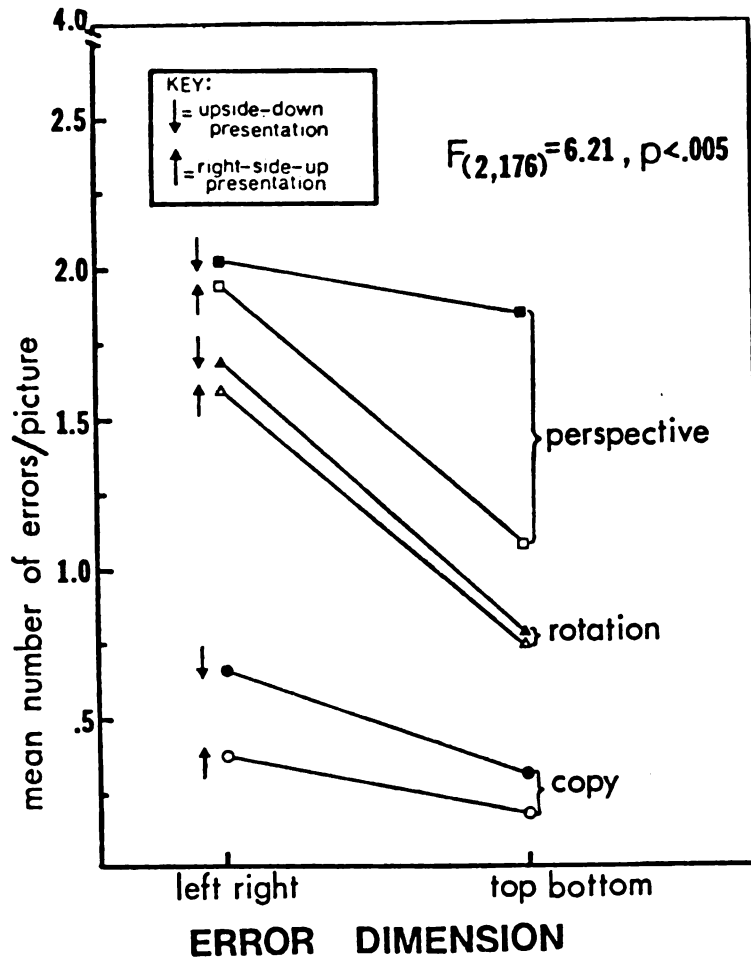


Figure 9 -- Mean number of orientation errors per picture in both error dimensions in each presentation within each condition, over all ages (ANOVA Condition x Presentation x Error Dimension interaction)

Condition were significantly different ( $t' = 3.04$ ,  $p < .001$ ), as indicated by the slopes of the lines in Figure 9. The Error Dimension effect was not significant for either Presentation in the Copy Condition ( $F's(1,88) \leq 1.22$ ,  $ps > .10$ , NS), as would be expected according to the Condition x Error Dimension interaction described in the preceding paragraph. In all other Condition x Presentation cells the Error Dimension effect was significant (all  $F's(1,88) \geq 7.11$ , all  $ps > .05$ ). The upside-down presentation in the Perspective Condition was predicted to be the most difficult task, and comparison of error rates for all Condition x Presentation cells indicates that it was the most difficult (see Figure 9). Perhaps a difficult task will increase top-bottom errors relative to left-right errors, which are already frequent. The equivalence of left-right and top-bottom errors in the most difficult task in the present study could not be a 'ceiling' effect as it is commonly defined--both Error Dimensions in that task average only two of four possible errors. However, the average number of errors per Error Dimension in the task are at chance level (2/4 or 50%), indicating maximal confusion on the part of the subjects as to the correct solution. Perhaps chance level error rates serve as a cut-off point or artificial 'ceiling' for maximum confusion about correct solution, and this level was reached only in the most difficult task for errors in both Error Dimensions. The error rates in the Perspective relative to the Rotation Condition, and especially the pattern of errors for the upside-down presentation in the Perspective Condition, support the idea that the two Conditions made different demands of the subjects.

The results of this analysis uphold many of the general predictions made about age, task difficulty, and the relative difficulty of left-right and top-bottom errors based on an environmental explanation of the relative difficulty of left-right to top-bottom. But these results do not indicate whether biological factors play a role in left-right difficulty and do not reflect the spatial configurations of the elements in the picture reconstructions. It was proposed that the role of biological factors in problems with left-right discrimination would be reflected in mirror-inversions rather than haphazard left-right errors. The reconstructions were therefore categorized according to their overall spatial configurations.

#### Analysis of Overall Configurations

The tracings of subjects' reconstructions from Tests R and P were assigned to the four scoring categories represented in Figure 10 as follows: (1) correct; (2) mirror-inversion; (3) copy; and (4) miscellaneous. In the correct solution, the subject correctly reversed both left-right and top-bottom dimensions, while in the mirror-inversion solution he reversed only the top-bottom dimension and "mirrored" the left-right from the standard. The mirror-inversion cannot be produced by any actual three-dimensional rotation of the standard but looks the way the standard would look in a mirror held at a 90° angle away from its bottom edge. The definition of the copy solution is self-explanatory and the copy is an incorrect solution for the Rotation and Perspective Conditions. All pictures fitting none of these categories were designated miscellaneous. The pictures in this group displayed haphazard, unsystematic errors,

