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The development of geometric form copying skills in normal and learning-disabled children

Goldberger, Ellen Margaret, Ph.D.

City University of New York, 1989

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A

THE DEVELOPMENT OF GEOMETRIC FORM COPYING SKILLS
IN NORMAL AND LEARNING DISABLED CHILDREN

by

ELLEN MARGARET GOLDBERGER

A dissertation submitted to the Graduate Faculty
in Psychology in partial fulfillment of the
requirements for the degree of Doctor of
Philosophy, The City University of New York.

1989

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This manuscript has been read and accepted for the Graduate Faculty in Psychology in satisfaction of the dissertation requirement for the degree of Doctor of Philosophy.

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Abstract

THE DEVELOPMENT OF GEOMETRIC FORM COPYING SKILLS
IN NORMAL AND LEARNING DISABLED CHILDREN

by

Ellen Margaret Goldberger

Adviser: Wilma Rosen, Ph.D.

Evidence was sought to further validate the development of form copying skills using the cognitive framework postulated by Piaget and Inhelder. In their stage theory of the development of representational space, they propose that children of different ages depict geometric forms according to the rule based system in which they are able to operate. A secondary goal was to examine the possible general effects of learning disabilities on drawing skills. A drawing test based on Piaget and Inhelder's theory was created using forms labeled a priori as demonstrative of topological, Euclidean, projective and horizontal-vertical axes spatial properties. Using this task, the precise goal was to demonstrate that drawing skills develop in a predictable order from topological to Euclidean and projective representations of space to the use of overall reference

systems. The test was administered to 354 youngsters in kindergarten through sixth grade and 26 learning disabled third and sixth graders. A Guttman analysis of the drawings of the normative sample supported Piaget and Inhelder's theory. Results indicated that there was a systematic developmental progression from topology to the use of overall reference systems and that failure at one level of drawing development precluded success at any higher levels. These results also indicated that subjects' levels of drawing development could be derived from the overall number of forms drawn correctly. Thus, this set of forms may be used to delineate different levels of form copying skills present in children 5-12 years of age. Further, distinct markers (test stimuli) were found that separated children of different developmental stages. Learning disabled children in both groups were significantly impaired compared with grade-matched controls on forms that represent transitional points in operational stages of development. These children had more difficulty developing complex form representational skills than the control subjects.

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I would like to thank my husband Josh Oppenheim, as well as my parents Avriel and Arnold Goldberger and my parents-in-law Arlene and Norman Oppenheim, for their constant support and encouragement, for they never doubted that this dissertation could and would be completed. Finally, I must express my gratitude to Marcel Proust for setting me on the path of higher learning early in my life.

Table of Contents

	<u>Page</u>
Approval	iii
Abstract	iv
Acknowledgements	vi
List of Tables	x
List of Figures	xii
Introduction	1
Piaget and Inhelder's Theory of the Development of the Ability to Copy Geometric Forms	1
Topological Space: Further Research and Divergent Views	6
Euclidean Space: Further Research and Divergent Views	14
Projective Space: Further Research and Divergent Views	27
Comments and Criticisms of Piaget and Inhelder's Overall Theory	29
Tests Used to Measure the Development of Form Copying Skills	35
Patterns of Functioning in Learning Disabled Children	41
Goals of the Current Research	47
Hypotheses	48
Method	51
Subjects	51

Table of Contents (continued)

	<u>Page</u>
Stimuli	52
Procedure	53
Results	54
Qualitative Scoring of the Drawing Test	54
Within Subject Analyses	54
Effects of Age, Grade and Sex on Drawing Performance	57
The Development of Quantitative Scoring Criteria	65
Quantitative Criteria	66
Error Patterns	68
Performance of Learning Disabled Subjects	69
Discussion	71
Implications of this Research for Prior Models	79
Implications of this Research for an Understanding of Cognitive Functioning	80
Limitations of the Current Research and Suggestions for Further Research	83
Appendices	85
Appendix 1: Qualitative Criteria used to Score Experimental Measures	85
Appendix 2: Measurements Used to Derive Quantitative Criteria	89
References	131

List of Tables

	<u>Page</u>
Table 1. Number of subjects within each 12 month interval	90
Table 2. Number of subjects by grade in each school and age range within each grade in each school	91
Table 3. Number of learning disabled subjects and their age ranges in each grade	92
Table 4. Guttman analysis using forms 1-11	93
Table 5. Guttman analysis using Low and forms 7 and 9-11	95
Table 6. Percent correct for each form in School 1 and School 2	96
Table 7. Percent correct for each form by grade in School 1	97
Table 8. Percent correct for each form by grade in School 2	98
Table 9. Percent correct for each form by age in School 1	99
Table 10. Percent correct for each form by age in School 2	100
Table 11. Mean number of forms correct within each grade in School 1 and School 2	101
Table 12. Mean number of forms correct within each age group in School 1 and School 2	102
Table 13. Mean number of consecutive forms correct within each grade in School 1 and School 2	103

List of Tables (continued)

	<u>Page</u>
Table 14. Mean number of consecutive forms correct within each age group in School 1 and School 2	104
Table 15. Number of protocols used for the discriminant analysis	105
Table 16. Percentage of qualitative and quantitative errors made by 5.0-5.11 year olds, 8.0-8.11 year olds and 11.0-11.11 year olds	106

List of Figures

	<u>Page</u>
Figure 1. Forms	107
Figure 2. Percent correct for each figure in School 1 and School 2	108
Figure 3. Kindergarten: percent correct for each figure	109
Figure 4. Grade 1: percent correct for each figure	110
Figure 5. Grade 2: percent correct for each figure	111
Figure 6. Grade 3: percent correct for each figure	112
Figure 7. Grade 4: percent correct for each figure	113
Figure 8. Grade 5: percent correct for each figure	114
Figure 9. Grade 6: percent correct for each figure	115
Figure 10. Age 5: percent correct for each figure .	116
Figure 11. Age 6: percent correct for each figure .	117
Figure 12. Age 7: percent correct for each figure .	118
Figure 13. Age 8: percent correct for each figure .	119
Figure 14. Age 9: percent correct for each figure .	120
Figure 15. Age 10: percent correct for each figure .	121
Figure 16. Age 11: percent correct for each figure .	122
Figure 17. Age 12: percent correct for each figure .	123

List of Figures (continued)

	<u>Page</u>
Figure 18. Mean number of figures correct by grade .	124
Figure 19. Mean number of figures correct by age . .	125
Figure 20. Mean number of consecutive figures correct by grade	126
Figure 21. Mean number of consecutive figures correct by age	127
Figure 22. Forms 7-8 (pre operational to concrete operational)	128
Figure 23. Form 9 (parallelogram)	129
Figure 24: Form 10 (obliquely oriented)	130

Introduction

Children of different ages copy geometric forms in diverse manners. Whereas a 3-year-old typically depicts a square and a circle with the same shape, a 7-year-old draws these forms so that each is delineated clearly by its own precise and unique characteristics. What changes occur that allow for such different renditions of these forms by the children? Is there a simple quantitative gain in accuracy that occurs with age, or are children of different ages using different rule based systems to guide them when they attempt to copy what they see?

