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Blind and sighted children's reasoning in transformational geometry: Modality specific and non-specific influences

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BLIND AND SIGHTED CHILDREN'S REASONING IN TRANSFORMATIONAL GEOMETRY: MODALITY SPECIFIC AND NON-SPECIFIC INFLUENCES

by

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Abstract

BLIND AND SIGHTED CHILDREN'S REASONING IN TRANSFORMATIONAL GEOMETRY: MODALITY SPECIFIC AND NON-SPECIFIC INFLUENCES

by

Nancy O'Donohue

Advisor: Professor Harry Beilin

The goals of this research were to understand how congenitally blind and sighted children develop knowledge of geometric congruence and transformations and, further, how different modes of processing spatial information affect this development. To achieve these goals we examined congenitally blind and sighted children's reactions to spatial tasks in light of theoretical issues related to geometric knowledge, individual differences and task differences.

The theoretical issues reviewed were: (1) Transformational understanding - Cognitive theory; (2) Correspondences - Constructivist theory; (3) Spatial knowledge in the blind child; (4) Gender differences in spatial knowledge; and (5) Task differences in geometric reasoning.

The subjects were two groups of congenitally blind (n = 18, n = 33) and two groups of sighted (n = 18, n = 24) children from 5 to 19 years of age. Four tasks were administered. Two tasks examined the child's ability to represent nonvisible transformations and two examined the

child's knowledge of correspondences and transformations. Because of the nature of the data and population tested, significant results could only be obtained for some tasks. The results below show trends (significant and nonsignificant) in the data.

The results tend to support and extend the Piagetian thesis that all children go through stages of transformational understanding which proceed from intrafigural to interfigural to transfigural knowledge. Further, there may be two sub-stages within the interfigural stage. Regarding correspondences, children appear to follow a constructivist model of end-point integration of parts. An interaction between correspondence and transformational knowledge was seen in the transfigural stage where multiple part correspondences tended to be associated with knowledge of difficult transformations.

Blind/sighted differences were seen generally favoring the sighted. The sighted do significantly better on recognition tasks and some flip tasks. They also tend to use external cues, impose external reference frames, benefit more from perceptual feedback and differentiate parts of the stimulus more easily. The blind appeared to use more movement memory and internal reference frames.

Significant gender differences favoring males were seen in both blind and sighted groups. These seemed to appear in two stages (8 and 14 years of age). Task differences were seen due to task demands, rotational extent, cues, stimulus

familiarity and stimulus configurations.

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CHAPTER 1

Introduction:
Goals, Theoretical Considerations and Research

Goals

The child's first experience with geometry is usually in high school, where geometry is presented as a formal definition-axiom-proof system. One study (Usiskin, 1982), exposing the poor preparation of approximately 2,700 high school students for this type of geometry, confirms the observations of educators regarding the state of geometry education. These educators have often argued for the early introduction of geometric concepts into elementary schools through systematic experiences with spatial tasks. Experience with spatial tasks would presumably increase the child's knowledge of geometric forms and develop an intuitive sense of space which, many feel, underlies full understanding of formal geometric reasoning (Lesh, 1976; Robinson, 1978).

However, the basis upon which early experience with spatial relations should be structured is unclear. Some, following Van Hiele's geometric model, have argued for a pedagogical approach to school instruction (Wirszup, 1976). Others emphasize that these experiences should parallel the child's naturally evolving spatial concepts as exemplified by the work of Piaget (Piaget, Inhelder, & Szeminska, 1960; Piaget & Inhelder, 1967) on space and geometry (Lesh, 1976;

Robinson, 1978; Weinzweig, 1978). Research in the Piagetian tradition has been criticized, however, for its emphasis on universal cognitive structures, an emphasis which many feel neglects the processing origins of these structures and the effects of task variables on performance (Lesh, 1976).

The research which we have undertaken is in the Piagetian tradition in that it aims to understand the child's naturally developing geometric concepts. However, it follows a current trend in both psychological and educational research (Beilin, 1984; Dean, 1979; Dean & Scherzer, 1986; Gholson & Beilin, 1979; Hiebert, Carpenter, & Moser, 1982; Lee, 1982) in that it is designed to integrate both structural and functional (process) theory. This was done through an analysis of the child's strategies and performance across geometric reasoning tasks. We have chosen, for theoretical reasons, to study both congenitally blind and sighted children's knowledge of geometric congruence and transformations.

The decision to study blind children was prompted by theoretical speculation (Piaget & Inhelder, 1971; Resnick & Ford, 1981; Shepard, 1978) and research (Connor & Serbin, 1980; Roberge & Flexer, 1983; Sherman, 1978) indicating that visual or spatial imagery may be important to mathematical reasoning and in particular to geometry reasoning. Although the origin of this imagery may not be specifically visual but rather motoric (Juurmaa, 1973; Saegert & Hart, 1978; Piaget & Inhelder, 1971), it is noted that congenitally blind children do poorly in spatial tasks. They lag behind their sighted

counterparts by four to six years in spatial reasoning, whereas there is only a one- to three-year lag in logical reasoning. In addition, blind children improve little in these tasks even with considerable intervention (Stevens & Grube, 1982). Explanation for this lag has been attributed to the fact that vision enhances spatial cognition for the following reasons. One, it motivates children to move toward and explore objects. Blind children are noticeably retarded in motor skills such as sitting, crawling, and walking (Fraiberg, 1977; Jones, 1975). Secondly, vision yields more information than the haptic or kinesthetic modalities, both of which in addition place heavier demands on the memory system (Millar, 1982, 1976). Finally, Warren (1984) suggests that vision acts as an organizing factor (e.g., as a feedback corrective system) for information derived from other modalities.

Our goals then were to understand how congenitally blind and sighted children develop knowledge of geometric transformations and, further, how different modes of processing spatial information affect this development. In order to achieve these goals we examined congenitally blind and sighted children's reactions to spatial tasks in light of theoretical issues related to general geometric knowledge as well as issues related to individual and task differences.

Regarding geometric issues, we looked at whether children's understanding of transformations was akin to cognitive (Piagetian) theory. We also examined how children set up correspondences between arrays. Here we looked at

whether the developmental pattern of children's strategies would support a constructivist point of view. This view argues that, developmentally, children first note the whole or the parts and then progress to differentiating the parts with the end point of development being the construction of the whole from the parts. Regarding individual differences there is, as noted above, theoretical speculation and research suggesting that visual imagery (and thus vision) is necessary to geometric processing. However, gender differences in processing spatial arrays have also been identified, and, in order to distinguish the effects of sight and gender, both will be examined. Finally, we looked at how task differences, due either to elements in the stimulus itself or to differential task demands, affect geometric processing. Theory and research related to all of these issues will be discussed below.

Theoretical Considerations and Research

Transformations: Cognitive theory.

Theory. One theoretical consideration in designing this study bore on the structural features of cognitive systems insofar as they are related to the child's developing knowledge of geometric invariances. Piaget's cognitive theory, particularly the standard theory, stressed the child's construction of invariances within a world of transformations. For space and geometry, Piaget's theory of cognitive development parallels the mathematical model of the Klein

Erlanger Program. Felix Klein in 1872 compared and hierarchically ordered geometries on the basis of the invariant properties preserved under geometric transformation. Within this hierarchy, topological geometry is considered most simple because it preserves the least number of invariants (e.g., order). Euclidean geometry is said to be most complex as it preserves all of the invariances of the more general geometries (e.g., the angles and parallelism of similarity transformations) and, additionally, preserves distance.

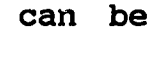
The present research examined cognitive systems as they apply to congruence and transformational concepts in Euclidean geometry. We looked at children's methods of establishing congruences between objects transformed in relation to each other by a reflection (flip) or a rotation. We also looked at transformational knowledge. According to earlier Piagetian theory, children's understanding of transformations emerges from their actual experiences in space in which transformed end-states arise from actual movements (Piaget & Inhelder, 1967).

However, Piagetian theory has evolved. One later formulation of this theory (Piaget, 1979) held that invariances (and thus congruence) over transformations are established by methods of correspondence and/or operational (reversible) thought. With correspondence, object states are compared (e.g., beginning and end points of a transformation), whereas operational thought requires that the transformed object be mentally reversed to its original state.

Correspondences are characteristic of the young child's competencies and only after approximately seven years of age is the child able to engage in operational thought.

More recently, Piaget and Garcia (1989) delineated a more comprehensive statement on children's developing ideas of geometric transformation which, they claim, parallels the historical development of these ideas. The child begins with an understanding of figures which includes only intrafigural analysis. This analysis (strict correspondence phase) is entirely concerned with the internal relations of the object and there is no consideration of the spatial container within which the object resides. The second interfigural phase begins at approximately seven years of age. Here children search for transformations relating the figures and establish interfigural correspondences across these spatial transformations. However, these transformations are not subordinate to a structured set of transformations, such as the set proposed by the Klein Erlanger Program, which was discussed above. This more sophisticated understanding of transformations, characterized by structure, is seen in the transfigural phase. Further, in this phase, correspondences are now formed between the elements of a given suprastructure (e.g., Euclidean space) and individual figural characteristics become irrelevant. Thus this more recent theory regarding developing knowledge of transformations interactively takes into consideration both correspondences and transformations. Additionally, it introduces the notion that a flexible

understanding of transformations requires that a mental space be structured to encompass, in subsets, the range of possible transformational types (similarities, projections, etc...).

Following Piagetian theory, the slide or translation () emerges as the easiest transformation under which congruence can be established. Here objects in the same orientation can easily be compared using intrafigural analysis, a method which is available to children under seven years of age. Congruence is established with more difficulty under flip () or rotational ( ) transformations, as the external spatial container though which figures are transformed must be taken into consideration. This occurs during the interfigural phase, but more complicated transformations of flips and rotations require a mental space characterized by structure which is seen in the transfigural phase.

Thus we have several issues to explore here stemming from the various stages of Piagetian cognitive theory. One issue concerns whether children understand the relationship between transformed end-states as a relationship between corresponding parts and/or as a relationship mediated by transformational movement. Further, this issue also concerns whether and/or how this understanding might be age dependent. The second issue addresses the way in which characteristics of the stimulus or the transformation might allow or disallow an interfigural analysis to take place. Finally, harking back to Piaget's original thesis, the last issue is concerned with how

experience affects children's understanding of transformations.

For practical as well as theoretical reasons, the first and last issues in particular are of importance to educators who have been using "motion" to introduce Euclidean transformational concepts. This choice of method is, as noted above, based on Piagetian theory in which movement is said to give rise to knowledge of end-state transformations. The second issue is of importance to educators who are concerned with how task differences affect performance (this is discussed further below).

Research. Concerning the relative primitiveness of these Euclidean transformations for children, research is consistent with the cognitive perspective in that the translation (slide) is the most easily understood transformation, with the reflection and rotation emerging later. Whether the child actually conceives of the transformations as physical motions or as relationships between end-states is still in question. Research with children between the ages of three and ten (Schultz, 1978; Moyers & Johnson, 1978) suggests that children focus on comparisons between end-states and ignore the transformation even when explicitly trained in the transformation involved. On the other hand, Perham (1978) found that first graders' ability to anticipate the end-state of a horizontal or vertical reflection was enhanced as a result of training involving the particular motion. However, no increase was found in the child's ability to anticipate

end-states of diagonal reflections or rotations as a result of training. It appears then that physical "motion" training may help the child, but limitations may be set by some cognitive factor operative within the child.

Also in question is the relative difficulty of the reflection and rotation. The majority of studies (Piaget & Inhelder, 1971, p. 106; Moyers & Johnson, 1978; Schultz, 1978) have found that the reflection is easier than the rotation. However, other studies (Beilin, 1984; Greco, cited in Montangero, 1976; Shultz & Austin, 1983) reported that the relative difficulty varied with the task. Moreover, in a study which required four- to seven-year-olds to superpose shapes, Piaget & Inhelder (1971) found that rotations were somewhat easier than reflections, especially for four-year-olds.

It appears, from the conflicting evidence given, that task variables are a factor which must be taken into consideration in resolving these issues. Specifically, task variables may encourage different methods of problem solving and thus affect, for example, the relative ease of transformations. Task variables will be discussed more fully below and were, to some degree, controlled for in our own research.

Correspondences: Constructivist theory.

Theory. Our second theoretical consideration is related to the first insofar as we will further explore the child's use of correspondences to determine congruency between arrays.

Specifically, we are focusing on whether a developmental pattern exists in the child's choice of particular aspects of the spatial configuration to use for comparison. According to the constructivists, e.g., Piaget and empiricists alike, the child is first aware of unorganized totalities or undifferentiated parts and with growth and experience progressively differentiates the parts. At the end point of the child's development is the construction of the integrated totality from a prior knowledge of the constituents of that totality.

Research. Work addressing this specific issue is meager. However, Thomas (1978) did find that first graders tend to focus on the sides of a triangle, whereas third graders' attention fluctuates between sides and vertices and sixth graders take both into consideration concurrently. In their studies on similarity transformations, Piaget and Inhelder (1967) noted that children attempting to match similar triangles first considered the overall pattern and in later stages focused on the parallelism of the sides and, subsequently, the equality of the angles. For Piaget et al. (1960), knowledge of angles implies a coordination between the length of the arms and the distance which separates them (p. 182).

Beilin (1984), studying the child's notions of congruence, found that children basically use two strategies to establish the congruence of triangles. These strategies are single edge matching of the sides, implying knowledge of the

parts, and superposing of the triangles, implying knowledge of the totality. They found that young children use single edge matching and older children superpose. These results however do not unequivocably support the constructivist position. Single edge matching of corresponding sides yields a regular figure (e.g., deltoid), and it is unclear as to whether children are basing their judgements of congruence on the equality of parts or on a gestalt-like whole. Further, there is a question as to whether superposing can be considered unequivocably to represent knowledge of the whole, as Piaget himself found superposing to occur in children younger than seven years.

In sum, prior research tends to support the constructivist position but not unequivocably. Since blind children should be less influenced by a concurrent gestalt and need to coordinate information from all parts of the spatial array in order to perceive the whole, information concerning their solution strategies may lead to an understanding of the conceptual structure basic to sighted as well as blind children's competencies.

Regarding issues concerning both transformations and correspondences, there appear to be clear conflicts in the research literature. As noted above, these problems may be due to a lack of attention to individual or task variables. In the remaining sections we examine theories and research regarding how both categories of variables affect children's performance and strategies on Euclidean spatial tasks.

Individual differences.

One strong focus of this research is the role which vision plays in the development of mental imagery and ideas of congruence and transformations. As seen above, Piaget holds that children judge congruence between arrays by establishing correspondences and/or by mentally transforming the stimuli aided by mental imagery. Specifically addressing geometric (spatial) reasoning, Piaget and Inhelder (1971) held that the mental spatial image plays a special representational role in that there is more or less complete homogeneity between the imaged form and the actual spatial operations, a relationship which does not exist in strictly logical operations. This issue was further addressed by Inhelder (1970) who noted that "imagery...fulfills the role of a symbolic tool that is complementary to language and, like language, promotes the progress of thought." Regarding its origins, she noted that "The development of symbolic imagery...depends to a large extent on external contributions" (p.580-81).

In line with Piagetian thought, others (see p.2 above) have also posited that spatial imagery or spatial ability is important to mathematical reasoning. Research regarding the relationship is ambivalent. Positive correlations between mathematics and spatial ability were reported by Connor and Serbin (1980); Roberg and Flexer (1983); and Sherman (1978). Armstrong (1981) and Clements (1981) found no relationship between the two measures. Others found that spatial ability was related to specific math courses such as statistics

(Elmore & Vasu, 1980), and geometry (Daniels, 1982). Daniels also found that spatial ability predicted scores on the mathematics section of the Scholastic Achievement Test (SAT), but it did not necessarily predict performance on high school mathematics courses, especially Algebra 1.

The use of imagery has also been shown to be detrimental to geometric reasoning. Millar (1982) and Vin Bang (cited in Montangero, 1976) each gave subjects, respectively, perspective problems and perimeter/area problems. Those subjects using visual rather than logical strategies fared poorly.

Thus the value of processing problems using spatial imagery is not clear. This may be due to the fact that geometry problems can be solved using either spatial or logical operations (Montangero, 1976), and individual and/or task variables may favor the use of one operation in lieu of the other.

Regarding individual differences in spatial reasoning, two groups, blind persons (Steven & Grube, 1982) and women (Linn & Peterson, 1985) have been identified as doing poorly in spatial tasks. Both groups also appear to have problems with mathematics (Feingold, 1988; Rossi, 1986). Theories regarding the etiology of poor spatial performance differ for each group and will be discussed more fully below.

In our study we focused on how vision per se, across gender, affects the development of mental imagery and congruence judgements. To do this we looked at how vision and

gender uniquely contribute to spatial reasoning. By examining strategies as well as performance, we attempted to understand the processes which different groups of children impose on spatial problems. Millar's (1982) work with the blind has led her to conclude that the modality through which persons experience their world affects their problem-solving responses. We suspect that this might be true for gender as well as blind/sighted differences.

We also focused on the development of these strategies over age. This is important as performance differences seen only in later years such as adolescence may have earlier processing origins. Studies by Dean (1979), Dean, Scherzer, and Chabaud (1986), and Inhelder (1970) illustrate this point. They found that, in order for children to mentally image transformations, they needed to have prior operational understanding of the concept of transformation.

Additionally, in order to optimize our chances of seeing processing differences, we constructed tasks which were reflective of the type of spatial tasks which generate differences due to sight (Stevens & Grube, 1982) and gender (Linn & Peterson, 1985). For conditions of both sight and gender, two types of spatial tasks show differences--mental rotations and cognitive mapping. Additionally, gender differences for sighted subjects are found on Witkin's Rod and Frame Task and Piaget's Water Level Task. Our tasks basically address mental transformations (flips as well as rotations) but include some factors, such as the influence of external

cues, which are involved in the Rod and Frame Task and the Water Level Task.

Following are two subsections concerning individual differences--one concerns blindness and the other gender. In each area we look at theories and research regarding differences in these particular groups.

Blindness. One issue surrounding spatial cognition and blindness has centered on whether vision, particularly early vision, is essential to the development of spatial cognition (Warren, 1984). Although several authors have argued that it is, in fact, essential (Bowers, 1979; Von Senden, cited in Bowers, 1979), current evidence clearly contradicts this position.

Researchers (Landau, Gleitman, & Spelke, 1984) studied a congenitally blind girl at the age of two years and again (Landau, 1986) at four years. She was given simple ambulatory and mapping tasks that required spatial inference, and performed similarly to sighted children of her age. Other researchers have found that although many congenitally blind children are delayed in spatial tasks, a few perform equal to their sighted peers in, for example, projective space concepts (Birns, 1986) and cognitive mapping tasks (Casey, 1978; Fletcher, 1980).

It appears then that some congenitally blind children can acquire good spatial concepts, but it is also clear that most are delayed in relation to sighted children. As noted above, work with blind children on Piagetian spatial tasks (Hatwell,

1966; Stevens & Grube, 1982) showed delays of four to six years on these tasks. Training improved performance on some (e.g., perspective) but not other (mental rotation) spatial tasks. Other studies with blind children confirm these delays in mental rotation tasks (Ittyerah & Samarapugavan, 1990; Millar, 1976), whereas other studies report delays in cognitive mapping (Casey, 1978; Fletcher, 1980; Reiser, Locke, and Pick, 1982).

Most theorists would agree that spatial cognition would pose some difficulty for the blind population but attribute this difficulty to different factors. Piaget and E.J. Gibson have commented on this delay in blind children and have related it to their own theories. Piaget, in a lecture (cited in Gottsman, 1976), stated that blind children, not being able to make the same early coordinations in space as sighted children, would be seriously impeded in both sensorimotor and representational intelligence. However, he did believe that this delay could be made up eventually.

Working within the Piagetian framework, Selma Fraiberg (1977) studied the development of a group of blind infants. She noted several delays in these children attributable (directly and indirectly) to their lack of sight. Specifically, congenitally blind children, having no visual stimulus to entice them to move into the world, were delayed in self-initiated motor movements such as sitting and crawling. The developmental sequence leading to object permanence was also delayed until children could coordinate

touch and sound at 10 months. Additionally, children did not spontaneously bring their hands together--an accomplishment important to object exploration. Blind children also had difficulty moving into an exocentric frame of reference as seen by their delay in differentiating "you" and "I" until five, rather than the normal three years of age. In sum, Fraiberg found delays in motor movement, space and object exploration, and in representation.

E. J. Gibson (1978) speaks of the development of the congenitally blind child in a review of Selma Fraiberg's (1977) book, Insight from the Blind. Gibson's ideas regarding this development derive from her own theory that the sighted person has perceptual "pickup" systems which have evolved to pick up information which is laid out relationally for them. She notes however that for the blind infant there are empty areas or "holes." Sounds, for example, cannot confer the tangibility of an object to the blind child. Similarly, the blind child cannot directly perceive the layout of the distal environment but instead must, with difficulty, construct and conceptualize this world. Lest it appear that this viewpoint has "constructivist" overtones more akin to Piagetian theory, Gibson makes it clear that, in her view, Piaget thought of his own children as if they were blind.

For those researchers working with the blind, theories regarding the etiology of these delays tend to fall into two categories. One addresses the inefficiency of the sensory systems available to the blind. The other focuses instead on

the differences inherent in the information processing characteristics of the various sensory systems.

In the inefficiency category is the work of Worshell (1951) and Warren (1984). Both speak of the congenitally blind child's inability to use vision and visual imagery to organize information coming from the remaining senses. These remaining senses are considered less adequate than sight for processing spatial information.

Worshell's thesis emerged from experiments with blind and sighted children, which indicated that only sighted children could mentally combine two forms presented to the child haptically. (This notion is challenged below.) Warren's conclusions come from reviewing years of data indicating that later - blind persons inevitably do better than their congenitally blind counterparts on spatial tasks. It is assumed that later - blind persons retain the ability to visualize their world and use these images to organize incoming information.

Those theorists who stress the differences by which information is gathered and organized in the sensory systems include Juurmaa (1973), Jones (1975) and Miller (1982). All three address the issue of blindness and focus on the differences between the sense of vision and the senses relying heavily on motor movement--haptics and kinesthetics. All note that, while vision is able to absorb large amounts of information holistically, the information derived from motor movement is more fragile for several reasons. It is

sequentially coded, requires more memory load to sustain and integrate it, and fades quickly unless overlearned.

To illustrate these differences, Juurmaa (1973) cites research comparing the ease of acquiring spatial information with the ease of transferring this information between the various sense modalities of vision, haptics and kinesthetics. Acquisition of spatial information was easiest in the visual and most difficult in the kinesthetic mode. However, the opposite pattern was seen when examining the transfer of information between modalities. Information learned in the kinesthetic mode could be transferred to the haptic and visual mode, but the reverse transfer was difficult.

Juurmaa interprets these results to mean that information from all of the sense modalities is spatially patterned but that those senses involving considerable movement memory require more time to pattern. Nevertheless, once patterned, these senses transfer information more easily to the remaining senses.

These two interpretations (inefficiency and differences) of blind children's spatial skills thus address two issues. The first concerns congenitally blind children's ability to form spatial images and focuses on Worshell's work. This research indicated that sighted but not blind children can mentally combine two forms perceived haptically into one holistic pattern. Analyzing the work further, Juurmaa (1973) showed that sighted and blind differences are only seen if the resulting pattern is optically familiar to the sighted group.

Forms equally familiar or unfamiliar to both groups show similar results. This indicates that sighted and blind children have equal ability to spatially pattern in the haptic mode.

The second issue relates to the lag in spatial development seen in the blind child. Juurmaa cites work by Gomulki (1961) regarding blind and sighted performance on ambulatory mazes. As might be predicted, the sighted did better than the blind in the early years, but by 15 years of age, the groups did equally well. This supports Juurmaa's thesis that the kinesthetic mode is difficult to pattern but, with experience, it patterns effectively. However, developmental factors also may come into play. According to Piagetian theory, adolescence brings with it formal reasoning and, in the spatial domain, fuller knowledge of Euclidean space. Casey (1978) found that blind children's skills in cognitive mapping related to their general cognitive ability. Thus, blind children may be more dependent than the sighted on strong cognitive skills to organize their spatial input and are therefore delayed in this area until knowledge of full Euclidean space evolves.

Jones' thesis (1975) is similar to Juurmaa's in its rejection of visual dominance of the spatial system. He further posits that, neurologically, the spatial senses operate as a unitary system, and that patterns of movement serve to integrate spatial information. With Fraiberg (1977), he stresses the role of vision in enticing children to explore

the world. He concludes that, where the nature of blindness precludes the easy acquisition of patterns of movement, we can expect deficits in spatial perception and thus in representation in the blind. However, the nature of blindness is a social as well as a physical construct. Teachers working with the blind frequently refer to a tendency of blind children (especially girls) to be overprotected, thus inhibiting free exploration. This is reiterated in Warren's (1984) review of the literature on blind children.

Millar (1982, 1976) focuses on the strategies which emanate from different sense modalities--strategies that, as noted above, can be either helpful or harmful when solving specific problems. She found that, in mental rotations tasks, performance by blind but not sighted children is negatively affected by increasing the extent of the rotation (Millar, 1976). She attributes this to blind children's use of a movement memory strategy and notes that larger rotations would require more memory load. Additionally, Millar (1982) notes that blind children are more apt to use themselves as a reference system while sighted children are more likely to use external references. For each group these systems of reference provide, and have provided in the past, the most reliable source of information about relationship among objects (including self).

These reference systems can also be sources of error. When attempting to construct a projective straight line, young sighted children can either be aided or distracted by the

external frame of reference provided by the edges of the table. In contrast, blind children ignore these "cues" and construct similar lines regardless of the shape of the table's boundaries (Birns, 1986; Simkins & Siegal, 1979). Errors are also seen with blind children. Birns notes that blind children incorrectly use a self-referent system during tasks in which children must identify mirror image counterparts (e.g., the left arm of the person standing opposite them). Similarly, Warren (1984) cites research findings indicating that blind children have difficulty identifying the relative position of two or more objects in space because of their egocentric frame of reference.

However, the use of a particular modality does not invariably determine the method of coding information. Hermelin and O'Connor (1972) found that information received visually is generally coded spatially and information received auditorially is coded temporally. Thus they predicted that when blind and sighted children were given ambiguous auditory stimuli which could be coded either spatially or temporally, each group would code the stimuli along the lines of their dominant modality for processing information. The results were as predicted with exceptions. The sighted coded the stimulus spatially and the blind temporally but 25% of the blind children also coded the stimuli spatially.

The question of course arises then as to how a small but noticeable group of blind children became inclined to code information in a way that would not be expected from their

sensory experience alone (Warren 1984).

Millar (1982) holds that although "preferred" strategies emanate from the use of a particular sense modality, other strategies--such as the use of external frames of references for the blind--can and should be taught. One aim of this study was to explore the development of children's natural strategies and the relationship of these strategies to performance so that possibilities for intervention might be identified.

In sum, it appears that blind children are capable of spatial reasoning but may be delayed due to lack of motor and object experience. This delay has been attributed alternately to the inefficiency of their basic modes of spatial processing and/or to their need for strong cognitive intervention in integrating spatial input from the haptic and kinesthetic modalities.

Our research attempted to clarify how blind and sighted children's strategies, emanating from their basic modalities for spatial processing, relate to their understanding of congruence and their ability to mentally image transformations. We predicted that blind children's strategies and performance would rely more or their evolving internal reference systems, whereas sighted children would be more dependent than blind children on external cues. Overall, we felt that the task information derived from both groups would help us to understand the processes that may be basic to the development of spatial knowledge as well as the processes that

are unique to each group.

Gender differences. Differences showing a male advantage in spatial reasoning were identified by Porteus in the early 1900s on a maze test that he constructed as an alternative to Binet's highly verbal intelligence test. In subsequent maze testing by Porteus and others, the male advantage still held in children as young as four to six years of age (cited by Harris, 1979).

Since then considerable work has been done; researchers have attempted to delineate the type of tasks on which we are likely to find gender differences as well as the age at which these differences first appear. Meta-analysis of performance on spatial tasks (Linn & Peterson, 1985) indicates that gender differences can be found on tests of spatial perception and mental rotation but not on tests of spatial visualization. A description of these tests and a summary of the above authors' analysis follows.

Tasks of spatial perception include Witkin's Rod and Frame Task and Piaget's Water Level Task. Psychometrically, both tasks are said to load on a kinesthetic, orientation or vestibular factor. Further, these tests both require that the subject focus on disembedding or overcoming distracting cues. In the Rod and Frame Task, subjects must determine the upright position of the rod given distracting orientations of the frame. Similarly, the Water Level Task requires that the subject maintain the horizonal position of the water level given various orientations of the container. Analysis of

sixty-two spatial perception studies indicated that gender differences could be seen clearly by eight years of age and that the difference is significant in populations over eighteen years of age.

That kinesthetic and external cues are involved in these tasks and are used differentially by gender is suggested in studies by Nyborg (1988) and Harris (cited in Linn and Peterson, 1985). Nyborg studied eight- to sixteen-year-olds' reactions to the Rod and Frame Task and concluded that fourteen- to sixteen-year-old boys are more likely than their female cohorts to use vestibular cues (60% versus 37%) to determine the upright. The Harris study of the Water Level Task found that when attention was focused internally on the water, gender differences were negligible. However, when focus was directed to the external container, strong gender differences emerged. These two studies suggest that males are more likely to use vestibular cues and females are more likely to rely on and/or be distracted by external cues in determining upright and horizontal positions.

Mental rotation tasks, generally require that subjects work quickly to locate a second instance of a given rotated figure. These tests include the Primary Mental Abilities test of space and Vanderburg and Kuse's version of the Shepard-Metzler Mental Rotation Test. The two tests differ in that the Vanderburg test uses 3-dimensional figures while the Primary Mental Ability test uses 2-dimensional figures. Regarding the cognitive processes involved, Linn and Peterson cite two

points of view. Shepard and Cooper argue for an analogue process in doing mental rotation tasks; i.e., that respondents' internal cognitive processes have a one-to-one correspondence with the external rotation of the objects. On the other hand, Pylyshyn suggests that analytic (i.e., logical) processing is used. Supporting the analogue thesis are data indicating that the time taken to do the task is directly related to the size of the angle through which the test stimulus must be rotated to achieve coincidence with the standard stimulus. Other data showing that response time increases with increased task complexity support an analytical processing model.

Gender differences on these tasks were found at the earliest age studied (10 to 13 years). However, differences were more robust on the Vanderburg task (weighted estimate of Effect Size = .94 for Vanderburg and .26 for Primary Mental Abilities-space). Essentially, differences were found in the rate in which the stimulus was rotated and not in accuracy. Kail, Carter and Pelligrino (cited in Linn and Peterson, 1985) also reported that females in their study of mental rotations showed a bimodal distribution of scores, with one part of the population performing at the same level as their male counterparts.

Linn and Peterson suggested that gender differences on this task may result from any of the following factors. One, females may adopt a less efficient part-by-part rotation strategy. If so, then the more complex (3-dimensional)

Vanderburg task (more parts) would show more sex differences than the less complex (2-dimensional) Primary Mental Abilities test. Secondly, this part-by-part strategy may be mediated by a meta analytic strategy which guides part selection. Thus, for tasks where analytic strategies are efficient, there would be few gender differences. Finally, they suggest that females may do poorly because they tend to exercise more caution in testing (e.g., double checking) and that this caution would inhibit task speed.

The final category of spatial tests for which no gender differences are reported is spatial visualization. This includes the Embedded Figures and Paper Folding Tasks. It is generally agreed that an analytical strategy is necessary to solve these tasks.

Comparing all three categories from a psychometric perspective, spatial perception (e.g., Rod and Frame Task) and spatial visualization (e.g., Embedded Figures Task) have been found to load on separate factors (vestibular versus analytical). Spatial visualization and mental rotation tasks have sometimes been found to load on the same factor (e.g., Paper Folding may involve rotation). However, unlike most analytical spatial visualization tasks, the Vanderburg test of mental rotation showed a low relationship to other factors identified as verbal, perceptical speed and visual memory (Linn & Peterson, 1985).

The above research suggests that there are gender differences in strategies (e.g., kinesthetic/analytic) used to

do spatial perception and mental rotation tasks. Other research in the realm of spatial tasks and science supports this idea. Ozer (1987) found that performance on Vanderburg's rotation task at 18 years of age correlated with performance I.Q. scores at 4 years of age for boys and 11 years of age for girls. Additionally, for 18-year-old girls only, performance on Vanderburg's task correlated with verbal I.Q. scores. Maccoby and Jacklin (1974) cite somewhat similar findings in relation to a physics achievement exam. Boys test better on visual spatial items, whereas girls do better on verbal items. However, they also note that differential methods of doing tasks do not automatically connote success or failure. They cite Vanderburg, who observed that Karl Pearson and Fisher used quite different methods to arrive at their geometric theories (analytical versus geometric analysis). Since our spatial tasks involve mental rotations and external reference cues (areas of strong gender differences), we examined our data with the above-cited strategy differences in mind.

Two areas of inquiry which have evolved from the above research on gender differences in spatial processes concern the origin of these differences and the practical import, if any, of spatial knowledge. Studies which examine the origins of these differences are generally structured to determine whether these differences are innate (physiological) or learned (social/environmental). Brain lateralization studies are characteristic of the former, whereas studies correlating gender identity with spatial skills are characteristic of the

latter. Those studies looking at the practical import of spatial differences generally look at the relationship between gender, spatial ability and mathematics.

Origins. Regarding the origins of these differences, there are those who suggest that if gender differences are found very early (Linn & Peterson, 1985) or if they are highly resistant to change (Caplan, McPherson, & Tobin, 1985), the differences must be innate. However, Newcombe (1982) and Millar (1982) both point to the fact that early experience (e.g., toys, gender roles, blindness) engenders preferred modes of processing information. This can occur at a very early age, and preferred strategies may be variable in their resistance to change. Given this background we will first examine studies which search for innate gender differences and then present those studies which look to the environment for these differences.

One innate cause of these gender differences was proposed by Stafford (cited in Boles, 1980), who attributed high spatial ability to a recessive gene on the X chromosome. Boles analyzed several years of studies testing Stafford's hypothesis which predicts certain familiar relationships regarding aptitude for spatial tasks. Because these predictions did not emerge in the data studied, he concluded that Stafford's hypothesis was invalid.

A second set of studies searched for innate causes of these gender differences through studies of brain lateralization patterns. These studies are based on the

assumption that cerebral functioning determines the intellectual processes and not the reverse. One subset of these studies has as its basis the fact that gender differences in spatial ability emerge around puberty. It was thought that later maturation (normal for boys) might result in greater hemisphere lateralization and increased specialization for spatial tasks (Waber, 1977). Newcombe, Dubas and Baenninger (1989) reviewed studies done over the past ten years including their own study of adult women. There was no evidence of higher spatial ability in late maturing women. However, they did find that women tended to process both verbal and spatial (dot location) tasks in the left hemisphere.

Tkacz (1982) studying college students found a gender difference in hemispheric processing of rotation tasks. Males processed these tasks in either hemisphere whereas, again, females used the left hemisphere. However, the hemisphere of processing did not relate to spatial ability. Instead, high spatial ability males and females were faster at encoding the task stimulus. In contrast, Bowers and La Barbara (1988) found that spatial ability was associated with particular hemisphere processing but that this difference was peculiar to task, not gender. Left hemispheric processing favored the Rod and Frame Task and right hemispheric processing favored rotation tasks. They also found that high spatial ability females and low spatial ability males sometimes did these tasks verbally. Finally, McGlone (1980) in her review of lateralization

studies found that males showed more of a decline in spatial ability than females with an assault on the right hemisphere. However, this was valid only if motor skills were involved in the task.