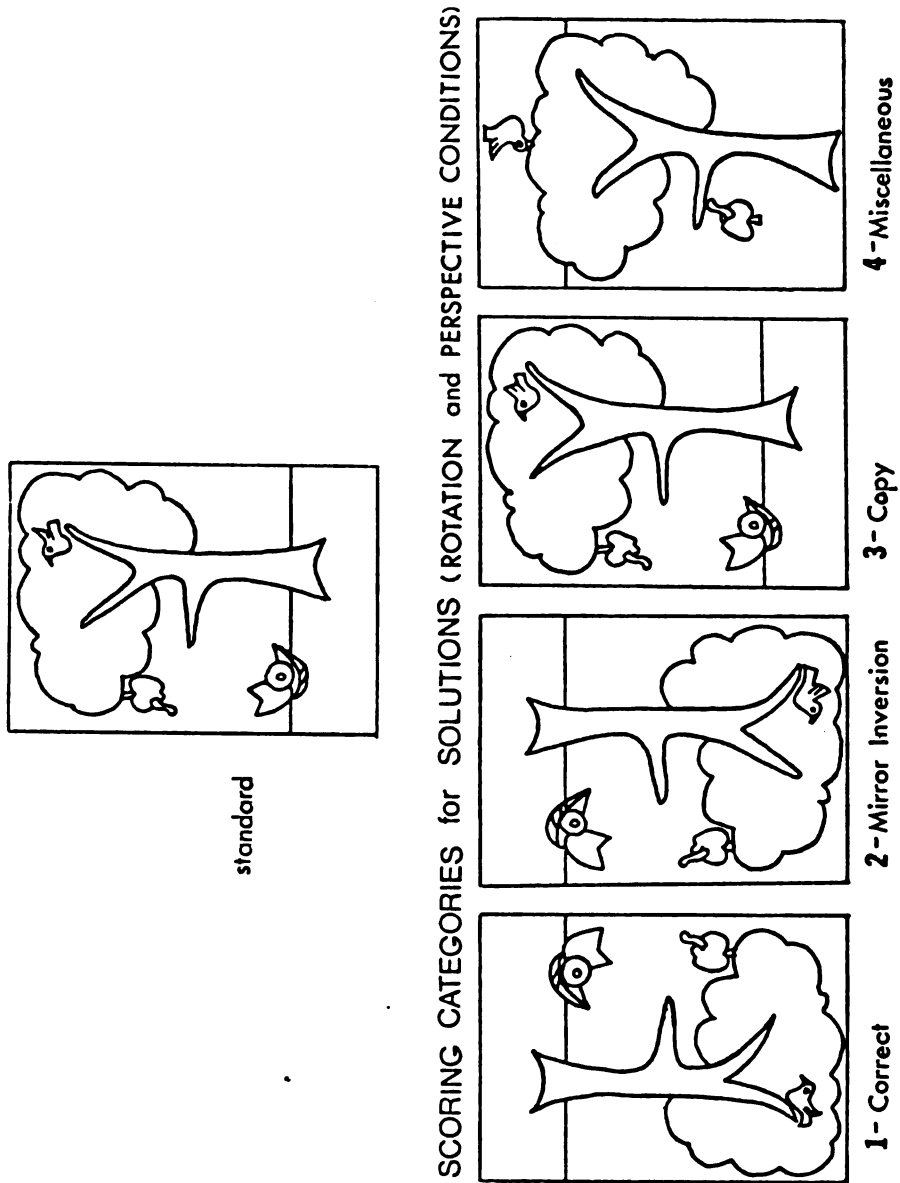


Figure 10 -- The four scoring categories for subjects' solutions to Tests R and P



as though the subject failed to note position and orientation cues in the felt pieces in either the standard or his reconstruction or both.

After the reconstructions were categorized by configuration, the percentage of pictures in each of the four scoring categories was determined at all levels for each Age, Sex, Condition (excluding the Copy Condition), and Presentation group. Table 3 shows the distributions of these percentages for each Age x Sex x Condition x Presentation cell. Kolmogorov-Smirnov tests were used to compare the distributions.

As Figure 11 shows, when distribution of the percentages of reconstructions in the four scoring categories were compared among the four age groups, summing over Sex, Condition, and Presentation, all distributions were significantly different from one another (all  $p_s \leq .05$  and  $\geq .001$ , all  $D_s \geq .15$ ). Examination of Figure 11 suggests that the differences, however, simply reflect a steady increase with age in the percentage of category 1 reconstructions, with no age differences in the distribution of incorrect solutions. The data, therefore, were reanalyzed for category 2 - 4 solutions only. Table 4 shows the percentages and actual numbers of picture reconstructions in the three incorrect solution categories for each Age x Sex x Condition x Presentation cell. Kolmogorov-Smirnov tests revealed no significant differences in distributions of reconstructions in these three categories for incorrect solutions (see Figure 12). At all ages the most frequent solution was category 2, the mirror-inversion, the least frequent category 4, the solution with unsystematic, haphazard positioning errors. If mirror-inversion reflects a

Table 3 -- Percentage of Pictures in each of the Four Scoring Categories for Tests R and P.

| Condition:                     |  | Test R        |      |      |     |             |      |      |      | Test P        |      |      |     |             |      |      |      |
|--------------------------------|--|---------------|------|------|-----|-------------|------|------|------|---------------|------|------|-----|-------------|------|------|------|
| Presenta-<br>tion:             |  | right-side-up |      |      |     | upside-down |      |      |      | right-side-up |      |      |     | upside-down |      |      |      |
| Scoring<br>Category:           |  | 1             | 2    | 3    | 4   | 1           | 2    | 3    | 4    | 1             | 2    | 3    | 4   | 1           | 2    | 3    | 4    |
| Group:<br>Males <sup>c</sup> : |  |               |      |      |     |             |      |      |      |               |      |      |     |             |      |      |      |
| K                              |  | 16.7          | 58.3 | 25.0 | 0   | 25.0        | 33.3 | 25.0 | 36.7 | 16.7          | 41.7 | 33.3 | 8.3 | 16.7        | 33.3 | 33.3 | 16.7 |
| 3                              |  | 41.7          | 58.3 | 0    | 0   | 50.0        | 33.3 | 0    | 16.7 | 41.7          | 50.0 | 8.3  | 0   | 25.0        | 8.3  | 50.0 | 16.7 |
| 6                              |  | 58.3          | 33.3 | 0    | 8.3 | 75.0        | 16.7 | 0    | 8.3  | 66.7          | 25.0 | 8.3  | 0   | 25.0        | 25.0 | 33.3 | 16.7 |
| C                              |  | 91.7          | 8.3  | 0    | 0   | 75.0        | 25.0 | 0    | 0    | 83.3          | 0    | 16.7 | 0   | 75.0        | 8.3  | 16.7 | 0    |
| Females:                       |  |               |      |      |     |             |      |      |      |               |      |      |     |             |      |      |      |
| K                              |  | 16.7          | 58.3 | 25.0 | 0   | 8.3         | 66.7 | 16.7 | 8.3  | 8.3           | 25.0 | 58.3 | 8.3 | 8.3         | 25.0 | 58.3 | 8.3  |
| 3                              |  | 50.0          | 41.7 | 8.3  | 0   | 33.3        | 58.3 | 0    | 8.3  | 66.7          | 16.7 | 16.7 | 0   | 25.0        | 25.0 | 41.7 | 8.3  |
| 6                              |  | 66.7          | 25.0 | 8.3  | 0   | 50.0        | 33.3 | 16.7 | 0    | 50.0          | 50.0 | 0    | 0   | 58.3        | 16.7 | 25.0 | 0    |
| C                              |  | 83.3          | 16.7 | 0    | 0   | 91.7        | 8.3  | 0    | 0    | 58.3          | 25.0 | 16.7 | 0   | 41.7        | 16.7 | 33.3 | 8.3  |