Piaget and Inhelder's Theory of the Development of the Ability to Copy Geometric Forms

Jean Piaget and Barbel Inhelder have studied the development of children's abilities to copy geometric forms in their work on the development of representational space (1948). They proposed a stage theory of development and argued that children, at different ages, depict geometric forms according to the rule based system in which they are able to operate. Thus, when the 3-year-old renders the square and the circle alike, his figures should not be viewed as incorrect; rather they can be described as appropriately conforming to the most basic rules of drawing representation such as the differentiation between open

versus closed figures. Further, when the 7-year-old copies these figures accurately according to conventional standards, these precise replicas are not only the result of maturity level alone, but more importantly, they are the result of the knowledge of the more sophisticated rule system available for the child to use.

Piaget and Inhelder argued that the growth and change of drawing skills in the child are dependent on the development of concepts of representational space. Accordingly, there is an ordered and invariant sequence of stages in this developmental process that parallels Piaget's general sequence of stages: preoperational, concrete operational and formal operational periods of cognitive development. Further, drawing skills are also dependent on the same mechanisms for developmental growth that are delineated in his general theory. Specifically, cognitive development hinges on conscious actions and a desire to understand the world; children are the active force in their development. Thus, children are not preordained to have the skills to construct photographic copies of figures. In order to draw forms accurately, children must learn the laws of form reconstruction in order to copy what they have seen.

The researchers explained that although young children perceive subtle differences in geometric forms, they are unable to construct these differences in their drawings

because they lack the necessary spacial concepts to guide them. Piaget and Inhelder claimed that drawing skills are first dependent on the properties of topological space because the actions that give rise to topological relationships are much more basic than those necessary for the abstraction of Euclidean relationships. For the latter, more ordering, organization and coordination of action is necessary (Martin, 1976).

Changes in topological forms are independent of changes in angle size, distance or straight lines. Thus, a figure can be pulled and stretched in any direction, as if it were on a rubber sheet, and still retain its identity (Courant and Robbins, 1956). Piaget argued that properties of topological space include the concepts of openness and closedness of curves, proximity (nearness), separation (the distinction of figures from one another), order (the sequence of forms), surrounding (enclosure) and continuity (the connectedness of points, lines, and planes).

Next, constructions are based increasingly on properties of Euclidean and projective space. The transition from topological to Euclidean space occurs when the child begins to analyze angles. Piaget and Inhelder argued that when children compare and contrast a circle and a square, they are not examining straight versus curved lines so much as they are studying the angles formed by the intersection of these lines. Thus geometric forms are

increasingly based on the precise rendition of metric properties and, as a result, angle size and line length are carefully measured and the child exhibits conservation of size, length and parallelity. In terms of their projective properties, when figures are drawn on a plane surface, straight lines remain straight, but their length and the angles they form are altered so that they maintain one coherent perspective for the viewer.

The development of drawing skills is completed when the child utilizes overall systems of horizontal-vertical coordinates and coordinated perspective. As a result, the child no longer is "pulled in" by the immediate surround of the drawing, but uses abstract axes to delineate figures accurately.

As is evident, the proposed ontogenetic sequence of geometry, from topology to Euclidean geometry, does not mirror the historical discovery of these geometries. Euclidean relationships had been formulated long before the discovery of topology in the 20th century. Piaget commented on this lack of consistency, explaining that the developmental process does not mirror the historic progression because of the greater number of conservations that children must maintain in order to grasp Euclidean relationships (Voyat, 1982).

Piaget and Inhelder proposed the following specific stages of development. In Stage 0 (ages 2.0-2.11),

drawings appear to lack purpose and seem to be composed of aimless scribbles. Stage 1 (ages 3-4) is composed of two substages. In Substage 1A drawings still seem to be scribbles, but they are based on the elementary topological relationship of closure. Thus, closed figures can be distinguished from open ones. In Substage 1B, drawings reflect the full range of topological relationships as mentioned previously. Consequently all closed figures look alike; a square, a circle and a triangle all appear as irregular closed shapes. At this point the copies may be called true drawings or representational constructions. In Stage 2 (about age 4 to 7), which is also composed of two substages, drawings gradually become differentiated according to their Euclidean characteristics. During Substage 2A, shapes are distinguished on the basis of angle size and line length. An attempt is made to draw inclinations accurately. As a result, squares are differentiated from triangles and circles from ellipses. At Substage 2B, simple oblique lines are drawn correctly and thus the child is able to copy a rhombus. Nonetheless, the Euclidean properties found in children's drawings at this stage are formed simply by perceptual and intuitive guesses rather than by logical reversible operations. Stage 3 (age 6.6-9.0) has two substages. Substage 3A marks the onset of concrete operations. Angle size, line length, parallels and distance are now conserved. That is, the



child has come to realize that these properties will remain invariant despite certain transformations. For example, the angle size formed by two intersecting lines will remain the same whether the baseline is drawn in a horizontal, vertical or oblique orientation. There is also a progressive awareness of orientation. These concepts pave the way for the attainment of overall reference systems that are put in place during Substage 3B. Only when the child can use an external frame of reference will s/he be able to depict figures accurately and in appropriate relation to their surroundings. These newly acquired reference points offer a concrete method to decipher accurate angle and line size and orientation as well as appropriate projective relationships. In Stage 4 (11-12 onward), the beginning of formal operations, the reference systems are now based on conventional and abstract systems. The child can compare several aspects of a figure at once such as its size, shape and perspective.

Topological Space: Further Research and Divergent Views

While Piaget and Inhelder's theory of the development of drawing skills appears coherent and plausible, how sound is it at a conceptual level? How accurately and thoroughly does it account for the data from research on the development of drawing skills? In the next part of the literature review, the validity of their theory will be discussed in terms of these questions.

Piaget and Inhelder's notions of topology and their claim that it accurately describes the young child's first most basic drawing skills have been widely debated (Kapadia, 1974; Martin, 1976; Ninio, 1979; Geeslin and Shar, 1979). Although these investigators used the words "topological" and "Euclidean" to describe figures, clear definitions of these terms were not given. A figure cannot be labeled as either topological or Euclidean using the criterion that one has features of the former while the other of the latter because all figures will contain both sets of properties. For example, a square defined in topological terms would be a closed figure lying within a specific plane. Defined in Euclidean terms, it would be described as a simple four-sided figure having four right angles whose lines are of equal length. In fact, a figure will contain just as many topological properties as Euclidean ones (Martin, 1976). Clearly, the differentiation does not lie inherently within the stimulus, but in the way we choose to look at it. Piaget and Inhelder did not make this distinction clear. It has also been suggested that the notion of topological primacy is tautological, since topological relations will be included in any form. Because any form that is not an accurate Euclidean representation may be called a topological success, the theory is neither provable nor disprovable (Ninio, 1979). However, this argument is not

necessarily true; if a square is incorrectly copied as an open form, it is not accurate by topological or Euclidean standards.

Further, Piaget and Inhelder's vague definition of topological invariants does not fall within the mathematical conception of this branch of geometry. They claimed that relationships of proximity, enclosure, continuity and order are topological invariants; mathematicians would disagree. There is no place for the concept of proximity in topology, because it implies an idea of distance that is a metric concept (Geeslin and Shar, 1979; Kapadia, 1974; Martin, 1976). Enclosure does not fall within the scope of topology unless one states that the figures lie within a specific plane. Otherwise, this figure, , would be homeomorphic or topologically equivalent to this figure, , because the only necessary invariants are that they be connected closed figures (Kapadia, 1974). The notion of continuity is not related to topology, since there are three distinct sets of objects: points, lines and planes, none of which are reducible or expandable to the others (Kapadia, 1974; Martin, 1976). Finally, the concept of order is not a topological invariant, since the field of topology deals with figures in and of themselves unrelated to other objects in a field (Martin, 1976). Thus, when Piaget and Inhelder described children as demonstrating an

understanding of topological relationships when they drew the features within a face in the correct relationship to each other, Piaget and Inhelder were not using the theory of topology in its mathematical form. The child could, in fact, have drawn a distorted face, similar to those of Picasso, and actually have been utilizing topological relationships accurately.