In sum, it appears that females may be more inclined to use left hemispheric processing, which presumably represents a more analytic or verbal approach to spatial tasks, but it is not clear that this is the cause of lower spatial ability. Males' ability to use right and left hemispheric processing may give them some advantage in some tasks especially if right hemispheric processing is involved with movement (see above--Shepard's notion of analogue processing). Again, we reiterate that even clear brain lateralization differences do not necessitate an innate explanation in as much as preferred strategies that are learned may determine a functional lateralization of the brain.

For social explanations of gender differences are studies which suggest that those social factors that contribute to the formation of "ideal male" behavior in our society also contribute to the development of stronger spatial ability. These studies examine the relationship between spatial ability and three factors: independence granting, gender concepts, and activity.

The first type of study is exemplified by Berry's (1971) cross-cultural research, in which he found that hunting societies that emphasized autonomy and personal achievement for both sexes performed well on spatial testing. The opposite

was true for strongly agricultural groups, which tended to be more heavily socialized and sedentary. Studies in the second group, gender concepts, generally support the notion that high masculine personality traits in girls are related to higher spatial ability (Newcombe & Bandura, 1983; Signorella & Jamison, 1986; Tkacz, 1982).

The final group of studies are based on a Piagetian model implicating movement in spatial knowledge and include studies of cognitive mapping. Matthews (1986), for one, examined the map-making capacities of 6- to 11-year-old children and found that, from an early age, boys showed a broader understanding of space, recalling places farther removed from home than did girls. Boys also excelled in cartographic competency and map accuracy. In a second study of mapping competency done in unfamiliar environs, Matthews (1987) found that "priming" the children for the task reduced the gender differences seen above for simple but not complicated mapping tasks. He attributes these gender differences to discrepancies in the range of movement allowed boys and girls in their home territory. Here he cites work by several authors (Hart, 1978; Landy, 1965; Munroe & Munroe, 1971) to substantiate his thesis that boys are allowed, either tacitly or openly, to roam more freely at an early age and that this difference increases after about 10 years of age.

Studies which examined the actual relationship between spatial activity and spatial ability (Baenninger & Newcombe, 1989; Newcombe, Bandura, & Taylor, 1983) have found a positive

correlation between the two measures. Further, Signorella, Jamison and Krup (1989) found a specific relationship between masculine spatial activities and performance on the Water Levels Task. It is tempting to suggest that the stronger spatial skills of the groups discussed above (Berry's hunting societies and the more "masculine" females) can be attributed to activity alone, a thesis which would be predicted from a Piagetian perspective. However, Signorella et al. (1989) found that sex, spatial activities and gender self-concept each make separate contributions to spatial ability.

In sum, neither innate/physiological nor social/environmental studies pinpoint a clear reason for gender differences in spatial ability, but both furnish leads in this direction. Brain lateralization and strategy may be interdependent and the relationship among four factors--gender concept, spatial activity, spatial ability and, again, strategy--might be clarified with a finer analysis of activities in early childhood.

The second issue raised in regard to gender differences in spatial ability is whether this difference has any real bearing on areas of children's knowledge other than cognitive mapping. As noted above, several researchers (e.g., Piaget et al., 1960) have held that spatial ability is important to mathematical reasoning. It is further noted that girls do poorly in math and spatial ability and that gender differences in these areas both arise in early adolescence and increase with age. Clear gender differences in mathematics favoring

boys have been documented by Armstrong (1981), Connor and Serbin (1980), Dees (1982), Feingold (1988), Hyde, Fennama and Lamon (1990), and Sherman (1980). It is, however, not clear whether there is a multiple relationship between gender, spatial ability and mathematics. Sherman (1980) found a relationship between mathematics and spatial ability for girls only, whereas Maccoby and Jacklin (1974) cite research indicating that this same relationship only occurs in boys. Signorella and Jamison (1986) looked at gender concept rather than gender and found that high masculinity or low femininity was associated with good mathematics and spatial ability scores. Differences in the research results were likely to be due to using different tests of mathematics and spatial ability with subjects who come from different populations. Research cited by two groups (Hyde et al., 1990; Maccoby et al., 1974) indicates that, at least for mathematics, the strength of gender differences varies with the populations studied.

In sum, girls appear to do more poorly than boys on spatial tasks involving spatial perception and mental rotation. Spatial perception tasks (Rod & Frame Task, Water Levels Task) are said to have as their basis a reliance on strong kinesthetic cues and the ability to ignore distracting external cues. Research suggests that mental rotation tasks have elements of both analogue and analytical processing as their basis. Strictly analytical tasks (Embedded Figures Test) show no gender differences.

Regarding the origins of these differences, there is some indication that gender differences exist in the cerebral processing of these tasks. Females appear to favor the left hemisphere, whereas males are reported to use both hemispheres. Since the left hemisphere is said to be more analytical, this accounts for the absence of gender differences on purely analytical spatial tasks. However, as noted above, these physiological differences need not be innate but may instead have their origins in learned strategies.

As to the practical impact of these spatial differences, it appears that clear gender differences in mathematics and spatial abilities can be reliably documented, especially beginning with high school. However, there is no consistent documentation of a relationship between spatial ability and mathematics. More work, using a broad range of measures for both of these constructs with systematically varied test populations needs to be done here.

Task variables. In the sections above, examples are given where researchers attempted to measure underlying "unitary" constructs such as spatial or mathematical ability using several tasks. They later found that the various measures used often reflected different intellectual processes or different aspects of that ability. Examples of this phenomenon are also seen in work on geometric reasoning done within the Piagetian tradition.

Dietz and Barrett (1978) looked at the performance of elementary education majors, who tend to be female, on two tasks: the Water Levels Task, which measures one's ability to use frames of reference; and, the Piagetian task for constructing Euclidean coordinates. According to Piaget and Inhelder (1967), both tasks have as their underlying construct the development of a Euclidean coordinate system. Subjects should therefore show mature performance on both tasks at the same time. It was found that, for the adults tested, the coordinate task was easy but the Water Levels Task was difficult even with training. They concluded that these tasks did not have the same underlying construct.

Similarly, Kidder (1978), working with 8- to 10-year-olds, tested Piaget's (Piaget et al., 1960) findings that children conserved length (a Euclidean concept) by 6 years of age. He used different stimuli and transformations from those used in the Piagetian task. Instead of rods he used triangles, and he expanded the transformations to include rotations and flips as well as slides. He found that children who could "classically" conserve length of rods over slides could not conserve the length of the sides of a triangle over the various transformations. Instead, children made the sides of the end-state triangle to be "like" (similarity geometry) instead of congruent to (Euclidean) the sides of the original triangle. He concluded that either children do not conserve length when performing more complex mental operations because they are centering on other attributes of the problem, or that

these transformations are not Euclidean (length preserving) at this age.

In attempting to account for these discrepancies, Lesh (1976) comments on the difficulty in equating tasks on the basis of their underlying operational structures and notes that transformation tasks often vary widely in their degree of difficulty. He concludes that "if operationally isomorphic tasks differ 'too much', it may be meaningless to equate tasks on the basis of operational structure" (p. 228). Supporting Lesh's position are several studies showing that variations in both stimulus and transformational factors do indeed affect the performance on spatial transformation tasks.

Stimulus factors which have been cited as affecting performance include size, familiarity, configuration, and dimensionality. In her work examining several factors affecting transformations, Schultz (1978) found that larger configurations which were meaningful or familiar to the child were easiest to transform. Working within the same general research project, Thomas (1978) found that the configuration of letters affected transformational ease--e.g., letters with rotational symmetry (N,S) were difficult to rotate. Finally, several authors (Clements, 1981; Moyers & Johnson, 1978) found 3-dimensional arrays more difficult to transform and analyze than 2-dimensional arrays.

Transformational factors include variations in both the extent and the end-state orientation of the transformation (Millar, 1976; Piaget & Inhelder, 1971; Schultz, 1978). In

general, transformations of larger extent with non-orthogonal end-states are more difficult to transform than those with smaller extent and orthogonal end-states. As seen above, Millar (1976) found blind children to be particularly affected by the extent of the transformation.

The type of transformation can also be a factor (as discussed in the section on mathematical and cognitive theory). Comparing the relative ease of transformations, particularly the flip (F) and rotational (R) transformations, the results are mixed. This may be due to yet another transformational factor--transformational demands which either focus on end-states or the actual transformation. Under the former we include recall and recognition demands and under the latter we include demands to either replicate the transformation or to identify the transformation intervening between end-states.

Research indicates that under demands focusing on end-states, subjects generally find it easier to recognize the end-state of a transformation than to regenerate or recall the intervening transformation and end-state, (Greco, cited in Montangero 1978; Inhelder, 1970; Piaget & Inhelder, 1971). According to Inhelder (1970), the lag between symbolization of results (recognition) and symbolization of transformations (recall) would seem to be explained by the fact that the child needs to understand what happens during the transformation before he can symbolize it in detail; the transformational image thus seems to be subordinate to operational activities

(p. 574).

Regarding the mixed results concerning the relative ease of the flip and rotation which were cited above (p. 10), a further analysis suggests that varying transformational demands influenced the outcome. Most of the studies that found the flip easier than the rotation required that the child establish congruence by a comparison between two end-states and/or to anticipate the end-state given the transformation. In the few studies in which the child was required to execute a transformation which would result in a correspondence between two end-states (Piaget & Inhelder, 1971; Beilin, 1984), the flip appeared to be the more difficult transformation.

Additionally, individual differences interact with task variables. As seen in research cited above, gender appears to interact with the type of transformation (rotation) and with the type of task cue utilized (kinesthetic/visual). The individuals's condition of sight (i.e., blind or sighted) is reported to interact with the rotational extent and with the type of reference demands (self/external) made by the task.

However, as Mayer (1982) reminds us, the point is not just to document the effects of task variation but to try to understand what is going on in the mind of the individual doing the task. Several examples of research attempting to forge links between task variables and cognitive reasoning are seen in the works of Greco (cited in Montangero, 1976); Kidder (1978); Moyers and Johnson (1978); and Perham (1978). As noted

above, Kidder (p. 36) suggested that children faced with complicated conservation of length tasks switch to a simpler level of geometric reasoning (similarity versus Euclidean). Moyers and Johnson, noting that 3-dimensional transformations posed more difficulty for children, tested the notion that 3-dimensionality was a formal operational (FO) concept. The notion was rejected, as both older (presumably FO) and younger children did better on 2-dimensional than 3-dimensional arrays.

Both Perham and Greco studied children's responses to a variety of transformation tasks and attempted to understand these responses in terms of cognitive developmental theory. As noted above (p. 10), Perham (1978), finding that first-graders had difficulty with transformations, attempted to train them to do transformations earlier using "motion geometry." Her results led her to conclude, in agreement with Piaget, that children could be trained to do simple transformations but that the success would be limited by cognitive factors related to age.

Greco's (cited in Montangero, 1976) work on flips and rotations is also in the Piagetian tradition. Working with older children, he constructed tasks in which he used letters (p d b g) which, when transformed by a horizontal (↓) or vertical (→) flip or a 180° rotation would all be variants of each other. Results indicated that transformational knowledge of vertical flips emerged earlier (7.5 years) than horizontal flips and rotations, both of which emerged between

11 and 13 years. However, by observing children's patterns of error, he concluded that to truly understand transformations, the child must be reasoning with group-like structures isomorphic to the logical operations of formal operations.

It may be a radical notion for some researchers that knowledge of transformations may fall within the realm of formal operational thought as children have generally been found to do many transformations by 8 or 9 years of age. However, Piaget and Inhelder (1971) did add one caveat: they held that transformational mental imagery emerges at around 7 or 8 years of age but that further development of this imagery depends on reasoning. Thus, stages of reasoning rather than stages of imagery should be seen after this age. During adolescence, knowledge of the Euclidean spatial system matures--knowledge which may interact with mental imagery to yield full transformational knowledge.

In sum, it appears that the data on geometric transformations within a developing cognitive system are more varied and inconsistent within a mathematical framework. It is thus necessary to take into consideration task differences and individual variability and attempt to find consistent influences despite these variables. It is also necessary to identify the cognitive processes responsible for the reported variations from basic patterns.

Our study was designed to clarify some of the issues that have been raised in the cognitive research reviewed. Given Piaget's claim that children establish geometric invariance

through both correspondences and transformational imagery, we looked at children's developing knowledge in both domains and particularly the relationship between children's knowledge of correspondences and their ability to understand transformations. In analyzing the data we took into consideration both individual and task variables. In general, we predicted that children's strategies would reflect their dominant method of experiencing the world.

We chose to study and compare the performance and strategies of blind and sighted children on geometric reasoning tasks as the theory and research reviewed indicated that sight may be important to understanding geometric space and transformations. Specifically, we expected blind children to have to construct holistic space from sequential processing and be less able than their sighted peers to use external references and a knowledge of mirror image relationships. We felt that studying both groups would clarify underlying patterns in the development of geometric reasoning as well as highlight differences in development due directly or indirectly to sight or lack thereof.

We also examined gender differences in transformations knowledge in an attempt to understand the differences favoring males which were seen in the literature reviewed. By examining these gender differences in both blind and sighted groups, we looked at whether these differences (if they exist) could be found across conditions of sightedness and, if so, would these differences be manifested similarly in both groups.

Finally, we examined all of the above issues under variations in task demands and task configurations in order to determine how the nature of the task influences children's strategies and performance.

Hypotheses

Hypothesis 1.

Children's understanding of transformations changes with age from an early understanding of transformational movement to a knowledge of full Euclidean space. Children at 7 or 8 years of age are able to fix this early knowledge of movement within a vague spatial context, aided by spatial cues. At approximately 11 years of age, children attain Euclidean spatial cognition, understanding transformations in a full spatial context.

This hypothesis follows from the work of the Piagetian group (1971, 1967, 1960); Dean, (1979); Greco (cited in Montangero, 1976); and Millar (1982). Piaget held that transformational imagery evolved at about 7 years of age from movement in space and that this imagery is influenced by content. Dean presented evidence indicating that knowledge of transformations precedes transformational imagery. Greco noted that full transformational imagery emerges with formal operational reasoning (as does Euclidean spatial knowledge). We then proposed that children between 7 and 11 years of age, lacking the ability to form a clear representation of space (Greco), have only generalized imagery and resort to external

cues (as noted by Millar) to deduce transformational end-states.

Hypothesis 2.

The above sequence of transformational knowledge is affected by task (below--a to e) and/or individual variables (below--sightedness-a, b, c; gender--f). Specifically, it would be affected by:

a) Cues present - In general, performance should be lower with fewer cues, especially for 8- to 10-year-old children who have not yet attained Euclidean spatial knowledge. The sighted child should be more affected than the blind child by this loss of cues and should be affected more on rotations than on flips. This would render blind and sighted performance more similar in that both groups would then be equally affected by the extent of rotations (90° > 270°).

This hypothesis is derived from Millar's work with blind and sighted children showing that the sighted were more likely to use external cues (1982), whereas the blind are more likely to be affected negatively by rotational extent (1976). As noted above, we assumed that the effect of cues would be strongest prior to the development of Euclidean spatial concepts.

We also took into consideration Birn's (1986) finding that blind but not sighted children have difficulty dealing with mirror image concepts. We thus predicted that the sighted, having the knowledge that simple mirror image end-

states result from flip transformations, would be less affected by low cues on the flip than on the rotational transformation.

b) Task demands: recognition versus recall - In these spatial tasks, recognition should be easier than recall, especially for the sighted with their greater experience in perceiving the end-states of transformations. This difference in recall/recognition should be seen primarily in children of approximately 5 to 10 years, who may not be able to do full Euclidean transformations but can recall end-states from experience.

This hypothesis is based primarily on Inhelder's (1970) paper on imagery, which supports the notion of recall/recognition differences and from the work of the Piagetian group (1967, 1960) on the development of Euclidean spatial concepts.

c) Types of transformations and methods used to evoke transformational knowledge - The relative ease of flips and rotations should interact with the experimental methods used to determine transformational knowledge (replication of transformation versus intuiting, or executing intervening transformations) and these differences should interact with sightedness.

The sighted, due to their knowledge of mirror image end-states, but not the blind, should find the flip easier than rotations in the replication condition. Both groups should find the rotations to be easier than flips if identification

of the transformation intervening between end-states is required. This hypothesis is prompted by the research, cited above, with sighted children on the ease of transformational types. This research indicates that replication studies found the flip easiest, and studies of intervening transformations found rotations easier than flips. We suggest that the latter result is due to the fact that, for both groups, the flip, but not the rotational transformation, require that the array be taken out of the 2-dimensional plane in which it is perceived.

d) The nature of the stimulus - Stimuli with strong external structure (e.g., angles) should engender earlier understanding of transformational relationships existing between end-states than would stimuli with internal structure (e.g., circular order within a disc).

We assumed that stronger external structures would allow for easy establishment of correspondences, which would lead to earlier transformational knowledge.

e) Familiarity of the stimulus - Using familiar objects, which ordinarily are easier to encode, should facilitate transformational skills.

This follows from Shultz's (1978) work showing that familiar objects were easier to transform than unfamiliar objects.

f) Gender differences - We expected to find the documented differences in mental rotation tasks favoring sighted boys. We made no prediction for the blind group.

Hypothesis 3.

Children should first focus on one part or on the general overall gestalt of the stimulus array. They should then progress to differentiating and coordinating parts of the stimulus and, finally, to analyzing the stimuli holistically.

This hypothesis is in accord with the research reviewed in the constructivist/differentiation section of this report.

Hypothesis 4.

In order to intuit the transformational relationship existing between two end-states, children should first be able to make a holistic analysis of these end-states integrating both parts and wholes of the figures.

This follows from Greco's work (cited in Montangero, 1976), which suggests that formal operational reasoning (and analysis) is necessary for full understanding of transformations.

Research Model

In order to test these hypotheses, we examined children's performance and strategies on several tasks. These tasks are grouped together below on the basis of theoretical similarity.

Initially, we gave the children a Pretest which was designed to insure that they understood the basic concept of "sameness" or congruence. Four experiments then followed and these were divided into the two major sections seen below. Table 1 summarizes the relationship between these tasks and

Table 1

Relationship of Specific Hypotheses to Specific Tasks

Hypotheses	Tasks			
	Tri. Tran.[a]	Fam. Obj.[b]	Stat. Tri.[c]	Stat. Disc[d]
Hypothesis 1 - Progress of Transformational Knowledge	t[e]	t	t_p[f]	t_p
Hypothesis 2 - Effect of Individual and Task Variables				
a. Cues, Rotational Extent	t	t		
b. Task Demands (rcl, rgn)	t			
c. Transformation Type/Methods	t		t	t
d. Nature of Stimulus			t	t
e. Familiarity of Stimulus	t	t		
f. Gender Differences	t	t	t	t
Hypothesis 3 - Constructivist versus Differentiation Theory			t	
Hypothesis 4 - Interaction of Transformational Knowledge with Holistic Analysis			t	t

[a]Triangle Transformation. [b]Familiar Objects. [c]Static Triangle. [d]Static Disc. [e]This hypothesis was tested by this task. [f]This hypothesis was only partially tested by this task.

the hypotheses tested.

1: Nonvisible transformation tasks - these experiments tested Hypotheses 1 and 2. Here we examined the child's ability to mentally imagine an unseen transformation under high and low cue conditions. Further, these tasks tested for differences due to individual and task variability. Individual variables included sightedness and gender, whereas task variables included transformational type and extent, task demands and stimulus familiarity. Included were the Triangle Transformation and Familiar Objects tasks.

2: Congruency/Transformation tasks - these experiments basically examined Hypotheses 3 and 4. Specifically, we looked at the child's ability to determine congruence and transformational relationships existing between two object arrays which differ from each other by a reflection (flip) or rotation. In order to also test for the effect of task configuration (Hypothesis 2c), this section was further subdivided into (a) tasks in which the objects have strong external, easily differentiated, structures such as angles and sides (Static Triangle task) and (b) tasks in which the arrays are circular and have an internal structure of order (Static Disc task). These external (2a) and internal (2b) structures determine both congruence and the transformational relationship existing between the two arrays.

In each section only one task was examined in detail--the Triangle Transformation Task and the Static Triangle Task. The remaining experiments will be presented briefly to furnish

either supporting material or additional insight.

CHAPTER 2 - Experiments

Methods

Research Design

The study employed a factorial design with four between-subjects factors--age (3 or 4 levels), sight (2 levels), cue (2 levels) and gender (2 levels); and 1 within subjects factor--task (4 levels).

The order of presentation was the same for all subjects but, within each task, some counterbalancing occurred (e.g., recall/recognition). The sequence of task presentation was as follows: (1) Pre-Test, (2) Triangle Transformation Task, (3) Familiar Objects Task, (4) Static Triangle Task, and (5) Static Disc Task.

Subjects

Subjects were divided into two groups (high cue, low cue) based on whether they received high (rectangular envelope) or low (square envelope) cue conditions on the Triangle Transformation Task. Both groups contained congenitally blind (blind) and sighted (sighted) children. Children were considered congenitally totally blind if they were blind from birth or, at most, a few months thereafter. These children were either totally blind or had light perception only. No disabilities other than blindness were evident from school records. All blind and sighted children fell within the normal

range of intelligence.

In the high cue group, eighteen 5- to 13-year-old sighted (sighted-high cue) children and eighteen 5- to 16-year-old blind (blind-high cue) children were tested. Mean age for 5- to 13-year-olds in each group was 9.6 years (see Table 2). Both groups came from a large urban setting and were strongly mixed both ethnically (African, European & South American ancestry) and racially (Black & Caucasian). The sighted children were from a parochial school in a working class neighborhood whereas the blind children, who were mainstreamed into the public school system, came from diverse neighborhoods in the city. Children tested in the low cue condition tended to be more homogeneous racially. The majority were white and most came from rural or suburban areas. The blind children (blind-low cue), ages 5 to 19 years, came from residential schools for the blind whereas the sighted children (sighted-low cue), ages 5 to 16 years, came mostly from a suburban school. Mean age for 5- to 13-year-olds in these groups was 9.1 years (sighted) and 9.6 years (blind) (see Table 2). There were thirty-three blind and twenty-four sighted subjects in this condition.

Regarding the equality of these groups within conditions of sight, identical tasks (which were not reported upon in this thesis) were presented to each group and served as a basis for comparison. These tasks involved determining congruence using various strategies which illustrated the child's knowledge of parts, wholes, ordering and frames of

Table 2

Mean Age of Subjects as a Function of Cue Condition, Sightedness and Age (in years) Group

	High Cue		Low Cue	
Age	Sighted(n)[a]	Blind(n)[b]	Sighted(n)[a]	Blind(n)[c]
5-7	6.5	6.4	6.2	6.8
8-10	9.8	9.6	9.0	9.4
11-13	12.5	12.8	11.5	12.5
14-16		15.4	14.7	15.0
17-19				18.0
5-13[d]	9.6	9.6	8.9	9.6
5-16[d]		11.0	10.4	10.9
5-19[d]				12.3

[a]N = 6 per age group. [b]In order of increasing age, n = 4, 6, 5, 3 per age group. [c]In order of increasing age, n = 3, 5, 5, 10, 10 per age group. [d]Mean age of groups within the given age range.

reference. Within conditions of sight, there were no overall significant differences between groups but each of the more suburban groups (blind and sighted children in the low cue condition) did nonsignificantly better than their urban counterparts.

Children were grouped in three-year age spans beginning at 5 years of age (e.g., 5-7, 8-10...). They were so grouped to roughly correspond to the ages at which Piaget found different levels of operations--preoperations, concrete operations and formal operations. We included older blind and sighted children to compensate for possible lags in development associated with either blindness or gender.

There were six sighted children in each age and cue group tested and the sample was divided equally by sex for each age. The number of blind children in each age group could not be as easily standardized. Table 3 shows the number of blind children in each cue condition subdivided into categories of age group and sex.

Materials

Pretest.

The pretest employed two different size cookie cutters in the shape of equilateral triangles and play-doh. Additionally, for the younger blind children three toothbrushes, two of which were used the same size and shape, were used.

Nonvisible Transformation Tasks.

Triangle Transformation Task. In the recall condition,

Table 3

Number of Male and Female Blind Subjects as a Function of Cue Condition and Age (in years) Group

	High Cue			Low Cue		
Age	Male	Female	Total	Male	Female	Total
5-7	3	1	4	2	1	3
8-10	4	2	6	1	4	5
11-13	3	2	5	2	3	5
14-16	2	1	3	7	3	10
17-19				2	8	10
5-13[a]	10	5	15	5	8	13
5-16[a]	12	6	18	12	11	23
5-19[a]				14	19	33

[a]Number of subjects per group for the given age range.

both groups used two congruent right triangles (3 3/8 in. x 4 1/2 in. x 5 5/8 in.) and an envelope. The envelope for the high cue groups was rectangular (6 in. x 7 in.) and for the low cue group was square (7 in. x 7 in.). In the recognition condition, one model triangle, the envelope and four sets of four congruent triangles, each set mounted on a 1/4 in. cardboard rectangle 6 in. x 24 in., were used (Fig. 1).

Familiar Objects Task. Four sets of objects, each set mounted in square cardboard gift boxes, and four identical sets of objects, unmounted, were provided. The sets consisted of a slipper; a ping pong ball and cotton ball; a plastic fork and spoon; and, a skeleton key. The former three sets were mounted in a 10 in. square box while the latter set was mounted in a 4 in. square box. Two similar empty boxes were also provided. For the sighted in Set 1, 2 black "envelopes" (16 in. sq. and 7 in. sq.), made by fastening 2 squares of imitation black leather with clips on each side, were used. All sets of materials were used in the flip transformation whereas the skeleton key was eliminated in the rotation transformation.

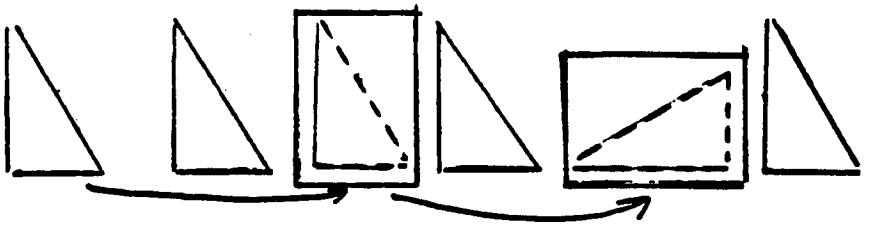
Congruence/Transformation Tasks

Static Triangle and Static Disc. For both of these tasks the pairs of figures were embedded like puzzle pieces in a rectangular piece of foamboard. The standard figure was fixed into the board, whereas the test figure could be removed and manipulated. The two tasks differed as follows.

1) The Static Triangle task (Fig. 2) comprised eleven

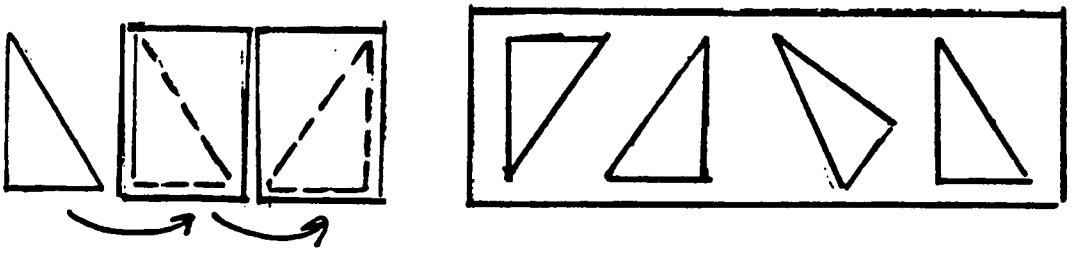
Recall

e.g. - 270°
rotation



Recognition

e.g. flip



Choice Triangles

Fig. 1 - Triangle transformation task: Recall and recognition conditions.

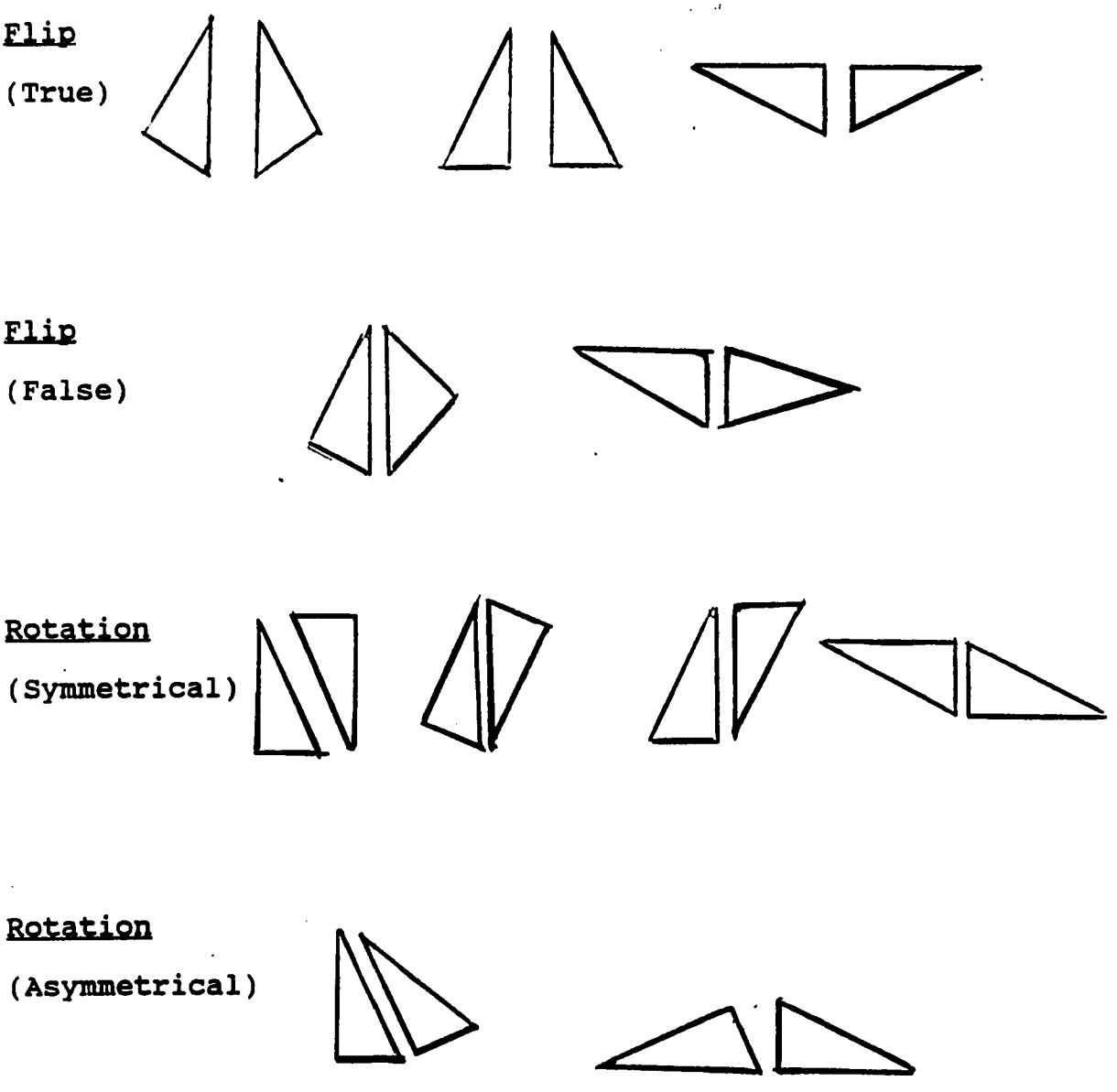


Fig. 2 - Paired configurations for Static Triangle Task.

sets of 2 triangles, 9 sets of which are congruent and 2 of which are noncongruent. All triangle sets contained at least one right triangle and the size of these triangles were either 3.5 in. x 4.5 in. x 5.7 in. or 3 in. x 4 in. x 5 in. The foamboard rectangle containing the triangle pairs was 12 in. x 8 in.

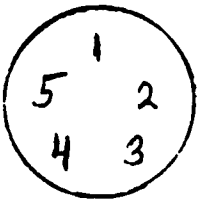
2) The Static Disc task (Fig. 3) consisted of seven sets of two 4-inch discs divided into 5 equal quadrants and embedded in a 12 in. x 6 in. piece of foamboard. Each quadrant contained a different textured material for the blind children and a different color for the sighted children. The materials differed for blind and sighted children in order to appeal maximally to the dominant sense modality which they used to differentiate the internal parts of the stimulus. The disc was the same on both sides. Four sets were congruent and three sets were noncongruent.

Procedure

Pretest.

The pretest which preceded the administration of the triangle congruency task was designed to ensure that the child understood the concept of congruence in respect to size and shape. This pretest was necessary since all tasks assumed that the child understood the basic congruence question asked about the various figures that differed by a transformation. In the

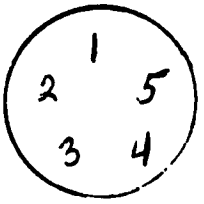
Standard Figure:

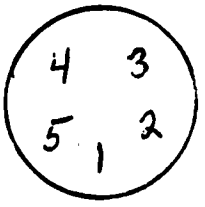


Test Figures:

Flip

Vertical

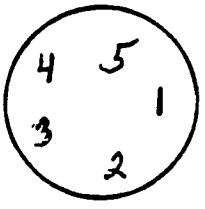


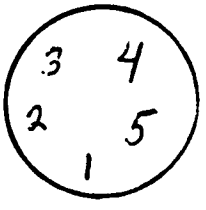


Horizontal

Rotation

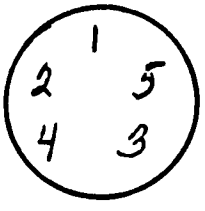
90°

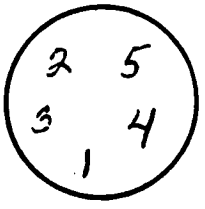




180°

Noncongruent





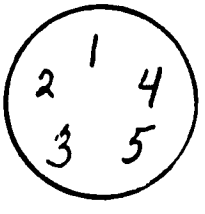


Fig. 3 - Paired configurations for Static Disc Task.

pretest the child was given some "play-doh" and a cookie cutter in the form of an equilateral triangle. The experimenter first demonstrated how the cookie cutter worked. Then the child was allowed to make his own triangular "cookies" with the cookie cutter. The experimenter then pointed out that all the resulting triangles were the same and asked why this was so. If the child had difficulty with this question, it was explained that the triangles were the same "because they were cut from the same cookie cutter." The youngest sighted children (5- to 7-year-olds) and all of the blind children were then presented with a smaller equilateral triangle cookie cutter and a "cookie" was cut out from the play-doh. The children were asked if this cookie was the same as the other cookie and why. None of the children responded yes and most gave a response based on size. If no reason was given, it was pointed out that these cookies were made from a different--smaller--cookie cutter. The youngest blind children (5- to 9-year-olds) were further presented with three toothbrushes, two of which were the same, and asked to find the toothbrushes which were exactly the same. All of the children could do this task.

Nonvisible Transformation Tasks

Triangle Transformation Task. In both the recall and recognition conditions, two model triangles were placed in the same orientation with the assertion that they were the same. The experimenter then slipped an opaque envelope (differing for high & low cue groups) over one of the triangles and

performed one of four transformations: a flip, a 90°c rotation, a 90°cc rotation and a 270°c rotation (Fig. 1, p. 58). In the recall condition, after the experimenter (alone for the sighted or with the blind child) performed each transformation, the child was requested to do the same with the model triangle, "so that it will look the way the triangle hidden in the envelope looks now." The recognition condition differed from the recall condition in that, after the triangle was transformed in the envelope, the child was asked to select from among four congruent triangles mounted in different orientations on a board, the one which "looks the same as the triangle hidden in the envelope looks now."