a. 1 = correct solution, 2 = mirror-inversion, 3 = copy, 4 = miscellaneous

b. n = 12, in each age x sex group

c. K = kindergarten, 3 = 3rd grade, 6 = 6th grade, C = college

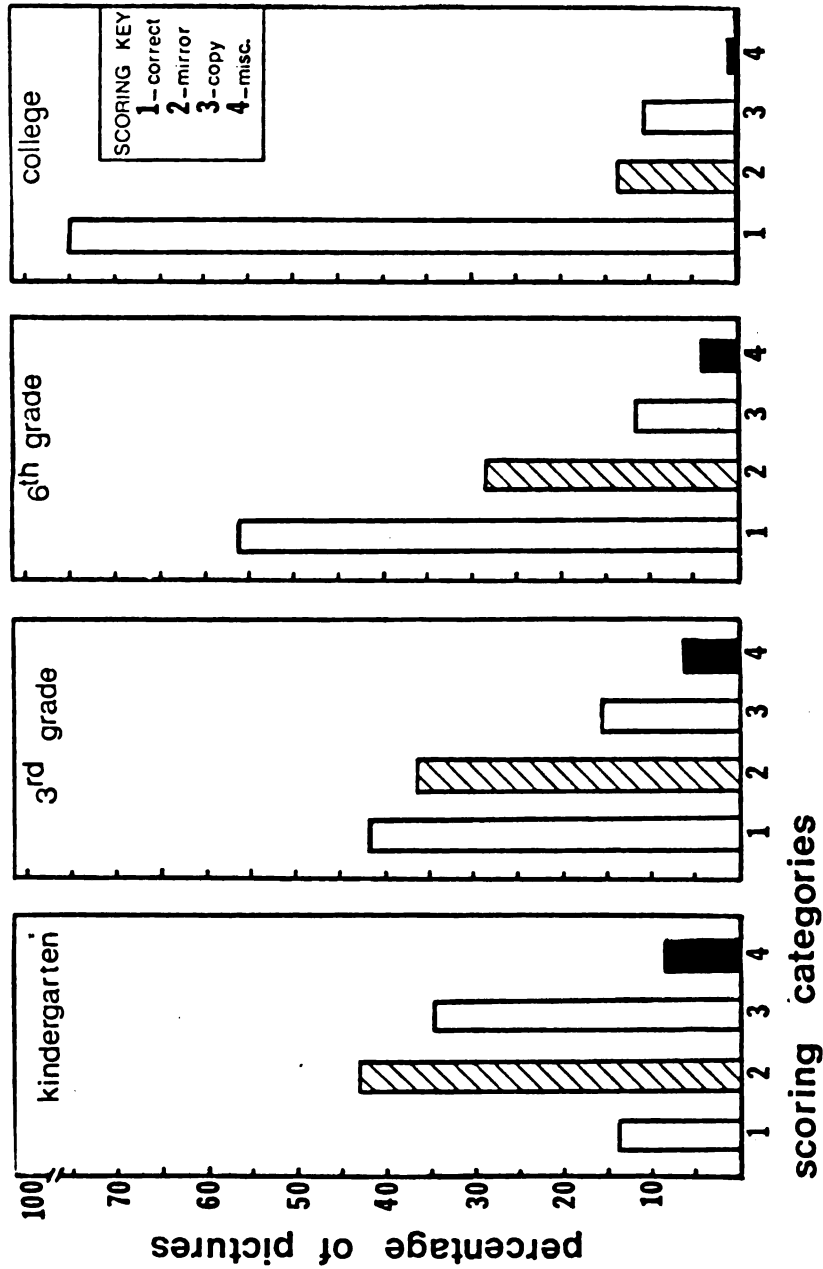


Figure 11 -- Frequency distributions of the reconstructions in the four solution categories, combining the Rotation and Perspective conditions, within each age group (based on 96 pictures per age group)

Table 4 -- Percentages of Pictures in each of the Three Scoring Categories for Incorrect Solutions on Tests R and P.

| Condition:                                             |   | Test R        |         |         |             |         |         | Test P        |          |         |             |         |  |
|--------------------------------------------------------|---|---------------|---------|---------|-------------|---------|---------|---------------|----------|---------|-------------|---------|--|
| Presentation:                                          |   | right-side-up |         |         | upside-down |         |         | right-side-up |          |         | upside-down |         |  |
| Scoring Categories: <sup>a</sup>                       | 2 | 3             | 4       | 2       | 3           | 4       | 2       | 3             | 4        | 2       | 3           | 4       |  |
| <u>Group<sup>b</sup>:</u><br><u>Males<sup>c</sup>:</u> | K | 70.0(7)       | 30.0(3) | 0       | 44.4(4)     | 33.3(3) | 22.2(2) | 50.0(5)       | 40.0(4)  | 10.0(1) | 40.0(4)     | 20.0(2) |  |
|                                                        | 3 | 100.0(7)      | 0       | 0       | 66.7(4)     | 0       | 33.3(2) | 85.7(6)       | 14.3(1)  | 0       | 11.1(1)     | 22.2(2) |  |
|                                                        | 6 | 80.0(4)       | 0       | 20.0(1) | 66.7(2)     | 0       | 33.3(1) | 75.0(3)       | 25.0(1)  | 0       | 33.3(3)     | 22.2(2) |  |
|                                                        | C | 100.0(6)      | 0       | 0       | 100.0(3)    | 0       | 0       | 0             | 100.0(2) | 0       | 33.3(1)     | 0       |  |
| <u>Females:</u>                                        | K | 70.0(7)       | 30.0(3) | 0       | 72.7(8)     | 18.2(2) | 9.1(1)  | 27.3(3)       | 63.6(7)  | 9.1(1)  | 27.3(3)     | 9.1(1)  |  |
|                                                        | 3 | 83.3(5)       | 16.7(1) | 0       | 87.5(7)     | 0       | 12.5(1) | 50.0(2)       | 50.0(2)  | 0       | 33.3(3)     | 11.1(1) |  |
|                                                        | 6 | 75.0(3)       | 25.0(1) | 0       | 66.7(4)     | 33.3(2) | 0       | 100.0(6)      | 0        | 0       | 40.0(2)     | 0       |  |
|                                                        | C | 100.0(2)      | 0       | 0       | 100.0(1)    | 0       | 0       | 60.0(3)       | 40.0(2)  | 0       | 28.5(2)     | 14.3(1) |  |