Although all researchers agree that the ability to copy figures becomes more refined and accurate with increasing age, they do not concur on the type of developmental process that is unfolding. Their arguments are based on their varied theoretical positions and on the results of their experimental studies. One common finding has been that curvilinear shapes appear to be copied accurately as early as all topological invariants are mastered (Lovell, 1959; Martin, 1976; Vurpillot, 1976). It is also argued that the topological stage does not accurately characterize the developmental process, since young children do not confuse many letters of the alphabet such as C, L, M, N, U, V, S, W and Z. These letters are all topologically equivalent (they are all defined as open figures) and thus should all be confused if the young child is operating solely under the principles of topology when copying these letters (Kapadia, 1974). This argument would be more convincing if the children examined had been between the ages of 2-and-a-half and three instead of

between the ages of five and six, because Piaget argued that children of this age should already possess some rudimentary understanding of metric concepts. A further piece of evidence that does not lend support to Piaget and Inhelder's theory was found when children aged 2.11-5.0 were asked to copy circles and triangles. These youngsters did not tend to draw a triangle incorrectly as a curved figure, a topological success; instead they often created an open figure, a topological failure (Maccoby and Bee, 1965). This general finding also has been noted by Graham, Berman and Ernhart (1960).

Various theoretical arguments have been proposed to account for these unpredicted findings. It has been argued that the hypothesis of topological primacy is too simplistic to account for the data (Vurpillot, 1976). Rather it appears that two spatial relationships or properties precede all others: that of the topological distinction between open and closed, and the Euclidean distinction between curvilinearity and rectilinearity. Although topological invariants are apparently easier to maintain than Euclidean ones, an awareness of both sets does not always result in the maintenance of the easier topological ones in lieu of the more difficult ones. Thus, it is not just a question of a simple hierarchy within which all topological relationships will be maintained before any Euclidean ones are attempted. Drawing

representation also depends on the complexity of the figure and the aspects of the form to be copied (Vurpillot, 1976). One way to account for the observation that children's copying errors do not always conform to topological successes and Euclidean failures is that the children in these studies were in conflict between the demands of topological and Euclidean principles (Thirion, 1969). While a young child ignores all Euclidean characteristics, the older child is becoming aware of Euclidean properties and tries to deal with both types of spatial systems simultaneously. As a result, the copying tasks become more difficult because he now tries to reconcile the two systems. Thus, at times, topological relationships may be sacrificed for the sake of imperfect metric ones (Thirion, 1969).

Nonetheless, it has been suggested that instead of trying to fit the data into a specific theoretical pattern, one ought to look at development as an increasing skill at ordering and organizing representations of figures (Martin, 1976). However, no explanation that accounts for the ordering and organization is given. Finally, it has been suggested that children's drawings become more accurate with age and that overall gradual improvement in all aspects of drawing representation is the unfolding phenomenon and not a developmental progression through discrete stages (Graham, Berman, and Ernhart, 1960). While

this statement is not false, it only describes the phenomenology and does not explain it. The findings that indicate that curvilinear figures are copied accurately at the same time that topological concepts are mastered suggest that perhaps children's development should be viewed with respect to their increasing skill at deriving relationships between lines and overall figures. At first the concepts depicted in drawings are seen to represent vague Euclidean relationships, but as they become more refined, they become accurate metric representations (Lovell, 1959, 1966).

Despite these contrary findings, there are others that support Piaget and Inhelder's proposal. When children, aged four to eight years, were required to discriminate a set of letter-like forms, the 4-year-olds made few errors on the topological transformations (i.e., when topological features of the forms were altered such that, for example, closed figures were changed into open ones) and the 8-year-olds were nearly perfectly accurate. On the other hand, errors based on changes in perspective of these forms remained high in all age groups. Further, errors in rotation and reversal and changes in lines to curves were high in 4-year-olds, but declined significantly in the 8-year-old group. These results suggested that while topological transformations are crucial for form identification and are learned at an early age, the more

complex Euclidean transformations, which are also important for form identification, are understood and utilized by age eight. Changes in perspective, however, are not essential for form discrimination and are not rapidly learned (Gibson, Gibson, Pick and Osser, 1962). When children were required to copy three forms of each letter-like figure--a topological transformation, a Euclidean transformation and a projective transformation--the findings confirmed those obtained by Gibson et al. (Benoit-Dubrocard, Deleane and Nichoff, 1984). Topological discriminations were made by children at an early age (six groups of children from ages four to seven were used in the study), while no reproductions of projective alterations were attained. Similar results were also found by Cousins and Abravanel (1971), who argued that the development of spatial awareness appears to progress from topological to Euclidean geometry. In addition, Cousins and Abravanel, like Piaget, also noted that the familiarity and the complexity of figures to be copied does affect the types of choices the child will make.

All of these findings suggest that there are some distinct qualitative differences between the ways in which younger and older children depict copies of geometric forms. However, the use of the term "topology" to describe young children's constructions does not appear to be accurate or to be truly representative of the way in which

children between the ages of two and four depict geometric figures. Nonetheless, it would be equally inaccurate to state that these young children are actually using Euclidean relationships in their drawings. As a result, a slightly different term, such as basic form geometry, might be more appropriate.

Euclidean Space: Further Research and Divergent Views

Unlike the controversial data from studies on topology that question the validity of Piaget and Inhelder's theory of the primacy of topological space, data from research on the development of Euclidean concepts is more consonant with the theory. While all researchers do not agree with the developmental pattern proposed by Piaget and Inhelder, their data can be fit appropriately into this theory and the findings can help expand and delineate the developmental sequence more precisely. Piaget and Inhelder have maintained that children, until the age of six to seven, are unable to copy many geometric forms using precise Euclidean coordinates. They explained that the difficulties arise from the inability to use an overall external frame of reference, a skill essential for the accurate reconstruction of angles and lines.

The major critic of this theory is Freeman (1980). He argued that the unfolding developmental pattern is the opposite of that proposed by Piaget and Inhelder. He maintained that young children, three to four years of age,

are extremely sensitive to external reference frames and rely on them to organize their perceptual experiences. As they grow older, they acquire other more flexible methods to categorize their perceptions that depend more and more on internal planning rules, such as higher on the page to indicate that the object is further away. When the transition is complete, by about age eight, they are able to use a complete internal framework.

While Freeman contended that his theory contradicted Piaget and Inhelder's hypothesis, predictions made from the two theories are actually quite similar. Both would argue that young children are unable to copy accurately various geometric forms because they "are reliant on" or "are unable to decenter from" the immediate framework to depict the figure's fixed Euclidean coordinates. Both cite the same types of evidence to support their claims. For example, Freeman stated that young children are very sensitive to the reference frame when drawing oblique lines. Their difficulties arise when they are presented with a conflict between the angle of the oblique line and the vertical-horizontal surround of the paper. He argued that these children do not lack the ability to draw obliques and are not ignoring the reference frame. Instead, they are in a "cue conflict analysis" dilemma. Piaget, however, argued that these children are unable to use the external frame systematically to guide their

constructions and, as a result, are pulled in by the salient horizontal and vertical cues. Again, this difficulty causes them to copy the lines in a distorted manner.