Familiar Objects Tasks. There were two conditions of cue for sighted children only. In the high cue group, children had vision whereas in the low cue group the children were blindfolded. Blind children, by definition, were under low cue conditions in both groups.

There were also two transformation conditions: rotations and flips. In the rotations condition there were six transformations; the three sets of objects (the key was eliminated) were each rotated 90° and 270°. Within the flip condition there were eight transformations. The four sets of objects were each flipped over the center vertical twice, once with the object(s) in the vertical orientation and again with the object(s) in the horizontal orientation.

In both transformations conditions the child was shown the box with the object(s) in it, and asked to duplicate the

configuration using identical objects in a box provided. The objects were then removed from this box and put aside. The first box was then covered (and for the sighted-high cue group placed in a square vinyl "envelope" to eliminate visual cues from the box) and one of the above transformations was performed on the box containing the object(s). The child was told to pretend that "you have X-ray vision and can see through the box" (sighted) or that "you can put your hands right through the box" (blind) and then to place his objects in his box so that they would "look (or feel) the same as the objects in the box do now." The child was also asked how he knew where the objects were located and responses were recorded.

Congruency/Transformation Tasks

Static Triangle and Static Disc Tasks. For each set of tasks, the child was shown the sets in random order and asked to judge congruence by visual or tactual inspection alone giving the reason for his judgement. The verbal protocol was the same for each child. The experimenter asked the following questions. "Are these two triangles (circles) the same?" "What is it about these two triangles (circles) that makes you think that they're the same (different)?" "Anything else?"

The sets chosen as congruent were then given to children and they were asked how they could "make them look exactly the same" on both sides of the board. The experimenter, using a different congruent set of triangles or discs, then showed the child that when two things are the same they will fit on top

of each other, so that they match. With the discs it was pointed out (not in order) that the sections matched (e.g., red on top of red). Lastly, subjects were asked to actually manipulate the task figure in such a way so that it resulted in the two figures being "the same".

Scoring

The method of scoring each task will be presented in the results section pertaining to that task.

Statistical & Percentage Analysis

Throughout the results section, two types of comparisons were made--statistical comparisons which were either significant or nonsignificant and qualitative comparisons based on percentage data. The latter comparisons were nonsignificant. We made qualitative percentage comparisons when statistical comparisons were nonsignificant but percentage data showed trends in a direction of interest. Percentage comparisons where also made where statistical (parametric and nonparametric) comparisons could not be made because of the low numbers of responses in each cell or because of insufficient range in the scores.

Statistical comparisons for cue groups, sightedness and age were made using MANOVAS whereas ANOVAS were used when simple comparisons for sight and age were done. MANOVA repeated measures were used for comparing a group's performance across tasks. Post hoc analyses were done using the Neuman Kuells Procedure and all significant comparisons

from these analyses will be reported at p = .05. If statistical comparisons were not possible and percentage comparisons were done instead, the research design utilized was labeled as an ANOVA or MANOVA type design.

When using percentage data, the average percent of correct response per blind or sighted group is calculated as an average of the percent of correct responses in each age group. This is done to compensate for the uneven number of subjects in each age group in the samples of blind children. Further, when reporting data, results will generally be presented first for the sighted and then for the blind groups as the sighted data are usually more regular and serve as a point of comparison. For this same reason, when discussing gender differences, males' responses will precede females' responses.

Results

In order to clearly distinguish between the significant and nonsignificant results, we will begin this section by summarizing the significant and nonsignificant (percentage data) findings. This summary will be followed by an extended analysis of the results by task where the findings will be presented as being either statistical (significant or nonsignificant) or qualitative (nonsignificant).

Statistically significant differences. Differences were found in performance by sightedness, gender, age group and task. Regarding sightedness, blind/sighted differences

favoring the sighted were found in two areas as predicted. One was in the recognition condition of the Triangle Transformation task ($F [1,63] = 7.51$ $p < .01$). The second area of difference (sighted > blind) occurred in the flip condition of the Static Triangle Task (imagination: $F [1,46] = 17.47$ $p < .001$; execution: $F [1,46] = 15.54$ $p < .001$).

Concerning gender, as predicted, differences favoring males were found in the rotation tasks of the Triangle Transformation task (recall condition only) and the Familiar Objects task. In the Triangle Transformation task these differences were seen only in the sighted group. The 8- to 10-year-old sighted group showed gender differences under high cue (rectangular envelope) conditions ($F [2,17] = 4.33$ $p < .05$). However, overall gender differences were found in the sighted low cue (square envelope) condition of this task ($F [1,23] = 7.11$ $p < .05$) as well as an interactional affect ($F [3,23] = 3.85$ $p < .05$) indicating strong differences favoring males in the 14- to 16-year-old group. In the Familiar Objects task no gender differences were seen in the high cue condition (sighted only - cues were provided by clips). However, gender differences were seen in both the low cue (no clips - blindfolded) sighted group and the combined low cue (no clips, no vision) blind groups. For the sighted group this difference only occurs in the 270° rotations ($F [1,17] = 4.50$ $p < .05$) whereas for the blind group this difference occurs overall ($F [1,27] = 10.58$ $p < .01$).

Age differences were seen in the Triangle Transformation

task recall condition (F [2,63] = 30.15 p <.01) and recognition condition (F [2,63] = 11.54 p <.01). In the recall condition each older age group did better than their younger counterparts with 11 - 13 > 8 - 10 > 5 - 7 year old age groups (p <.05). Eight- to 13-year-olds do better than 5 - 7 year olds in the recognition condition (p <.05) of this task.

Significant differences due to task variation also occurred. Both sighted and blind were affected by rotational extent under low cue conditions of the Familiar Objects tasks such that, as predicted, 90° > 270° (sighted: F [1,17] = 37.55 p <.001; blind: F [1,27] = 14.12 p <.01). Again as predicted, the sighted (but not the blind) do better in the recognition than in the recall condition of the Triangle Transformation task (high cue: F [1,17] = 8.82 p <.01; low cue: F [1,17] = 4.53 p <.05).

Nonsignificant differences. As noted above these results were obtained from percentage data only. Statements here are tentative and need further verification. These nonsignificant results both support and extend the above findings. Like the above findings, differences were found in the areas of sightedness, gender, age and task variation. In the area of sightedness, blind/sighted differences in cue use seemed to occur in the 5- to 10-year-age group. When cues were reduced the younger sighted seemed to be more affected than their blind cohorts in that they appeared to make errors which resulted in lower scores in transformational performance. These errors often made use of alternate cues.

Additional qualitative gender differences were found in the Triangle Transformation task and the Static Triangle task. In the rotation tasks of the Triangle Transformation task recall, under both high and low cue conditions, the performance of blind boys resembled that of sighted boys and tended to be better than that of blind girls. In the rotation tasks of the Static Triangle task, sighted males and females showed the same age-related sequence of strategies but males tended to exhibit these strategies earlier and showed asymptote performance earlier than females. Males also did somewhat better than females on the more difficult asymmetrical rotations.

Several age differences were found which interacted in some instances with cue, gender and sightedness. One, when high and low cue conditions of the Triangle Transformation and Familiar Objects tasks were compared for the more difficult rotations, low cue conditions seemed to result in a lesser performance in the 11- to 13-year-old blind and sighted groups. In the Triangle Transformation task only males did well here (low cues) at 14 years of age whereas males and sighted females did well under low cues at 14 years of age in the Familiar Objects task. Secondly, flip and rotational transformations tended to be differentiated at approximately 14 years of age for the sighted and 17 years of age for the blind (Static Triangle task). Finally, as predicted, Triangle Transformation recognition scores tended to be better than recall scores only in the 5- to 10-year-old age group for the

sighted.

There were also several task differences. Regarding differences due to transformational extent, it appeared from data in the Triangle Transformation recall task that transformations of small extent (flip, 90°) were generally easier than those of large extent (270°). This is in accord with the significant findings from the Familiar Objects task. Concerning the relative ease of familiar versus abstract arrays, it appeared that only females (blind and sight) were positively affected by using familiar arrays. The effect of the structure of the array (externally bounded triangles versus internally organized discs) on transformational knowledge was also examined. The transformations intervening between pairs of triangle tended to be seen as flips and those between pairs of discs tended to be seen as rotations prior to the age when these transformations were differentiated. Regarding cue conditions per se, as noted above, low cue conditions tended to results in lesser scores in the 11- to 13-year-old group and lesser scores overall for females.

These results significant and nonsignificant -- will now be examined within the realm of the tasks to which they belong.

Nonvisible Transformation Tasks.

Task 1: Triangle Transformation Task

Scoring. Subjects were scored for performance and for strategies. Two criteria were used to determine overall group

performance: total percentage of correct responses (full transformation and correct end state) and the age at which 50% or more of the responses were correct (50% criterion). Strategies were classified according to the descriptive criteria given in Table 9 in the strategy section (pp. 98-99). As noted above, research designs for nonstatistical analyses will be identified as ANOVA or MANOVA type designs.

All results will refer to the 5- to 13-year-old age group unless otherwise indicated. In the text below we will examine performance (A) and strategy (B) differences first for conditions of sight and then for conditions of gender within and across conditions of sight.

Sighted-Blind Differences. (A) Performance. Within each condition of recall (1) and recognition (2), as defined in the methods section, we examined the effects of varying cues (high cue versus low cue) on sighted and blind children's ability to represent transformations using both statistical and qualitative analyses. For each condition, we first looked at children's overall knowledge of transformations and then examined their ability to represent transformations of differing types (flips versus rotations), rotational extents (90° versus 270°) and rotational direction (90° clockwise [90°c] versus 90° counterclockwise [90°cc]). Next we compared response patterns in the recognition and recall tasks (3) under both high and low cue conditions. Because of a discrepancy between rotational performances on 90°c/recall and 90°c/recognition we then reanalyzed these data to clarify the

effect of extent on rotational representation. We then summarized the results of the performance data (4).

1. Recall. Regarding cue conditions, we predicted that the sighted would do better than the blind under high cue (rectangular envelope) conditions but that under low cue (square envelope) conditions, their performances would be more equal. Although we predicted that, in general, the high cue groups would do better than the low cue groups, we also predicted that the resulting sighted/blind equality in the low cue group would be due to a sharper difference between high and low cue scores for the sighted than for the blind group. This difference would be seen particularly in the 8- to 10-year-old sighted group who would be most affected by low external cues. In order to statistically test this hypothesis a MANOVA with three between subjects factors of cue (2 levels), sight (2 levels) and age (3 levels) was performed.

Overall, no statistically significant differences were found for either conditions of cue (high [rectangular envelope] versus low [square envelope]) or sightedness (sighted versus blind) but there was a main effect for age ($F[2,52] = 30.15$ $p < .01$). Using the Neuman Kuell's procedure, age differences were seen such that each of the older age groups does better ($p < .05$) than the younger age groups (11 to 13 > 8 to 10 > 5 to 7 years) with the exception of the blind-low cue group. Here, the older blind-low cue groups (8 to 13 years) did better than the 5- to 7-year-old group ($p <$

.05)

However, when we examined this same data qualitatively (nonstatistically) for the percent of correct responses (Tables 4 [high cue] and 5 [low cue]) per group (age and sight) for the combined rotations and flip (R_T + F) or for the combined rotations alone (R_C), we saw <u>trends</u> in the hypothesized direction (i.e., sighted high cue > blind high cue = sighted low cue = blind low cue). This trend is stronger for the combined rotations (R_C) than for the rotations and flips (R_C + F). In the combined rotations (R_C) the sighted high cue group (Table 4) did nonsignificantly better than the remaining groups (Tables 4 & 5: sighted- high cue = 41%, sighted-low cue = 26%; blind-low cue = 24%, blind-high cue = 28%). As a result, in accord with our predictions, but not statistically significant, it appears, at this point, that the sighted did somewhat better than the blind in high cue conditions. In low cue conditions, sighted and blind children's performances were more nearly equal.

The hypothesized disparity in 8- to 10-year-old sighted children's correct responses due to low cues did not occur. However, a nonsignificant difference in correct responses instead occurred in the 11- to 13-year-old group (high cue - 83% versus low cue - 50%). Moreover, it occurred here with blind subjects as well (high cue - 60% versus low cue - 27%). These results suggest that the use of cues by sighted children may convey some advantage, but that both blind and sighted children rely strongly on cues in the 11- to 13-year-old

Table 4

Triangle Transformation Task - Recall Condition: Correct Responses under High Cue Conditions as a Function of Sightedness, Transformation and Age (in years) Group (in percentages)

		Flip(F)	Rotations(R)			$R_{Total(c)}$[a]	R_c+F[b]
Age	n		90°cc	90°c	270°c		
				Sighted			
5-7	6	17	0	0	17	6	8
8-10	6	67	50	17	33	33	42
11-13	6	67	100	67	83	83	79
5-13[c]	18	50	50	28	44	41	43
				Blind			
5-7	4	0	0	0	0	0	0
8-10	6	67	0	17	17	11	25
11-13	5	100	60	20	100	60	70
14-16	3	67	33	33	67	44	50
5-13[c]	15	56	20	12	39	24	33
5-16[c]	18	58	23	18	46	30	40

[a]Combined rotations. [b]Combined rotations and flips. [c]Mean percentage of correct responses per group within given age range.

Table 5

Triangle Transformation Task - Recall Condition: Correct Responses under Low Cue Conditions as a Function of Sightedness, Transformation and Age (in years) Group (in percentages)

		Flip(F)	Rotations(R)			$R_{Total(c)}$[a]	R_c+F[b]
Age	n		90°cc	90°c	270°c		
			Sighted				
5-7	6	17	17	0	0	6	8
8-10	6	50	67	0	0	22	29
11-13	6	100	83	33	33	50	62
14-16	6	100	83	33	50	56	67
5-13[c]	18	56	56	11	11	26	34
5-16[c]	24	67	63	17	21	33	42
			Blind				
5-7	3	0	67	0	0	22	17
8-10	5	60	60	20	20	33	40
11-13	5	80	60	20	0	27	40
14-16	10	70	70	30	60	53	58
17-19	10	40	50	0	0	17	23
5-13[c]	13	47	62	13	7	27	32
5-16[c]	23	53	64	18	20	35	39

[a]Combined rotations. [b]Combined rotations and flips. [c]Mean percentage of correct responses per group within given age range.

period.

We also qualitatively examined children's performance on individual transformations. When comparing data for individual transformations (flips, rotations, flips and rotations), the range in scoring precluded using statistical analyses. These performances can again be seen on Tables 4 (high cue) and 5 (low cue) where percentage data for individual transformations are given by sight and by age group. Additionally, Figure 4 shows the predicted and actual patterns of performance on individual transformations within each group (sight/cue). Figure 5 depicts the ages at which 50% of the responses are correct for each transformation within each group (sight/cue).

For the flip transformation, we predicted that the sighted, having had more experience with seeing "opposite" end-states emerge from these transformations, would do better than the blind on this task. Contrary to expectations, sighted and blind children did equally well on flip transformations and appeared to be unaffected by cue conditions (average = 52% correct). Across conditions of set and sightedness, using the 50% criterion, the flip seemed to appear early (5 to 10 years old).

Regarding rotations, we predicted that different rotational relationships would emerge under different conditions of cue and sightedness. In the high cue (rectangular envelope) condition, we expected only the blind to be affected by rotational extent such that, for the blind, $90° > 270°$ but, for the sighted, $90° = 270°$. However, with

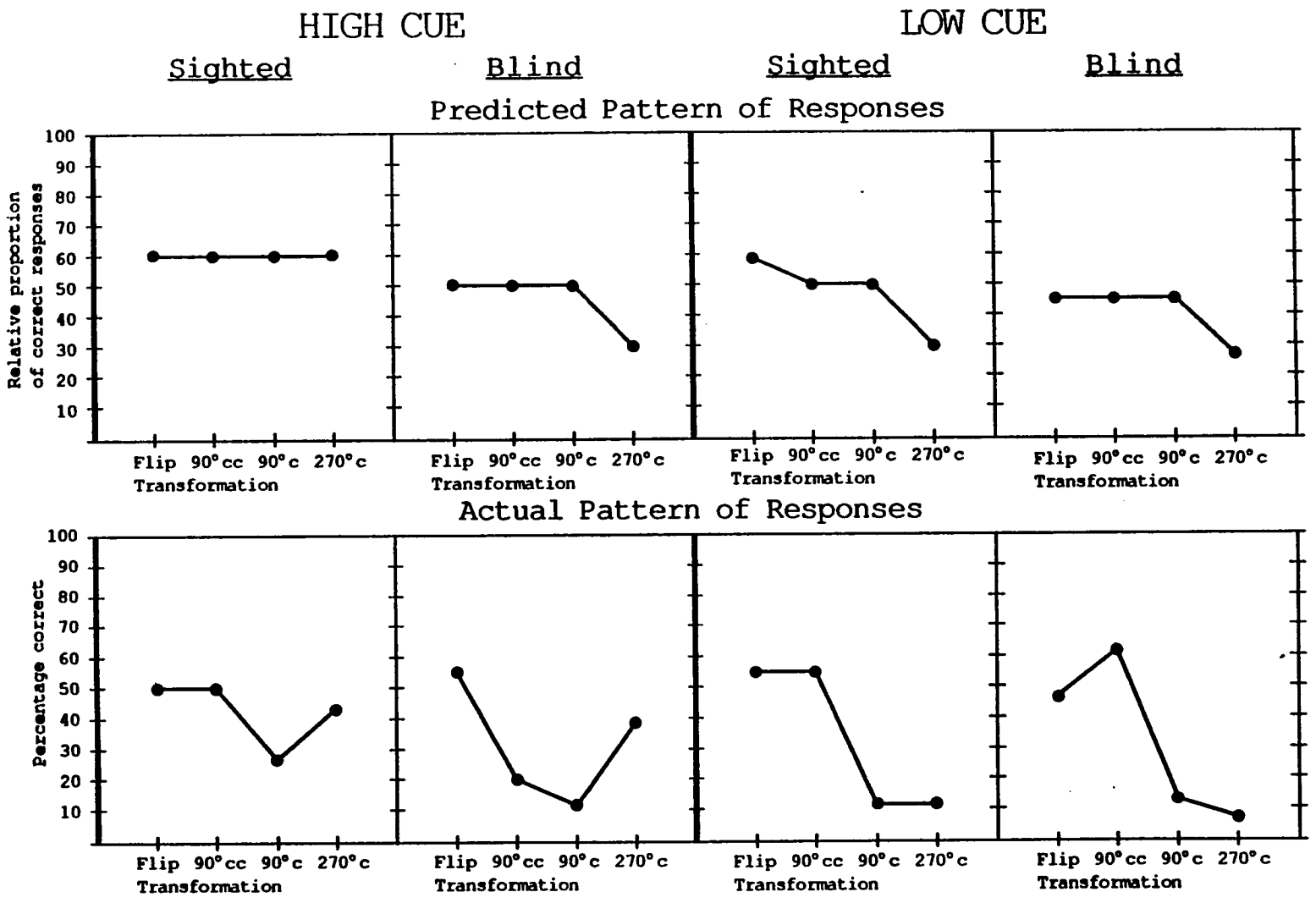


Fig 4. Triangle Transformation Task-Recall: Predicted and actual patterns of performance on individual transformations for each 5 to 13 year old group by sight and cue condition.

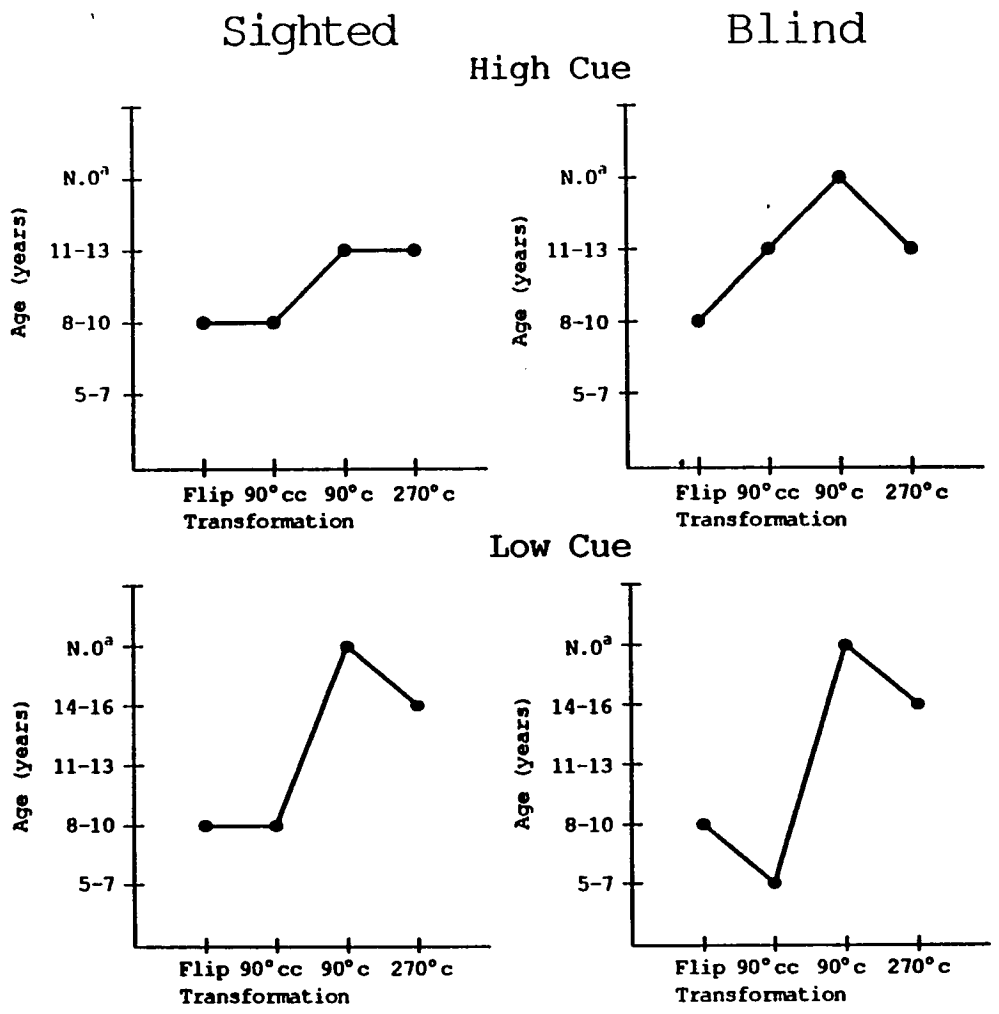


Fig 5. Triangle Transformation Task-Recall: The age groups in which 50% of the responses were correct on each transformation for each group by sight and cue condition.
[a]Not observed within the given age range.

reduced cues (square envelope), we expected the sighted and blind performance to be equal so that both groups would find 270° rotations more difficult than 90° rotations.

Our hypotheses were inconsistently supported by the percentage data (nonsignificant) in the high cue groups (Table 4). For the blind group, no 90° rotation (90°c [clockwise] = 12%, 90°cc [counterclockwise] = 20%) was easier than the 270°c (39%). In the sighted group, only 90°cc (50%) was equal to 270°c (44%) and, unpredictably, both of these rotations seemed to be easier than 90°c (28%). In the low cue groups (Table 5) our overall and specific predictions fared better. Sighted and blind performances on 90°cc were good and both did poorly on 90°c and 270°c so that, for all rotations, as predicted, sighted and blind children's performances seemed to be remarkably similar in both the pattern and level of their response. Both appeared to find 90°cc (sighted = 56%, blind = 62%) easier than 270°c (sighted = 11%, blind = 7%). However, against our prediction, 90°c (sighted = 11%, blind = 13%) was seemed to be as difficult as 270°c for both groups. This discrepancy in response levels between 90°c and 90°cc will be explored further below.

Again, using qualitative analyses (nonsignificant), we compared performance on individual transformations for interactive effects between age and cuing conditions (Tables 4 and 5). As noted above, 11- to 13-year-old sighted and blind subjects in the high cue groups did nonsignificantly better than their counterparts in the low cue group (sighted: 83%

versus 50%, blind: 60% versus 27%). Examining individual transformational performance, this discrepancy in performance appeared to be due to a lesser performance in the low cue condition for 270°c (sighted: 83% versus 50%, blind: 100% versus 0%) and for 90°c (sighted 67% versus 33%)--both blind groups are low here (20%). Additionally, these same difficult rotations appear, if at all, three years later (11 versus 14 years) in the low cue condition. (See section on gender differences below.)

Regarding the general age of achievement for individual transformations (Fig. 5), we examined these transformations qualitatively using the 50% criterion (50% or more of the responses are correct). The 90°cc rotation, like the flip, generally appeared early (5-10 years), and was not detrimentally affected by low cues. In contrast, under high cue conditions, 90°c and 270°c appeared later (11 to 13 years), if at all, and tended to be affected negatively by low cues. Correct responses for the latter rotations under low cues, as noted above, were lower and generally appeared later.

It appears from the above data that there is a statistically nonsignificant trend indicating that sighted and blind children's ability to mentally rotate stimuli depends on age, rotational extent, cues and, perhaps, varying task demands (90°c versus 90°cc). The ability to do simple 90° rotations seemed to appear earlier and to be generally easier than 270° rotations and more complex rotations of small extent.

Regarding the relationship between flips and rotations we predicted that a loss of cues would affect the sighted group more strongly on rotations than flips. Thus, in low cue conditions, flips would be easier than rotations. Comparing qualitative percentage scores only, this seemed to occur as predicted (sighted-high cue: flip = 50%, rotations = 41%; sighted-low cue: flip = 56%, rotations = 26%). Contrary to expectations, both blind groups also did well in the flips (average = 51%) and as expected, poorly on rotations (average = 26%). This resulted in the sighted group, sans cues, once again seeming to perform no differently than the blind groups with flips easier than rotations. However, as noted above, when we examined the data further, we found that for most groups the flip was more nearly equal to the simpler 90°cc rotations and appeared to be easier than the more difficult 90°c and 270°c rotations.

In summary, the only statistically significant result for the Triangle Transformation task thus far occurred for the combined transformations in the recall condition. Here, statistically significant differences were found only for age. However, making qualitative comparisons using percentage data (nonsignificant results), some trends are indicated. For one, the sighted children's performance appeared to be somewhat less under low cues as predicted. However, the blind children's performance was also somewhat less. For both, this lower performance seemed to occur mostly in those rotations which appeared after 11 years--270°c and, for the sighted,

90°c. These fluctuations in performance resulted in the sighted and blind showing apparently equal levels and patterns of performance under low cue conditions such that flip = 90°cc > 90°c and 270°c.

Contrary to prediction, qualitative analysis also indicated that the flip may be an equally easy transformation for the blind and the sighted. Regarding the effect of extent on rotations, varying cue conditions did not seem to affect sighted/blind performance in the high cue group as expected. However, it appears that, under low cue conditions the simpler 90°cc (but not 90°c) was nonsignificantly easier than 270°c for both groups as predicted. The discrepancy in performance between 90° c and 90°cc may be attributed to differences in task demands which we will discuss below.

2. Recognition. As in the recall condition, we predicted that there would be a lower performance under low cue conditions than under high cue conditions for sighted and blind groups, but that there would be a greater discrepancy in performance due to cue condition for sighted groups. However, unlike the recall condition, we now expected the sighted to do significantly better than the blind in both cue conditions given their greater experience with observing end-states of transformations. We tested our predictions using a MANOVA design with three between subject factors of cue (2 levels), sight (2 levels) and age (3 levels). As in the recall condition, we also analyzed our results for nonsignificant

differences using percentage data alone. This was done, again, because the nature of the data did not always allow for statistical analysis. Tables 6 and 7 show mean percentage responses by sight and age group for high cue (6) and low cue (7) groups and for individual as well as combined rotations.

Contrary to prediction we found no statistically significant difference in performance between high and low cue conditions for sighted or blind subjects. However, statistical data show, as predicted, that the sighted did better than the blind in the combined transformations ($F\ [1,63] = 7.51$, $p < .01$). Statistical differences could also be seen between age groups ($F\ [2,52] = 11.54$ $p < .01$), with ages 8 to 13 years better than 5 to 7 years old ($p < .05$). Using qualitative data, certain trends were seen which were not seen in the statistical data. Data showing the percent of correct responses per group again suggested that there was an tendency, as in the recall condition, for the sighted more than the blind groups to be somewhat more affected by fewer cues (combined transformations [R_c + F]: sighted-high cue = 67%, sighted-low cue = 50%; blind-high cue = 38%, blind-low cue = 42%). The percentage data also showed the overall sighted advantage over the blind in recognition scores to be somewhat less under low cue conditions (29% to 8%).

Individual transformations were also examined qualitatively using a MANOVA repeated measures type design with three between subject factors of sight (2 levels), cue (2 levels) and age group (3 levels) and one within subject factor

Table 6

Triangle Transformation Task - Recognition Condition: Correct Responses under High Cue Conditions as a Function of Sightedness, Transformation and Age (in years) Group (in percentages)

		Flip(F)	Rotations(R)			$R_{Total(c)}$[a]	R_c+F[b]
Age	n		90°cc	90°c	270°c		
				Sighted			
5-7	6	67	50	50	17	39	46
8-10	6	100	67	67	50	61	71
11-13	6	83	83	83	83	83	83
5-13[c]	18	83	67	67	50	61	67
				Blind			
5-7	4	0	25	0	0	8	7
8-10	6	50	83	67	0	50	50
11-13	5	60	80	40	60	60	60
14-16	3	67	100	100	67	88	83
5-13[c]		37	63	36	20	39	38
5-16[c]		44	72	52	32	52	50

[a]Combined rotations. [b]Combined rotations and flips. [c]Mean percentage of correct responses per group within given age range.

Table 7

Triangle Transformation Task - Recognition Condition: Correct Responses under Low Cue Conditions as a Function of Sightedness, Transformation and Age (in years) Group (in percentages)

		Flip(F)	Rotations(R)			$R_{Total(c)}$[a]	R_c+F[b]
Age	n		90°cc	90°c	270°c		
				Sighted			
5-7	6	17	50	50	0	33	29
8-10	6	83	67	67	33	56	62
11-13	6	100	50	33	50	44	58
14-16	6	100	100	67	50	72	79
5-13[c]	18	67	56	50	28	44	50
5-16[c]	24	75	67	54	33	51	57
				Blind			
5-7	3	33	0	67	0	22	25
8-10	5	60	40	60	0	33	40
11-13	5	60	80	80	20	60	60
14-16	10	60	70	60	40	57	58
17-19	10	60	90	70	50	67	65
5-13[c]	13	51	40	69	7	41	42
5-16[c]	23	53	48	65	15	48	50

[a]Combined rotations. [b]Combined rotations and flips. [c]Mean percentage of correct responses per group within given age range.

of task (4 levels). As noted above, the results concerning individual transformations were based only on percentage data due to insufficient variation in the measures. Thus the differences seen were not statistically significant. Tables 6 and 7 show percentage means for performance on individual rotations for high (6) and low (7) cue groups. Figure 6 shows, for each group (sight/cue) predicted and actual patterns of performance on individual transformations. Figure 7 illustrates the ages at which 50% of the responses were correct on each transformation for each of these same groups.

For the flip transformation, we again predicted that the flip would be generally easier for the sighted than for the blind. This prediction appeared to be supported by the percentage data (sighted-high cue = 83%, blind-high cue = 37%; sighted-low cue = 67%, blind-low cue = 51%). Again, the sighted/blind difference was less under low cue conditions. This in turn resulted in a different age pattern under different cue conditions. Using the 50% criterion (50% or more of the responses are correct), flip knowledge appeared in the 5- to 7-year-old group for the sighted-high cue but appeared later, in the 8- to 10-year-old group for the sighted-low cue, blind-high cue and blind-low cue (Fig. 7). Again, under low cue conditions, the sighted seemed to perform more like their blind counterparts. We will examine this sighted-high cue/sighted-low cue age difference again when we look at strategy data for the flip transformation.

For rotations, recognition data for all groups appeared

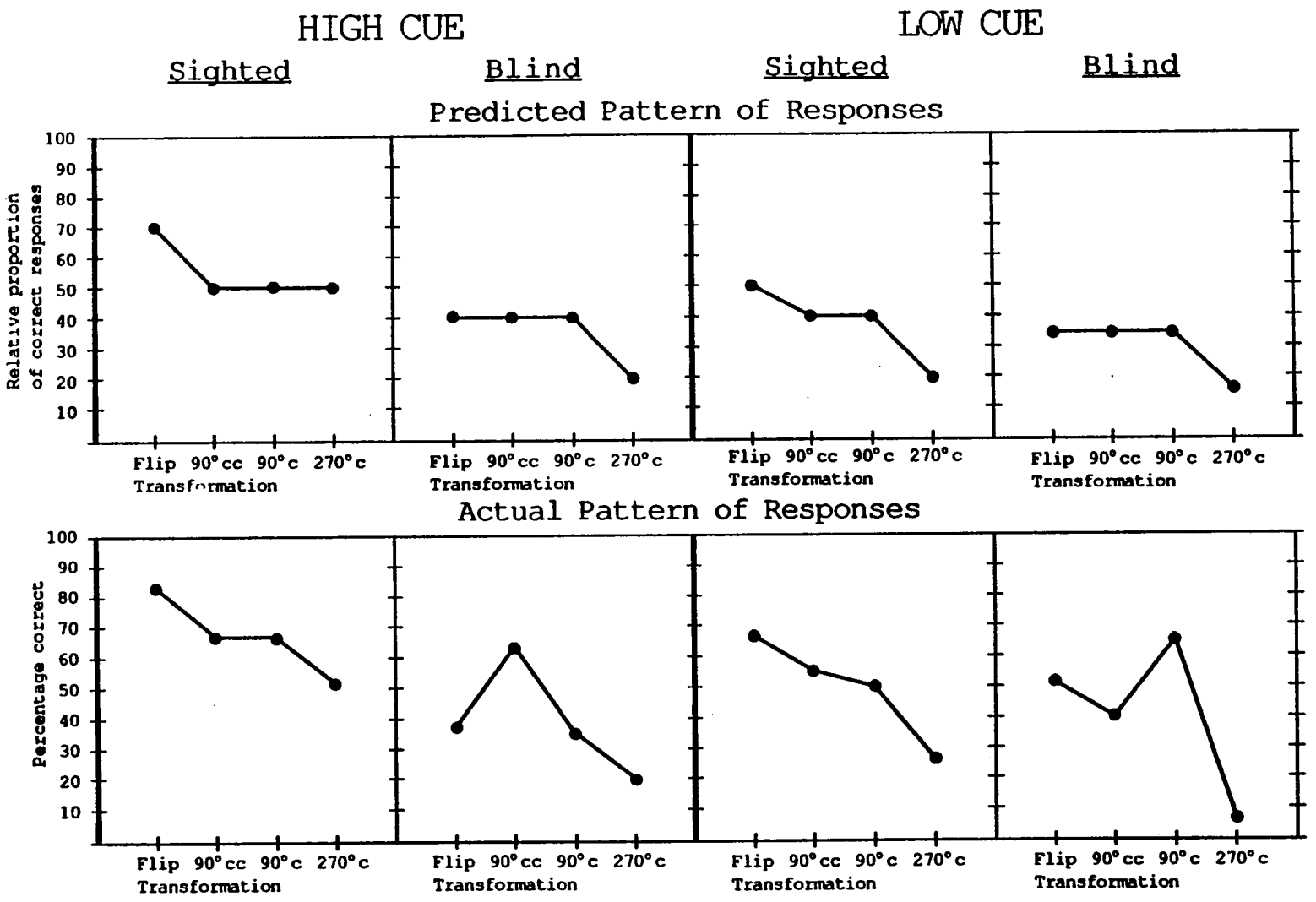


Fig 6. Triangle Transformation Task-Recognition: Predicted and actual patterns of performance on individual transformations for each 5 to 13 year old group by sight and cue condition.