a. 2 = mirror-inversion, 3 = copy, 4 = miscellaneous

b. the numbers in parentheses after each percentage refer to the actual number of pictures scored in that category for each age x sex group

c. K = kindergarten, 3 = 3rd grade, 6 = 6th grade, C = college

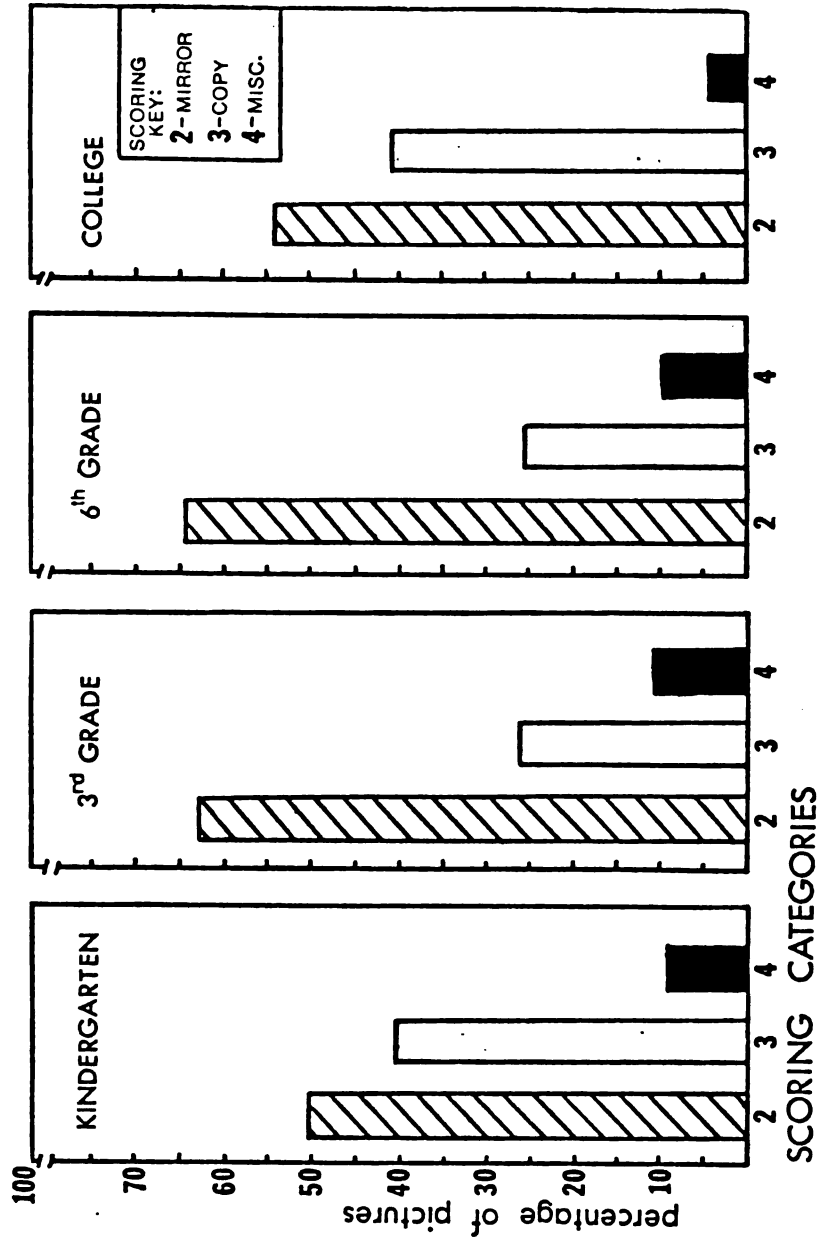


Figure 12 -- Frequency distributions of the reconstructions in the three scoring categories for incorrect solutions, combining the Rotation and Perspective conditions, within each age group (the numbers in parentheses above each bar refer to the actual number of pictures in that category)

neural-structural basis for left-right difficulty while haphazard and unsystematic errors indicate that the difficulty stems mainly from experiential factors, then these results support the neural-structural interpretation.

Distributions of reconstructions across the originally-named four scoring categories were compared for the Rotation and Perspective Conditions, and most of the age differences seen in Figure 11 appeared again (see Figure 13). In the Rotation Condition all differences were significant (all  $p$ s  $\leq .025$  and  $> .001$ , all  $D$ s  $\leq .21$ ). In the Perspective Condition the effect was less strong, with age differences significant (all  $p$ s  $\leq .025$  and  $> .001$ , all  $D$ s  $\geq .25$ ) except for third grade versus sixth grade, and sixth grade versus college ( $p$ s  $> .05$ ,  $D$ s  $\leq .18$ , NS). Also the distributions for the two conditions were significantly different in all age groups (all  $p$ s  $> .005$  and  $\leq .025$ , all  $D$ s  $\geq .21$ ) except sixth grade ( $D = .13$ , NS). However, these differences again could represent an increase with age in frequency of correct solutions in both conditions and the greater difficulty of the Perspective than the Rotation Condition. The Rotation versus Perspective Condition differences may result from a simple decrease in correct responses and increase in proportion of each incorrect solution in the Perspective Condition (see Figure 14), rather than from differences in the distributions of the incorrect solution types. When the distributions of the three incorrect solution categories were compared in the Rotation Condition and the Perspective Condition, there were no significant changes over age for either condition (all  $p$ s  $> .05$ , all  $D$ s  $< .28$ , NS). Though the distributions in each condition look different over age, the differences