Piaget's point of view seems to be the most parsimonious. Indeed, children have difficulty copying geometric shapes especially when the immediate surround does not have the same contours as the figure to be copied. He would not have argued that young children's skills in this area are not constantly improving; nonetheless, he also would not have stated that children have a preordained ability, at the age of four, to draw angles and lines in their precise Euclidean form, even when given optimal conditions. To argue, as Freeman did, that children actually have all of the necessary abilities but that the frame of reference caused conflict for them until the age of eight is to state that they are unable to dissociate themselves from the immediate surround and to use it to their own advantage until they are age eight, an argument similar to what Piaget might have maintained.

This inability to use systematically external reference frames has been observed with the use of other types of constructional tasks as well. When youngsters aged 3.0-5.10 were asked to reconstruct displays using paper strips and squares, they completed the task with much greater success when required to copy single-axis displays

than double-axis displays (designs requiring the coordination of both X and Y axes) (Rosser, Horan, Mattson and Mazzeo, 1984). The difficulty did not reside in the number of pieces needed for reconstruction, since the children were able to copy the designs having the greatest number of pieces when the designs were in the single-axis condition. The children's difficulty seemed to be related to the number of axes to be coordinated. They did not seem to utilize an external coordinate system that would have given them a guide for the placement of the markers.

Children have been noted to have similar problems when required to copy patterns on a checkerboard. Preschoolers had great difficulty reconstructing oblique lines on a checkerboard (Olson, 1970). Specifically they were unable to copy patterns using more than one axis. While 5-year-olds were able to copy designs in two dimensions, such as a diagonal, they were not capable of copying patterns in which each element was displaced on the horizontal and vertical axis, such as a "W." These difficulties, again, appear to be related to the children's inability to use an external coordinate system to organize their designs (Halford and MacDonald, 1977).

Not only does the young child's difficulty using external coordinates impede his accuracy in reproducing Euclidean forms, preferences seem to interfere as well (Braine, 1973). Preschoolers appear to be biased towards

rotating figures to their phenomenally upright positions. Young children appear to judge the orientation of figures as correct when the salient focal feature of the form is at the top of the figure and when there is a vertical orientation of the principal lines of the figure. Thus, if the figure to be discriminated was in its apparent upright position, the child would not make rotational errors, while youngsters would make these mistakes when the figures were not in the preferred orientation. Further, when 4- and 5-year-olds were asked to copy figures in their phenomenally upright positions, they made significantly fewer errors than when these same figures were presented in other orientations. Interestingly, after the age of five to six, children were much more reluctant to label abstract figures as right side up or upside down (Eldred, 1973). This developmental pattern has been found in Japanese children in Hong Kong as well (Goodnow, Young, and Kvan, 1976) since they, too, made more rotational errors when the figures to be copied were not in their phenomenally upright positions. Thus, there appears to be a common developmental error pattern in the way that forms are copied by children of differing ages across cultures. It would seem that youngsters' nascent abilities to use external reference axes, which begin to develop around the age of five, may be partially responsible for their newly found ability to discriminate and to copy figures in their actual

orientations and may explain their newly found reluctance to label figures as upright or not.

Piaget and Inhelder argued that the child develops the capacity to reproduce vertical and horizontal lines simultaneously and subsequently learns to reproduce oblique lines. This contention has been challenged. When nursery school children were asked to reproduce horizontal and vertical lines within a circular frame instead of within the typical rectangular frame present on a sheet of paper, their copies of vertical lines were significantly more accurate than those of horizontal and oblique lines (Berman, Cunningham and Harkulich, 1974). The difference in accuracy between lines in the latter two orientations was insignificant. These results suggest that when vertical and horizontal referents are eliminated from the immediate surround, a different developmental sequence emerges.

The child's sensitivity to the immediate surround is given further support when preschoolers were asked to reproduce horizontal, vertical and oblique lines within a rectangular frame. Their constructions of horizontal and vertical lines were equally accurate, while their reproduction of oblique lines was significantly less precise, unlike the results when they were asked to draw these lines within a circular reference frame (Berman, 1976). The immediate surround again seems to make a

significant difference in the type of drawing skills displayed. The change in accuracy of reproduction of the horizontal and vertical lines is significant as well as the types of errors demonstrated. When youngsters drew horizontal lines incorrectly, they were reproduced as verticals and vice versa. Further, when mistakes on oblique lines were made, the lines were drawn in the opposite direction or as horizontals or verticals. These results again indicate that children of this age tend to use the external frame as a rough overall guide and remain unable to use it in a systematic fashion to help code precise orientation. Indeed, the young child's initial capacity to reproduce a line in a horizontal orientation seems to be largely determined by the shape of the immediate frame of reference. As Piaget and Inhelder have noted, young children appear to be pulled in by their immediate external surround. Until they are able to decenter from these stimuli, their reproductions will be governed largely by the shape of the immediate frame of reference. Thus, while Piaget and Inhelder's overall theory concerning children's inability to utilize external frames of reference systematically is again confirmed, their proposed developmental sequence of line copying skills appears to warrant further study. Youngsters initially appear able to draw vertical lines, subsequently horizontal lines and finally oblique strokes.

Piaget and Inhelder have also discussed the general difficulty children have in reconstructing oblique lines. They conclude that it is only when youngsters reach the period of concrete operations and, hence, are able to decenter from the immediate reference frame that they are able to copy oblique lines accurately. Other researchers have examined the development of this skill in greater detail and have proposed specific hypotheses to account for children's difficulties. While the theories differ, all appear to be related to Piaget and Inhelder's basic and critical observation that the young child's inability to free himself from the immediate surround results in inaccurate reproductions.

One explanation (Bryant, 1969) for children's poor reconstruction of oblique lines is related to their tendency to code the orientation of lines within a display in terms of whether these lines are parallel to other lines in the frame of reference. Thus, children typically depend on the sides of the sheet of paper and use a match-mismatch code. As a result horizontal and vertical lines produce a match signal, the former with the top and bottom edges of the paper and the latter with the right and left sides. Oblique lines, however, produce only a mismatch signal, since they are not parallel to any of the sides. As is clear, this coding device distinguishes horizontal from vertical lines and obliques from these two orientations.

It does not differentiate, however, obliques from each other, since they only produce a general mismatch signal. However when 5- to 7-year-olds were asked to recall oblique lines situated within a diamond framework having different colored edges, they completed the task more accurately. This finding lends further support to the theory since, in this task, the children would be able to use a specific match signal to aid in recall of oblique lines.

Data from additional research casts doubts on the validity of the match-mismatch hypothesis. Specifically, when children were asked to copy oblique lines on diamond-shaped cards whose sides were not color coded, their performance did not improve significantly. These findings suggest that the framework itself is not the salient factor causing accurate or inaccurate recall of figures. Instead, it would seem that there are other cues being used to register orientation, such as color (Stein and Mandler, 1974).