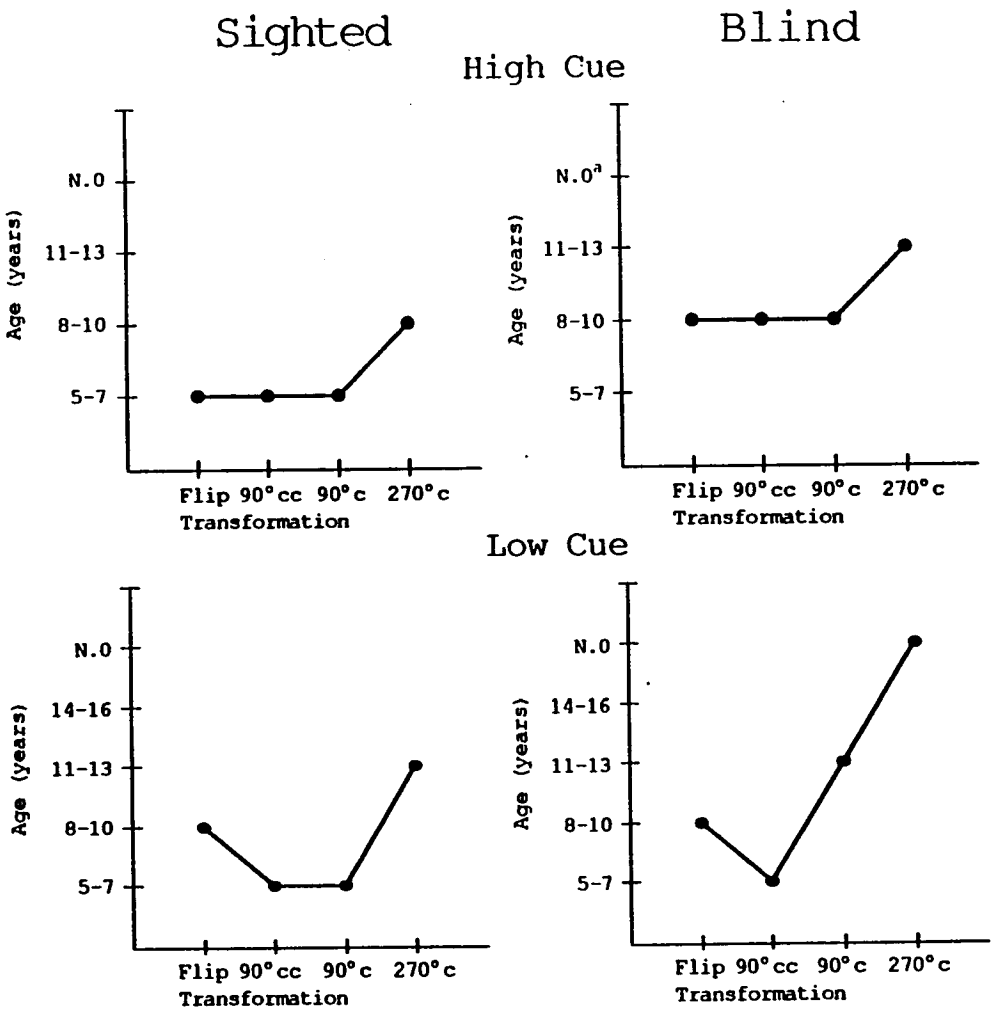


Fig 7. triangle Transformation Task-Recognition: The age groups in which 50% of the responses were correct on each transformation for each group by sight and cue condition.

to be in the direction predicted for blind and sighted-low cue performance on rotations (90° > 270°). These qualitative differences due to extent (90° versus 270°) were seen most clearly for the blind (average: 52% versus 13%) and the sighted-low cue (53% versus 28%) whereas these differences were somewhat less so for sighted-high cue (67% versus 50%). The blind group had more inconsistent response patterns within the 90° rotations, but in general, the relationship between 90° and 270° rotations (90° > 270°) held across conditions of sightedness and cue (Tables 6 and 7, Fig. 6). This pattern was confirmed using the 50% criterion (Fig. 7). Using this criterion, the 90° rotations appeared before 270° rotations in all groups. Additionally, comparing the age patterns of the individual transformations across sightedness and cue condition (Fig. 7), only the more difficult 270° rotation (which appears at a later age than the other transformations) seemed to be again, as in the recall task, negatively affected by low cue conditions. The 270° rotation appeared one (sighted-low cue) or two (blind-low cue) age groups later than it appeared for the high cue group (8 to 14 versus 11 to 19 years).

Regarding the relationship between <u>flips</u> and <u>rotations</u> we predicted that the flip would be easier than the rotations for the sighted but not the blind groups. Overall, using percentage data only, this appeared to be true (sighted: flip = 75%, rotation = 53%; blind: flip = 44%, rotation = 40%). However, across conditions of cue and sightedness, when we

examined the relationship between the flip and the individual rotations, we found results similar to those found in the recall condition (only 90°c differs). Using the 50% criterion for the percentage data, the flip, 90°cc and 90°c all seemed to be generally easier and appeared earlier (5- to 10-years) than 270°c (8- to 19-years).

To summarize the results from the recognition condition, as predicted, the sighted did significantly better than the blind in recognizing end-states of transformations but this sighted/blind difference was somewhat less apparent under low cue conditions. However, using nonsignificant percentage data, sighted and blind children appeared to be alike, in that the same order of transformational difficulty existed in recognizing end-states of transformations. For both, partial transformations (flip, 90°cc, 90°c) seemed to be easier and to appear more frequently in the younger groups than was the fuller transformation - 270°c. Further, as in the recall condition, the transformation which appeared later under high cue conditions (270°c) seemed to be most negatively affected by low cues.

3. Recall versus Recognition. We predicted that recognition would be easier than recall for all, but especially for the sighted group. We also posited that this difference would be seen primarily in the 5- to 10-year-old group where full Euclidean spatial knowledge does not generally manifest itself. In order to test differences

between recognition and recall we used a MANOVA repeated measures design with one between task variable (2 levels). Tables 4 to 7, as noted above, show percentage differences in recall (Tables 4 and 5) and in recognition (Tables 6 and 7) performance for conditions of sight, cue and age group. Fig. 8 compares recall and recognition performance on individual transformations for each group (sight/cue) of 5- to 10-year-olds.

Statistically, recognition was easier than recall for the sighted as predicted (sighted-high cue $F(1,17) = 8.82$ $p < .01$, sighted-low cue $F(1,17) = 4.53$ $p < .05$) but not for the blind. The remaining results, were based on percentage data and, thus, only show trends in certain directions. For one, this data showed the sighted recall/recognition difference to be considerable (average = 30% points) before 11 years of age but to be negligible after this age (Tables 4 to 7). As might be predicted from the recognition data seen above, this 5- to 10-year-old recall/recognition difference (Fig. 8) appeared to be related to a rise in the flip and 90° rotations (particularly 90°c) in the recognition condition of both high and low cue sighted groups (average: recall = 25%, recognition = 61%). The 270° rotation, which appeared at a later age, seemed to be relatively unaffected by recall/recognition demands in the 5- to 10-year-old age group (average: recall = 13%, recognition = 25%) or in the 11- to 13-year-old group (average: recall - 58%, recognition = 67%). For 5- to 10-year-old blind children, recognition also appeared to be generally

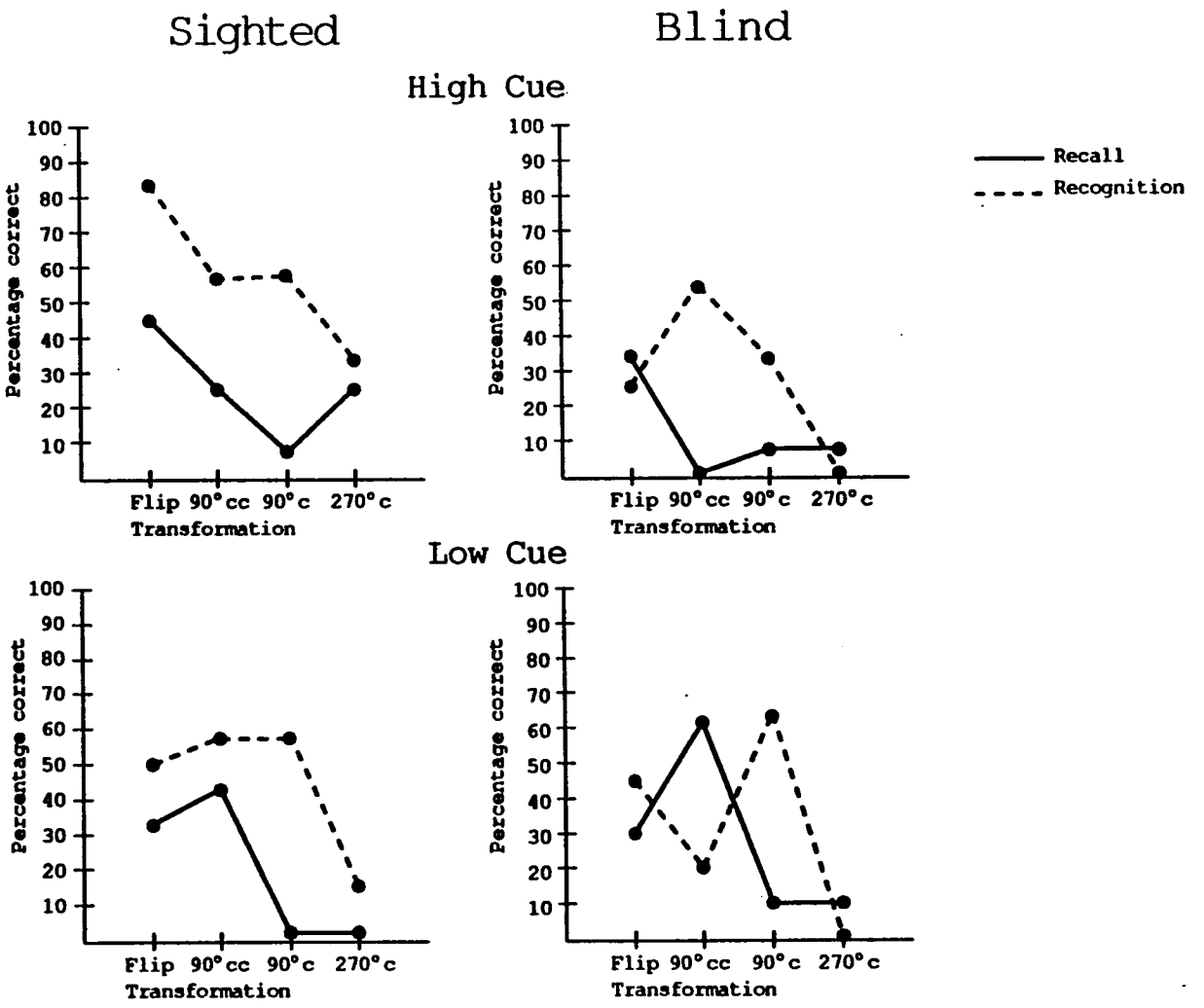
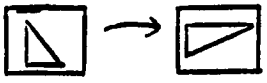
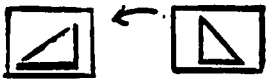


Fig 8. Comparison of recall and recognition responses (percentage correct) for individual rotations in each 5-to-10-year old group by sight and cue condition.

easier than recall but only on the 90° rotations and most consistently on 90°c (average 90°c and 90°cc: recall = 21%, recognition = 43%). For the blind groups neither the flip (63% versus 72%) nor 270° rotations (19% versus 0%) were affected positively by recognition conditions.

In order to reconcile the differences between the responses to 90°c/recall (difficult) and 90°c/recognition (easy) across sightedness and cue conditions we analyzed the data further for both sighted and blind groups using percentage means only (nonsignificant). We found that 90°c yielded high incidences of one error in the recall condition. For all rotations, in order for children to mentally rotate the triangle within the envelope with precision, they had to maintain the strict relationship between the sides of the envelope and the triangle as the two undergo rotation. This was particularly difficult for children to do in 90°c () as children appeared to have a general sense of the extent of the rotation (as also seen in 90°cc) but showed a strong inclination to align one of the longer sides of the triangle with the horizontal (). (Only the older sighted group in the high cue condition could overcome this inclination.) In the remaining rotations, these "partially correct" errors were low as, within a reasonable area of extent, one of the longer sides of the end-state triangle was correctly parallel to the horizontal (e.g., 90°cc: ).

We re-examined the data for 90°c responses and included

"partially correct" error responses in the correct response. We then compared these combined responses with children's correct recognition responses using percentage data. This comparison can be seen in Table 8. We found that 90°c/recall (correct + partially correct) more nearly seemed to approximate correct responses for 90°c/recognition and, like the latter, appeared earlier than 270°c. This suggested that the ability to mentally represent rotations of small extent appeared early. However, in replicating these transformations, children (particularly younger sighted children and most blind children) appear to be strongly inclined to align one of the longer sides with the horizontal axis. Even older sighted children were more vulnerable to this error under low cue conditions.

In summary, comparing the recall and recognition conditions, only the sighted did significantly better under conditions of recognition than recall. The percentage data suggest (nonsignificantly) that this difference occurred more so in the 5- to 10-year-old group as predicted. However, this 5- to 10-year-old difference represented an increase in performance only for partial (flips and 90° rotations) and not for full (270°c) transformations. Further, using percentage data blind children also appeared to do better on 90° rotations in the recognition condition, and both blind and sighted children seemed to show particularly large gains on 90°c/ recognition. Examining this 90°c rotation for errors in the recall condition, the percentage data suggested that the

Table 8

Triangle Transformation Task - 90°c Rotation: Comparison of Correct + Partially Correct Responses with Correct Recognition Responses as a Function of Sightedness, Cue Conditions and Age (in years) Group (in percentages)

Age		Responses			Responses	
(yrs)	n	Rcl(C+Cp)[a]	Rgn(C)[b]	n	Rcl(C+Cp)[a]	Rgn(C)[b]
			High Cue Condition			
		Sighted			Blind	
5-7	6	50	50	4	0	0
8-10	6	67	67	6	67	67
11-13	6	100	83	5	100	40
14-16				3	67	100
5-13[c]	18	72	67	15	56	36
5-16[c]				18	58	52
			Low Cue Condition			
		Sighted			Blind	
5-7	6	50	50	3	0	67
8-10	6	33	67	5	60	60
11-13	6	83	33	5	60	80
14-16	6	83	67	10	80	60
17-19				10	90	70
5-13[c]	18	56	50	13	40	69
5-16[c]	24	63	54	23	50	65

[a]Recall condition (correct + partially correct responses). [b]Recognition condition (correct response). [c]Mean percentage of responses per group within given age range.

general extent of the 90°c rotation could be represented early but that children are inclined to incorrectly align a longer side of the triangle with the horizontal axis.

4. Summary. An overview of the performance data (recall, recognition, recall/recognition) yields some statistically significant results. However, most of the results are nonsignificant (based on percentage data alone). These latter results indicate some trends for further study. Testing for statistically significant differences in the recall condition, no differences were found due to sightedness or cue conditions. For the recognition condition, significant differences were found due to sightedness but not cue condition with the sighted doing better than the blind. Comparing recall and recognition conditions, only the sighted did significantly better in the recognition condition. For both recall and recognition conditions significant age group differences were found with older children doing better than their younger counterparts.

Examining percentage data only (nonsignificant), trends have been found in both the recall and recognition condition which address the above findings and also explore other areas. The data from both conditions suggest that the sighted are somewhat more affected by low cues than the blind. When comparing performance under high and low cue conditions, the sighted showed lower percentage performance on recall and recognition tasks in the low cue group. However, it appears that, in reality, both blind and sighted children's

performance was negatively affected by low cues but only for those transformation tasks which showed success after 11 years of age (90°c, 270°c).

Under low cue conditions the performance of the sighted and the blind groups seem to become more alike both in pattern and level of response such that, in the recall condition, flip = 90°cc > 90°c and 270°c and, in the recognition condition, flip = 90°cc = 90°c > 270°. Examining the differential recall/recognition responses seen for 90°c, it appeared that 90°c/recall posed specific problems. Children could rotate the triangle an approximately correct number of degrees but were inclined to align a longer side with the horizontal axis. However, they could recognize the correct end-states of this rotation (90°c/recognition). This finding suggested that in general, simple flips and partial rotations were easier than full transformations.

Regarding the recognition condition per se, the sighted advantage seemed to be somewhat lessened under low cue conditions. We also examined the sighted subjects' recognition/recall differences (significant) using percentage data. This difference appeared to occur only in the 5- to 10-year-old sighted group as predicted, and only for partial transformations. However, in actuality, compared to the 90°/recall, both the sighted and the blind seemed to do better in the 90°/recognition overall and especially in the 90°c/recognition. Neither group does better on 270°c/recognition.

Sighted/Blind Differences. (B) Strategy. We examined children's strategy data, across conditions of sight and cue for the existence of the age-related strategy differences hypothesized above. (See Table 9 for strategy definitions.) We posited that early movement strategies would be replaced, at approximately 8 years old, by a generalized knowledge of space, aided by cues. At 11 years of age, knowledge of full Euclidean space would appear. Thus, Movement Generalized Space/Cues Euclidean space.

In order to examine this thesis we used only percentage data (nonsignificant) due to the limits imposed by our data (low numbers per cell, etc...) as discussed above. Thus, this entire section on strategies will only show trends in strategy deployment over age and will yield no significant results. The model which was used to examine our data was a MANOVA type design with three between subject factors of sight (2 levels), cue (2 levels) and age groups (3 to 5 levels). Using this model, we examined data from the rotations (1) in detail and we also briefly looked at those aspects of flip (2) strategies which bore on this issue.

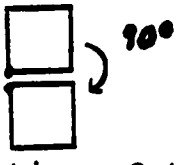
We also examined, using percentage data, Millar's thesis (3) that two factors, blind children's use of strong movement memory and sighted children's use of a visual regeneration strategy, were responsible for the differences that she found in sighted/blind performance on 270° rotations. In her study the resulting pattern for the sighted was 90° = 270°, and for the blind was 90° > 270°. Using an alternate method of

Table 9

Triangle Transformation Task--
Strategies Measures

Children's strategies in the recall condition were divided into six categories:

1. Refuse/No Change - Either the child refused to do the task or the child placed the triangle in its original position.
2. Inappropriate - The child inappropriately flipped and/or rotated the triangle--generally at random.
3. Movement - The child either over- or under-extended the rotational movement of the triangle.
4. Place - The child used cues from where the envelope was finally placed on the table to determine the end-state of the triangle. For example, the envelope in the 90°c rotation was rotated clockwise from its pivotal position in the lower left-hand corner. This results in the envelope going from the top to the bottom of the table.



Subjects interpreted this to be a 180° rotation of the triangle (up-down). Similarly, in a 270° rotation, the envelope goes from the top right- to the top left-hand corner of the table, and subjects saw this as a 360° rotation (up-down-up).

5. Partially Correct - The child was approximately correct but appeared to use cues from the end-state position of the envelope edge to determine the final state of the triangle. Thus, in a 90° rotation, the

envelope and triangle move from  to  .

Subjects using the edges of the envelope as a guide incorrectly saw the end-state of the triangle rotation as  . Similarly, the 270° rotation was seen as  .

6. Correct Transformation

Additionally:

a. Responses are described as "more spatially correct" to include both partially correct and correct responses.

b. Responses 2 to 4 can be either aligned or nonaligned with the perpendicular axes of either the envelope or table. The following responses were considered, respectively, aligned ( ) and nonaligned ().

evaluating children's ability or proclivity to use movement memory or other strategies we examined this thesis. To do this we used an ANOVA type model with two between subject variables of sight (2 levels) and cue (2 levels). Finally we summarized (4) our overall strategy findings.

1. Rotations.

We compared rotational strategy data only for the clockwise rotations (90°c and 270°c). This was done primarily because the 90°cc showed little strategy development. Prior to correct responses on 90°cc (which appeared early), children generally made movement responses. The two clockwise rotations which we examined were combined to give a general sense of blind/sighted differences. However, these same rotations were analyzed separately in the section dealing with gender differences. This was done to discern strategy differences (if any) due to rotational extent (90° versus 270°), which might interact with conditions of sight, gender and/or cue.

For the high cue groups, Table 10 presents percentage data showing strategy responses by conditions of sight and age group. Fig. 9 represents similar information for both high and low cue group in graphic form. We used both of the above to discern strategy patterns. In the sighted group, there appeared to be a general strategy pattern for the rotations. At first there was a strong movement (50%) response with some place (use cues from the table) and partially correct responses in this 5- to 7-year-old group. At 8 years, responses which were correct or partially correct (58%) were

Table 10

Triangle Transformation Task - Recall Condition: Strategy Patterns for Clockwise Rotations (90° + 270°) under High Cue Conditions as a Function of Sightedness and Age (in years) Group (in percentages)

		Strategies						
Age	n	R/NC[a]	I[a]	M[a]	P[a]	Cp[a]	C[a]	NA[a]
				Sighted				
5-7	6	0	0	50	17	25	8	33
8-10	6	0	0	33	8	33	25	33
11-13	6	0	0	0	0	25	75	0
5-13[b]	18	0	0	28	8	28	36	22
				Blind				
5-7	4	13	25	63	0	0	0	63
8-10	6	0	0	50	0	33	17	8
11-13	5	0	0	0	0	40	60	0
14-16	3	0	0	17	0	33	50	17
5-13[b]	15	4	8	38	0	25	26	24
5-16[b]	18	3	6	32	0	27	32	22

[a]Abbreviations are defined in Table 13. Briefly, they have the following connotation: R/NC - refuse/no change of position; I - inappropriate transformation; M - correct movement, inaccurate end state; P - triangle's end state is based on the end state of the envelope in relation to the table; Cp - partially correct; C - correct; NA - triangle is not aligned with the perpendicular axis. [b]Mean percentage of responses per group for the age range given.

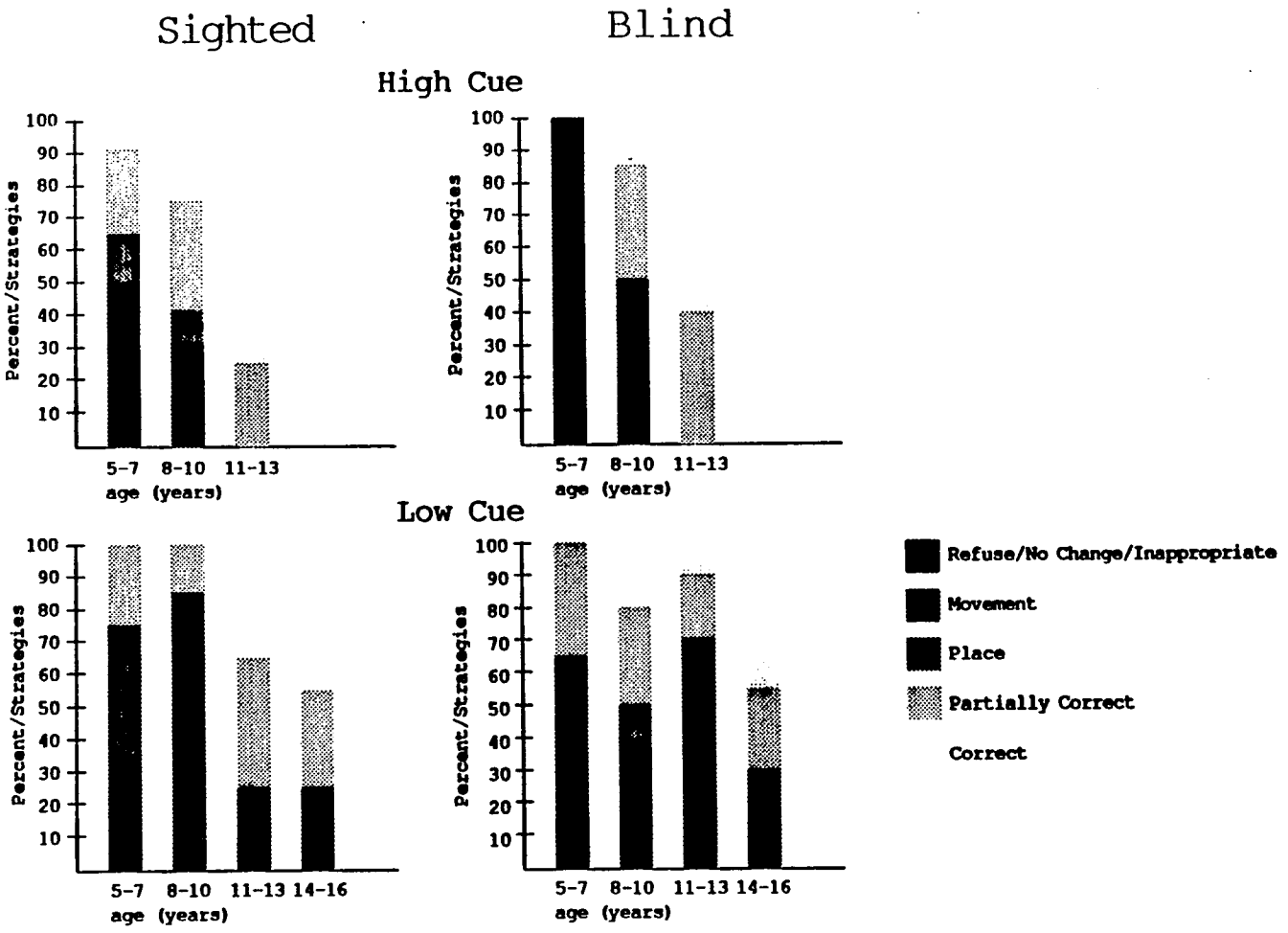


Fig 9. Triangle Transformation Task: Percentage of strategies seen in each age group for each condition of sightedness and cue.

seen. Strong correct responses appeared at 11 years of age. Responses which were not aligned with the perpendicular appeared in the younger (5-10) but not the older (11-13) age groups (33% versus 0%).

For the blind-high cue children (Table 10), the dominant early response was again one of movement (62.5%). The remaining responses were poor -- refuse, no change and inappropriate. In the middle years (8 to 10 years old) more spatially correct strategies (correct and partially correct = 50%) appeared but movement strategies were equally large (50%). Correct responses were seen in the older 11-to 13-year-old group (60%). Nonalignment responses were seen more frequently in the younger (5-10) than in the older (11-16) age groups (38% versus 8%).

Comparing the blind and sighted group, the patterns were similar. Strong movement responses were seen in the youngest years (5-7) and more spatially correct (partially correct and correct) responses were seen in the middle years (8-10). Correct responses seemed to occur more at 11 years. This latter appearance of correct responses appeared to coincide with a virtual disappearance of nonalignment responses. However, sighted/blind differences are also seen in most of the age groups. In the youngest group only sighted children showed evidence of using external cues (place + partially correct: 42% sighted; 0% blind). In the older groups, the blind showed a weaker correct performance than the sighted (83% sighted, 60% blind). This weaker correct response could

be attributed to poor performance by blind children on 90°c. This was noted in the performance section above and will be discussed in more detail below in the section on gender differences.

We used information from Table 11 and Fig. 9 to examine strategies used under low cue conditions. Analogous to the table for the high cue conditions, Table 11 presents strategy data in percentages by age group and condition of sight. Fig. 9 presents this information graphically. The sighted group (low cue) again showed age differences in strategies but this pattern deviated from the pattern seen in the high cue group. In comparison to the high cue group, the youngest sighted subjects in the low cue group showed less movement responses (25% versus 50%) and more place responses (50% versus 17%). Here sighted children used cues from where the envelope was placed on the table to deduce the end-state of the transformed triangle. This place response was the dominant strategy (58%) of the younger, 5- to 10-year-old sighted groups. More spatially correct strategies (correct + partially correct = 75%) appeared later than in the high cue sighted group, at 11 instead of 8 years of age and correct responses never became dominant (33% to 42%) in the older years as they did in the high cue group (75%). Nonalignment responses showed the same age pattern as was seen under high cue conditions and appeared in younger sighted children's responses more frequently (5-10 years = 25%, 11-16 years = 4%).

Blind children's strategies were also affected by low

Table 11

Triangle Transformation Task - Recall Condition: Strategy Patterns for Clockwise Rotations (90° + 270°) under Low Cue Conditions as a Function of Sightedness and Age (in years) Group (in percentages)

		Strategies						
Age	n	R/NC[a]	I[a]	M[a]	P[a]	Cp[a]	C[a]	NA[a]
				Sighted				
5-7	6	0	0	25	50	25	0	25
8-10	6	0	0	17	67	17	0	25
11-13	6	0	0	8	17	42	33	0
14-16	6	0	0	8	17	33	42	8
5-13[b]	18	0	0	17	44	28	11	17
5-16[b]	24	0	0	15	38	29	19	15
				Blind				
5-7	3	0	17	17	30	33	0	33
8-10	5	0	0	40	10	30	20	40
11-13	5	0	0	50	20	20	10	50
14-16	10	0	0	20	10	25	45	15
17-19	10	0	5	40	0	55	0	25
5-13[b]	13	0	6	36	20	28	10	41
5-16[b]	23	0	4	32	18	27	19	35

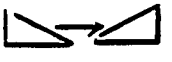
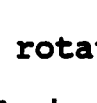
[a]Abbreviations of strategies defined in Table 13. Briefly, they have the following connotation: R/NC - refuse/no change of position; I - inappropriate transformation; M - correct movement, inaccurate end state; P - triangle's end state is based on the end state of the envelope in relation to the table; Cp - partially correct; C - correct; NA - triangle is not aligned with the perpendicular axis. [b]Mean percentage of responses per group for the age range given.

cues. In comparison to their cohorts under high cue conditions, they experienced, as did the sighted, a later appearance of more spatially correct (correct + partially correct) responses (11 versus 8 years of age) and a lower overall correct response. Their use of movement strategies was seen into at least the 13th year (8- to 13-year-olds = 45%) and correct responses do not appear in any strength until later, in the 14th year (45% C). Comparing blind children in the high and low cue conditions, the average percent of nonalignment responses per age group for 5- to 16-year-olds in the low cue group is greater by 13 percentage points and is distributed over a larger age range than seen in the low cue group.

Contrasting blind and sighted groups' reaction to low cues, it appears that both groups were affected adversely. For both, the ages differences in strategy (movement → more spatially correct → correct) seen under high cue conditions were not the same as those seen under conditions of low cues. Instead, the sighted under low cue conditions, relied on table cues in the younger years and only at 11 years of age did they show adequate use of more spatial strategies - 3 years later than was seen in high cue conditions. Correct responses were never dominant. The general pattern of blind children's strategies resembled the pattern seen in high cue conditions, but movement responses remained strong longer and correct responses did not appear with any strength until later, at 14 years of age. Nonalignment responses of sighted children were

unaffected by low cues whereas these same responses were somewhat greater in most age groups of blind children.

Rotational strategy comparison data will be considered again in the discussion of gender differences. In the gender context, more regularity in performance and strategy was evident.

2. Flip. In both the recall and recognition condition of the flip transformation, certain errors were seen which indicated verbal/spatial confusion on the part of younger subjects. Children seemed to translate the spatial "flip" into the verbal concept of "opposite." Thus, instead of flipping the triangle across the vertical axis (), children either flipped it down () or rotated it 180° (). Both of these responses resulted in an "opposite" but incorrect response.

This error was generally seen in the 5- to 7-year-old group. In the high cue group, the youngest blind children made this error with greater frequency than sighted children (sighted-high cue = 8.3%, blind-high cue = 25%). However, in the low cue condition, more instances of this error were seen in the sighted group (33%), although the blind group's response was similar to that of their high cue cohorts (17%). This increased verbal/spatial error in the sighted group (low cue) suggests that some younger sighted children, tend to use cues from the array to correctly execute some spatial tasks.

3. Millar's thesis. Before summing up sighted/blind differences in overall strategy, we will examine Millar's

thesis that different strategies of the sighted (visual regenerations) and the blind (movement memory) were responsible for the sighted/blind differences in rotational extent that she found (sighted: 90° = 270°; blind: 90° > 270°). Although we did not obtain this pattern as predicted in the high cue group, we nevertheless felt that it would be useful to examine our data for specific differences due to sightedness and rotational extent. Given Millar's hypothesis, we examined 5- to 13-year-old children's ability to attain an approximately correct (within 45°) rotational movement for 90° and 270° under both high and low cue conditions (Table 12). If Millar is correct, then the movement memory strategy used by the blind would make it more difficult for them to approximate 270° than 90° rotations. In contrast, a visual regeneration strategy would make it equally easy for sighted children to approximate 90° or 270° rotations. Cue conditions should affect neither group.

Against our prediction, the blind were equally adept at remembering both 90° and 270° approximate rotational movements under conditions of high and low cues. Low cues did affect blind children's overall performance slightly (63% versus 53%). The sighted behaved as predicted but only under high cue conditions (90° = 83%, 270° = 78%). Under low cue conditions there was a lower performance for both rotations but especially for 270° (90° = 56%, 270° = 28%). This 270° difference in performance due to cue conditions was particularly strong in the 5- to 10-year-old group where the

Table 12

Triangle Transformation Task - Recall Condition: Approximately Correct Responses by 5- to 13-year-olds as a Function of Rotational Extent, Sightedness and Cue Conditions (in percentages)

	High Cue		Low Cue	
Rotation	S[a] (n=18)	B[a] (n=15)	S[a] (n=18)	B[a] (n=13)
90°c	83	64	56	51
270°c	77	61	28	56

[a]S = sighted groups; B = blind groups.

performance under high cue = 67% and under low cue = 8%. In the 11- to 13-year-olds the difference in high/low cue performance is less (100% versus 67%).

Overall, our data suggested that blind children's difficulty with large rotations is not due to movement memory per se as they were equally adept at rotating arrays of small and large rotations into approximately correct end-states. It also suggested that younger sighted children's ability to do equally well on large and small rotations may be due to cue use and not to their ability to regenerate a visual image of the array as only under high cue conditions are they unaffected by rotational extent.

4. Summary. Regarding the strategy data, it should be understood that these results are not statistically significant and only indicate trends in performance. With this condition in mind, it appears that our hypothesized age related differences in transformational knowledge (Movement ⟶ Generalized Space/Cues ⟶ Euclidean Space) were supported for the sighted and blind but only for mental rotations performed under high cue conditions. Low cues affected strategies of both sighted and blind children. Under low cue conditions, the sighted were more likely than their high cue counterparts to revert to place strategies in the younger (5 to 10) years and to show more spatially correct (correct-partially correct) strategies later, at 11 years old, never achieving strong correct responses. Blind children were less affected by low cues in the early years but, like the

sighted children, stronger spatially correct responses seemed to appear later, at 14 instead of 8 or 11 years of age as in the high cue group. Low cue conditions elicited somewhat more movement and nonalignment responses in the blind but not the sighted. Young sighted children were also affected in the flip transformation by low cues. These children, like their blind cohorts, made errors suggesting a verbal/spatial confusion of the concept of "opposite."