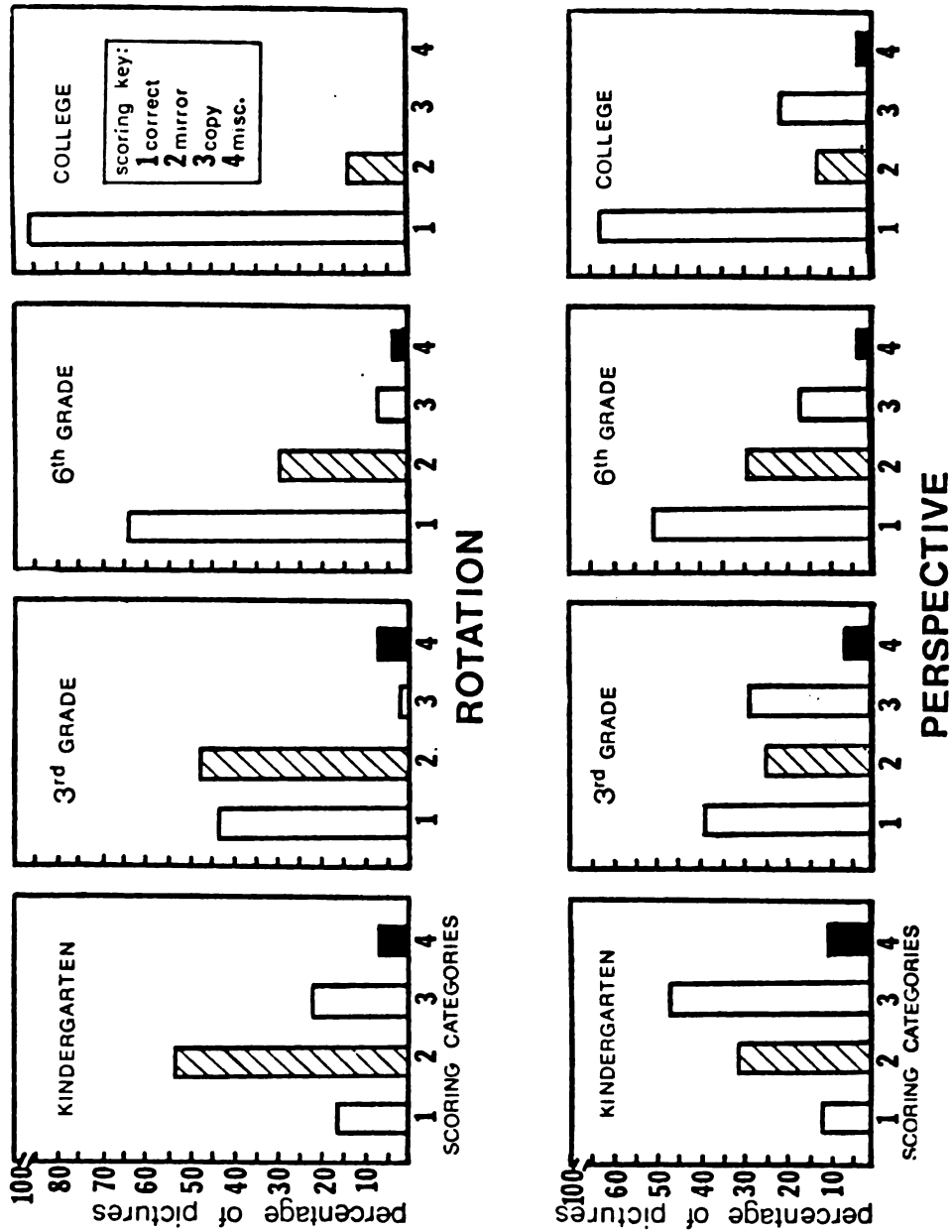


Figure 13 -- Frequency distributions of reconstructions in the four solution categories in the Rotation and Perspective conditions, within each age group (based on 48 pictures per age x condition group)