As noted previously, when children copy diagonal lines, their mistakes tend to be systematic (Berman, 1976). Two theories have attempted to characterize the types of errors. When youngsters between the ages of three and five were required to reconstruct oblique lines from previously drawn horizontal, vertical and oblique baselines, they tended to construct angles that were more perpendicular

than the actual stimuli. This tendency has been labeled the perpendicular effect. This effect is noted to be a basic and pervasive geometric error that is made without reference to the overall frame of reference within which the child is working (Ibbotson and Bryant, 1976).

Interestingly, it occurs much less frequently when the baseline used is vertical than when it is horizontal or oblique. This phenomenon has been called the vertical effect.

While this hypothesis is intriguing and casts some doubt on Piaget and Inhelder's theory, since it states that children's reliance on the immediate surround is not the source of their problems, it requires further proof. It would be necessary to demonstrate that children truly are unaffected by the background in which they work and that they are not using subtle cues in the surround. To begin to examine this question, the shape of the background on which the children are required to respond would have to be varied systematically and subsequent differences in their reconstructions would have to be examined. If there were differences, further support for the match-mismatch theory and Piaget and Inhelder's theory would be found. If no differences were noted, further proof for the perpendicular bias and vertical effect would be demonstrated.

Interestingly, when diagonal lines are drawn more perpendicularly than they should be on horizontal and

oblique baselines, they do tend to give the resulting figure a perceptual attribute of greater stability and increased verticality. This orientation bias has been noted in young children previously (Braine, 1974).

In another study, 5-year-olds were required to copy an oblique line onto a doglegged angle. (A doglegged angle is an oblique angle where one ray is either vertical or horizontal.) The copied line had to originate at the vertex of the doglegged angle. The results from this study (Bremner and Taylor, 1982) were somewhat different from those of Ibbotson and Bryant's 1976 study. The children tended to distort the figure by bisecting the doglegged angles, instead of by altering the figure to form right angles (the perpendicular effect). Specifically, when asked to copy oblique lines perpendicular to the doglegged baselines and to copy oblique lines to bisect doglegged baselines, the children copied the latter more accurately. These findings suggested that the perpendicular effect is just a particular instance of a more general tendency in young children to bisect angles. It has been proposed that children try to produce symmetry or simplicity in their constructions and that they accomplish this goal when they bisect angles. Interestingly, the bisection tendency was found only when the doglegged baselines were in oblique orientations. The age of the children used in this part of the study was 5.9 years, however, and as a result they may

have been able to handle the two other orientations more proficiently than the younger subjects (between three and five years of age) in Ibbotson and Bryant's study. Thus, once again, children's internal biases are suggested as the cause of their inaccuracies.

Nonetheless, further research cast doubt on Bremner and Taylor's bisection hypothesis. When children were asked to copy triangles and were given the horizontal and vertical baselines, no simple bisection effect was found. Results indicated that perpendicular lines were drawn with the greatest accuracy and that 45-degree angles tended to be reduced in size from the vertical baselines and increased in size from the horizontal baselines. The overall effect was to make the copied lines more vertical than the stimuli actually were. These data do not support the bisection theory, since oblique lines from vertical baselines were not drawn to make the angles more symmetrical. It has been concluded that a form of the vertical effect may be operating here or that the type of distortion of oblique angles is different when using vertical baselines than when using horizontal baselines (Pigram, 1984).

Results from all of these studies give further evidence that young children do not simply commit random errors when copying oblique lines. The precise nature of their errors, however, remains unclear. It is not possible

to make comparisons between all of these studies, since the nature of the stimuli has been altered in each experimental design, previous methods and results have not been replicated before new techniques have been implemented and the ages of the children were different. These studies once again raise a crucial point: the results and the theorized developmental underpinnings can change as the stimulus set is altered. Because of all of these issues, it is clear that more work in this area is necessary if we are to understand the precise nature and development of children's abilities to reconstruct oblique lines.

Despite the lack of understanding concerning the precise nature of the development of oblique lines, two general conclusions may be drawn from the research. First, the evidence does not favor a conception of form copying development that is based on the growth of piecemeal skills. Instead, the evidence is in favor of a general stage theory of drawing development. It suggests that as children learn different rules, all of their form copies change in systematic ways, as may be seen by the nature of their successes and failures when copying horizontal, vertical and oblique lines. Second, while it is not clear what factors cause the children to err in the typical manners that they do, it is evident that they are governed by their own internal reference frames or by external reference frames. Both of these conclusions fit into

Piaget and Inhelder's general description of the development of form copying skills, since they suggest that development is rule based and that errors are due to an inability to utilize accurately an external reference frame.

Projective Space: Further Research and Divergent Views

Piaget and Inhelder have argued that children are unable to show depth relationships accurately in their drawings until they are able to use overall reference systems. They have observed that children encounter an additional difficulty when attempting to represent projective relationships; the structure of the third dimension does not lend itself to a simple translation of the represented image onto a two-dimensional space (e.g., paper), unlike Euclidean relationships. As a result, youngsters must learn certain rules that will enable them to portray perspective accurately in their drawings. These researchers have not examined all of the developmental precursors of the mature attainment of projective relationships in their theory and as a result suggest that before the age of nine, youngsters are completely incapable of accurately portraying any kind of depth in their drawings.

Further research in this area suggests that while young children are unable to use the conventional adult methods to depict depth, they attempt to convey this

spatial component systematically through a series of other graphic means. Their methods appear to be rule governed and increasingly complex. When directed to draw one object behind or in front of another, children at the age of five will draw them in a vertical relationship to each other (Cox, 1978). By the age of eight, children will draw one object enclosed in another and, by the age of nine, children occlude part of the further object with the object in front to express depth (Freeman, 1977; Light and MacIntosh, 1980). These findings demonstrate that projective relationships develop in an organized manner. Further, they indicate that although young children are unable to use the conventional rules of perspective in their drawings, they are aware of the existence of depth relationships and attempt to convey this connection between objects in a systematic, rule governed manner. While these findings amplify Piaget and Inhelder's theory, they do not contradict Piaget and Inhelder's basic contention that below the age of nine, children are incapable of reconstructing forms in perspective, such as cubes and cylinders. Most important, they give further credence to Piaget and Inhelder's basic assertion that the development of copying skills proceeds in an orderly, rule governed manner. Once again, children's growing skills are not viewed as the result of piecemeal learning, but as logical

steps resulting in the attainment of the ability to copy forms in perspective.

Comments and Criticisms of Piaget and
Inhelder's Overall Theory

Not only have specific points within Piaget and Inhelder's developmental theory been criticized, but also their overall concept of a stage model of development. In general, arguments center around (1) whether development is continuous and quantitative in nature, or whether it is discontinuous, proceeding in discrete stages and qualitative in nature and (2) the manner in which task demands influence level of performance. Other models of development have been proposed to address these issues.