We tested Millar's hypothesis that the blind would be more affected by the extent of the rotation than would be the sighted because the blind use movement memory (subject to decay over time and space) whereas the sighted could use a more wholistic visual regeneration strategy to do these tasks. Our data suggest that blind children, using whatever strategy, are equally adept at rotating nonvisible figures to approximately correct locations regardless of extent. The data also indicated that sighted children (particularly 5- to 10-year-olds) may have used cues from the arrays in the high cue task to correctly do these rotations. Without cues from the array 5- to 10-year-old sighted children used more cues of place to (erroneously) fix the end state of the rotation. This increase rendered the rotations of large extent more difficult than those of smaller extent.

Gender differences. (A) Performance. Statistical significance could only be obtained for the sighted groups where the number of subjects per age group (n = 3) was regular throughout. The number of subjects per age group for blind

children ranged from 1 to 8 and this should be taken into consideration when evaluating the percentage data for trends. Gender differences were seen only in the rotational tasks of the recall condition. No gender differences were found for rotations in the recognition condition or for flip transformations. We will first present a statistical analysis and then a qualitative percentage analysis (nonsignificant) of the rotational/recall data. In order to test for gender differences in the sighted groups (high cue/low cue), an ANOVA design with two between subject factors of sex (2 levels) and age (3 or 4 levels) was used. Percentage data showing gender differences by sight, age group and rotational extent can be found in Tables 13 (high cue) and 14 (low cue). Figure 10 depicts similar data for all groups (sight/cue) for the combined rotations only.

Gender differences in performance were found for both sighted groups. In the sighted-high cue group (Table 13), no overall gender differences were seen but there was an interaction between gender and age ($F [2,17] = 4.33$ $p < .05$) such that gender differences were found in the 8- to 10-year-old group ($p < .05$). In the sighted-low cue group (Table 14), overall gender differences were found ($F [1,23] = 7.11$ $p < .05$) as well as an interactional effect ($F [3,23] = 3.85$ $p < .05$) such that differences were strongest in the 14- to 16-year-old group ($p < .05$).

Using percentage data only (nonsignificant) and, comparing the performance for the combined rotations of males

Table 13

Triangle Transformation Task - Recall Condition: Gender Differences in Correct Rotational Responses under High Cue Conditions as a Function of Sightedness and Age (in years) Group (in percentages)

	Male					Female				
Age	n	90°cc	90°c	270°c	R_c[a]	n	90°cc	90°c	270°c	R_c[a]
					Sighted					
5-7	3	0	0	0	0	3	0	0	33	11
8-10	3	100	33	67	67	3	0	0	0	0
11-13	3	100	67	100	89	3	100	67	67	78
5-13[b]	9	67	33	56	52	9	33	22	33	30
					Blind					
5-7	3	0	0	0	0	1	0	0	0	0
8-10	4	0	25	25	17	2	0	0	0	0
11-13	3	100	33	100	78	2	0	0	100	33
14-16	2	50	50	50	50	1	0	0	100	33
5-13[b]	10	33	19	42	32	5	0	0	33	11
5-16[b]	12	38	27	44	36	6	0	0	50	17

[a]Mean percentage of correct rotational responses per group within given age range.

Table 14

Triangle Transformation Task - Recall Condition: Gender Differences in Correct Rotational Responses under Low Cue Conditions as a Function of Sightedness and Age (in years) Group (in percentages)

	Male					Female				
Age	n	90°cc	90°c	270°c	R_c*	n	90°cc	90°c	270°c	R_c*
					Sighted					
5-7	3	33	0	0	11	3	0	0	0	0
8-10	3	100	0	0	33	3	33	0	0	11
11-13	3	67	33	33	44	3	100	33	33	56
14-16	3	100	67	100	89	3	67	0	0	22
5-13*	9	67	11	11	30	9	44	11	11	22
5-16*	12	75	25	33	44	12	50	8	8	22
					Blind					
5-7	2	100	0	0	33	1	0	0	0	0
8-10	1	100	100	0	67	4	50	0	25	25
11-13	2	100	0	0	33	3	33	33	0	22
14-16	7	86	43	71	67	3	33	0	33	22
17-19	2	100	0	0	33	8	50	0	0	17
5-13*	5	100	33	0	44	8	28	11	16	
5-16*	12	97	36	18	50	11	39	8	15	17

*Mean percentage of correct rotational responses per group within given age range.

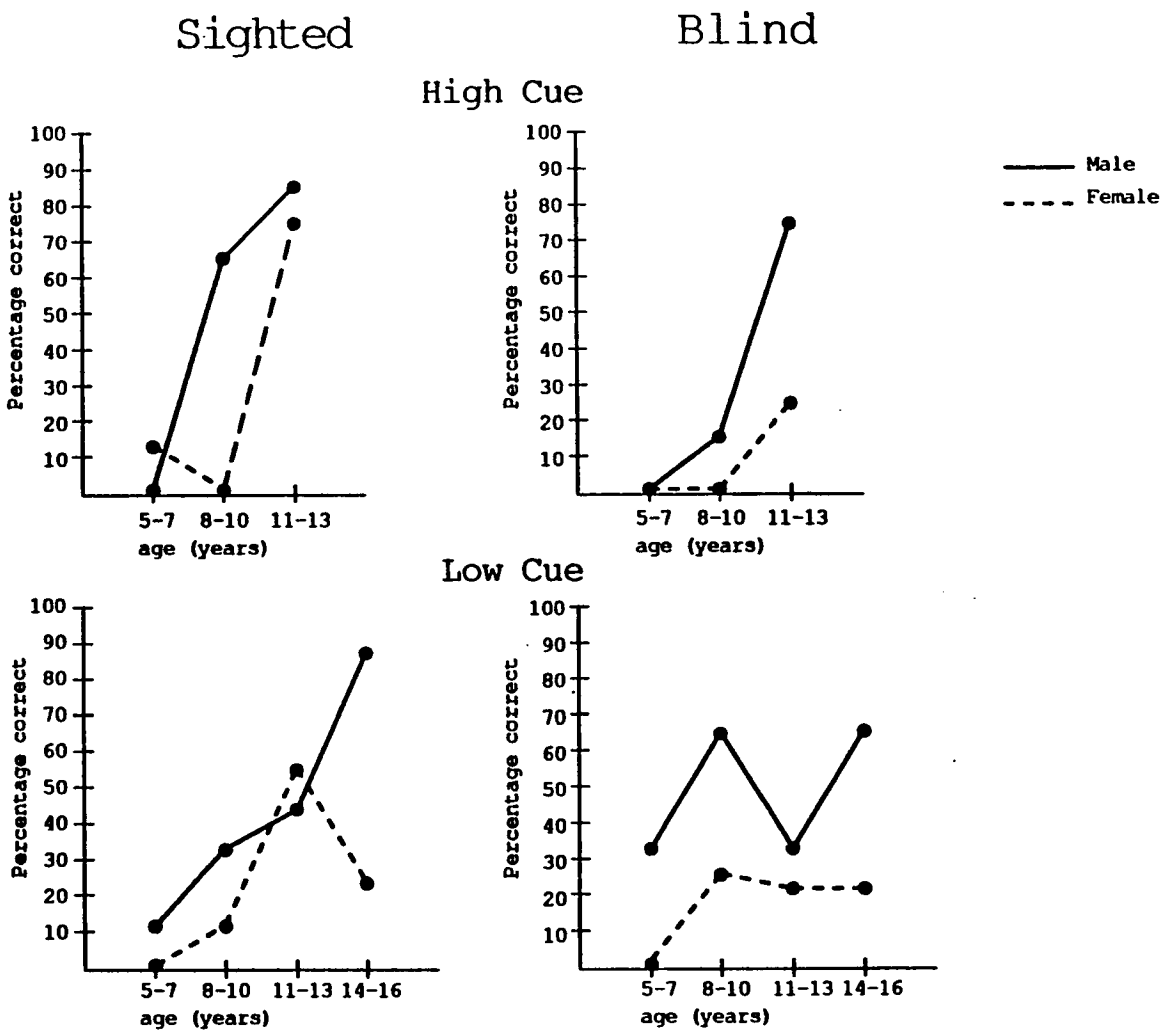


Fig 10. Triangle Transformation Task-Recall: Gender differences in rotational performance by age group for each condition of sight and cue.

and females in the high cue group across conditions of sightedness (Table 13, Fig. 10), it appeared that males did better than their female cohorts in both blind (32% versus 11%) and sighted (52% versus 30%) groups. Specifically, as noted above, sighted males did better than sighted females in the 8- to 10-year-old group (67% versus 0%) and blind males seemed to do better than blind females in the 11- to 13-year-old group (78% versus 33%). However, the total number of blind females was low (n = 6).

Within gender, the sighted appeared to do better than the blind. Sighted males showed a stronger spatial response than blind males in the 8- to 10-year-old group (67 versus 17%) and sighted females showed a stronger spatial response than blind females in the 11- to 13- year-old group (78 versus 33%). Sighted females' and blind males' performances were roughly equivalent and both showed strong spatial performance at 11 years old (78%).

In the low cue groups (Table 14, Fig. 10), males again seemed to do better than females in both blind and sighted groups. For the sighted group, this effect was largest in the oldest age group (14 to 16 years) and, here, on the most difficult 90°c and 270°c rotations (males = 83%, females = 0%). However, comparing the low cue group to their high cue sighted cohorts both males and females in the low cue 11- to 13-year-old age group did poorly on these rotations (92% versus 55%). On the other hand, 14- to 16-year-old sighted females (but not males) continued to do poorly on these rotations under low cue

conditions (0%). The rotation least affected by low cues was 90°cc but gender differences could still be seen. Sighted males in both cue conditions were successful (100%) here at 8 years old whereas sighted females were successful later, at 11 years old.

For low cue blind children, the overall data again appeared to favor blind males. However, the data for each age group were even more erratic than seen in the high cue group and, for 5- to 13-year-old males, the number of subjects per age group was low (n = 1 or 2). What may be safely surmised from the data is that, like the sighted males, there was a strong 14- to 16-year-old correct performance seen in blind males (n = 7) on the more difficult 90°c (43%) and 270°c (71%). Again, like the sighted male, 90°cc is strong (97%) and appears early (5 years of age). In comparison, blind low cue females, like sighted- low cue females, seemed to do more poorly than males on the difficult (90°c and 270°c) rotations -- especially in the 14- to 16-year-old age group (average: females = 17%; males = 57%). They also did only moderately well on 90°cc after 8 years old (females = 42%; males = 97%).

To summarize this section on gender differences in performance, statistical and nonstatistical results are presented. Statistical data indicated that sighted gender differences could be seen under both high and low conditions. Gender differences in performance by age occurred in the 8- to 10-year-old sighted high cue group and in all age groups of the sighted low cue group but particularly the 14- to 16-year-

old age group.

The percentage data (nonsignificant) suggest some trends. In general, gender differences in performance seemed to appear early as, across conditions of cue and sight, males were able to transform simple 90°cc rotations at an earlier age than females. However, at 11 years, some holistic Euclidean knowledge appears to emerge for all male and female groups but this level of knowledge needs to be sustained by external cuing systems. This view was supported by data indicating that those 11- to 13-year-olds (blind and sighted) who did complex nonvisible rotations under high cue conditions seemed to perform better than those who did these tasks under low cue conditions. On the other hand, both significant and nonsignificant data also indicated that, across conditions of sight, at approximately 14 years of age, there appears in males but not in females the ability to transform arrays regardless of available external cues. In order to determine whether there are more subtle differences appearing at an earlier age which might account for these gender differences in performance, we examined gender differences in strategy.

Gender differences. (B) Strategy. We once again examined the premise of Hypothesis 1--that transformational knowledge proceeds from Movement General space/cues Euclidean space. Further, we separately analyzed the clockwise rotations (90°c, 270°c) in order to look for differences in strategy development that might be attributed to rotational extent in interaction with sight, gender, age group and/or cue

condition. Again, as with the general strategy data above, we used percentage data only, which yielded only nonsignificant results. There results were analyzed to indicate trends in transformational strategy. We examined the given hypothesis using a MANOVA-type design with three between subject variables of sight (2 levels), gender (2 levels) and age group (3 to 5 levels) and one within subject variable of rotational extent (2 levels). Tables 15 to 20 show the percentage of strategy responses by sight gender, age and rotational extent. Fig. 11 depicts this information graphically for the combined rotations.

Again, data from blind children were less clear, due possibly to the irregularity in the numbers of subjects per age group, but trends may still be seen. As noted above, the numbers of children in both sighted and blind age groups are generally small so caution should be used in interpreting these data. Strategy definitions can be found in Table 9.

Results (nonsignificant) from the high cue group (Tables 15 to 17, Fig. 11) seemed to indicate that both blind and sighted males were more likely than females to show regular age-related strategy changes. In the sighted group (Table 15), males exhibited age-related strategy changes similar to that seen in the developmental progression posited above in Hypothesis 1. Combining rotations, movement (67%) responses were seen in the 5- to 7-year-old sighted male group and more spatial (correct = 50%, partially correct = 33%) responses appeared in the 8 to 10 year-old age. More correct responses

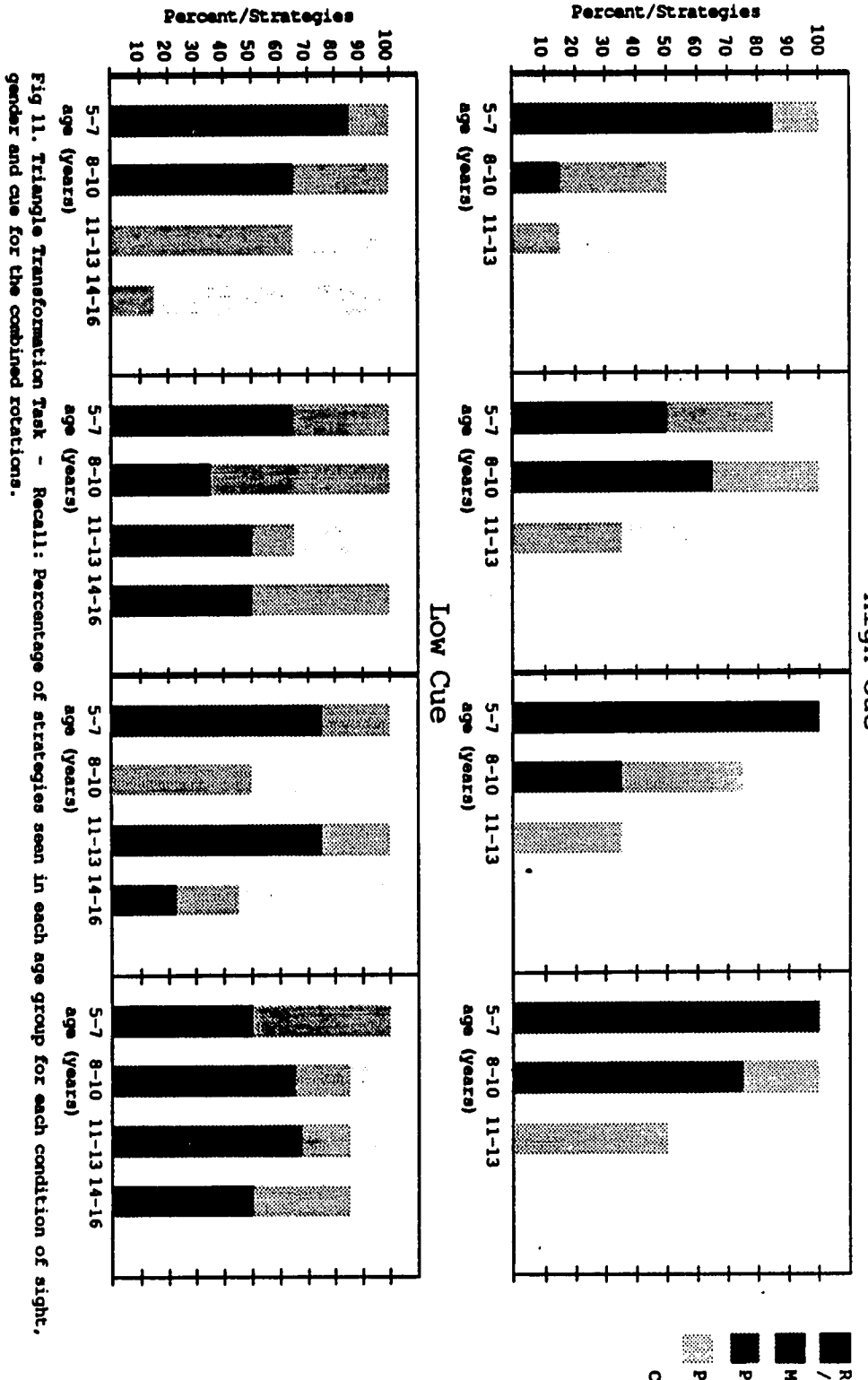


Fig 11. Triangle Transformation Task - Recall: Percentage of strategies seen in each age group for each condition of sight, gender and cue for the combined rotations.

Table 15

Triangle Transformation Task - Recall Condition: Gender Differences in Strategy Patterns on 90° and 270° Rotations for the Sighted Group under High Cue Conditions as a Function of Age (in years) Group (in percentages)

					90° Rotation							
	Male						Female					
Age	n	R/NC/I[a]	M[a]	P[a]	Cp[a]	C[a]	n	R/NC/I[a]	M[a]	P[a]	Cp[a]	C[a]
5-7	3	0	33	33	33	0	3	0	0	33	67	0
8-10	3	0	0	0	67	33	3	0	67	0	33	0
11-13	3	0	0	0	33	67	3	0	0	0	33	67
5-13[b]	9	0	11	11	44	33	9	0	22	11	44	22
					270° Rotation							
5-7	3	0	100	0	0	0	3	0	67	0	0	33
8-10	3	0	0	33	0	67	3	0	67	0	33	0
11-13	3	0	0	0	0	100	3	0	0	0	33	67
5-13[b]	9	0	33	11	0	56	9	0	44	0	22	33

[a]Abbreviations are of terms defined in Table 13. Briefly, they have the following meaning: R/NC/I - refuse/no change of position/inappropriate transformation; M - correct movement, incorrect end state; P - triangle's end state is determined by the end state place of the envelope on the table; Cp - partially correct; C - correct. [b]Mean percentage of responses per group for the given age range.

(83%) were seen in the oldest 11- to 13-year-old male group. In contrast, younger (5- to 10-year-old) sighted females showed few progressive age-related differences in strategy. The youngest group showed strongly mixed strategies whereas the 8- to 10-year-olds showed movement responses (67%). Finally, correct responses (67%) appeared at 11 years. Across genders, differences were seen in responses to rotational extent (90° versus 270°) but only in the youngest (5- to 7-year-old) age group. Here both male and female children made responses to 90°c which indicated the use of spatial cues (place and partially correct = 83%). However in 270°c, children could only manage less spatially aware movement responses (83%).

Gender differences in the blind group (Table 16) seemed to show a similar pattern to that of the sighted group. The males made movement (50%) and inappropriate (33%) responses at 5 to 7 years old and more spatial responses (correct = 25%, partially correct = 37.5%) in the middle (8 to 10) years for both rotations. The dominant response for younger blind females (5- to 10-year-olds) was a movement response (88%). Both males and females, as in the sighted group, made correct responses (100%) for 270°c. Correct responses for 90°c were seen for some 8- to 16-year-old blind boys (38%) but none were seen for blind girls. Clear strategy differences could not be discerned for the different rotations.

Across sight, gender and age, nonalignment responses were also examined (Table 17) for the combined 90°c and 270°c

Table 16

Triangle Transformation Task - Recall Condition: Gender Differences in Strategy Patterns on 90° and 270° Rotations for the Blind Group under High Cue Conditions as a Function of Age (in years) Group (in percentages)

						90° Rotation						
	Male						Female					
Age	n	R/NC/I[a]	M[a]	P[a]	Cp[a]	C[a]	n	R/NC/I[a]	M[a]	P[a]	Cp[a]	C[a]
5-7	3	67	33	0	0	0	1	0	100	0	0	0
8-10	4	0	25	0	50	25	2	0	50	0	50	0
11-13	3	0	0	0	67	33	2	0	0	0	100	0
14-16	2	0	0	0	50	50	1	0	100	0	0	0
5-13[b]	10	22	19	0	44	19	5	0	50	0	50	0
5-16[b]	12	17	15	0	45	27	6	0	63	0	38	0
						270° Rotation						
5-7	3	33	67	0	0	0	1	0	100	0	0	0
8-10	4	0	50	0	25	25	2	0	100	0	0	0
11-13	3	0	0	0	0	100	2	0	0	0	0	100
5-13[b]	10	11	39	0	8	42	5	0	67	0	0	33
5-16[b]	12	8	29	0	19	44	6	0	50	0	0	50

[a]Abbreviations are of terms defined in Table 13. Briefly, they have the following meaning: R/NC/I - refuse/no change of position/inappropriate transformation; M - correct movement, incorrect end state; P - triangle's end state is determined by the end state place of the envelope on the table; Cp - partially correct; C - correct. [b]Mean percentage of responses per group for the given age range.

Table 17

Triangle Transformation Task - Recall Condition: Gender Differences in Nonalignment Responses under High Cue Conditions as a Function of Sightedness and Age (in years) Group (in percentages)

	Sighted		Blind	
Age	Male(n)[a]	Female(n)[a]	Male(n)[b]	Female(n)[c]
5-7	33	33	33	100
8-10	0	67	0	25
11-13	0	0	0	0
14-16			0	50
5-13[d]	11(9)	33(9)	11(10)	42(5)
5-16[d]			8(12)	44(6)

[a]N = 3. [b]In order of increasing age, n = 3, 4, 3, 2 per age group. [c]In order of increasing age, n = 1, 2, 2, 1 per age group. [d]Mean percentage of responses per group within given age range.

rotations. Overall, males made fewer nonalignment responses (sighted and blind = 11%) than females (sighted = 33%, blind = 41%). Further, for males, nonalignment responses were confined to the youngest (5 to 7) years whereas, for females, these responses were also seen in the 8- to 10-year-old group (sighted) or later (blind). Regarding the percentage of subjects involved, fewer males (sighted = 11%, blind = 25%) than females (sighted = 44%, blind = 50%) made nonalignment responses.

Overall, it appears that, with a greater number of cues, blind and sighted males followed the pattern of transformational knowledge predicted in Hypothesis 1. The youngest group represented transformations as movement and then in the middle age (8 to 10) group there were more spatially correct (correct and partially correct) responses with some reliance on cues. Concurrent with this greater spatial response, nonalignment responses were low (0%). At 11 years old, both male groups made strong correct responses. Blind and sighted females showed a more erratic and/or a more abrupt pattern of responses. Movement responses dominated most of the transformations for 5- to 10- year-old females (with more partially correct responses seen at times for 90°c). During this age span nonalignment responses were relatively high. At 11 years old, similar to their male counterparts, strong correct responses were seen for 270°c. However, sighted females did better than blind females on 90°c. The latter never achieved a fully correct response here.

In sum, under high cue conditions, the predicted pattern of age-related strategy change (Movement ⟶ Generalized Space/Cues ⟶ Euclidean Space) appeared to be valid for males more so than females. Gender differences in strategies across sight appeared strongest in the 8 to 10 age group where males but not females made more spatial responses and no nonalignment responses.

Blind/sighted differences seemed to occur in the 90°c rotation. Young (5- to 7-year-old) sighted but not blind children could use external cues (partially correct and place) to place the triangle, and older sighted children could maintain the separate boundaries of the triangle and envelope over rotations. Within the blind group, males seemed to do better on this task than females.

In addition, strategy differences due to rotational extent (90° versus 270°) were seen in both male and female sighted groups. Here partially correct and place responses appeared at an earlier age and/or were stronger in 90°c than 270°c.

For the low cue group, (Tables 18 to 20, Fig. 11) lessening of cues seemed to affect strategy responses similar to the way it affected performance responses--more negatively in females than males. However, of all of the low cue groups only the sighted male group exhibited a pattern of regular age-related strategy differences for both rotations. Nevertheless, even this pattern was affected by low cues and differed from the pattern seen in high cue males. Place

strategies increased and the more sophisticated spatial strategies were seen at a later age under low cues.

Examining the sighted strategies (Table 18) for gender differences, the following patterns were seen. Males but not females showed a regular age-related pattern in 90°c such that early place responses (67%) gave way to more spatial responses (partially correct = 67%, correct = 17%) in the 8- to 13-year-old group. Correct responses (67%) were seen in the oldest group (14- to 16-year-olds). In 270°c, early movement responses (67%) were replaced by place responses (100%) in the 8- to 10-year-old group. Spatial responses (partially correct = 67%, correct = 33%) appeared at 11 years old and correct responses (100%) at 14 years. Thus, under low cue conditions spatial responses were seen later in 270° than in 90°c, but correct performance was achieved for both rotations at the same age of 14 years. This pattern contrasted with the male pattern in high cue conditions where these strategy patterns were compressed such that, for both rotations, spatial responses appeared at 8 years old and correct responses at 11 years old.

For sighted females, age patterns in strategies, erratic under high cue conditions, were even more so under low cue conditions. There was no systematic or even abrupt pattern of age-related differences in the more spatial and/or correct responses for either rotation. In comparison, in the high cue group correct responses appeared abruptly at 11 years. However, for this low cue group partially correct spatial

Table 18

Triangle Transformation Task - Recall Condition: Gender Differences in Strategy Patterns on 90° and 270° Rotations for the Sighted Group under Low Cue Conditions as a Function of Age (in years) Group (in percentages)

					90° Rotation							
	Male						Female					
Age	n	R/NC/I[a]	M[a]	P[a]	Cp[a]	C[a]	n	R/NC/I[a]	M[a]	P[a]	Cp[a]	C[a]
5-7	3	0	0	67	33	0	3	0	0	33	67	0
8-10	3	0	0	33	67	0	3	0	0	100	0	0
11-13	3	0	0	0	67	33	3	0	0	33	33	33
14-16	3	0	0	0	33	67	3	0	33	0	67	0
5-13[b]	9	0	0	33	67	11	9	0	0	56	33	11
5-16[b]	12	0	0	25	50	25	12	0	8	42	25	8
					270° Rotation							
5-7	3	0	67	33	0	0	3	0	33	67	0	0
8-10	3	0	0	100	0	0	3	0	67	33	0	0
11-13	3	0	0	0	67	33	3	0	33	33	0	33
14-16	3	0	0	0	0	100	3	0	0	67	33	0
5-13[b]	9	0	22	44	22	11	9	0	44	44	0	11
5-16[b]	12	0	17	33	17	33	12	0	33	50	11	8

[a]Abbreviations are of terms defined in Table 13. Briefly, they have the following meaning: R/NC/I - refuse/no change of position/inappropriate transformation; M - correct movement, incorrect end state; P - triangle's end state is determined by the end state place of the envelope on the table; Cp - partially correct; C - correct. [b]Mean percentage of responses per group for the given age range.

strategies did appear earlier and were stronger in 90°c than 270°c.

Comparing the strategies of sighted males and females over the entire age span studied (5- to 16-year-olds), it appears that for males, low cues only delayed their ability to exhibit spatial strategies and correct responses in relation to their high cue cohorts. However, for females, low cue conditions appeared to impair their ability to make correct responses overall. Under low cue conditions, both males and females used cues from where the envelope was placed on the table (place). However, this cue dependency appeared to be stronger in females (46%) than males (21%).

Examining gender differences in the low cue blind (Table 19) group for 90°c, little change was seen in the gender patterns observed in the high cue group. Partially correct responses appeared at 8 years old and, overall, males seemed more likely than females to exhibit fully correct responses (33% vs. 11%). However, as with sighted males, correct responses were now mostly confined to the 14- to 16-year-old group where 43% (n = 3) of their responses were correct.

In 270°c both males and females appeared to be affected by low cues--females more so than males. Compared to high cue males, low cue males did not show the age-related pattern of increasing spatial responses. Instead partially correct (50%), movement (33%) and place (17%) responses were seen until correct responses (71%) appeared at 14 years. Blind females, like sighted females, also failed to exhibit the abrupt

Table 19

Triangle Transformation Task - Recall Condition: Gender Differences in Strategy Patterns on 90 and 270 Rotations for the Blind Group under Low Cue Conditions as a Function of Age (in years) Group (in percentages)

					90° Rotation							
	Male						Female					
Age	n	R/NC/I[a]	M[a]	P[a]	Cp[a]	C[a]	n	R/NC/I[a]	M[a]	P[a]	Cp[a]	C[a]
5-7	2	0	0	100	0	0	1	100	0	0	0	0
8-10	1	0	0	0	0	100	4	0	50	0	50	0
11-13	2	0	50	0	50	0	3	0	33	0	33	33
14-16	7	0	14	0	43	43	3	0	33	0	67	0
17-19	2	0	0	0	100	0	8	0	13	0	87	0
5-13[b]	5	0	17	33	17	33	8	33	28	0	28	11
5-16[b]	12	0	16	25	23	36	11	25	24	0	38	8
					270° Rotation							
5-7	2	0	50	0	50	0	1	0	0	0	100	0
8-10	1	0	0	0	100	0	4	0	50	25	0	25
11-13	2	0	50	50	0	0	3	0	67	33	0	0
14-16	7	0	0	29	0	71	3	0	67	0	0	33
17-19	2	0	100	0	0	0	8	13	63	0	25	0
5-13[b]	5	0	33	17	50	0	8	0	39	20	33	8
5-16[b]	12	0	25	26	38	18	11	0	46	14	25	15

[a]Abbreviations are of terms defined in Table 13. Briefly, they have the following meaning: R/NC/I - refuse/no change of position/inappropriate transformation; M - correct movement, incorrect end state; P - triangle's end state is determined by the end state place of the envelope on the table; Cp - partially correct; C - correct. [b]Mean percentage of responses per group for the given age range.

appearance of correct responses at 11 years old as seen in the high cue group. Instead, movement responses dominated most age groups (8- to 16-year-olds = 61%) and spatial responses were low.

Nonalignment responses (Table 20) seemed to be basically unaffected by the presence or absence of cues although nonalignment responses were somewhat more prevalent in the low cue blind group. Both male groups appeared to have lower nonalignment responses (sighted = 11%, blind = 25%) than females (sighted = 22%, blind = 50%). As in the high cue groups, these nonalignment responses were no longer present at 8 years old for sighted males and at 11 years old for sighted females. They were pervasive for blind females. Blind males showed relatively low periodic nonalignment responses. Again, as in high cue conditions, the percentage of 5- to 16-year-old males exhibiting nonalignment responses (sighted and blind = 17%) was lower than the percentage of females (sighted = 28%, blind = 64%). However, in low cue but not high cue conditions, blind females appeared more likely than sighted females to make these responses.

Gender Differences Summary Gender comparisons of both performance and strategy under high and low cue conditions resulted in some significant and nonsignificant gender differences as well as some nonsignificant differences due to sight and rotational extent. Regarding these results, it appears that differences between conditions of sight on this type of mental rotation tasks may be less than differences

Table 20

Triangle Transformation Task - Recall Condition: Gender Differences in Nonalignment Responses under Low Cue Conditions as a Function of Sightedness and Age (in years) Group (in percentages)

	Sighted		Blind	
Age	Male(n^a)	Female(n^a)	Male(n^b)	Female(n^c)
5-7	33	17	25	50
8-10	0	50	0	50
11-13	0	0	50	50
14-16	0	17	0	50
17-19			25	25
5-13[d]	11	22	25	50
5-16[d]	8	21	19	50

[a]N = 3. [b]In order of increasing age, n = 2, 1, 2, 7, 2 per age group. [c]In order of increasing age, n = 1, 4, 3, 3, 8 per age group. [d]Mean percentage of responses per group within given age range.

between conditions of gender. (However it must also be kept in mind that the number of subjects involved in these comparisons were often low.)

Statistically significant differences could be obtained only for sighted children's performance data. Here, under high cue conditions, males did better than females in the 8- to 10-year-age range. For the low cue conditions males do better overall than females and especially so in the 14- to 16-year-old age group.

Results from qualitative percentage data suggested further trends. In the high cue condition, both of the male (but not female) groups seemed to show age-related differences in strategies similar to the predicted pattern of Hypothesis 1 (Movement ⟶ Generalized Space ⟶ Euclidean Space). Movement responses were seen early and spatial responses appeared at 8 years old coinciding with the disappearance of nonalignment responses. Females seemed to show poor age-related strategy patterns at this age (5 to 10 years old) and continued nonalignment responses into the older years. In both blind and sighted groups the simple 90°cc rotation appeared earlier in males than in their female cohorts. For all groups correct responses on the more holistic 270° rotation seemed to appear at 11 years old. Some blind/sighted differences could be seen on the more complex 90°c rotation where correct responses again were seen more so for the sighted than for the blind at 11 years old. However, within the blind group, males appeared to do better than females on this rotation.

Examining qualitative data in the low cue condition, blind and sighted males seemed more alike in performance than in strategy development. Both blind and sighted males exhibited strong performance early on 90°cc and later, at 14 years old, on 90°c and 270°c. Only the latter rotations appeared to be affected by low cues as correct responses appeared at an earlier age (11) in the high cue groups. Sighted males alone continued to show strong age-related spatial patterns. Blind and sighted females again showed poor age-related strategy patterns and appeared to be strongly affected by low cues. Spatially correct responses for difficult rotations were made by older high cue but not low cue females. Nonalignment responses for all low cue groups were similar to those shown in high cue groups. Blind/sighted differences were seen in cue use. The sighted, especially females, now use cues from the placement of the envelope on the table (place) to fix the end-state of the rotated triangle.

Qualitative data was also used to examine differences in response due to rotational extent. These differences appeared to be most evident in the sighted group. In the high cue group, young males and females seemed to show more spatial cue use on 90°c and more movement responses on 270°c. In low cue conditions, males exhibited spatial strategies earlier in 90°c than 270°c and females showed stronger overall spatial responses for 90°c than 270°c.

Triangle Transformation Task: Overall Summary

The following results are tentative due to the small size of the sample and the lack of statistical significance for many of the findings which have been discussed above. Results will be labeled as significant or nonsignificant (n.s.).

Hypothesis 1 stated that age-related changes in knowledge of spatial transformations would be seen. We would first see in children an early knowledge of movement (5- to 7-years-old) and then a generalized knowledge of space aided by cues (8 to 10 years old). Finally, at approximately 11 years, children would understand full transformations within a holistic Euclidean spatial framework (Movement ⟶ Generalized Space/Cues ⟶ Euclidean Space).

Our qualitative results (n.s.) showed that only sighted males consistently had age-related differences in their strategy patterns which resembled the hypothesized pattern. Blind males showed this age-related strategy pattern under high cue conditions and blind and sighted females showed few age-related differences under any cue condition. Good knowledge of Euclidean space appeared at 11 years of age for all but only under high cue conditions. Under low cue conditions this knowledge appeared in 14 year old males but not at all in females (significant for the sighted, nonsignificant for the blind).

Hypothesis 2 states that various factors will affect transformational knowledge. These factors include:

a) Cues. We predicted that the 8- to 10-year-old sighted children would be more negatively affected than blind children by low cues. Thus, under low cue conditions, sighted and blind children's performance would be more nearly equal. Specifically, we posited that, although the sighted and blind would differ in their reactions to rotational extent under high cue conditions (sighted: 90° = 270°; blind: 90° > 270°), under low cue conditions, sighted/blind performance would be similar (90° > 270°).

Results from a qualitative analysis of the data (n.s.) indicate that under both recall and recognition conditions the sighted performance was somewhat less in low cue conditions than in high cue conditions such that in low cue conditions, their patterns and level of performance were similar to those seen in the blind. However, our predictions regarding the exact relationship between transformations (e.g., 90° > 270°) were not always correct.