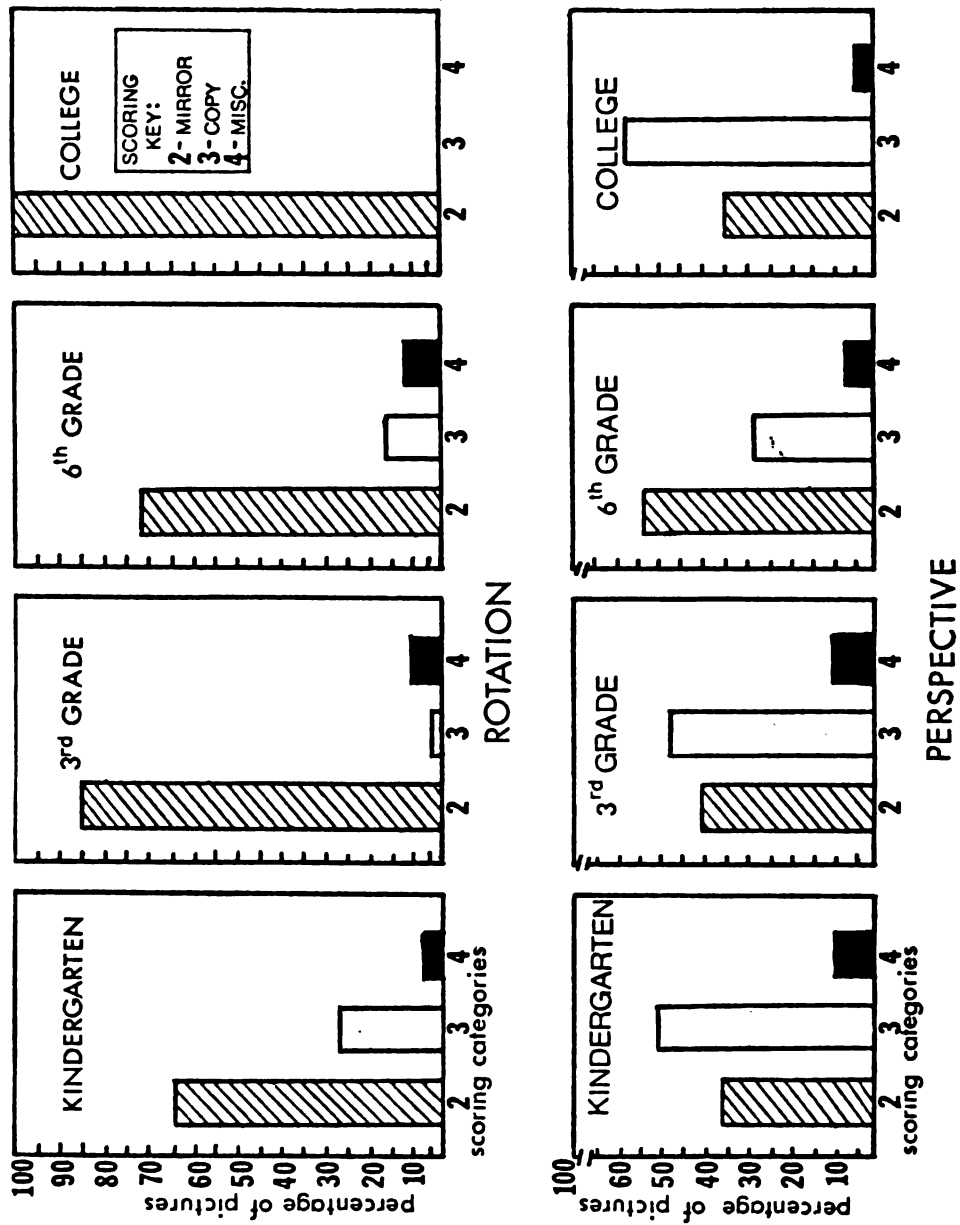


Figure 14 -- Frequency distributions of reconstructions in the three solution categories for incorrect solutions in the Rotation and Perspective conditions, within each age group (the numbers in the parentheses above each bar refer to the actual number of pictures in that category)



fall short of significance because of low n's in the cells of the incorrect solution categories, especially for older groups. However, there still were significant differences in distribution between the two conditions for all age groups (all  $p$ s  $\leq .05$  and  $> .01$ , all  $D$ s  $\geq .30$ ) except sixth grade ( $D = .16$ , NS). Thus although a rotation of the standard and this type of perspective change produce the same retinal image, the two tasks were not psychologically equivalent, even though the subject need not have taken someone else's viewpoint in the perspective condition. Not only was the Perspective Condition more difficult than the Rotation, as indicated by number of errors and incorrect solutions, but subjects seemed to respond to the Rotation Condition differently than to the Perspective Condition. For most ages, there are differences in the distribution of several types of incorrect solutions in these conditions, the mirror-inversion being the most likely in a rotation test and the copy the most likely in a perspective change test. Note that these differences in distributions of error showed up in the college sample even though overall error levels were so low in that age group. That copy solutions were more numerous than mirror-inversions in the Perspective Condition for three age groups qualifies support for the neural-structural model proposed to explain left-right confusion. Two possible explanations for the greater incidence of copy than mirror-inversion solutions in the Perspective Condition are: (1) in a very difficult task mental rotation abilities may "break down" and the subject therefore is likely to give the simplest solution requiring no mental rotation (i.e., the copy solution); (2) in the Perspective Condition there may be neural-structural factors

affecting performance other than those proposed in the model outlined earlier.

## DISCUSSION

In summary, the following predictions were supported: As differing amounts of experience would indicate, reconstructing a right-side-up picture was easier than reconstructing an upside-down picture, and tasks increased in difficulty from Copy Condition to Rotation Condition to Perspective Condition. Subjects made significantly more left-right than top-bottom errors in all conditions tested, indicating a greater difficulty in mastering the former dimension. When separate tests on Error Dimension effects were run for each age group, the Error Dimension effect was significant for children while adults showed only a tendency toward more left-right than top-bottom errors. Although incorrect solutions in the combined mental inversion tasks decreased with age, subjects at all ages who incorrectly solved the tasks were more likely to produce a mirror-inversion than other types of incorrect solutions, reflecting a biological basis for left-right confusion. However, when the solutions to the Rotation and Perspective Conditions were examined separately, at most ages subjects who gave incorrect responses in the latter task more often gave copying solutions rather than mirror-inversions. In addition, the present study supports the supposition that people solve the problems differently and not that there is simply more of a problem with representing a different viewpoint in imagining a perspective change than a rotation.

Role of Experiential Factors in Left-Right Errors

As pointed out earlier, many researchers have proposed that the greater difficulty of left-right than up-down discrimination results from environmental factors, such as orientation cue salience and practice in those dimensions. The present study supported findings that children do have more trouble with left-right than up-down (top-bottom). The basis for the greater difficulty of left-right cannot be inferred from the data on left-right and top-bottom orientation errors. However, since we may reasonably assume that most children have had much more practice copying than turning things upside-down, and least practice with turning themselves upside-down, the role of environmental influences can be inferred from the data on the Condition effect. The subjects made the fewest errors in the what was assumed to be most familiar task, the most errors in the situation to which they have presumably had least exposure. Thus practice or amount of experience affects learning of these spatial operations and, presumably, these spatial dimensions too. People have had less practice with the left-right dimension than with the more salient, more clearly-cued top-bottom dimension.