Piaget and Inhelder argue that at each stage of development, children are able to reconstruct forms in characteristic ways due to the skills they have available to them. Piaget and Inhelder believe that skills from lower stages are not lost, but are integrated into the newly found abilities available at more advanced stages. Clearly development, to them, is not continuous, but based on the growth of increasingly complex, more highly integrated, cognitive structures. Support for their overall theory of drawing development has been demonstrated by Peel (1959). Using a Guttman scalogram analysis, he demonstrated their proposed developmental sequence. However, results from this statistical analysis indicated

the existence of only four basic stages, as well as a need for the revision of their age equivalents. Some researchers disagree with the stage theory, stating that the developmental growth found in children is a reflection of continuous change, rather than discontinuous change, in which the reconstructed form increasingly approaches the original in all dimensions (Graham, Berman and Ernhart, 1960). They argued that the mechanisms for development are the children's efforts to correct their errors of over- and under-estimation of all aspects of the figure they are attempting to copy. Results from a study in which these researchers rated the drawings of children between the ages of 2-and-a-half and five on the basis of topological and simple Euclidean relationships led them to these conclusions. Specifically, they found that while some characteristics were easier than others to reproduce, there was no evidence of the sudden emergence, gaps or uneven development of the characteristics studied. Thus, it was most meaningful to classify the data according to the children's attempts to estimate accurately the size and shapes of the figures to be copied. There are, however, several problems with this study. First, since the age range was so constricted, the transitional points between stages could not be evident. Second, the individual intelligence scores of the children ranged from deficient to superior. The IQ range clearly could have influenced

how various children responded and masked differences among them (Beery, 1982; Koppitz, 1963).

Freeman (1980) also questioned Piaget and Inhelder's stage theory. He agreed that the skills used by children at different ages are rule based, that children's performance does improve over age and that context plays a crucial role in development. The convergence of the theoretical viewpoints ends here, however. The crux of the difference resides in Freeman's belief that the relationship between drawing skills and spatial understanding is akin to the relationship between speech and language, while Piaget and Inhelder view drawing skills as a basic representational ability similar to language. Thus, Freeman believed that difficulties in form reconstruction are the result of difficulties in organization and deployment of the spatial knowledge the child already has. Indeed, as noted previously, he maintained that children, by the age of three, are endowed with the ability to reconstruct any figures, but that specific task demands can make it very difficult for them to demonstrate their skills. Thus, children as they grow do not change the strategy they use to construct figures; rather, they simply become more adept at handling performance biases and task demands. Clearly, Piaget and Inhelder do not believe that children use one basic strategy throughout their development when attempting to

copy geometric forms. On the contrary, they argued that different methods of representation are used, depending on the developmental stage of the children.

Other criticisms of Piaget and Inhelder's theory have been made on the basis of task demands. Children may be seen as developing one concept prior to another, depending on the tasks selected. An instance of this issue, already noted, is the data from the studies of Berman et al. (1974) and Berman (1976) on the development of horizontality and verticality. The results indicated that the shape of the paper determined which of these skills was demonstrated initially. The importance of this issue has also been demonstrated in a study in which children aged seven to nine had to demonstrate an understanding of the horizontal and the vertical by (1) showing the water level in puddles, (2) the water level in tilted jars, (3) the angle of trees on a mountain and (4) a light bulb hanging from a string in a car traveling up an incline. Results indicated that the first and third tasks were easier than the second and fourth. Clearly the familiarity of the task was the determining factor as to whether an apparent understanding of the horizontal preceded that of the vertical for these youngsters. These findings emphasize the importance of the tasks used in developmental studies when making predictions about level of a particular skill (Mackay, Brazendale and Wilson, 1972).

It has also been noted that while the fully competent youngster can perform a wide variety of tasks with equal ease, the child who is in the process of acquiring skills will have more difficulty (Rosser, Mazzeo and Horan, 1984). Specifically, they found that axis complexity and response mode (e.g., matching, recall, reconstruction) significantly affected performance. They argued that the findings demonstrated that while a set of geometric skills may be within the capabilities of young children, the youngsters are not always able to demonstrate them because of the types of response demands. It is important to realize that the abilities required for perceptual discrimination (matching tasks), recall and reconstruction are related, but not identical. Competence in one area does not necessarily imply comprehension or competence in the other areas, since they each require a unique subset of skills. As a result, the assumption should not be made that a child has a complete understanding of a property if he is able to demonstrate it only in one of the areas.

It has also been suggested that the stage of development demonstrated in any drawing is itself dependent on the task demands, which are imposed in the drawing situation (Barrett, 1983). Specifically, the production of a drawing is determined by the cumulative effects of many cues. The initial set of cues resides in the reference frame of the blank paper. As soon as children make a mark

on the paper, an altered set of cues emerges. This change and diminution of degrees of freedom available to the children continues as they progress through the drawing process. As a result, a more appropriate model in which to examine drawing skills is one that utilizes notions of task demands and cue-dependency, rather than on a general notion of stages of development. It is not suggested that Piaget's general stages of development are not valid; however, it is argued that the level of analysis in this theory is too general and that a more accurate theory rests on the analysis of drawing demands.

While many of the studies used to criticize Piaget and Inhelder's theory are flawed, the researchers have raised an important point. When examining the development of drawing skills, the influence of task demands should be more carefully monitored, since the shape of the surround appears to influence production. However, to argue, as Freeman does, that the task demands are the only factor hindering the demonstration of fully competent skills appears fallacious. Further, the methods used to demonstrate that development is merely a quantitative accretion of skills are clearly inadequate.

Tests Used to Measure the Development
of Form Copying Skills

Historically, the ability to copy geometric forms has been considered one aspect of intellectual development. As a result, copying skills have been included in many intelligence tests beginning with the Stanford Binet (Terman and Merrill, 1960). Other measures utilizing a form copying component include the Griffith Scales, the Cattell Infant Intelligence Scale (Cattell, 1947), the Bayley Scales of Infant Development (Bayley, 1969), the Wechsler Preschool and Primary Scale of Intelligence (Wechsler, 1960) and the McCarthy Scales of Children's Abilities (1972). Currently, two other measures in wide use for the assessment of these particular skills are the Bender Gestalt Test of Visual Motor Integration and the Beery Developmental Test of Visual Motor Integration.

The Bender Gestalt was originally developed by Laretta Bender in 1938. She adapted figures used by Wertheimer for his studies on visual gestalten for this copy task. The gestalt function, she believed, was demonstrated by the ability to respond to a pattern of visual stimuli as a whole. She argued that the ability to perceive and to copy the figures was indicative of the pattern of growth and level of maturity within the individual. It was assumed that the resulting gestalt was determined by the sensory motor action patterns within the

individual and that the gestalt would vary in different states of maturation and pathology. According to this theory, visual motor patterns were thought to arise from motor behavior modified by the visual field (Bender, 1938). Bender argued that the development of this function occurred in the following order: first, circular movement was controlled, then, differentiations between figures and their backgrounds were made so that figures were organized into patterns. Next, orientation of horizontal lines and directionality were completed, followed by the development of verticalization and finally by diagonal orientation. The process would be completed when there was a differentiation and separation of the figure and its parts (Bender, 1970).

Although Bender designed this test for children and adults, she did not develop an objective scoring system. Koppitz (1963) provided a developmental scoring procedure for this measure for children aged 5 to 10. She, like Bender, argued that this test provided a systematic exploration of the level of visual motor perception in individuals and that it was sensitive to abnormal patterns of development, such as disturbances in affect and learning skills. Koppitz, noting that children with behavioral and learning problems often performed poorly, suggested that these problems were the result of perceptual deficits. Koppitz devised two developmental

scoring systems--one to measure visual motor perceptual skills and the other to examine emotional adjustment. The visual perceptual maturity level was derived using an overall score from the nine figures. Koppitz used several of the following criteria when evaluating each figure; distortion of shape, rotation, integration and perseveration. She argued that children varied not only in their rate of development, but also in the sequence in which they acquired various visual motor gestalt functions.