In the recall condition, the predicted relations under high cue conditions appeared only inconsistently. However, under low cue conditions, blind/sighted performance seemed to become more alike such that flip = 90°cc > 90°c and 270°c. Upon closer examination, it became apparent that 90°c was rendered more difficult than 90°cc because its configuration made it more vulnerable to a specific error. If we allowed for this error, 90°cc = 90°c. Thus, 90° appeared to be easier than 270° as predicted (n.s.).

It appeared that, in the recall condition, the sighted

were more affected (n.s.) by low cues than the blind as predicted. In reality, both tended to be affected (n.s.) by low cues as only the more difficult transformations which appeared at 11 years of age in high cue conditions (270° c, 90°c) were affected by low cues. Since 90°c appeared not at all in the blind, they were less affected overall by low cues. Thus, our predictions for strong negative low cue effects in 8- to 10-year-old sighted children seemed to be rendered invalid. The sharpest difference in performance (n.s.) between high and low cue groups was seen at 11 years of age and older in both blind and sighted children.

When we further examined these data qualitatively for gender differences in the effects of low cues, we found that across conditions of sightedness, gender differences existed. With low cues, males exhibited strong spatial responses on the more difficult rotations three years later (11 versus 14 years old) than with high cues. Most low cue females were unable to do these same rotations at any age.

In the recognition condition, sighted performance again was somewhat less (n.s.) under low cues than under high cues such that under low cues, the pattern and level of transformational performance of the sighted resembled that of the blind. Here, as predicted, 90° rotations appeared to be easier than 270°. The overall transformational pattern which was seen was: flip = 90°cc = 90°c > 270°. Again, low cues for both sighted and blind children negatively affected (n.s.) only those rotation(s) which appeared relatively late under

high cue conditions (270°c).

Low cues also affected the overall (recall/recognition) strategy patterns of the sighted group (n.s.). Under low cues, sighted children reverted to using cues from the general place of the envelope on the table. Also, 5- to 7-year-old sighted children, deprived of envelope cues in the flip transformation, made errors suggesting that "flip" was understood as a generalized "opposite."

b) Task demands. We predicted that children, especially sighted children, would do better on these tasks under conditions of recognition rather than recall. We also expected the sighted to do better than the blind on recognition tasks given their greater store of experience with observing end-states of transformations. We expected this experience to aid them particularly in the ages (5 to 10 years old) prior to the development of full Euclidean spatial knowledge.

As predicted, the sighted but not the blind did significantly better on recognition than recall, and the sighted did significantly better than the blind on recognition tasks. The sighted differences in recall/recognition appear to be primarily in the 5- to 10-year-old group (n.s.). However, both blind and sighted did better (n.s.) in recognition than recall on partial rotations (90°--especially 90°c) and neither was affected by task demands on more holistic (270°c) rotations.

c) Transformational type. We predicted that sighted/blind differences would be seen in the relationship between flips

and rotations due to the greater sighted experience with the mirror image end-states resulting from perceived flip transformations. Thus, we predicted the flip to be easier than the rotations for the sighted under replication conditions but not for the blind. Results (n.s.) suggest that, across conditions of cue and task demand, for both groups, the flip seemed to appear early and was generally equal to 90° rotations. The flip was only easier (n.s.) than the more difficult rotations (270°c recall/recognition, 90°c recall).

d) Gender differences. We predicted that sighted males would do better than females on rotations. As outlined above, blind (n.s.) and sighted (significant) males did better than their female cohorts on rotational transformations and this difference appeared to be particularly evident under conditions of low cues. Males also showed (n.s.) lower nonalignment responses which generally terminated at an earlier age and they appeared to be less dependent on external cues than females. These differences were only found for rotational transformations in the recall condition.

In order to validate and extend the above findings, we will now briefly present some of the results of the Familiar Objects Task. This task was similar to the Triangle Transformation Task but, instead of triangles, sets of familiar objects were transformed.

Task 2: Familiar Objects Task

Rotation. Table 21 shows the percentage of correct responses for males and females in each condition of sightedness and cue (sighted high cue, sighted low cue, blind) and each age group for each rotation (90°, 270°) of the Familiar Objects Task. The two blind groups were combined as there were no differences in the task and no significant differences in performance. The hypotheses which we tested in this task were similar to those tested in the Triangle Transformation task. We expected the sighted to be unaffected by rotational extent under high cue conditions (90° = 270°) but that, under low cue conditions, sighted and blind would be equally affected by extent such that rotations of small extent would be easier than rotations of large extent (90° > 270°). We also predicted that, for the sighted, we would find gender differences favoring males. We examined the hypotheses concerning gender differences for each group using ANOVAS with two between subject factors of gender (2 levels) and age (3 or 4 levels). For each group we also tested for differences due to rotational extent using MANOVA repeated measures with one within subject factor of rotational extent (2 levels). We will present these results and then qualitatively compare these data to rotation tasks in the Triangle Transformation Task/recall (Tables 13 and 14). The 90° rotation of Familiar Objects task will be compared to 90°cc of Triangle Transformation task as both are simple 90° rotations.

Table 21

Familiar Objects Task: Gender Differences in Correct Rotational Responses as a Function of Sightedness and Cue Conditions (S_1, S_2, $B_{1\text{-}2}$)[a], Rotational Extent and Age (in years) Group (in percentages)

	Males			Females		
Age	$S_1(n)$[b]	$S_2(n)$[b]	$B_{1\text{-}2}(n)$[c]	$S_1(n)$[b]	$S_2(n)$[b]	$B_{1\text{-}2}(n)$[d]
			90° Rotations			
5-7	22	11	40	22	11	17
8-10	67	89	93	89	33	39
11-13	100	78	100	100	78	67
14-16		100	93		89	67
17-19			83			83
5-13[e]	63	59	78	70	41	41
5-16[e]		69	81		53	47
			270° Rotations			
5-7	22	0	13	33	0	0
8-10	56	44	67	78	11	17
11-13	89	56	20	89	33	33
14-16		78	78		78	25
17-19			50			46
5-13[e]	56	33	33	67	15	17
5-16[e]		44	44		31	19

[a]S_1 - sighted group under high cue conditions, S_2 - sighted group under low cue conditions, $B_{1\text{-}2}$ - combination of blind groups which are both under low cue conditions. [b]N = 3. [c]In order of increasing age, n = 5, 5, 5, 9, 2 per age group. [d]In order of increasing age, n = 2, 6, 5, 4, 8 per age group. [e]Mean percentage of correct responses per age group within given age range.

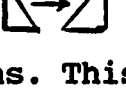
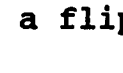
When in the high cue condition, sighted males and females did equally well on both transformations (average = 83%) in the 8- to 13-year-old age range and no statistically significant differences were seen for gender or rotational extent. For the combined 5- to 13-year-old blind group, who by definition (no sight) were under low cue conditions, statistically significant differences due to gender ($F [1,27] = 10.58$ $p < .01$), favoring males, and rotational extent ($F [1,27] = 14.12$ $p < .01$), favoring 90°, were evident. Examining the percentage data (Table 21) for qualitative gender differences in performance, blind males did well in the 90° rotations at 8 years old (96%; 8 to 13 years old) whereas blind females do well later, at 11 years old (67%). For the 270° rotations, the males' performance fluctuated after 7 years old. The highest levels of response were seen at 8 to 10 (67%) and 14 to 16 (78%) years of age. Females generally did poorly on this rotation but in the oldest years (17 to 19) they did somewhat better in their performance (46%).

Sighted males and females in the low cue condition performed similarly to the blind children. Statistically significant differences were seen for rotational extent (90° > 270°, $F[1,17] = 37.55$ $p < .001$) and for gender (males > females: $F [1,17] = 4.50$ $p < .05$) but only for 270° rotations. Examining the data qualitatively it appears that sighted males, like blind males, did well on 90° rotations beginning at 8 years of age (88%) and did their best performance on 270° rotations at 14 to 16 years (77%). This was a difference of 3

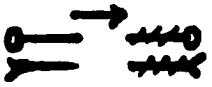
years in relation to their high cue cohorts. Low cue sighted females also seemed to show lower performance than high cue females. However, unlike their male counterparts, not only did 270° rotations appear later (14 versus 8 years of age) but 90° rotations also appeared later (11 versus 8 years of age) under low cue conditions. These age differences in rotational appearance between high and low cue sighted females resulted again in a stronger blind/sighted similarity in female performance for 90° rotations under low cues. Nevertheless, sighted females did better than blind females on 270° rotations as only sighted females did well here at 14- to 16-years-old.

If we qualitatively compare these results to the same children's performance on the Triangle Transformation task (Tables 13 to 14) we find strong similarities and some differences. Examining these data, we see that blind and sighted <u>males'</u> performance on the Familiar Objects task under high (sighted only) and low cue conditions (sighted and blind) was similar to their performance on the Triangle Transformation task. Under low cue conditions the 90° rotation (Familiar Objects) like 90°cc (Triangle Transformation), appeared early and was relatively unaffected by low cues. Low cues seemed to delay performance on the 270° rotation on the Triangle Transformation task (sighted and blind) and the Familiar Objects task (sighted) such that both blind and sighted subjects exhibited strong correct responses 3 years later, at 14 years, under low cue conditions of both tasks.

It appears that blind and sighted females in the low cue condition did better on rotations with familiar objects than with more abstract triangles. Sighted females in high cue situations did well (89%) at 8 years old on the Familiar Objects task and later, at 11 years old (100%) in the Triangle Transformation task. In the low cue group of the Familiar Objects task, 90° and 270° rotations appeared (78% correct) three to six years later than was seen in the high cues group. However, in the low cue Triangle Transformation task, performance on 270°c was consistently poor (0% to 33%) regardless of age. Similarly, blind females (8- to 19-year-olds) appeared to do better in the Familiar Objects task (90° = 64%; 270° = 30%) than in the Triangle Transformation task (90°cc = 42%, 270°c = 15%) under low cue conditions.

Flip. Two errors which resulted from the flip transformation of the Familiar Objects task are of note. The first error, referred to as a verbal/spatial error, was also seen in the Triangle Transformation task. Here children appeared to confuse the verbal and spatial concepts of "opposite." In the Familiar Objects task, sighted children made more of these errors on the vertical flip task () under low cue conditions than under high cue conditions. This resulted in two responses; a 180° rotation () or a flip down (). For the 5- to 10-year-old group, these errors comprised 4% of the sighted-high cue children's response, 15% of the blind children's responses and 25% of sighted-low cue children's responses. Thus, under low cue conditions sighted

responses seemed more similar to the responses of blind children.

The second error occurred with sighted children in the horizontal flip task (). It occurred more when children had their sight and cues were present (sighted-high cue) than when children were blindfolded and cues were relatively absent (sighted-low cue). In this error sighted-high cue children placed the array in the correct general location for the end-state. However, they did this by rotating the array 180° () and ignored the actual flip transformational which would result in an inverted array. Since these errors involved primarily the slipper array and the fork/spoon array, only these will be presented. These errors comprised only 8% of the responses when children were deprived of sight. In the sighted condition 17% of these errors were recorded for 5- to 7-year-olds and these errors increased to 44% for 8- to 10-year-olds.

The first verbal/spatial error suggests that young sighted children have only a vague sense of the end-state of flip but can use cues to bring this end-state into focus. The second error suggests that young sighted children, especially 8- to 10-year-olds, think of transformations as end-state places and not as transformational movements.

Both of these errors, particularly the second error, are of interest in regard to our next set of tasks--The Congruency/Transformation Tasks. These tasks were designed to find out how children determine congruency between transformed

arrays and further, how children understand the transformations which intervene between two arrays.

Nonvisible Transformations - Summary

Statistically significant findings will be summarized first and these will be followed by a summary of the qualitative percentage data. Statistically significant differences were found for sightedness, gender and task demands. Blind/sighted differences favoring sighted subjects were found, as predicted, in the recognition condition. Again as predicted, gender differences favoring sighted males were found in the high cue (8 to 10 years of age) and low cue (overall - especially 14 to 16 years of age) condition of the Triangle Transformation rotation task. In the Familiar Objects Task gender differences were found favoring both sighted and blind males in the low cue condition. Thus across tasks and condition of sight it appears that males generally do better than females under low cue conditions. Differences due to varying task demands are seen for rotational extent and recognition/recall conditions. As posited, in the Familiar Object task both blind and sighted subjects found 90° rotations to be easier than 270° rotations under low cue conditions. Also, as predicted, the sighted found recognition to be easier than recall in the Triangle Transformation task.

Analyzing the nonsignificant qualitative data certain trends were also seen. It appears that for blind and sighted children, the highest level of Euclidean space was seen at

approximately 14 years of age. At this age, without cues, several children could mentally transform complex arrays of rotations of differing extent. These same transformations could be done by most subjects at 11 years old but only when more cues were present. During the years between 8 and 10 years old, some children could do partial rotations or even full rotations when appropriate cues were available. Also at this age, children appeared to focus more on end-states than on transformations. In the 5- to 7-year-old group, mental transformational ability was poor, but again, some simple end-states of transformations were identified in the presence of cues.

The qualitative findings regarding the individual transformations of the Triangle Transformation task were similar to the significant findings for these transformations in the Familiar Objects task (90° > 270°). Partial transformations (flip and simple 90° rotations) seemed to appear earlier (8- to 10-year-olds) and to be easier than full (270°) or more complex (90°c/recall) transformations which were evident at 11 years old. Only the latter transformations which appeared later seemed to be negatively affected by low cues in both of the above nonvisible transformation tasks.

Blind and sighted children behaved both differently and similarly in the Triangle Transformation task. Sighted children seemed to do somewhat better than blind children on this task under high cue recall conditions. However, under low cue recall conditions, the pattern and level of performance of

blind and sighted children was usually quite similar. As noted above, in the recognition condition of this task the sighted did significantly better than the blind, but again, the pattern of performance on individual transformations was similar. Also, although only the sighted found recognition of end-states significantly easier than recall of the same end-state (see above), the blind also seemed to find most partial rotations (90°) somewhat easier in the recognition condition. For both blind and sighted children, only partial transformations (flip and/or 90° rotations), which appeared early (8-10 years), seemed to be positively affected by the recognition condition. Not surprisingly then, these recall/recognition differences were generally seen only in the younger children (5- to 10-years-old).

Other areas where blind and sighted children seemed to differ were on some specific rotations and strategies. Most blind children had great difficulty with the complex 90°c/recall task. This task required subjects to maintain multiple spatial boundaries in the array in the face of strongly competing cues. Regarding external referencing strategies, sighted/blind differences were primarily seen in the low cue condition. Here, sighted but not blind use cues from where the envelope was placed on the table as a reference.

As noted above, statistical gender differences were found across conditions of sight. Additionally, qualitative differences were seen such that spatial knowledge (90°cc and

low nonalignment errors) seemed to appear earlier and a stronger pattern of age-related spatial strategies tended to be seen in males. In comparison, females seemed to show fewer age-related strategy patterns and spatial knowledge appeared later, at 11 years old. Compared to their high cue peers, males under low cue conditions seemed to achieve success on complex transformations later, at 14 years old. Additionally, blind but not sighted males' age-related strategy patterns appeared to be weaker under low cues. In contrast, blind and sighted females' spatial responses on complex transformations under low cue conditions seemed to be generally poor compared to high and low cue male responses and high cue female responses.

Interestingly, females but not males tended to do better on rotations when using familiar objects rather than triangles. Sighted females appeared to do better with 270° rotations under low cue conditions and blind females tended to do better in overall performance.

Congruence/Transformation Tasks

Task 3: Static Triangle Task

This task consisted of several groups of triangle transformations (see Fig. 2); flips, false flips, symmetrical rotations, and asymmetrical rotations. The flip group comprised arrays of paired congruent triangles flipped in

relation to each other whereas the false flip group had triangles pairs that only appeared to be congruent and in a flip relationship to each other. Rotational arrays consisted of 2 congruent triangles rotated in relation to each other. In the symmetrical rotations the triangles are in a relationship of overall symmetry whereas in the asymmetrical rotations no paired symmetry is seen. Children are asked to judge the congruence of the triangles in the array. They are then asked to both imagine (I) and execute (E) the transformation intervening between end states of the transformed triangles.

In the first section we presented children's congruence judgements for each group of transformations to show how the configuration influenced their judgements. In the second section, for most transformational groups, we first examined children's views of intervening transformations. We then looked at the strategies (verbal) that they used to determine congruence and compared these strategies with their overall transformational performance. Because of the verbal nature of congruence strategies, we did not expect them to perfectly reflect the child's cognitive processes. Instead we expected them to give us only a general idea of the developmental progression in children's criteria for congruence and thus only a general idea of the interaction between these strategies and children's transformational understanding. Finally, where applicable, we examined gender differences in strategies and performance.

Again, as in the previous tasks, results are either

statistically significant or qualitative - based on percentage data. Statistically significant differences between sighted and blind groups are only seen in the flip transformation. As we shall see, these results are clarified by the strategy data. The remaining results are all qualitative and generally show trends in specific directions when examined either alone or in conjunction with the remaining sets of transformations. In these sets of tasks both statistical and qualitative comparisons are made between two sightedness groups (sighted, blind) and four age groups (3 year age spans from 5 to 16 years of age) unless otherwise indicated. Again research designs for qualitative analyses will be described as ANOVA or MANOVA type designs.

The coding (definitions and abbreviations) for all performance and strategy data can be found in Table 22. Abbreviations were used primarily in the tables where shortened definitions of the same can be found.

Congruency Judgements. Here we simply measured whether the child correctly judged the arrays to be "the same" or "not the same". The results, which are grouped by transformational type, can be seen in Table 23. Results given below are nonstatistical percentage data only as the nature of the data (insufficient variation in some scores) precluded statistical analysis. We examined the data using a MANOVA repeated measures type design with one between subject variable of sight (2 levels) and one within subject variable of task (4 levels).

Table 22

Static Triangle Task - Performance and Strategy Measures

1. Performance

   a) Congruence judgements - children's judgements that the triangles are the "same" or "not the same" are either correct (C) or incorrect (X).

   b) Transformation judgements - children's judgements of the transformation intervening between end states are either correct (C) or incorrect (X) - for statistical purposes only.

   c) Overall transformation performance - for the combined imagination (I) and execution (E) conditions, the following performance measures are applicable to the congruent arrays of the flips, the symmetrical rotations and the asymmetrical rotations.

      i. Correct transformation (C). For the symmetrical rotations this is further divided into a correct rotation (C_R) and a correct double flip (C_{FF}).

      ii. Correct by trial and error (C_{TE}).

      iii. Incorrect - "not the same" (X_{NS}).

2. Strategies

   a) Transformation strategies - conditions of:

      i. Imagination;

Correct (C) and, for rotations,

Correct rotation (C_R) and Correct double flip (C_{FF})

Incorrect rotation (X_R)

Incorrect flip to match one congruent side (X_{FC})

Incorrect flip (X_F)

Incorrect transformation other than rotation or flip (X_O)

Incorrect "not the same" response (X_{NS})

ii. Execution;

Correct (C) and, for rotations,

Correct rotation (C_R)and Correct double flip (C_{FF})

Correct trial and error double flip (C_{TEFF})

Correct trial and error (C_{TE}

Incorrect "not the same" (X_{NS})

b) Congruence strategies - strategies were divided into five basic categories as follows:

i. Incorrect/Vague (I/V) - children either incorrectly judged the congruency/ incongruency of triangle parts or they based their judgements on vague similarities such as "they're the same size (shape)".

ii. Correct "overall" (C_O) - children's reasons are more specific but they are

"overall" in that they do not match specific parts. Statements in this category include "It's shaped overall like a rectangle," "You can turn it over," and "The sides are the same on both triangles." This strategy has a relatively low incidence. It was therefore generally combined with the following strategy (see under "combinations" below).

iii. Correct part (C_P) - children correctly matched a part common to both triangles.

iv. Correct parts (C_{PS}) - children correctly matched more than one part of the same type (sides or angles) common to both triangles.

v. Correct angle/side (C_{AS}) - children correctly matched both sides and angles common to both triangles.

Combinations of the above strategies have been made for each type of transformation so that for the:

Flip: Correct match of congruent parts = Correct parts + Correct angle/side. ($C_{CS} = C_{PS} + C_{AS}$).

Flip and Rotation: Correct match of

overall figure or one specific part. The latter dominates here. Correct part/ overall = Correct "overall" + Correct part ($C_{Po} = C_o + C_P$).

Table 23

Static Triangle Task: Congruence Judgements - Average Percentage of Correct Responses per Age (in years) Group[a] as a Function of Transformation Type and Sightedness

		Transformation Type[b]			
Group	n	F	FF	R_S	R_A
Sighted	24	93	60	86	40
Blind	23	87	18	67	39

[a]Age groups were 5 to 7, 8 to 10, 11 to 13, and 14 to 16 years of age. [b]Codes for transformation types can be found in Table 22 (2a). Briefly: F - flips, FF - false flips, R_S - symmetrical rotations, R_A - asymmetrical rotations.

Sighted/blind patterns were similar--both groups of children seemed most likely to judge arrays which were symmetrical (flip, symmetrical rotations) or close to symmetrical (false flip) as congruent. Asymmetrical arrays (rotations) were judged as not congruent. Within the symmetrical groups (flip, symmetrical rotations), particularly in the 5- to 10-year-old age group, mirror image arrays were slightly easier (flip: sighted = 86%, blind = 80%) than arrays that were not mirror image (symmetrical rotations: sighted = 73%, blind = 65%). Sighted and blind children in most age groups had difficulty seeing the asymmetrical rotations (sighted = 40%; blind = 39%) as congruent. They differed somewhat in their response to the nearly symmetrical false flip arrays. The sighted had some difficulty seeing the triangles as different in the younger years, but the blind generally did very poorly here (sighted = 60%; blind = 18%). The reason for this discrepancy in judgement will be explored further in the following section related to children's understanding of flip transformations.

Flip Transformations. We first compared the transformational success and processes that blind and sighted subjects brought to bear on the true flip task (Table 24). Both statistical and qualitative percentage data analyses were done. Statistical data was obtained using an ANOVA design with 2 between subject variables of sight (2 levels) and age group (4 levels). An ANOVA was done for each of 2 task demands (imagination and execution of the transformation intervening

Table 24

Static Triangle Task - Flip: Transformational Strategies as a Function of Age (in years) Group, Condition of Sight and Task Demands[a] (in percentages)

		Strategies[b]						
		Imagination				Execution		
Age	n	X_{NS}	X_O	X_R	C	X_{NS}	C_{te}	C
		Sighted						
5-7	6	17	0	17	66	22	11	67
8-10	6	11	0	0	89	11	0	89
11-13	6	0	0	0	100	0	0	100
14-16	6	6	0	0	94	6	0	94
		Blind						
5-7	3	34	22	33	11	78	0	22
8-10	5	7	13	33	47	60	7	33
11-13	5	14	0	33	53	40	0	60
14-16	10	17	7	13	63	33	4	63
17-19	10	3	4	15	78	7	15	78

[a]Task Demands include imagining and executing the intervening transformation. [b]Codes for transformational strategies are given in Table 22 (2a). Briefly: X_{NS} - not the same, X_O - incorrect transformation other than rotation, X_R - incorrect rotation, C_{te} - correct by trial and error, C - correct.

between triangle end states). Percentage data can be seen in Table 24 and shows transformational success and strategies as a function of sight, age group and task demands.

Statistical results show that the sighted do better than the blind on the flip transformation in both imagination ($F [1, 46] = 17.47$ $p < .001$) and execution ($F [1, 46] = 15.54$ $p < .001$) conditions. Examining percentage data using a qualitative analysis, it seems that for the sighted, the flip transformation appeared in the early years with most (67%) of the errors occurring in the 5- to 7-year-old age group. On the other hand, blind children, especially those between the ages of 5 and 10 years, seemed to find this transformation difficult (average = 28%). They achieved moderate success at 11 years old (60% in execution) and greater success at 17 years of age (78%). Examining transformational errors, it is of note that, in the 5- to 13-year-old blind group, 33% of the subjects saw the flip as a rotation (X_R).

We also examined children's reasons (strategies) for declaring the arrays congruent and qualitatively examined how these reasons interacted with their overall transformational performance. (See Table 22 for coding of congruence strategies [2b] and overall performance [1c].) The data for congruence strategies (Table 25) were organized using an ANOVA-type model with 2 between subject variables of sight (2 levels) and age group (4 levels). This nonsignificant percentage data indicated that, for sighted children, there appeared to be a progression of strategies for judgement. The 5- to 7-year-olds

Table 25

Static Triangle Task - Flip: Congruence Strategies as a Function of Age (in years) Group and Condition of Sight (in percentages)

		Strategies[a]		
Age	n	I/V	C_{po}	C_{cs}
		Sighted		
5-7	6	66	17	17
8-10	6	28	50	22
11-13	6	0	44	56
14-16	6	0	61	39
		Blind		
5-7	3	56	44	0
8-10	5	33	27	40
11-13	5	27	33	40
14-16	10	6	47	47
17-19	10	11	41	48

[a]Codes and descriptions of congruence strategies can be found in Table 22 (2b). Briefly: I/V - incorrect match of parts/vague, C_{po} - Correct match of one part or overall match, C_{cs} - correct match of congruent parts.

incorrectly matched parts or made vague comparisons by size or shape (I/V = 66%). Older 8- to 10-year-olds progressed to matching one part of the stimulus or noting overall characteristics of the stimulus array such as its rectangular form (C_{PO} = 50%). In the oldest groups (11- to 16-year-olds), 100% of the judgements were based on either one part/overall (C_{PO}) strategies seen in the 8- to 10-year-olds or on strategies matching various congruent parts of the stimuli (C_{CS}). For the blind group, less progression in the strategies could be seen. A drop in incorrect/vague strategies was seen at 8 years old (56% to 33%) and again at 14 years old (27% to 6%). Strategies matching one part or the overall array (C_{PO}) fluctuated but strategies matching congruent parts (C_{CS}) remained somewhat consistent after 7 years old (40% to 48%) so that, at 14 years old, the combination of the latter two (more mature) strategies peaked at 94%.

We examined the interaction between these congruency strategies and overall performance (Table 26) for each condition of sight using percentage data only (nonsignificant). The results showed that, for the sighted there was little relationship between the two save that the highest level strategies matching congruent parts (C_{CS}) yielded no "not the same" (X_{NS}) responses. In contrast, blind children's verbal strategies appeared to be more related to their performance. Incorrect/vague (I/V) strategies which made up 20% of the total responses seemed more likely, proportionately, to result incorrectly in "not the same" (X_{NS})

Table 26

Static Triangle Task - Flip: The Relationship of Congruence Strategies to Overall Performance as a Function of Sightedness (in percentages)

	Strategies[a]			
Performance[b]	I/V	C_{po}	C_{cs}	
	Sighted n = 24			
				(% Tot. Perf.[c])
X_{NS}	4	6	0	(10)
C_{te}	1	4	1	(6)
C	17	35	32	(84)
(% Tot. Strat.[d])	(22)	(45)	(33)	(100)
	Blind n = 33			
				(% Tot. Perf.[c])
X_{NS}	14	15	7	(35)
C_{te}	1	6	5	(13)
C	5	19	28	(52)
(% Tot. Strat.)	(20)	(40)	(40)	(100)

[a]Codes and descriptions of congruence strategies can be found in Table 22 (2b). Briefly: I/V - incorrect match of parts/vague, C_{po} - Correct match of one part or overall match, C_{cs} - correct match of congruent parts. [b]Codes for overall performance are: X_{NS} - not the same, C_{te} = correct by trial and error, C - correct. [c]Percentage of total performance. [d]Percentage of total strategies.

judgements (70%). The highest level congruent parts (C_{cs}) strategy which makes up 39% of the total responses seemed more likely to result in correct judgements (70%).

In sum, it appears, at this point, that blind children had difficulty understanding the flip transformation until they could analyze the stimulus to such a degree that they were able to correctly identify at least one part common to both triangles. Sighted children, in contrast, seemed to easily discern flip transformations even without strong analytical skills, which appeared in the 11 year old group. In order to verify this tentative conclusion we examined data from the false flip transformation.

The false flip (Imagination) task (Table 27) data led to a modification of the above tentative conclusions. Only percentage data are presented. Table 27 shows the percent of imagined transformational strategies (See Table 22, 2ai for coding) as a function of age group and sight for the false flip transformation. This nonsignificant percentage data was analyzed qualitatively using an ANOVA type model with two between subject variables of sight (2 levels) and age group (4 levels).

Both sighted and blind children seemed to react to the false flip task similarly to the way they reacted to the flip task until they were, respectively, 11 (sighted) or 17 (blind) years of age when correct responses prevailed. The younger sighted tended to see the false flips as flips (X_r = 50% for 5- to 10-year-olds) until 11 years of age. Five- to ten-year-

Table 27

Static Triangle Task - False Flip: Transformational Strategies as a Function of Age (in years) Group and Condition of Sight (in percentages)

		Strategies[a]			
Age	n	X_o	X_R	X_F	C
		Sighted			
5-7	6	0	17	50	33
8-10	6	0	8	50	42
11-13	6	0	0	0	100
14-16	6	0	0	0	100
		Blind			
5-7	3	33	50	0	17
8-10	5	20	40	20	20
11-13	5	0	40	50	10
14-16	10	0	25	40	35
17-19	10	0	6	44	50

[a]Codes for transformational strategies are given in Table 22 (2ai). Briefly: X_o - incorrect transformation other than simple rotation or flip, X_R - incorrect rotation, X_F - incorrect flip, C - correct.

old blind children tended to see the false flips as rotations (X_R = 43%). For the blind, flip (X_F) responses appeared at 11 (as in the flip transformation) and remained strong (45%). Only in the 17- to 19-years-old group did 50% of blind children correctly perceive these stimuli as noncongruent.

Strategy data (not shown) for congruency judgements in the false flip task showed that 70% of both blind and sighted children either correctly or incorrectly compared noncongruent parts of the triangle pair. For sighted children using this strategy, 86% of 5- to 7-year-olds, 57% of 8- to 10-year-olds and only 5% of 11- to 16-year-olds declared these noncongruent parts to be the same. Blind children using this strategy showed a more protracted and less differentiated development. Here 93% of 5- to 13-year-olds, 66% of 14- to 16-year-olds and 47% of 17- to 19-year-olds saw these noncongruent parts as the same. It appears then that, with age, blind children had far more difficulty than sighted children differentiating similar but noncongruent parts of a stimulus.

In sum, the flip and false flip data, when examined as a whole, suggested that only at 11 years of age, were sighted children fully able to analyze the stimulus, and, as a result, understand and implement the criteria for determining congruence between 2 similar stimuli in mirror image relationship to each other. The blind children's responses were more complicated. Data from the flip task suggested that blind children in the 11- to 13-year- old, group analyzed stimuli holistically, sufficiently matching parts, so that

they could correctly bring together or superpose congruent mirror image stimuli. However, as data from the false flip task reveal, this holistic analysis was not necessarily a quantitative analysis but rather an ability to perceive the 2 stimuli as similar integrated wholes which could be related. A quantitative analysis is evident in the oldest 17- to 19-year-old group, when children were able to distinguish flips from false flips. The earlier holistic analysis, however, appeared to bring blind children from 2-dimensional perception to 3-dimensional thought so that they shifted from perceiving stimuli in mirror image relation as rotations (2-dimensional) to seeing them as flips--transformations in a dimension less directly perceived by the blind.

Rotational Transformations. In the symmetrical rotation tasks as in the flips, we compared blind and sighted children's performance and strategies and the interactions between the two. For the asymmetrical rotations we focused primarily on overall performance and noted interactions between congruence strategies and overall performance which were of importance. For each set of rotations in each condition of task demand (imagination, execution), we tested for differences between groups using an ANOVA design with 2 between subject variables of sight (2 levels) and age group (4 levels). Statistically there was no difference between blind and sighted groups for symmetrical or asymmetrical rotations. In order to understand the latter finding, we looked at performance strategies using an ANOVA-type model with two

between subject variables of sight (2 levels) and age group (4 levels) and one within subject variable of task demand (2 levels). We obtained only nonsignificant percentage data here.

Regarding the symmetrical rotations, Table 28 shows children's transformation strategies (in percentages) as a function of sight, age group and task demand. For the latter, children were asked to both imagine and, later, to execute the transformation intervening between end states. Examining the children's responses (for coding see Table 22, 2a) it appears that until 14 years of age, the sighted saw rotated triangles, which were in a symmetrical relationship, as flips. They first (5 to 10 years of age) imagined the intervening transformation as a flip to match one congruent part of each triangle (X_{FC} = 38%) and executed this match correctly with trial and error flips (C_{TEFF} = 42%). Later, in the 11- to 13-year-old group, they "correctly" perceived that the 2 triangles could be brought together by a double flip involving 2 congruent parts (C_{FF} = 42%). At 14 years old, sighted children were able to image and execute the intervening rotational transformation (C_R: average = 54%).

Blind children's responses followed the pattern seen in their responses to the flip and false flip tasks in that younger blind children imagined these transformations--"correctly" in this case--as rotations (8- to 13-year-olds = 45%). At approximately 11 years old, flip responses matching one part appeared (X_{FC} = 35%), and at 14 years old some correct double flip responses (C_{FF} = 18%) were also evident. This 11-

Table 28

Static Transformation Task - Symmetrical Rotations: Transformational Strategies as a Function of Age (in years) Group, Condition of Sight and Task Demands[a] (in percentages)

		Strategies[b]									
		Imagination					Execution				
Age	n	X_m	X_o	X_{rc}	C_{rr}	C_s	X_m	C_{rs}	C_{rsrr}	C_{rr}	C_s
					Sighted						
5-7	6	33	8	38	0	21	37	0	42	0	21
8-10	6	17	8	38	25	12	21	0	42	25	12
11-13	6	4	4	25	42	25	4	0	25	42	29
14-16	6	0	12	17	17	54	0	0	17	33	50
					Blind						
5-7	3	50	17	0	0	33	58	17	0	0	25
8-10	5	20	20	5	5	50	40	5	5	5	45
11-13	5	20	5	35	0	40	35	15	20	0	30
14-16	10	25	10	20	18	27	42	7	5	23	23
17-19	10	28	3	25	0	44	34	11	8	0	47

[a]Task Demands include imagining and executing the intervening transformation. [b]Codes for transformational strategies are given in Table 22 (2a). Briefly: X_m - not the same, X_o - incorrect transformation other than X_{rc}, X_{rc} - incorrect flip to a congruent part, C_{rs} - correct by trial and error other than C_{rsrr}, C_{rsrr} - correct by trial and error double flip, C_{rr} - correct double flip, C_s - correct rotation.

to 16-year-old increase in flip responses was accompanied by an age-related drop in rotational responses to 25%. In the 17- to 19-year-old group, rotational responses (C_R) rose again to approximately 46%.

Contrasting blind children's responses under conditions of imagination and execution, 5- to 7-year-olds had an approximately equal number of "not the same" responses (average = 54%) in both conditions. However 8- to 16-year-olds, who appeared more likely than 5- to 7-year-olds to imagine the triangles as the same, had difficulty executing a transformation when their original concept of the intervening transformation (e.g., flip) did not render the triangles congruent. Instead of the prolonged trial and error period seen with the sighted, they tended to give up relatively quickly and incorrectly declare the 2 triangles to be "not the same". Thus, unlike the younger sighted children who were correct by trial and error, 8- to 16-year-old blind children were less likely to do well on tasks of execution than in tasks of imagination regarding the judgement of "sameness" (Incorrect "not the same" [X_{NS}]: imagination = 22%, execution = 39%).