The experiential explanation for the special difficulty of left-right nevertheless does not adequately account for all present findings. For one thing, if left-right were more difficult than top-bottom only because of experiential factors, the difference in performance in the two dimensions should disappear at some age. Once top-bottom is mastered and a "floor" in top-bottom errors is reached, the individual will no longer learn much from experience with top-bottom. At that point he would still be learning from left-right experience. Mastery

of left-right would eventually be reached, at about twelve years according to Piaget (1928), at which time one would expect left-right errors to be rare and performance in the two dimensions to be about equal. At least if left-right errors are more frequent than top-bottom after twelve years, left-right errors should be haphazard, indicating a failure to note the less salient left-right cues. According to the present data, this may or may not be the case. Although adults, with infrequent errors, erred more in the left-right than the top-bottom dimension, the difference in errors was not significant for that age group. However, the configuration analysis showed predominantly mirror-inversion rather than haphazard errors in the Rotation Conditions, even for adults. Recall, too, the results from Pretest A--subjects of all ages easily noted and matched left-right and top-bottom orientation cues of small two-dimensional objects with outlines in various orientations, which indicates that failure to note left-right cues in the felt pieces probably did not underlie most left-right errors in the three test conditions.

#### Neural-Structural Factors

Analysis of the distributions of reconstructions over all possible solution configurations revealed that subjects of all ages who failed to solve the mental inversion tasks produced more mirror-inversions than other types of incorrect solutions. It was hypothesized that if the problem with left-right discrimination is at least partly neural-structural, this would be reflected in a left-right mirroring tendency. The mirror-inversion shows that subjects had not failed to notice left-right cues. The subjects who gave this solution noted orientation and position cues and realized that there must be some

systematic way to deal with left-right. Unsystematic, haphazard left-right errors were rare.

These data thus support the neural-structural model proposed earlier. Left-right is more difficult than top-bottom at least partly as a result of neural-structural factors, as reflected in the incidence of mirror-inversions, especially in the Rotation Condition. Greater left-right than top-bottom nervous system and body asymmetry lead to more confusions in the former dimension, and because of the connections in the visual cortex the left-right confusion is reflected as a mirror-image error.

This neural-structural model for the effects of visual cortex connections on left-right errors suggests several hypotheses for further testing. Since there are no callosal connections between the primary visual areas of the cerebral hemispheres, but only interhemispheric visual association area connections, we would expect left-right mirror-image errors in interhemispheric memory transfer rather than a perceptual inclination toward confusion of left-right mirror-images. One study supports the prediction that the left-right mirror-image confusion is not the result of perceptual factors (Corballis, Miller & Morgan, 1971). Memory of figure orientation should be poorer for figures with a "left-right" orientation than a "top-bottom" orientation. And if the proposed biological factors lead to left-right mirror-image confusion, they should be operating in infancy. Consequently, infants should find it more difficult to discriminate left-right than top-bottom mirror-image figures when the pairs are aligned as mirror-images, although both discriminations would be easier if pair members were in aligned rather than mirror-image positions.

The preceding discussion of biological bases for left-right confusion is not meant to imply that the left-right problem is the result of biological factors alone, with environmental and experiential factors playing no role. Undoubtedly both sets of factors interact in contributing to the problem, as can be seen from evidence on orders of task difficulty based on differences in experience and from the improvement in performance over age.

#### Differences Between Imagining a Rotation and Imagining a Perspective Change

Previous research has reported a performance difference in children's predictions of the effects of rotating an object array versus their predictions of a perspective change, or the view an observer of the array would have after a change in his position. Huttenlocher and Presson (1973) concluded from their study that the performance differences between their rotation and perspectives change tasks were primarily the results of egocentrism, defined as the inability to predict another's point of view. The present results indicate that this explanation is insufficient; at least when people are asked to predict the effects of turning object or observer upside-down, the difficulty in the perspectives change problem is not in predicting another person's viewpoint. However, it is important to begin by noting that any conflict between the two studies in results or conclusions may arise from methodological differences. Mental operations were carried out for the vertical plane in the present study, while in the horizontal plane for the other. People have more daily experience with changes in the latter dimension (walking around things) than with the former (being upside-down).

The present results indicate that a mental perspective change is more difficult than a mental rotation when the task is to turn object or observer upside-down. This is true even when the subject need not imagine another person's point of view in the perspective change test, suggesting that difficulty in representing another person's viewpoint may not be the basis for the performance difference. In addition, the configuration analysis of the picture reconstructions shows that, except for sixth graders, distribution of the three incorrect solutions were different in the Rotation and Perspective Conditions. This finding suggests that people at most ages mentally represent the two actions differently, and that these differences are not based on difficulties in representing another person's viewpoint in a perspective change task. At least for many subjects this is true, although geometrically and logically the two actions would yield identical effects on the appearance of the pictures. However, as in most behavioral studies, there were individual differences in approaching the tasks, and a range in ability to solve the tasks at each age. Some subjects did seem to use the same operations for the two tasks. A few subjects at the oldest age levels spontaneously remarked that the two operations were geometrically equivalent ("...Oh, that's the same as turning it upside-down..." said one sixth grade subject in the Perspective Condition), suggesting that they used the same mental representation for both the Rotation and Perspective Conditions.

Since the commonest incorrect solution in the Perspective Condition was to copy the picture as it was displayed, the possibility remains that there are more problems in representing some change in viewpoint in the Perspective than the Rotation Condition. Although the subjects



did not have to represent a change in another person's viewpoint, they did have difficulty representing a change even in their own viewpoint, which they did not have to do in the Rotation task. The present findings thus support, at least in part, the conclusions Huttenlocher and Presson (1973) offered, that differences in mental operations for rotation versus perspective change tasks are the result of difficulty in imagining a change in position with respect to the array.

Yet neither do the results of the present study indicate egocentrism (difficulty in imagining a change in position with respect to an array) is the only cause for the relative increase of the copy solution in the Perspective Condition. The performance differences may be traceable to differences in amounts or quality of experience with the two actions. Also, there is evidence of a neural-structural basis for orientation constancy, the tendency of the subject to perceive objects in the world as remaining upright while his head is being tilted sideways. As a cat's head is tilted sideways, some of the cells in its visual cortex continue to respond to an objectively (with respect to gravity) vertical bar rather than responding only to bars that are vertical with respect to the cat's retina (Denney & Adorjani, 1972; Horn, Stechler & Hill, 1972). Human psychophysical research indicates analogous processes in the human visual association cortex (Aubert, 1861, cited in Mitchell & Blakemore, 1971; Mitchell & Blakemore, 1971). This neural-structural factor may bias subjects toward copying the presented picture when asked how the picture would look to them if they were upside-down. Such a bias should hold even for an imagined picture, since it is highly likely that the same cells and neural structures are used in imagining as in perceiving. Probably both neural-structural and experiential factors

play parts in performance differences for rotation and perspective change tasks.