Beery created, and has subsequently revised, another test examining the development of copying skills: the Developmental Test of Visual Motor Integration (VMI) (1967) and the revised form of this test (1982). He contended that this task was designed to measure the changes in eye-hand coordination that occurred as the child matured and specifically that the test delineated the degree to which visual perception and motor behavior were integrated. The task is comprised of 24 geometric forms to be copied and is scored according to qualitative criteria specific to each figure. The norms for the revised test indicate that it is useful for children whose chronological age places them between 2.11 and 14.6 years. While Beery's scoring criteria appear to be straightforward, a large number of subjective scoring judgments are required. For example, on forms 1-18 there

are unclear qualifiers such as "predominantly," "slight" and "good" that permit subjective evaluations of the productions. Further, while most examples illustrate correct and incorrect figures clearly, there are a few instances in which contradictions are evident. When scoring agreement between a psychology extern and elementary school teachers was compared, individual correlations ranged from .39 to .79 (Pyrzwansky, 1977). These results suggest the need for greater clarification of the scoring criteria.

Both the Bender Gestalt and VMI suffer from serious flaws. The VMI has no theoretical underpinnings. The concepts on which this test is based, "visual motor integration" and "perception," are neither adequately defined nor is an explanation given as to how they are interrelated, though Beery states that they are causally related. When developing his test, Beery simply collected norms on the age at which figures were adequately copied and devised scoring criteria with which to rate the accuracy of the drawings. Indeed, the only assertion that may be made safely is to what age level the youngster's visual motor skills correspond.

A similar criticism may be leveled against the Bender Gestalt test. While this measure is based on gestalt theory, it remains unclear how visual perception and motor skills can be wholly responsible for the child's

developing copying skills. Visual perception implies a level of visual analysis unrelated to any kind of complex conceptual integrative functioning; motor ability suggests the physical dexterity and speed available to the children when they are required to complete the task. While the authors may have intended to convey different levels of functioning by the use of these terms, it is not at all clear from their discussions. Further, as on Beery's test, neither Bender nor Koppitz has provided any precise explanation of how different patterns of poor visual perceptual performance should be interpreted.

As a result of these difficulties, it is not surprising that differences between these two tasks, supposedly measuring the same construct, are often found. When results from Bender and Beery protocols were compared for 64 children aged six to nine, the tests had a shared variance of only 38%. The results suggest that while the two measures are statistically related, one cannot conclude that they measure the same visual motor construct, since 62% of the variance between the measures could not be accounted for (Porter and Binder, 1981). Similar results were found when non-Indian and Indian children, aged six to eight, were administered both tests. Here 65% and 74% of the variance could not be accounted for. These findings again indicate that the two tasks are clearly not interchangeable, despite the fact

that they do share some common properties (Connelly, 1983). While a high percentage of the variance (73%) was shared by the two tests in another study (Breen, 1982), the individual test performances were highly varied, since at least one third of the scores differed by a minimum of 18 months. In another study, in which the authors concluded that the tests did measure similar constructs (Skeen, Norton and Book, 1982), the individual results from subjects were again dissimilar; 47% of the subjects demonstrated a discrepancy of more than 12 months on the two tests. Thus, these tests can provide significantly disparate results with nontrivial clinical findings.

When discrepant performance on the two measures is examined more closely, scores from the Bender Gestalt are often found to be higher. These results were apparent when kindergarten through third grade children were tested on both tasks. The Bender Gestalt yielded age equivalent scores 11 months higher than those from the Beery (Siewert and Breen, 1983). Further, in a group of children in kindergarten through third grade, the mean difference between the two tests ranged from a low of 6.8 months to a high of 11.2 months (Lehman and Breen, 1982). Results from second graders revealed a significant difference of 7 months (Brown, 1977). When results from learning disabled and control subjects aged 7-10 were compared, the average difference between the two measures was 9 months

(Armstrong and Knoff, 1982). In addition, when the performance of learning disabled subjects aged 7.10-11.9 was compared, a 14 month difference was found (Breen, Carlson and Lehman, 1985). Only one study was found that demonstrated higher scores on the Beery (DeMers, Wright and Dappen, 1981).

Results from all of these studies clearly suggest that the two tests are not interchangeable and that they measure similar, but non-overlapping, drawing abilities in youngsters. These discrepancies may arise from the lack of a clear definition of the constructs that the tasks purport to measure, the scoring criteria and the skills that are necessary for adequate performance in this area of functioning.

Patterns of Functioning in Learning Disabled Children

In general, learning disabled children perform unlike their normal peers on measures of cognitive ability and academic achievement. Specifically, learning disabled youngsters are noted to perform much more proficiently on tasks requiring spatial analysis and constructional skills than on tasks requiring linguistic conceptual abilities (Lueger, Hilgendorf, Albott and Gill, 1985). Thus, this group often attains greater scores on the Performance subtests of the WISC and WISC-R than on the Verbal subtests (Breen, Carlson and Lehman, 1983). Specifically, they perform most proficiently on the subtests requiring

analysis, synthesis, and reconstruction of spatial arrays such as Block Design, Object Assembly and Picture Completion. When large (25 points or more) Verbal-Performance IQ discrepancies are found on the Wechsler Scales, significant academic problems have frequently been noted as well. Specifically, when the Verbal IQ was lower, the children demonstrated academic and psycholinguistic deficits, and when the Performance IQ was lower, the children demonstrated deficits in copying skills, as well as problems in reading and arithmetic (Bloom, Topinka, Goulet, Reese, and Podruch, 1986).

When the subtests of the WISC or WISC-R are divided into four separate categories of spatial abilities, verbal conceptual abilities, sequencing abilities and acquired knowledge, learning disabled children were most proficient within the spatial category and least proficient on the sequencing tasks (Bannatyne, 1968, 1974). Similar results have been found by other researchers as well (Bloom, Topinka, Goulet, Reese and Podruch, 1986; Mishra, 1984; Smith, Coleman, Doeckki and Davis, 1977). When Bannatyne's recategorization of the subtests was applied to previously identified learning disabled children, relatively low and high IQ subgroups demonstrated similar patterns with mean spatial scores significantly higher than mean conceptual scores that were higher than sequential or acquired knowledge scores. Thus, verified

learning disabled children, regardless of IQ, appear to have been characterized primarily by a singular pattern of scores on the WISC and WISC-R (Smith, Coleman, Dokecki, and Davis, 1977). While this complete categorization scheme has not been validated by cross-cultural research, learning disabled Mexican-American youngsters also demonstrated their most proficient skills within the spatial modality (Mishra, 1984).

A small group of learning disabled youngsters has also been identified who have deficiencies only in nonverbal spatial abilities and demonstrate lower Performance than Verbal IQs. In one study 16% of reading disordered youngsters shared this pattern (Mattis, French and Rapin, 1975), while another study revealed its presence in children with deficits in arithmetic (Rourke and Finlayson, 1978).

Historically, drawing skills have been linked to spatial abilities on intelligence tests, as is noted by the inclusion of the Geometric Designs subtest on the Performance Scale of the Wechsler Scales for preschoolers. This view has been substantiated by findings from studies in which reading disabled youngsters have been matched with control subjects on Performance IQ scores. Results indicated that their copying skills on the Bender Gestalt did not differ (McManis, Figley, Richert and Fabre, 1978) and their scores on the Draw-A-

Person test were similar, while their scores on the Verbal subtests of the WISC-R were lower (Stanley and Watson, 1980).