Comparing the two groups on the symmetrical rotations task, both sets of children appeared to follow patterns similar to those found in the flips and false flips. The younger sighted children saw these symmetrical rotations as flips--simple and then multiple. At the age of 14, flips and rotations became differentiated. Young blind children saw

these transformations as "rotations", and at 11 years old the concept of a more 3-dimensional flip appeared. At 17 years old, they again viewed these intervening transformations as rotations. Thus both blind and sighted groups seemed to have similar age-related patterns in that these transformations were seen as flip relationships between parts prior to being understood as rotations under both imagination and execution conditions. The groups appeared to differ in that younger blind children were more likely than sighted children to act as though these transformations were "rotations." However, they were less likely than the sighted to be able to superpose the triangles, even by trial and error, when they had correctly judged them initially to be the same.

We also examined congruency strategies (Table 29) used by the sighted and blind groups, using an ANOVA-type design with two between group variables of sight (2 levels) and age group (4 levels). Only nonsignificant percentage data were obtained. Codes for congruence strategies can be found in Table 22, 2b. We noted strong similarities between the two 5- to 10-year-old groups. 5- to 7-year-old blind and sighted children tended to use incorrect/vague strategies (sighted = 58%, blind = 67%). At 8 years of age, a mixture of strategies was seen, the majority of which (approximately: 67% sighted, 55% blind) matched at least one congruent part of the stimulus pair. At 11 years of age, blind and sighted children differed. Sighted children had a sharp drop in incorrect/vague strategies (I/V: 33% to 4%). Thus, about 90% of sighted children now used

Table 29

Static Triangle Task - Symmetrical Rotations: Congruence Strategies as a Function of Age (in years) Group and Condition of Sight (in percentages)

		Strategies[a]			
Age	n	I/V	C_{PO}	C_{PS}	C_{AS}
		Sighted			
5-7	6	58	34	4	4
8-10	6	33	38	25	4
11-13	6	4	54	38	4
14-16	6	0	33	46	21
		Blind			
5-7	3	67	33	0	0
8-10	5	45	30	10	15
11-13	5	40	50	5	5
14-16	10	30	47	8	15
17-19	10	25	25	39	11

[a]Coding and description of congruence strategies can be found in Table 22 (2b). Briefly: I/V - incorrect match of parts/vague, C_{PO} - Correct match of one part or overall match, C_{PS} - correct match of more than one part of the same kind, C_{AS} - correct match of both angles and sides.

strategies matching one or more parts (C_{PO} and C_{PS}). At 14 years old, there was an increase in those strategies matching two or more parts (C_{PS} and C_{AS}: 42% to 67%) and especially in those strategies matching sides and angles (C_{AS}: 4 to 21%). In contrast to the sighted group, the 11- to 16-year-old blind group predominantly matched one part of the stimulus (C_{PO} = 49%). Only the 17- to 19-years-old group matched 2 or more parts of the stimulus (C_{PS} and C_{AS} = 50%). Thus it appeared that, in relationship to sighted children, blind children were delayed in their ability and/or proclivity to differentiate parts and to establish congruence between multiple parts of stimuli (14 years versus 17 years of age).

The relationship between congruence strategies and overall performance for each blind/sighted group is shown in Table 30. Using percentage data only, there appears to be a nonsignificant close relationship between strategy and performance for both sighted and blind groups. For both, incorrect/vague strategies (I/V: sighted = 24%, blind = 37%) were proportionally more likely to lead to "not the same" responses (63% sighted, 73% blind). Strategies matching one or more similar parts or noting the overall figure (sighted = 68%, blind = 51%) led to a mixture of transformational responses, most of them being either correct or correct by trial and error (C_{TE}). For both blind and sighted groups strategies noting both, angles & sides (C_{AS}: sighted = 8%, blind = 12%) led to a higher proportions of correct rotational responses (C_R: sighted = 63%, blind = 67%).

Table 30

Static Triangle Task - Symmetrical Rotations: The Relationship of Congruence Strategies to Overall Performance as a Function of the Condition of Sight (in percentages)

	Strategies[a]			
Performance[b]	I/V	C_{PO}	C_{PS}	C_{AS}
	Sighted n = 24			
X_{NS}	15	1	0	0
C_{TE}	8	17	13	1
C_{FF}	1	9	9	2
C_{R}	0	12	7	5
	Blind n = 33			
X_{NS}	27	9	2	0
C_{TE}	5	13	5	2
C_{FF}	0	2	3	2
C_{R}	5	11	6	8

[a]Codes and description of congruence strategies can be found in Table 22 (2b). Briefly: I/V - incorrect match of parts/vague, C_{PO} - Correct match of one part or overall match, C_{PS} - correct match of more than one part of the same kind, C_{AS} - correct match of both angles and sides. [b]Performance is coded as follows: X_{NS} - not the same, C_{TE} - correct by trial and error, C_{FF} - correct double flip, C_{R} - correct rotation.

To summarize our qualitative (and thus tentative) findings thus far on children's understanding of symmetrical flips and rotations and near symmetrical (false flip) arrays, it appears that blind and sighted children's understanding of rotational transformations followed their patterns for understanding transformations between triangles related by flip transformations or a false flip "transformations". Young sighted children (5- to 10-years of age) tended to see all triangles in true or false symmetry as flips uniting one congruent part. At 11 years old, sighted children considere more than one part of the stimulus. This was evident in their congruence strategies (flip: multiple parts match - C_{cs}) and their transformation strategies (symmetrical rotations: double flip - C_{FF}). It may also be surmised by the increase in correct responses for the false flip task. At 14 years old, parts of the stimulus were differentiated more flexibly and became integrated (symmetrical rotation: 2 part matches - especially with angles and sides [C_{AS}]). Rotations were now differentiated from flips.

Just as the young sighted children apparently saw the above symmetrical transformations as point-to-point flips, young blind children tended to see them as point-to-point "rotations". The appearance of the flip response at 11 years old for symmetrical rotation, flips and false flip transformations suggested that the two triangles were perceived as generalized wholes in symmetrical relationship. This symmetry now appears to indicate a point-to-point flip

transformation. That the parts of the triangle were not clearly differentiated at this age (11 years) is suggested by strategy data from the symmetrical rotation and false flip transformations. In the symmetrical rotations, children matched only 1 part or noted the overall stimulus configuration. In the false flip, most children matching incongruent parts saw them as the same. Only at 17- to 19-years of age did we see strong symmetrical rotation strategy evidence of blind children differentiating parts of the stimulus. At this age there was also a sharp increase in correct transformational responses in symmetrical rotations, false flips and flips.

For the asymmetrical rotations (R_A) only overall performance will be examined in detail (Table 31) using percentage data only. An ANOVA-type model was used with 2 between subject factors of sight (2 levels) and age group (4 levels). Since double flip (C_{ff}) responses were low (1 per sighted/blind group), they were absorbed into general correct responses. Results are not statistically significant.

Results show different trends for the sighted and blind groups. The sighted group basically viewed these rotations incorrectly as "not the same" (64%). Only in the 14- to 16-year-old group were 75% of the responses correct. The 8- to 13-year-old blind group, as might be expected from their performance on the above transformations, viewed these transformations "correctly" as rotations (45%). This rotational response was less at 14 years old and "not the

Table 31

Static Triangle Task - Asymmetrical Rotations: Overall Performance as a Function of Age (in years) Group and Condition of Sight (in percentages)

		Performance[a]		
Age	n	X_{NS}	C_{TE}	C
		Sighted		
5-7	6	67	25	8
8-10	6	67	8	25
11-13	6	58	17	25
14-16	6	17	8	75
		Blind		
5-7	3	83	0	17
8-10	5	50	10	40
11-13	5	50	0	50
14-16	10	55	15	30
17-19	10	73	0	27

[a]Codes for overall performance are given in Table 22 (1c). Briefly: X_{NS} - not the same, C_{TE} - correct by trial and error, C - correct.

same" responses were 73% at 17- to 19-year-old. There was no resurgence of correct rotational responses (C_R) as seen in the oldest blind group for the symmetrical rotations.

Examining strategy data (not shown) for congruence judgements, strategies contrasting 2 or more parts were few. These strategies were evident only in the 11- to 16-year-old sighted and 17- to 19-year-old blind group and comprised 33% of strategies in these age groups. Generally comparing the relationship between congruence strategies and overall performance, there appeared to be some link between incorrect/vague (I/V) strategies and "not the same" (X_{NS}) responses. Of the "not the same" responses given, 67% of sighted and 82% of blind children responses were associated with incorrect/vague congruence strategies. Two-part strategies yielded a higher level of correct transformational responses than did 1-part/overall (C_{PO}) strategies for the sighted (78% versus 44%), but not the blind (67% versus 71%). Here we must take into consideration that simple one-part-to-one-part congruence strategies often appeared to accompany what seems to be primitive "rotational" responses in blind children.

In sum, sighted children behaved as might have been predicted from symmetrical rotation transformations with rotations correctly appearing at 14 years old. Blind children, however, had no commensurate rotational response at 17 years old as might have been predicted from their symmetrical rotation data. Clearly, for the blind even more than the

sighted, symmetricality seems to be important to transformational understanding. However, since in both groups multiple matches of parts were made earlier in symmetrical than in asymmetrical arrays, it also appears that symmetricality may generally facilitate the process of breaking down the stimulus into parts. This in turn may facilitate transformational knowledge as seen above by the apparent relationship between multiple parts congruence strategies and transformational knowledge. Possible reasons for blind/sighted differences in asymmetric arrays will be discussed below.

Gender differences were also evident in the rotational responses--primarily with the sighted group. These differences, which were not statistically significant, were seen in both symmetrical and asymmetrical rotations. In both groups we will focus on how sighted males and females imagined the intervening transformations. Tables 32 and 33 compare gender responses by age groups on, respectively, symmetrical and asymmetrical rotations using an ANOVA-type model with 2 between group variables of gender (2 levels) and age groups (4 levels). Only nonsignificant percentage data will be presented.

Comparing responses on symmetrical rotations (Table 32), at 8 years of age, males seemed less likely than females to make "not the same" (X_{NS}) responses (0% versus 33%), and more likely to make correct (double flip and rotation) responses (58% versus 17%). Both groups appeared to show an age-related

Table 32

Static Triangle Task - Symmetrical Rotations: Gender Differences in Sighted Transformational Strategies as a Function of Age (in years) Group - Imagination Sub-Task Only (in percentages)

		Strategies[a]				
Age	n[b]	X_{NS}	X_O	X_{FC}	C_{FF}	C_R
			Males			
5-7		33	9	33	0	25
8-10		0	17	25	33	25
11-13		0	0	25	25	50
14-16		0	25	8	8	59
			Females			
5-7		33	8	42	0	17
8-10		33	0	50	17	0
11-13		8	8	25	59	0
14-16		0	0	25	25	50

[a]Codes for transformational strategies are given in Table 22 (2ai). Briefly: X_{NS} - not the same, X_O - incorrect transformation other than a flip, X_{FC} - flip to one congruent part, C_{FF} - correct double flip, C_R - correct rotation. [b]N = 3.

Table 33

Static Triangle Task - Asymmetrical Rotations: Gender Differences in Sighted Overall Performance as a Function of Age (in years) Group (in percentages)

		Performance[a]		
Age	n[b]	X_{NS}	C_{TE}	C
		Males		
5-7		83	17	0
8-10		67	0	33
11-13		67	0	33
14-16		0	0	100
		Females		
5-7		50	33	17
8-10		66	17	17
11-13		50	17	33
14-16		33	17	50

[a]Codes for overall performance are given in Table 22 (1c). Briefly: X_{NS} - not the same, C_{TE} - correct by trial and error, C - correct. [b]N = 3.

pattern of incorrect flip (X_{FC}) → correct double flip (C_{FF}) → correct rotation (C_R). However, males had their strongest correct double flip responses at 8 years old (33%) and females at 11 years old (59%). Similarly, strong correct rotation responses (50%) for males appeared at 11 years old and for females later at 14 years old. Thus, sighted males, again, as in the Triangle Transformation task, appeared to have an advantage in relation to females which appeared in the middle age groups (8 to 13 years). Regarding gender differences in the blind group for symmetrical rotations, no clear patterns could be seen.

In the asymmetric rotations (Table 33), sighted gender differences were again evident. Since these rotations did not engender a strong flip (X_{FC} or C_{FF}) response, we examined overall performance only (for coding, see Table 22, 1c). The data here showed no 8- to 10-year-old male advantage. Instead, both 5- to 10- and 11- to 13-year-old male and female groups had a strong incorrect "not the same" (X_{NS}) response. It was only at 14 years of age that we see gender differences with males having more correct rotational responses (C_R) than females (100% versus 50%). No differences for the blind group were discerned.

Thus it appears that the male advantage in spatial rotations seen in 8- to 10-years-olds and 14- to 16-year-olds in the Triangle Transformation task was again apparent in the Static Triangle task for the sighted group only. Here the male advantage tended to be seen in the symmetrical rotations at 8-

to 13 years of age and in the asymmetrical rotations at 14- to 16-years of age.

Summary: Static Triangle Tasks. Data from the Static Triangle tasks (nonsignificant) suggests that young blind and sighted groups are likely to judge symmetrical and near-symmetrical arrays as congruent and asymmetrical arrays as noncongruent. However, the ability to make fine distinctions between these congruent and noncongruent arrays appears to develop in interaction with their ability to break up the triangle into clear parts which can be correctly matched. For the sighted, the ability to distinguish between flips and false flips occurred at 11 years old. At this age, congruence strategies from the flips and transformational strategies from the symmetrical rotations suggested that children were increasingly able to match two or more congruent parts. Blind children were able to distinguish between flips and false flips at 17 years old, when congruence strategies for symmetrical rotations showed an increase in children matching two or more parts.

Congruence strategies followed similar overall age-related patterns for both groups. For sighted and blind children, lower level incorrect/vague strategies were less evident by 8 years old when children could correctly match one or two parts of the stimulus. For sighted children, at 11 years old the ability to match 2 parts of symmetrically oriented stimuli was evident. At 14 years old this multiple matching strategy became dominant with symmetric and, to a

lesser degree, asymmetric rotations and included both angles and sides. Blind children at 11 years of age matched only one part with rotations and one or two parts with flips. Only at 17 years of age did blind children make strong multiple matches with rotations and this was more prevalent in symmetrical rotations. Given the differences in strategies between symmetric and asymmetric arrays, it appears that symmetrical arrays may facilitate the process of breaking figural wholes into parts. For both blind and sighted subjects, multiple matches were made earlier and with more frequency in symmetrical rather than in asymmetrical arrays.

Transformational knowledge showed a similar age-related pattern, which differed somewhat for blind and sighted groups. Younger sighted children tended to view all of the symmetrical triangle pairs as potential flip transformations bringing together a common part. At 11 years of age, flips and false flips were differentiated and rotations were more likely to be considered double (2 part) flips. Only at 14 years of age were symmetrical rotations differentiated from flips and asymmetrical rotations declared to be congruent and in rotational relationship to each other. In contrast, young blind children tended to view transformations as rotations. Only at 11 years old did blind children perceive symmetrical transformations (including rotations) as flips, and only at 17 years of age were flips, false flips and symmetrical rotations differentiated. Blind children did poorly on asymmetric rotations.

Regarding the possible interaction between congruence criteria and transformational knowledge we see both specific and general evidence in support of this interaction. For rotations, incorrect/vague strategies were linked with "not the same" responses, whereas strategies matching angles and sides tended to be associated with correct rotational responses. In the blind group, strategies matching congruent parts tended to be linked with correct flip responses (difficult for the blind). Other more general evidence also supports an interaction between congruence criteria and transformational knowledge. The sighted were able to differentiate flips and false flips at 11 years of age at the same time that congruence criteria (single/multiple parts match) and transformational strategies (double flips for rotations) suggest that triangles were being increasingly broken down into clear parts. Rotational transformations were understood at 14 years, when sighted children's rotational congruence strategies were dominated by multiple comparison criteria, with clear evidence of children using both angles and sides in their verbal judgements. For blind children, a clearer relationship between congruence criteria and transformations occurred at 17 years of age, where there is evidence of more multiple comparison strategies in symmetrical rotations and, also, a greater understanding of rotations, flips and false flips. That symmetrical arrays can be considered holistically by the blind prior to this time, at 11 years of age, was suggested by the increase in flip

transformations here. However, the absence of a full quantitative analysis of the figure at this point is indicated by the delay in flip and false flip differentiation until 17 years old.

Thus, blind and sighted children appear to be similar in several ways. Incorrect/vague strategies were seen in the youngest 5- to 7-year-olds and then 1- and 2-part comparisons at 8 years of age. Both groups appeared to analyze the stimulus more holistically at 11 years of age. Regarding rotations, both perceived rotations to be flips between one and two parts of the stimulus before fully understanding them as rotations and, for both, the ability to make multiple comparisons tended to coincide with a stronger understanding of rotations. Blind and sighted children differed in that early one-part comparisons of triangles tended to result in primitive flips for the sighted and primitive rotations for the blind. Holistic analysis at 11 years of age seemed to be quantitative for the sighted but not for the blind, leading to an earlier differentiation of flips and false flips for the sighted. True rotations appeared earlier for the sighted than the blind and asymmetric rotations were difficult for the blind.

Gender differences were seen mostly in the sighted and only with rotations. In the symmetrical rotations, sighted males tended to show more advanced congruency strategies in the 8- to 13-year-old group and although both genders showed an age-related pattern of transformational strategies, more

sophisticated strategies were evident at an earlier age in males. In the asymmetrical rotations, sighted males appeared to do better than females only at 14 years old, where their responses were 100% correct. This age pattern mimics the male advantage age pattern seen in the Triangle Transformation task.

Task 4: Static Disc Task

Only a few points of interest in the Static Disc task (Fig. 3) results will be noted. As above, our analysis here will be qualitative and based on percentage data. One point of interest is that young sighted and blind children both saw all flip and rotational transformations basically as rotations. Rotational responses for flips was most evident in the 8- to 10-year-old group (75%) for the sighted, and the 11- to 13-year-old group for the blind (70%). These peak responses coincided with the ages at which sighted (61%) and blind (80%) realized that the noncongruent discs were "not the same". This suggested an increase in ordering strategies here and that these ordering strategies may be linked to rotational responses. That the blind were delayed in regard to the sighted appeared to be due to their inability to hold a referent point while ordering.

At the next stage, transformations were generally seen as flips--more evident with the sighted than the blind. Thus 100% of 11- to 13-year-old sighted children and 37% of 14- to 19-year-old blind children saw the "opposite" 180° rotation as a

flip. This suggested that the stimulus was now understood holistically as "opposite" and broken down into parts that were being matched, but parts and whole were not integrated. At 14 to 16 years of age, sighted children again, as in the younger 5- to 10-years, saw the 180° rotation as a rotation (67%), suggesting an integrated analysis of the stimulus. Blind children continued to do poorly here (14- to 19-year-olds = 37% correct).

Results from the Static Disc and Static Triangle tasks suggest at least three points. One, the configuration of the stimulus, especially with younger children, can determine transformational response (triangles = flip; disc = rotations). Secondly, this response may depend on the type of perceptual experience which the child had with the given stimuli (e.g., sighted perceive "flip" earlier). Finally, different levels of figural analysis can be linked to a piecemeal type of transformational knowledge (e.g., some flips or some rotations). However, for full transformational understanding, an analysis of parts reintegrated into the whole appears to be necessary.

General Discussion

The intent of this study was to understand children's developing knowledge of congruence. However, knowledge of congruence implies some understanding of transformations (i.e., that arrays can be transformed in space and still be congruent). According to Piaget (1979), this transformational

knowledge may entail being able to represent transformations and/or being able to establish correspondences across transformations. Thus we studied children's ability to mentally represent directly experienced transformations as well as transformations that were not experienced but were presumed to intervene between two perceived end-states. In addition, we examined children's ability to set up correspondences between end-states and looked at the relationship between this ability and the child's understanding of transformations. Within this framework, we focused on how different perceptual experiences (sighted/blind) affect this development. We also examined how gender and task differences influence this knowledge. Our results corroborate and extend the findings of other researchers and will be discussed in relation to our hypotheses and, later, in relation to a general statement regarding the development of transformational knowledge.

Before discussing our results, it should be noted that many of our results were based on percentage data and were not statistically significant. This occurs for three reasons. Given the nature of the subject population we often had insufficient numbers of children in the different age groups to make statistical comparisons. Also, our measures (correct/wrong) often did not provide the necessary variability for statistical analysis. Finally, we sometimes examined percentage data when no statistical significant was seen but percentage results were, nonetheless, in a direction

of interest. Significant results were found only for Hypothesis 2 which was concerned with the effects of individual and task factors on transformational knowledge. The remaining results which were not significant (n.s.) will be identified as such.

Our discussion will first focus on our hypotheses regarding children's knowledge of transformations (Hypotheses 1 and 2). We will then discuss children's knowledge of correspondences (Hypothesis 3) and, subsequently, the relationship between transformational and correspondence knowledge (Hypothesis 4). We will then attempt to integrate these into a general statement of transformational development.

Regarding transformational knowledge, our first hypotheses posited a developmental progression such that movement → space/cues → Euclidean space. The latter was to be achieved at 11 years of age. However, in our second hypothesis, we proposed that certain individual factors (sightedness, gender); task factors (task demands, transformational demands, rotational extent); and, stimulus factors (transformational type, familiarity, structure) would, alone or in interaction with other factors, affect transformational knowledge. Since Hypotheses 1 and 2 are interactive, some task and individual differences will be discussed in general as they impact on Hypothesis 1. We will then dwell in more detail on the differences posited in the various subhypotheses contained in Hypothesis 2.

Hypothesis 1. As noted above, we proposed that, regarding transformational knowledge, children would first understand transformational movement and then, at approximately 7 or 8 years of age, have a general representation of space which would be supported by cues. Finally, at 11 years, full representation of Euclidean space would emerge. It appears from our strategy data (which were based on percentages only and were not significant [n.s.]) that whether on not this is a good model of developing transformational knowledge depends very much on the factors delineated in Hypothesis 2. One factor affecting this pattern was the transformational demands of the task (replicating versus identifying intervening transformations). Other factors include the gender of the subject, whether or not cues were available and also, perhaps, how one defined cue use. At this point, we will discuss our hypothetical model only in terms of one set of transformational demands--replication (Triangle Transformation task and Familiar Object task). This was done for two reasons. One, most of the experimental variables posited to affect transformational knowledge were tested only in the replication condition. Secondly, the proposed model appeared to be most applicable to children's ability to replicate the transformation of a hidden object (transformation but not object is observed). We will discuss the results from the remaining transformation tasks later in the section concerning transformational variations (Hypothesis 2).

In the results section we noted that several strategies

were used by subjects to do the Triangle Transformation rotation tasks. The most prevalent were movement, place, partially correct and correct responses. We interpreted both place and partially correct responses as instances of cue use. Place responses combined general rotational responses with cues from the table. Partially correct responses appeared to indicate that the child knew the general spatial extent of the rotation but confused the boundaries of the triangle and the envelope (thus using envelope cues). Alternately, during this strategy the child may have been using cues from his body or from the edge of the table, both of which are parallel to the horizontal edge of the envelope and also to the edge of the triangle (under a partially correct error).

Given our definition of cue use it appears (n.s.) that males but not females followed the proposed pattern of transformational development and followed it most precisely under high cue conditions. For both blind and sighted males movement responses were prevalent in the early years (5-7), partially correct responses (spatial + cues) were seen in the middle years (8-10) and correct responses appeared at 11 years of age. With the advent of more spatial responses (8 years), nonalignment errors declined. Females went from predominantly movement responses to correct responses at 11 years. At this point, nonalignment responses also declined. No spatial + cue stage was seen.

Under low cue conditions an age extended version of the hypothesized progression tended to be seen in sighted males

(n.s.). Spatial + cue responses appeared from 8 to 13 years and were again accompanied by the decline of nonalignment responses. Correct responses appeared now at 14 years. Blind males had correct responses at 14 years but less progression was seen in their responses due perhaps to the low number of subject (n = 5) in the 5- to 13-year-old group. Blind and sighted females did poorly showing little or no progress toward more correct responses. Nonalignment responses change little under different cue conditions--especially with the sighted.

This data suggest that optimally, transformational knowledge may develop in four stages for both blind and sighted children. However, depending on other factors, all of these stages may not be seen. In the earliest stage children appeared to be able to represent the given movement, transitively inferring the movement of the object from the movement of the envelope. These data appeared to support the work of Dean (1979) and Dean et al. (1986) which indicated that transformational thought preceded more precise imagery of transformations. However, further analysis of our data showed that knowledge of transformational movement seemed uncertain prior to about 11 years of age (or older). From 5- to 7-years of age verbal spatial errors were seen in which children confused concepts of the spatial and verbal "opposite." Also, in the 8- to 10-year-old age group, sighted children replicating the transformations of familiar objects ignored the observed transformation in order to get to the apparent

end point (incorrect) by means of an erroneous transformation. In both of the above cases the actual transformation was observed by the child. When children tried to imagine transformations intervening between end states (to be discussed below), they fared even worse in their knowledge of transformational movement. In essence, it appears the young (5- to 10-year-old) children can represent the movement of an observed transformation but that other factors such as the salience of the end state position may take precedence. This would support, to some degree, the findings of Moyers and Johnson (1978) where children of this age focused on end states and ignored transformation even after training in the latter.

In the second apparent stage of transformational development, general partial spatial knowledge appeared but it was cue dependent. Partially correct errors were prevalent here. This stage appeared only in males and at this point males could and did use (we assume) the perpendicular reference from the beginning and end state of the envelope (or table) to properly align the end state of the triangle on the perpendicular axis.

The next proported stage seemed to appear at approximately 11 years of age. Space was now holistic (270° could be represented) and analytical (in 90°c, the boundaries of the triangle and the envelope could be differentiated). However, external cues seemed to be needed to support these processes. Males and females succeeded at this stage. Only at

this point did females appear to use the perpendicular reference from the envelope (or table).

In what appears to be the final stage, beginning at 14 years of age, children seemed to be able to impose their own frame of reference on the array and external cues became unnecessary to transformational representation. In the triangle transformation task only males were successful here but in the familiar objects tasks sighted females were also successful. This suggests that there may be at least two aspects to transformation tasks--encoding and transforming. We will discuss this below in the section on stimulus variables (familiarity) in Hypothesis 2.

Of primary interest here is the fact that, even given the limits of the qualitative analysis, there were few blind/sighted differences seen in this pattern of development. This lends some support to, first of all, Piaget's notions of universal cognitive structures. It also to some degree supports Jones (1975) and Juurmaa's (1972) contention that all of the senses are capable of being spatially patterned. Moreover, the given data do not support the idea that blind children will be necessarily delayed because of the increased memory load necessary to integrate parts of the stimulus. (Juurmaa, 1972, Millar, 1976). Instead, these tentative results are in line with other studies which found that some blind children of all ages behave almost exactly like their sighted peers (Birns, 1986; Casey, 1978; Fletcher, 1980; Hermelin et al., 1972). On the other hand, although the

overall developmental pattern is similar for blind and sighted children, we also found differences in performance which will be elaborated upon in the sections relating to blind/sighted differences in Hypothesis 2.

Also of interest was the fact that there was little variation with cue condition in the ages at which, nonalignment responses disappeared. For boys this tended to be 8 years of age and for girls, 11 years of age. At these different points, it appears that each of the groups began to use cues to fix the spatial transformations. Cues of perpendicularity did not change over cue conditions and thus, neither did the ages at which children ceased their nonalignment responses.

Additionally, of note is the male's decided advantage over females in the 8 to 10 age group (significant for the sighted). We would suggest here that this is because, at an early age, males more than females use their body as a spatial referent to analyze parts of the stimulus. In contrast, females appear to rely on cognitive analytic structures which emerge at approximately 11 years old (Piaget et al., 1967) to do these same tasks. This will be discussed below in relation to gender differences (Hypothesis 2).

Hypothesis 2. It is clear from the above that certain variables such as gender and cues can have some effect on overall transformational knowledge. That experience can affect mental imagery and therefore transformational knowledge has been noted by Inhelder (1979). Lesh (1976) points out that

task variables also affect our ability to do transformations. Further, Mayers (1982) notes that, we must try to understand how and why these variables affect knowledge. Given the above, we chose to study how certain individual variables, task variables and stimulus variables affected transformational knowledge. Specifically, we posited that differences due to the condition of sightedness would occur in four areas--cue use, effect of rotational extent, response to recognition demands and the effect of transformational type (flip, rotation). No differences due to sightedness were expected for variations in stimulus familiarity or structure. Nor did we expect blind/sighted differences in the way in which transformational types (flips, rotations) interacted with transformation demands (replication, intervening transformations). We made no statement regarding blind/sighted differences in gender responses. We will first discuss those variables for which we posited sighted/blind differences.

Regarding sighted/blind differences in spatial knowledge, differences favoring sighted children have been found in the literature and in our data. Piaget suggested that these differences could be due to delayed sensory motor coordinations and that blind children would be capable of eventually catching up to sighted children. Other researchers have attributed these differences in spatial skills to more specific causes. In essence they see the sighted as having several possible advantages over the blind. First, the sighted can use external cues and thus establish external frames of

reference (Birns, 1986; Millar, 1982; Simkins et al., 1979). Secondly, they note that the sighted children's greater experience may give them a richer storehouse of mental images (Juurmaa, 1972)--especially mirror images (Birns, 1986). Third, the sighted can clearly benefit from visual feedback (Warren, 1984). Conversely, blind children are said to use a self-referent system, have a poorer store of mental images, and use perceptual feedback only with difficulty. Our research shows sighted/blind differences (significant and nonsignificant) in two hypothesized areas: cue use (n.s.) and imagery (significant); and, two nonhypothesized areas; use of perceptual feedback (n.s.) and reference systems (n.s.). These will be discussed below.

Cues. Our hypothesis regarding cue use also involves rotational extent. We posited that under high cue conditions only the blind would be negatively affected by increasing rotational extent. However, under low cue conditions we expected both groups to be similarly affected so that rotations of small extent would be easier than those of large extent. This was based on Millar's papers of 1976 and 1982. In 1976, she hypothesized that the sighted/blind discrepancy in rotational performance which she observed in her own study was due to the fact that the blind use moment memory and that the sighted use visual regeneration to do these tasks. Since movement memory decays rapidly over time and space, larger rotations would be more difficult to remember than smaller rotations. Visual regeneration, being neither time nor space

dependent, should not be affected by rotational extent. In 1982, Millar, in a different context, noted that the sighted were more likely than the blind to use external cues (a position supported by data from Birns, 1976, and Simpkins et al., 1979). This notion led to our hypothesis that it was external cues and not visual regeneration that was responsible for Millar's (1976) sighted/blind differences in rotational extent. Thus, under low cue condition we expected these differences to disappear. We also expected the sighted to be most affected by low cues in the 8- to 10-year-old range before knowledge of Euclidean space emerged.

Our results on the Triangle Transformation and Familiar Objects tasks were mixed under high cue conditions and did not necessarily resemble the pattern seen in Millar's study but overall the sighted did somewhat better (n.s.) than the blind. We suggest that this pattern difference was due to the fact that our tasks differed considerably from Millar's. However, our results under low cue conditions were precisely as hypothesized (n.s.). Sighted/blind performance was equal and 90° rotations were generally easier than 270° rotations for both groups (significant for the Familiar Objects task only). Qualitatively, for the Triangle Transformation task, this difference occurred under conditions of recognition as well as recall. Only the 90°c/recall transformation appeared difficult here but when analyzed for errors, 90°c/recall was, for the most part, at least partially correct in the early years suggesting that a general knowledge of small spatial extent

appears early.

It appeared then that sighted tended to be more affected than the blind by low cues (n.s.) given their somewhat lesser performance under low cue conditions. We had posited an 8-10 year old drop in performance for the sighted due to low cues. However, the relationship of the sighted and the blind with cue use was more complex. It appeared that both blind and sighted children's performance suffered most (n.s.) under low cues in the 11- to 13-year-old age group and then only in the most difficult transformations. At this age, we also see the third stage of transformational development as posited above where full and difficult spatial transformations are represented but cues are needed by blind and well as sighted children to keep spatial parameters intact.

The sighted but not the blind also appeared (n.s.) to use cues prior to 11 years of age. At noted above, with low cues verbal/spatial errors tended to increase for the 5- to 7-year-olds. Also, without strong envelope cues, 5- to 10-year-old sighted children (especially females) appeared to revert to using cues from the table (place cues). That the blind children showed no evidence of using cues prior to 11 years of age may be due to two factors. One, they may not perceive the cues inherent in the rectangular envelope prior to 11 years and secondly, they generally do not perceive distal cues (Gibson, 1978). The notion that blind children do not perceive stimuli (e.g., rectangular envelope) holistically until 11 years of age was suggested by results from the Static Triangle

task. Here the flip relationship began to be perceived at 11 years of age. We interpreted this to mean that each triangle could be viewed holistically and brought together in a more holistic 3-dimensional space. This was also the age at which both blind and sighted children represented transformations holistically (270°). Thus holistic perception of an envelope for a blind child may involve far more cognitive intervention than it requires for a sighted child. This idea is in agreement with Casey (1978) who worked with blind children on cognitive mapping tasks.

We also addressed Millar's contention that the blind/sighted differences which she observed in performance on rotations of large extent were due, respectively, to movement memory and visual regeneration strategies. Our tentative results (n.s.) indicated that blind children did equally well at reaching the approximate locations of large and small rotations regardless of cue conditions. Thus, if they are using movement memory, this, per se, is not responsible for their differential performance on rotations of differing extent. However, 5- to 10-year-old sighted children had strong differences in rotational performance (90° > 270°) due to differing rotational extent but only under low cue conditions. This again suggested strong cue use in younger sighted children. It also suggested that this may be the factor (or at least one factor) in the sighted children's success in Millar's 1976 work--not visual regeneration as posited.

Flip transformation. Supported by research from Birns

(1986) who found mirror image representation poor in blind children, and Perham (1978) who found that knowledge of flip transformations can be enhanced by experience, we posited that the flip transformation would be easier for the sighted than the blind. This was based on the thesis that the sighted would have more experience with mirror image end states emanating from flip transformations. For the most part these results were not seen in the replication tasks (Triangle Transformation and Familiar Object) but were seen (significant) in the Static Triangle task which deals with intervening transformations. The latter result indicated that the sighted may have stronger imagery or knowledge of mirror end states with their intervening transformations.

We suggest that it is possible that these hypothesized sighted/blind differences were not obtained in the replication/flip condition (blind = sighted) because blind children, having experienced the flip movement with the experimenter, simply replicated the given movement with the object having no real image of the transformation or end state. This addresses the issue of experimental clarity. Given the condition of blindness, it is difficult at times to separate motor representation from imaginal representation. A more ideal task to measure flip representation in the replication condition (flips would seem to be easier than rotations to physically mimic) might utilize the apparatus in Piaget's et al. (1971) 180° rotation of beads task (p. 135). Here blind children would directly experience the "flip"

transformation. However, they would have to imagine that a flip would reverse the order of the beads, a reversal which would not be directly experienced during the transformation. That the blind did somewhat more poorly than the sighted on the flip recognition task suggests that the blind may be less likely than the sighted to understand that a flip transformation results in a reversal of position.

Task demands - recall/recognition. We also examined blind/sighted differences in the recognition task. We based our hypotheses here on the work of Inhelder (1979) and Juurmaa (1972). The former noted that the development of imagery depended on the child's experience whereas the latter found blind/sighted differences in object matching (favoring the sighted) which appeared to be solely based on children's familiarity with the objects. This suggested a dearth of objects images or templates for the blind. Given the above, we predicted that the sighted would do significantly better than the blind in the recognition task which we presumed would benefit from enhanced end state imagery. This in fact occurred as predicted. We also expected that only the 5- to 10-year-old sighted would do significantly better on recall than recognition. The latter ages were posited as we expected children to be relying more on end state imagery at these ages and more on cognitive Euclidean thought after 10 years of age. This prediction was qualitatively (n.s.) verified suggesting that sighted children of this age have a greater store of images which they can evoke before more exact Euclidean

derived end state knowledge is present. That the blind have a lesser store of images is understandable from a cognitive as well as an experiential point of view if, as we theorized above, blind children do not perceive entities holistically until approximately 11 years of age.