A point of interest is that the sixth graders who erred in the mental inversion tasks, unlike the other age groups, produced mostly mirror-inversion in both the Rotation and Perspective Conditions. This departure from the general pattern at this age (eleven to twelve) fits the Piagetian framework of stages in cognitive development. The distributions of incorrect solutions in the two mental inversion tasks indicate that sixth graders, unlike other age groups, use the same mental operation to solve both tasks, although they still err more often in the Perspective than the Rotation Condition. Their use of the same mental operation for the two tasks could be the result of their achieving formal operational ability to solve problems, thus realizing that the two tasks produce equivalent results.

Why, then, did college students who gave incorrect solutions seem to revert to treating the tasks differently? Since they are past the dawning of formal operations, they may not have been as consciously searching for logical similarity between the two tasks as the sixth graders. Comments made by some of these subjects indicated that orientation constancy, rather than difficulty in representing a different viewpoint, influenced them to copy the standard in the Perspective test ("...it would look just the same to me...", "...when I'm upside-down it's just that I am. Things don't look upside-down--I do. I would still see it the way it looks to me now," "I thought it would look the same to me."). At the same time, behavior and comments of the younger subjects using the copy solution in the Perspectives test indicate that egocentrism (inability to represent a change in viewpoint)

was the larger influence for them ("...I don't know! Can I turn my head upside-down and look?", "I understand. Do I put it sideways?" One boy said, "Oh, it would look upside-down!" and then simply copied the standard right-side-up). At this point, however, it is mere conjecture that different factors cause the same behavior at different ages. The possibility should be studied further, perhaps by having subjects of different ages look at pictures while their heads are tilted or upside-down and then, once they are right-side-up again, orienting the picture to show how it had looked to them. Another test would be to compare responses to the conditions used in the present study with responses of the same subjects to the conditions in the Huttenlocher and Presson study (1973), because of the different spatial planes focused on in the two studies. Orientation constancy may affect responses to instructions to imagine being upside-down, but would not affect responses to instructions to imagine being on the other side of an array.

It should be noted that there were no sex differences in any of the analyses. The tasks were spatial in nature, suggesting that boys would do better than girls (see review by Schmidt, Note 6). However, closer inspection of the research on sex differences in spatial skill reveals that the female disadvantage appears mostly in spatial tasks that cannot be easily solved through verbal mediation. In spatial tasks which could be clearly solved by verbal means, sex differences do not appear, suggesting that: 1) females are more likely than males to attempt verbal strategies to solve problems; and 2) verbal mediation is less efficient than kinetic-kinesthetic or visual imagery for solving many traditional visual-spatial tasks (see reviews by Harris, Notes 7 &

8). The tasks used in the present study were complex and apparently could have been solved through either spatial operations (kinetic kinesthetic-visual imagery) or verbal mediation, or by a combination of the two strategies. Comments solicited from about half the subjects support the interpretation that the tasks were solved by varied means by both sexes, which may explain the lack of sex differences found in this spatial task. After testing, the experimenter asked those subjects, "How did you imagine (or, to the younger subjects, "...think of...") how the pictures would look upside-down? What did you do in your head so you could find the answer?" Some subjects indicated the use of static visual imagery ("...I just tried to get a picture of it upside-down."), some kinetic visual imagery ("...imagined it turning slowly..."), kinetic kinesthetic-visual imagery ("...imagined turning myself upside-down and watching the picture..."), verbal mediation through verbally telling oneself rules about inverting ("...told myself to make things on the right be on the left..."), and combinations of visual imagery and verbal mediation ("...pictured a piece and then told myself how to reverse it left to right.").

In conclusion, it is suggested that both in the case of left-right discrimination difficulties and performance differences between rotation and perspective change tasks, some structures of the human nervous system predispose us to make certain types of left-right errors. The major neural-structural factor involved is the structure and connections of the visual processing areas of the cerebral hemispheres. As age and experience increase, the environment interacts with and modified these neural connections and structures, weakening but never eliminating

response tendencies such as the mirror-inversion response to a mental picture inversion test. As suggested earlier, there are several possible causes for the weakening of this biological tendency with age among them: 1) maturation of the cortex, which is important in the inhibition of responses (Brackbill, 1971); 2) effects of experiences on connections and response properties of central nervous system cells (see review by Kolata, 1975; Rosenzweig, Bennett & Diamond, 1972); and 3) increasing ability to use language as self-regulation of behavior (Luria, 1959; Kohlberg, Yaegel & Hjertholm, 1968). Although the formal data from the present study cannot be used to support any of these possibilities, there is anecdotal support from this study for 3).

Generally, the kindergarteners who verbalized during their task solutions did not correctly regulate their task-solving behavior by their statements (e.g., "It would look upside-down" said one little boy who then simply copied the standard; "They look upside-down when I hang from a tree. Everything would be upside-down" was followed by a copy of the standard). Some third graders showed somewhat more sophisticated verbal self-regulation through self-guiding private speech (one said, apparently to himself, "Things look the same but they're coming out of the ground or roof" as he correctly solved the task). One third grade boy seemed to show a higher form of verbal self-regulation, inner directed speech, as he inaudibly mouthed words to himself (presumably about task solutions) throughout the tasks. However, he produced mostly mirror-inversions. Sixth grade and college students showed a mixture of self-guiding private speech (sixth grade: "This here," "Bird upside-down," "Let's see, put these legs here," "Right-side-up? Right-side-up!"; college:

"Hm, flip or twist?", "Is this how I do it?", while placing and moving the felt pieces, "Oh, the engine is backwards!", while changing the orientation of the engine in the train picture) and inaudible muttering or inner directed speech, both of which in nearly all cases corresponded with correct solutions. The college students displayed more of the (higher level) inner directed speech than the sixth graders, which consisted of muttering that was often accompanied by hand gestures of turning things over with empty hands. However, the effects of verbal regulation and maturational changes in the central nervous system on age changes in ability to solve mental rotation tasks will need further study before they can be delineated.

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