When the data were qualitatively analyzed (n.s.) for performance on individual transformations, limits were seen on the recall/recognition differences noted above. These differences seen for the sighted were only seen with partial transformations and were also seen to a lesser degree in partial (90°) rotations for the blind. Both blind and sighted groups did considerably better (n.s.) in the recognition condition of the difficult 90°c rotation. These data suggest, as did Perham's (1978) studies, that there are cognitive limits to the benefits of experience. For both groups, only partial transformations can be represented as end state images prior to 11 years of age. That flips showed no recall/recognition differential for the blind suggests, in accordance with Birn's (1986) work, that the blind have a poor store of mirror image concepts.

There were two additional blind/sighted differences which we found that were not specifically addressed in our hypotheses but which were discussed directly or indirectly in our Introduction section. These issues included Warren's (1984) perceptual feedback hypothesis and children's preferential use of reference systems.

Perceptual feedback. Warren's thesis is that the sighted

are at an advantage because of their ability to use visual feedback to correct errors. This appeared to be true in the Static Triangle rotation task where the sighted more so than the blind were able to correct their errors in transformational judgement when allowed to manipulate the stimulus and make correct responses by trial and error. The blind children's inability to do as well as the sighted may be due to their lack of imagery for use as a template to help exploration. Alternately, as noted above, it may be, as Casey (1978) suggests, that cognitive intervention is more important to perception for the blind than the sighted and, as a result, the young blind may be less able than the young sighted to perceive stimuli wholistically. Other data discussed below also suggest that blind children may be further delayed in their ability to make fine differentiations among parts of the stimulus.

Reference systems. The second issue relates to what we believe is the tendency of blind and sighted children to use different reference systems. According to their performance on the given tasks, blind children appear to rely on the self as a reference point whereas sighted children seem capable of using external frames of reference. This idea is supported by the data in which blind but not sighted children seemed to do poorly on tasks (n.s.) that involved dominant lines which were not centered on the perpendicular axis (90°c of Triangle Transformation task, asymmetrical rotations of the Static Triangle task). Blind but not sighted children also had

difficulty establishing an external referent from which to commence ordering (n.s.). We would thus suggest that both younger and older blind children use their own bodies with its perpendicular coordinates as a stationary frame of reference and have difficulty aligning themselves with other reference axes which are not strictly aligned with the body's vertical or which are absent. An alternate explanation for blind children's failure on some of these tasks is that they cannot cognitively do the multiplicative functions necessary to understand the concept of the diagonal. A way of testing the latter notion would be to correlate children's performance on Piaget's test of "Locating a Point in 2 or 3 Directions" (Piaget et al., 1960) with their responses to a task such as the asymmetrical rotations task.

Summing up, we saw significant and nonsignificant blind/sighted differences in the use of imagery, cues perceptual feedback and references systems. In relation to imagery, the sighted superiority (significant) on recognition tasks suggests that the sighted have a greater store of images. However, for both the sighted and the blind these images would seem to be limited by cognitive ability as only partial transformations were imaged prior to 11 years of age (n.s.). Additionally, the sighted appeared more likely than the blind to image intervening flip transformations. Regarding the use of cues, the sighted seemed to be more likely than the blind to use cues to aid performance prior to 11 years of age (n.s.). However, both groups tended to use cues to do

difficult and holistic transformations in the 11- to 13-year-old age group (n.s.) before full knowledge of Euclidean space emerged (14 years). Regarding Millar's (1976) hypothesis it appears that, for the young sighted, cue use and not visual regeneration may be responsible for sighted advantage in rotational tasks for when cues were lessened, 90° > 270° for both groups. That the blind children did not use cues prior to 11 years may be because they could not cognitively perceive these cues. The perceptual feedback hypothesis of Warren suggesting that the sighted are more likely than the blind to benefit from perceptual feedback appeared to be true (n.s.). For the blind, perceptual feedback may involve more cognitive processing than it does for the sighted. Finally, blind children may be more likely than sighted children to use self as a frame of reference (n.s.). This may be responsible for their relatively poor performance on tasks in which dominant aspects of the stimulus are not in line with the body's vertical axis.

The remaining subhypotheses concern individual and task variables for which no sighted/blind differences were hypothesized. We expected all groups to be similarly affected by the given stimulus familiarity and structure and also by the interaction between transformation types and transformational demands. Gender differences favoring males were only posited for the sighted. We made no hypotheses here regarding the blind. We will discuss the effects of task familiarity first and the effects of gender differences last.

In between we will discuss as a unit the remaining variables (task structure, transformation type and transformational demands) as there was unforseen nonsignificant interactions amongst the three. We will also discuss here the effects of another stimulus factor--symmetry--which appeared to affect performance. Although strong significant differences were found for gender and were not generally found for the remaining variables, we discussed gender last as the other variables were often factors in our analysis of gender differences.

Familiarity. We expected both blind and sighted groups to find familiar household objects easier to transform than more unfamiliar abstract objects (triangles). We based this premise on Schultz's (1978) work with objects of varying familiarity and also on the notion that familiar objects would be easier to encode. As expected we found no sighted/blind differences. However, we did find that only females were somewhat more likely to do better on nonvisible transformations using familiar objects rather than triangle (n.s.). Thus it may be that transforming the object is less of a problem for females than encoding the object. Given Tkacz's (1982) thesis that encoding is a primary factor in mental rotations, we suggest that females but not males may have difficulty with encoding the more abstract triangular figure. The reason for this may reside in the fact that it is necessary to impose a frame of reference on the triangle and envelope in order to maintain the separate boundaries lines of each object and its parts and

yet maintain the relationship between these various boundaries. With familiar objects the boundaries lines of the object are more likely to be encoded strongly as one unit with clearly related parts. A minimal frame of reference needs to be imposed in order to separate and maintain the relationship between the object and the container.

However, facilitating the encoding process by using familiar objects does not entirely eradicate gender differences in transformational knowledge. Under low cue conditions of the Familiar Objects task sighted males and females have equal performances at 14 years but, prior to this, gender differences favoring males are seen to a lesser degree in transformational knowledge (270° is significant). We would again suggest that younger males may have an advantage in that they can use a strong body referent system for analyzing and transforming stimuli. This will be discussed more in the section below on gender differences.

Transformational type/demands, task structure. The next hypotheses regarding transformational performance--how different transformational demands affect the relative ease of transformational types and how task structure affects performance--will be discussed together for 2 reasons. One, both of these hypotheses primarily involved transformation tasks in which the intervening transformation had to be identified from the given end states. Second, there was an interaction between the hypotheses such that, for the intervening transformations, the ease of the transformational

type seemed to depend upon the structure of the stimulus. After discussing these two variables, we will discuss the effects of stimulus symmetry on performance.

In the first subhypothesis above we proposed that the blind and sighted would be similarly affected by how transformational demands affected the ease of the transformational type. We expected the flip to be generally easier under replication conditions and rotations to be easier under conditions in which the intervening transformation needs to be identified. Our hypothesis was based on past research (noted above) and on the notion that, for the flip, mirror image end states are easy to replicate. However, when identifying intervening transformations, flip but not rotational motion requires the subject to mentally take the object out of the plane in which it is perceived, making rotations easier. The second subhypothesis states that we expected that stimuli with clearly defined external structures (e.g., points and sides) would facilitate the child's understanding of intervening transformational relationship. Conversely, we expected that stimuli with less pronounced internal structures (a ring of colors on a disc) would delay this same knowledge. This was based on the idea that clearly defined boundaries would allow children to set up correspondences between the two arrays facilitating transformational knowledge. This follows from Piagetian (1979) theory regarding transformations and correspondences.

Regarding our predications concerning the relative ease

of transformations, it is only partially true that flips are easier than rotations in the replication conditions (Triangle Transformation task). For all groups, as noted previously, flips and partial rotations were generally easier (n.s.) than more holistic or more complex rotations. This suggests, as noted above, that images of all partial transformations (including flips) can be formed early.

In order to discuss the second part of this thesis (rotations easier in tasks of intervening transformations) and transformational knowledge in general we need to qualitatively examine the results from the Static Triangle and Static Disc tasks and include the factor of stimulus structure. In essence, knowledge of intervening transformations was similar to children's knowledge of replication transformations (noted above) in that this knowledge was generally not solidly achieved until after 10 years of age. Prior to 11 years of age, children appeared to have poor transformational knowledge of intervening transformations (n.s.). They tended to see the relationship between figures as a relationship between the isolated parts of the figures (more of this in the section on correspondences - Hypothesis 3). Given their experience and/or the configuration of the stimuli, children perceived that different transformations would bring the part or parts together. Thus, with the triangle pair in a symmetrical rotational configuration, sighted children, noting only one common side of the two triangles, will say that they can be superposed by a flip bringing these common sides together.

Blind children noting this same common part will "correctly" say that they can be superposed by a rotation bringing the common sides together. However, later (11 to 16 years of age) when evidence (270° rotation) suggests that they perceive space more holistically, blind children also see the relationship between these symmetrically apposed triangles as flips matching one common part. Only later do both blind and sighted children see this relationship correctly as a rotation. In a similar vein, when attempting to superpose discs, a less externally bounded figure, young blind and sighted children now seen both flip and rotational arrays as rotations.

Thus our hypothesis that intervening rotational transformations would be easier than flips is not true because the choice of the intervening transformation appears to depend upon interactions involving the structure of the array, the cognitive level of the child and the child's experience with transformations. Triangles with their sharply delineated parts evoked a flip response from the sighted when in symmetrical rotational relationship. We suggest that this is so because the array presented a strong "opposite" image with distinctly matching parts which in their experience indicates a flip. As noted above, the blind probably cannot perceive this holistic symmetrical "opposite" until knowledge of holistic Euclidean space emerges. In contrast, the configuration of the discs appears to promote in both blind and sighted children a continuous unanalyzed ordering strategy which in turn prompts

a more continuous rotational response. It is only at 11 years of age that this whole seems to be broken down into parts and the parts matched across 3-dimensional space permitting both correct and incorrect flips (180° rotation = "opposite" = flip). That blind and sighted children eventually differentiate flips and rotations correctly can again be attributed to cognitive development which allows them to integrate aspects of the stimulus (this will be discussed later in Hypothesis 4).

It appears from our data regarding intervening transformations that, overall, the mature flip response does appear to emerge before the mature rotational response (n.s.). However, In order to truly understand the relative difficulty of these transformations, we need to look further at how children make congruence judgements (Hypothesis 3) and how these judgements relate to their knowledge of transformations (Hypothesis 4). Our data also lead us to conclude that for a more comprehensive picture of transformational relationships we would also have to vary our tasks more for symmetricality and, within symmetricality, for the orientation of the axis of symmetry. Symmetricality as a stimulus factor affecting transformational performance will now be discussed.

Symmetricality. This was a factor which seemed to particularly affect performance (n.s.) on the Static Triangle Task. Triangle pairs in symmetrical or near symmetrical relationship were more likely to be identified correctly (flips and rotations) or incorrectly (false flips) as the

"same." Triangle pairs in asymmetrical relationship were judged as "not the same." Even older blind children and sighted females had difficulty judging the congruent asymmetrical arrays (rotations) correctly. Sighted males succeed here at 14 years of age.

Regarding the apparent ease of the flip transformation, it appeared from our data that when 2 triangles were perceived holistically as symmetrically opposed around the vertical axis and, further, that part(s) could possibly be matched, the intervening transformation was identified as a flip. However correct, this was still probably done by a primitive analysis. We suggest that at this point children were aligning the central vertical axis of their bodies with the vertical axis separating the two triangles. They then formed a more or less vague picture of the remaining parts and declared them to be "opposite." Parts were brought together in a flip motion but these parts were not clearly delineated (false flip) and not all parts were taken into consideration (rotation). Thus a flip may be "easy" because only primitive notions are necessary in order correctly judge triangles in a flip relationship around a central vertical axis. In support of this, Greco (cited in Montangero, 1976) found that flips around the horizontal axis were equal in difficulty to rotations. We suggest that children must take a more analytical rather than body centered approach to this problem. In a similar vein, sighted males see rotated triangles symmetrically related around a vertical axis as rotations (a

sophisticated response) at 11 years of age but do not understand asymmetrically related rotations until 14 years. We suggest again that the vertical axis is aligned with the body's axis and allows for easier discernment of and therefore integration of parts. Without this easy body/object match, children must impose their own frames of references on the display to judge equality of parts and wholes. In sum, we propose that symmetricality allows the children to break down the stimulus into parts because the stimulus and its parts can be matched to the body and its parts. This in turn can facilitate transformational knowledge.

Gender differences. We hypothesized that gender differences would be seen in rotation tasks for the sighted. We made no predictions for the blind. Our hypothesis was based on the fact that gender differences have been documented (Linn & Peterson, 1985) on spatial tasks involving external referents (Rod and Frames Task, Water Levels Task) and mental rotations. As noted above, our study provides evidence of significant and nonsignificant gender differences in performance and strategies for blind as well as sighted groups. Significant differences were seen in sighted (Triangle Transformation and Familiar Objects tasks) and blind (Familiar Objects tasks) groups particularly under low cue conditions. Additionally, nonsignificant differences were seen such that males 8- to 10-years of age show more advanced spatial strategies than their female cohorts on rotational tasks falling on the perpendicular axis. Also, only older (14 years

of age) males do well on complex transformations without cues (Triangle Transformation--sighted/blind) and on symmetric and asymmetric rotations (Static Triangle task - sighted only). In general, without cues, sighted and blind females did more poorly than males, especially on more difficult transformations, and sighted females were more likely than males to use the framework of the table as a substitute cue. Females did better in low-cue conditions using familiar objects.

The idea that males are more spatially advanced than females supports the work of Ozer (1987) and others, who found early gender differences (cited in Linn and Peterson, 1985). That females are more dependent on external cues can be seen in the findings on the Water Levels Task and the Rod and Frame Tasks (Harris, in Linn et al., 1985; Nyborg, 1988). Our results are also in accord with these studies regarding the age (8 years) at which these differences were seen. Also, our findings showing that females did better rotating familiar objects lend some support to Tkacz's thesis (1982) that encoding is a primary factor in mental rotations.

The data (significant and nonsignificant) indicate a possible two-stage development in male spatial responses. The first increase in spatial knowledge occurred at 8 years of age and involved knowledge of symmetrical arrays only. The second stage occurred at 14 years of age and all arrays were included (at least for sighted males). We suggest that in the first stage a strong experiential physical space is present which is

based on using self as a referent. In the second stage we propose that a cognitive, analytical space appears which is based on the imposition of external referents on space.

When discussing symmetricality, we proposed that, in general, all younger children use their bodies as general vertical references. We further suggest here that at an early age (first stage) males are more likely than females to reference parts of their body to parts of the stimulus (other than vertical) when stimulus parts are easily perceived. This would allow them to break up the triangle (but not the disc) stimulus early (correct double flip strategy for the Static Triangle task appears at 8 years for sighted males and 11 years for sighted females). We propose that females break up a clearly defined stimulus only at 11 years when cognitive analytical skills emerge. This is also the time when both males and females can analyze the less clearly defined disc into parts. How this analysis into parts relates to transformation knowledge will be discussed further under Hypotheses 3 and 4. In the second stage of development, we suggest that males are able to impose their own frames of reference on even difficult stimulus configurations. Here they can rotate nonvisible transformations without cues. Moreover sighted but not blind males can free themselves from a self frame of reference when imposing external frames of references (asymmetrical rotations).

Brain lateralization studies lend some support to this thesis. Some of these studies indicate that males use both

hemispheres of the brain in spatial tasks (Tkacz, 1982), whereas females tend to use only the left, more analytical, hemisphere (Newcombe et al., 1989). Further, McGlone (1980) found that males were negatively affected in spatial tasks by a right-hemispheric assault, but only if the task involved movement. Given the work of Matthews (1986, 1987) and others, the male's greater spatial knowledge may have its origins in the greater mobility of boys. We suggest further that this proposed strong male self referencing may have its origins in the rough and tumble play seen more frequently in males than females. Thus, it is possible that the limitation on males regarding symmetrical arrays prior to 14 years of age is due to the child's use of a right hemispheric, self-referent, movement-oriented spatial system. Only at 14 years of age does the left hemispheric analytical externally referenced system (no cues) appear to take hold. This thesis could be tested developmentally by simultaneously testing children's cognitive and hemispheric reactions to spatial tasks that would lend themselves to this type of analysis.

Although similar gender differences are found in sighted and blind groups, we cannot necessarily conclude that these differences are innate. As noted in the introduction, across conditions of sight, males and females are treated differently. Females tend to be overprotected and males tend to be permitted a larger range of movement (Matthews, 1986, 1987). Additionally, boys' play activities require more self/other referencing (e.g., baseball, wrestling, etc...)than

do most girls' activities.

At this point, one can only identify areas of difficulty and suggest providing experience to females in areas that may be correlated with spatial knowledge. Two such areas might be early training in body/spatial relations, and age-appropriate training in reducing dependence on external spatial referents. At the same time, in the latter training, subjects should be focused on the given spatial transformation.

Experimental Variables - Summary

We will now briefly summarize our discussions regarding Hypothesis 2-- the effect of individual and task variables on transformational performance. Statistically significant differences were found for sightedness (recognition, flip transformations), task (90° > 270°) and gender. Nonsignificant differences were found for sightedness regarding cue use, perceptual feedback and referencing systems. Concerning sightedness and imagery, it appears that the sighted have a greater store of experienced images making recognition tasks and some flip transformation tasks significantly easier for them than for their blind cohorts. It also appears that the sighted were more affected (n.s.) than the blind by cues such that, sans cues, partial rotations become significantly easier than more holistic rotations (90° > 270°) for both blind and sighted. After 11 years of age both blind and sighted were affected (n.s.) by cues on difficult transformations and we attributed this age shift in blind children's cue use to their

now being able to perceive the cues. That difficult (e.g. 270°) rotations only appear at 11 years under high cues suggests emerging Euclidean structures here. That low cues prevent these same rotations from emerging until 14 years of age suggests a higher stage of Euclidean thought which is free of the need for cue support seen in earlier stages.

Other nonsignificant task and individual differences were seen--sometimes in multiple interaction. Blind/sighted differences in performance on transformation tasks were also seen in perceptual feedback and in the ability to deal with other than a perpendicular (self-oriented) stimulus. In these areas (as in imagery and cue use) the sighted did better than the blind. We suggest that reasons for these blind/sighted difference in all of the above may include the inability of the blind to perceive the stimuli holistically until 11 years of age or later. Also the blind may have less experience overall with objects. Finally, it appears that the blind, not being easily able to perceive external cues, may be strongly inclined to develop a self referent system.

By varying transformational demands (replicated versus intervening transformations) interactively with stimulus demands (triangle versus disc), it became more obvious how tentative transformational knowledge is prior to 11 years of age or older. This is substantiated by errors (e.g., visual spatial) made in the nonvisible transformation tasks. Reasons were given for these results based mostly on children's notions of developing correspondences.

Gender differences were found (n.s.) for the effects of familiarity on transformational knowledge and we attributed this to easier encoding. For both blind and sighted groups significant gender differences in transformational knowledge favoring boys were pervasive in the low cue condition. They occurred predominantly in 2 stages--at 8 years and again at 14 years. The former age corresponds with Piaget's stage of beginning transformational knowledge and the latter age with our notion of a fully developed Euclidean system. These different stages were discussed from a cognitive/strategy perspective. Suggestions for possible origins of gender differences were based on differential male/female experience.

Hypothesis 3. For our third hypothesis we looked at the criterion which children used to set up correspondences between two arrays in order to determine congruence. We hypothesized that children would first identify congruent arrays by comparing one part of each arrays or by making gestalt-like holistic comparisons between arrays. Children would then, with age, proceed to clearly differentiating and matching parts of the arrays. Finally children would compare arrays as wholes with integrated parts. This constructivist viewpoint was supported by the research of Beilin (1984) and Thomas (1978).

The data from the Static Triangles task regarding transformation strategies and congruence judgements are nonsignificant but tend to support the hypothesis that the development of the correspondence systems is constructivist in

nature. Transformation strategies (overt movement) for doing symmetrical rotational transformations indicated that children tended to match one (flip) and then two parts (double flip) before rotating the stimulus as a whole. When making congruence judgements young children first appeared to see arrays "holistically" in that, as noted above, they judged symmetrical or nearly symmetrical arrays as "the same." Noncongruent arrays that were nearly symmetrical and congruent asymmetrical arrays were not correctly judged until later, suggesting a more complicated analysis of the figures. This was reflected in their congruence strategies (responses as to why two triangles were or were not the same).

The differences in congruence judgements in the age groups noted above suggest a progression of congruence strategies. Our data here seemed to show that young children first noted vague similarities whereas older children noted one and then two common parts. Finally, for some, both angles and sides could be seen to correspond, suggesting integration of the different aspects of the stimulus. Further evidence of this integration was seen in the relationship between higher-level angle/sides strategies and transformational success which we will discuss below.

These data basically confirm the work of Thomas (1978) and Beilin (1984), who both found that children's correspondences progressed from matching isolated parts to matching integrated parts (Thomas) or wholes (Beilin).

Hypothesis 4. the question raised in this hypothesis

concerned how congruence (or correspondence) strategies related to children's knowledge of both replicated and intervening transformation. We directly tested this hypothesis only in the set of intervening transformations but we will also note, where applicable, how this hypothesis may relate to replicated transformations. We specifically proposed that children must analyze the stimuli holistically in order to have knowledge of intervening transformations. Our qualitative data (congruence strategies of the Static Triangle task) suggest (nonsignificantly) that this is true as children who noted both sides and angles were more likely than children using other strategies to correctly identify the intervening transformation. However, other children, generally those labeling congruent and similar (sides or angles) multiple parts, sometimes also identified the intervening transformations correctly. We believe that this occurred, in part, because of the more imprecise verbal method used to elicit knowledge of correspondences. We also observed transformational performance patterns (Static Disc Task) which supported our hypothesis. In this task children saw the intervening transformation as a rotation until 11 years of age. At this age parts began to be isolated and the vaguely perceived whole (e.g., "opposite") was subordinate to the parts. Configurations were then correctly and incorrectly identified as flips. At 14 years, flips and rotations were differentiated suggesting an integration of parts and wholes.

Several factors were instrumental in helping to delineate

this tentative model of the development of the correspondence/transformation system which will be discussed below. These factors, which include sightedness, gender and various stimulus variables, also helped us to understand, to some degree, the relationship between flip and rotational transformations. Children's developing notions of flips and rotations, in turn, helped us to understand the relationship between correspondences and transformations. For example, if we had examined only sighted children's performance on paired triangle arrays which were symmetrical around the vertical axis, we would have concluded that flips were the more primitive transformations. Yet blind children saw these arrays as being rotations and then flips and then, at a later age, flips were differentiated from rotations. If we, additionally, bring in other studies, we can confuse the issue further. Greco (cited in Montangero, 1976) found flips over the horizonal to be equal in difficulty to rotations and harder than the flip over the vertical. Thus, data relating to these variables raise the question as to what constitutes the essential elements of developmental progress regarding correspondence/transformation relationship such that the above responses would be seen.

Our data suggest that primitive rotation and flip responses emerge from the child's inability to adequately analyze the stimulus. Prior to 11 years of age, one or two parts of the stimulus may be identified and matched correctly (sighted-flips, blind-rotations) or incorrectly with no

appreciation of the whole. The particular intervening transformation that is imagined by the child to exist between the given end states depends on an interaction between the stimulus configuration, and the child's cognitive level coupled with his or her previous experience. Symmetrical arrays with stimuli composed of clear parts will elicit a flip response in younger sighted but not blind children. We suggest as noted above, that sighted children have more experience in mirror image flip relations and that blind children do not perceive this flip relationship until 11 years of age when a more holistic knowledge of stimuli emerges. In contrast, a configuration with identifiable parts that are internal and circularly ordered elicits a rotational response from both blind and sighted children. We suggest that unanalyzed ordering in taking place here and parts cannot be separated and brought together across a more 3-dimensional space.

At 11 to 13 years, the whole can be appreciated and broken into parts but parts predominate. Thus children seen rotations "holistically" as a double flip between sides and see the 180° rotation as a "holistic" opposite with matching parts to (incorrectly) flip together. At this age, responses which involve breaking down the whole into parts (correctly and incorrectly) only take place if the axis of symmetry is vertical. As noted above, we believe that children of this age are still limited by reference to the vertical self just as children of this age are dependent on the cues from the envelope in the Triangle Transformation task.

True transformational knowledge (asymmetrical rotations) cannot be accomplished until 14 years of age when children can potentially impose their own frames of reference and thus symmetry on spatial entities. However, just as females and blind children had difficulty transforming spatial arrays in the Triangle Transformation task, they also have difficulty transforming asymmetrical rotations. It appears that most females need strong external cue support to use as a frame of reference whereas most blind children continue to use the vertical self as a referent--both of these strategies being anathema to solving the asymmetrical rotation task.

In order to test this thesis regarding the development of the correspondence/transformation relationship, more work needs to be done in this area varying stimuli for structure, symmetry and orientation.

Transformational Knowledge. We posed a question early in our Introduction section: is the child's developing knowledge of transformations akin to the cognitive developmental (Piagetian) theory of transformations. Cognitive theory (Piaget et al., 1967, 1971, 1979, 1989) has evolved over the years but, at this point, basically takes into consideration correspondences between end states as well as the intervening transformational motion. In the latest theory, Piaget and Garcia (1989) posited that children's developing transformational knowledge occurs in three phases. In the first phase, the intrafigural phase, the child is concerned with the relationships within an object and ignores the

spatial container in which the object resides. The second phase, the interfigural phase, which begins at approximately 7 years of age finds children searching for transformational relationships and establishing correspondences across these spatial transformations. The final transfigural phase is characterized by structure. Correspondences are now formed between the elements of a given suprastructure (e.g., Perspective space) and figural characteristics become irrelevant. We believe that our data closely approximate this Piagetian view.

Interpreting our significant and nonsignificant results within this framework, we note that children in the intrafigural phase were low in transformational knowledge (Triangle Transformation and Familiar Objects tasks). Regarding children's knowledge of correspondences in the Static Triangle task, children's congruence judgements were generally based on vague or incorrect correspondences.

In relation to Piaget's next interfigural phase, we suggest from our data that this phase has two subphases. In both of these subphases children make correct correspondences across transformations. They also set up correspondences with the perpendicular references inherent in self and also with those found in external referents (nonperpendicular arrays are difficult). These subphases differ in that children in the first subphase (8 to 10 years) form these correspondences across partial space whereas those in the second subphase (11 to 13 years) can make these same correspondences in holistic

space.

Several achievements are characteristic of this first subphase. Males could do partial 90° rotations at 8 years of age (n.s.) but made errors such that the final result always fell along the line of the perpendicular of the envelope or of the self (correct + partially correct error). If stimuli had prominent parts and were symmetrical about the vertical axis, arrays, children vaguely analyzed there stimuli into parts and part-to-part matches were made that ignored the whole. Similarly, in the Familiar objects tasks children perceived observed flips as relationships between part to part end states and rotated the array 180° to achieve (incorrectly) the same end. In the literature both Moyers and Johnson (1978) and Schultz (1978) note that children of this age ignore transformations in favor of end states.

In the second subphase, children now comprehend holistic space but parts predominate. Correspondence are made between parts of the whole and external or self referenced perpendicular cues in order to comprehend transformational relationships. In this subphase the holistic nonvisible transformation (Triangle Transformation and Familiar Objects tasks) could be accomplished but only by setting up correspondences with perpendicular cues. In the Static Triangle task, rotated triangle pairs symmetrically aligned along the vertical could be wholistically broken down into parts and parts matched by a double flip--not a rotation. Asymmetrical rotations could not be similarly broken down. As

noted above, discs were seen holistically but parts predominated again and the 180° rotation was seen as a flip between parts. In appears that a strongly analytic holistic space prevails in this subphase as wholes can be analyzed into parts which can be corresponded. Males and females do equally well here suggesting a basis for them doing equally well on tests such as the Embedded figures test which requires analytical skills but which also gives strong cue support.

In the next transfigural phase (14 years of age and older) children understand space as an entity which can potentially utilize multiple frames of reference (Projective, Euclidean, Similarity...). At this point, children can impose these frames of reference on space as necessary. No dependency on cues of self or external reference is seen. Children can do mental transformations without cues. Flips and rotations become differentiated as parts and wholes are integrated and, according to Piaget, seen in terms of the larger structure of space.

This framework allows us to make sense of our own data and of some of the research found in the literature. Where we have task variability (cues, structure, symmetry, task demands, etc...) prior to approximately 14 years of age we will see strong variability in children's performance as this performance will vary with the type of structural supports provided to the subject. Individuals also differ in their need for task support and this affects their patterns of development. For the most part, both blind and sighted females

appear to need more perpendicular structural support to exhibit strong transformational knowledge and thus show a lower incidence of transfigural spatial knowledge. Blind children, needing to "construct" holistic space (no visible support), are delayed in reaching higher levels of spatial thought as within this holistic space (11 years of age) the stimulus must again be broken down into parts and then integrated. Also, although the blind (males) do not need cues to do the more difficult rotations of triangle transformation task they are limited in that they have difficulty dealing with stimuli which are not aligned with the perpendicular suggesting a continued need to use the self as a reference.

The phases as delineated above need further work. This is especially so in the subphases of the interfigural phase as it is in these subphases that task variability is most influential. Specifically, we see that more research is needed in the area of referencing. Does the dependency on perpendicular references stem from a body referencing base? Are males inclined to use their bodies as perpendicular references earlier than females and can they break up the stimulus earlier by referencing parts of the stimulus to body parts? How might blind children be trained to use and impose other than a self frame of reference (some blind children can do this)? As mentioned previously, in order to untangle these issues, tasks must vary considerably in both stimulus structure as well in task demands.

Conclusions

Statistically significant differences were found which were related to Hypothesis 2 -- the effect of individual and task variables on transformational knowledge. Specifically we found differences as predicted due to sightedness, gender and task. In regard to sightedness, the sighted did better than the blind on recognition tasks and on flip tasks involving intervening transformations. Both of these results suggest that the sighted have a greater store of imagery in general and flip imagery in particular. Gender differences in rotational tasks favoring males were evident in both blind and sighted groups but more so, statistically, for the sighted groups. Regarding task differences, both blind and sighted groups reacted similarly (Familiar Objects task) to increasing rotational extent under low cue conditions such that 90° was easier to imagine than 270°. Also only the sighted found recognition to be easier than recall.

We included the above statistically significant findings in our summary below. This summary which is organized around general topics and which includes nonsignificant (n.s.) as well as significant findings is meant to point to trends in transformational knowledge which were indicated by our full data.

Transformational knowledge. Regarding the development of children's knowledge of transformations and correspondences, the research results which were based mostly on nonsignificant

percentage data tended to support and extend the Piagetian thesis that transformational understanding proceeds from intrafigural to interfigural to transfigural knowledge. Moreover, it appears that there may be two subphases within the interfigural phase. In the first subphase children seemed to focus more on simple part-to-part correspondence, whereas, in the second subphase, they seemed to perceive both wholes and parts but parts predominated. Further, the development of correspondences appeared to follow a constructivist pattern in that there were age-related changes with young children making gestalt and simple part-to-part comparisons and older children comparing multiple, and in some cases, integrated parts. The two systems of correspondences and transformations appeared to interact most clearly at the highest transfigural level where children establishing correspondences to both sides and angles seemed to be more likely to understand difficult transformations.

At the lower levels of transformational/correspondence knowledge, children at the intrafigural phase (5-7 years of age), appeared to be able to represent some transformational movement but were less likely than older children to correctly match congruent parts over spatial extent. Children in the interfigural phase (8 to 13 years of age) searched for transformational relationships but needed cue support to establish correspondences. In the first part of this phase (8 to 10 years of age) children could imagine simple partial transformations and make part-to-part matches over spatial

extent. In the second part of this phase (11-13 years of age), they could imagine full transformations and make multiple part matches but, again and more obviously, only with supporting cues. Throughout the lower phases, children's knowledge appeared to be influenced by task configurations. Only in the last transfigural phase (14-19 years of age) were flips and rotations truly differentiated and understood.

Blind/sighted differences. Significant and nonsignificant (n.s.) differences due to sightedness could be seen, generally favoring the sighted. The sighted did significantly better than the blind at recognition tasks suggesting that they have a richer store of mental images. Since the blind could form mental images, we attribute this difference to the greater experience of the sighted and to the possibility that holistic images cannot be constructed or perceived by the blind until 11 years of age. The sighted also had a significantly stronger grasp of the intervening flip transformation suggesting greater experience with the mirror image end states resulting from this transformation. Nonsignificant differences were also seen. The sighted (especially the younger sighted) seemed to make more use of external cues, and perhaps as a result of this, they seemed more likely than the blind, at a later age, to impose external reference system on asymmetrical arrays. The data also indicated that the blind tended to use both movement memory and self-referent system for doing transformations--both of which can be adequate under some but not all circumstances. The sighted also appeared to benefit

more than the blind from perceptual feedback and seemed more likely to make earlier fine differentiations in the stimulus than did the blind.

Given these differences, the similarities of sighted/blind patterns of age-related differences in the transformational area appear remarkable. In the nonvisible transformations tasks, differences across gender were often significant whereas those differences across sight were nonsignificant. In congruency/transformation tasks the apparent pattern, if not the timing, of age-related differences was quite similar.

Gender differences. Both blind and sighted groups exhibited significant gender differences favoring males in the nonvisible transformation tasks. The sighted also showed nonsignificant gender differences favoring males in the Static Triangle task. These differences -- significant and nonsignificant -- seemed to occur in two stages. At 8 years of age males' spatial strategies were superior to females on symmetrical arrays that were aligned with the perpendicular-- an advantage we propose is due to a strong self-referent system. A further advantage is seen at 14 years of age where males, especially sighted males, were more likely than females to impose an external referent system on difficult low cue arrays. Both blind and sighted females appear to be more dependent on external cues but, within this framework, they can be highly analytical regarding space.

Task differences. Significant differences were found due

to task demands (recognition/recall) and rotational extent (90° vs. 270°). Nonsignificant differences were found due to cues, task demands (imagination/execution), stimulus familiarity and stimulus configuration. These task differences interacted with conditions of sight (task demands, cues and configuration) and gender (familiarity) as follows. Compared with the blind group, the sighted seemed to be more affected by cue variation, did significantly better at recognition tasks, and appeared to benefit more from the execution condition (perceptual feedback). Further, there were nonsignificant young sighted/blind differences in transformational understanding which interacted with the stimulus configuration. Triangle pairs engendered an intervening flip response for sighted and a rotational response for the blind. Discs pairs engendered a intervening rotational response for both groups. Finally, only females tended to be affected positively by the familiarity of the stimulus.

In sum, these significant and nonsignificant results suggest that after the intrafigural phase (absence of spatial transformational awareness) and prior to the transfigural phase (full spatial analysis without cues), performance will be affected by individual variables in interaction with task variables. Individuals need varying levels and types of support and these can be provided for differently by different tasks. We would further note that only by studying variation in these factors can we arrive at a fully delineated knowledge

of children's evolving concepts of spatial transformations and by doing so provide educational support where necessary.

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