While results from spatial analytic tasks on intelligence tests are often higher in these children, it has been asserted that deficient form copying skills are related to learning disabilities (Bender, 1938, 1970; Koppitz, 1963, 1975; Beery, 1967). Subsequently, it was noted that the relationship between visual perceptual skills and school achievement had never been clearly established (Salvia and Ysseldyke, 1978; Larsen and Hammill, 1975). A major flaw in the studies that demonstrated a relationship between constructional skills and academic achievement is that they fail to take differences in intelligence levels into account. As a result, the differences often found between children may be attributable to differing overall levels of intelligence and not to the competency of their drawing skills. In fact, when the variance attributable to intelligence levels was statistically controlled, the relationship between form copying skills and academic functioning appeared to be minimal (Larsen and Hammill, 1975; Wright and DeMers, 1982).

The results from many studies examining form copying skills indicate that there is a large percentage of children who perform adequately on these tests who

demonstrate academic difficulties and an equally large percentage who do poorly on these measures, but exhibit no academic trouble (Larsen and Hammill, 1975). For example, conflicting results were found when performance on the Bender Gestalt Visual Motor Integration Test was used to predict reading skills. In one study there was no relationship between the two skill areas (Giebink and Birch, 1970). However, Keogh (1965) found that good performance on the Bender Gestalt was indicative of efficient reading skills, while poor performance was not indicative of reading level. In two studies (Conner, 1968, 1969) poor Bender Gestalt performance occurred in individuals in both high and low reading groups. When results from the Developmental Test of Visual Motor Integration were correlated with academic achievement (overall score on the Stanford Achievement Test), the VMI accounted for only 9.3% of the test variance (Duffy and Ritter, 1976). All of these findings suggest that while copying abilities may bear a relationship to WISC-R scores, they do not appear to be skills essential for adequate academic functioning.

Further, in adults it has also been noted that not all individuals with drawing deficits have difficulties completing other spatial tasks, such as the construction of block or stick patterns. This dissociation has been found in 26% of patients with focal lesions who exhibited

deficits in copying skills (Benton, 1979). Results from the Developmental Test of Visual Motor Integration indicated that learning disabled subjects scored more than one standard deviation below their mean age performance level and that this score was well below their Wechsler Performance Scale scores (Breen, Carlson and Lehman, 1985). Difficulties within the graphomotor sphere do appear to pervade both representational drawing skills (such as facial depiction) as well as form copying skills. When representational drawing skills of normal and learning disabled children were examined, clear differences were noted between the two groups (Pontius, 1976, 1981). When dyslexic children aged 7-14 drew human faces, the upper part of the face appeared distorted. Their representations looked like neolithic faces such that there was a continuation of the forehead into the nose, with no indication of a narrowing, indentation or discontinuity at the bridge of the nose (Pontius, 1976). These children also had difficulty copying six Bender Gestalt designs when required to rotate them. Their errors were evident in the right-left or up-down displacement of obliquely oriented asymmetric parts of the figures. No errors were made on global rotations of the figures, however. These results suggest that the dyslexic children have difficulty discriminating angles

other than right angles, especially those in diagonal or oblique orientations (Pontius, 1981).

Thus while reading and learning disabled children as a whole appear to demonstrate competent skills when required to complete constructional tasks, subtle problems have been noted on occasion on spontaneous drawings and copying tests and can, at times, be dissociated from problems on other spatial tasks. All of these findings suggest that, currently, the results from tests measuring form copying skills do not appear to be extremely useful in predicting the presence, absence or nature of learning disabilities in children. While these results may be due to the fact that this is an isolated skill unrelated to any other cognitive areas, this finding may also be related to the ways in which this skill has been examined. Perhaps many of the tasks in current usage measuring this skill are not sensitive to the parameters that link copying abilities to other aspects of cognition. As a result, it is important to continue to study development in this area, applying Piaget and Inhelder's overall cognitive approach, since, perhaps, this theoretically based viewpoint can shed more light on the relationship between drawing skills and other cognitive abilities.

Goals of the Current Research

The purpose of this study was to examine the developmental progression of copying abilities in children

and to demonstrate that drawing skills develop in a predictable order from topological to Euclidean delineations of spatial properties to the ultimate use of overall reference systems. To accomplish this goal, a new drawing test based on Piaget and Inhelder's theory of representational space was developed. The test was comprised of a series of geometric forms adapted from those illustrated by Piaget and Inhelder (p. 54) and those developed on the basis of the theory proposed by those investigators. To examine developmental trends, the test was administered to children aged 5-13 years. Another goal of this study was to examine the possible general effects of learning disabilities on drawing skills. Thus, two age groups of learning disabled children were also given this test.

Hypotheses

1. Intraindividual Development.

a. There will be a systematic developmental progression of forms passed by each child in the following order: topological, Euclidean, overall reference systems, including horizontal-vertical axes and perspective.

b. If failure occurs at one level, no forms at higher levels will be passed.

2. Interindividual Development

a. There will be a systematic developmental progression of forms passed by children of increasing age and grade level that follows the order described in Hypothesis 1a.

b. If failure occurs at one level, no forms at higher levels will be passed.

3. There will be distinct plateaus or markers that separate children of different developmental stages. These points will be represented by performance on pivotal forms: those forms presumed to mark a transition from preoperational to concrete operational skills. These forms examine the ability to copy acute and oblique angles, parallel lines (e.g., a diamond), and obliquely oriented figures.

4. Older children will make different types of errors than younger children, since their mistakes will center around accurate measurements of the lines comprising the forms, while the younger children will err when trying to recreate the basic shape of the forms.

Learning disabled subjects

Because a learning difficulty often suggests the presence of a different and/or disordered developmental pattern, these children are expected to perform unlike the control subjects.

5. Specifically, children with learning disabilities will draw fewer correct figures.

6. Learning disabled children will fail at developmentally lower pivotal points than grade-matched control subjects.

Method

Subjects

Control subjects were 354 children in regular classes, kindergarten through Grade 6, enrolled in two parochial schools under the jurisdiction of the Archdiocese of New York City. There were 199 subjects from School 1 and 155 subjects from School 2. The age range was 60-155 months. More complete descriptions of the control subjects with respect to age and grade are found in Tables 1 and 2, respectively.

The two experimental groups were composed of learning disabled (LD) youngsters from public schools on Long Island. Group LD 1 was composed of 13 children in Grade 3 and Group LD 2 had 13 children in Grade 6. All LD youngsters had a WISC-R Verbal IQ, WISC-R Performance IQ or Kaufman-ABC score of 90 or above. LD was defined as 1.5 years below expected grade level in any academic area, as measured on a standardized test such as the Wide Range Achievement Test, Key Math Test, Test of Written Spelling, Peabody Individual Achievement Test, or Woodcock Reading Mastery Tests. These tests were scored using the chronological age of the child. All LD subjects had deficient reading scores. Two third graders and four

sixth graders also had deficient math scores. Exclusion criteria were history of neurological damage, head injury, encephalopathic events, diagnosed attention deficit disorder or hyperactivity. A complete description of the experimental subjects is found in Table 3.

Stimuli

The drawing task was based on Piaget and Inhelder's theory of the development of representational space. Thus, the 15 forms to be copied were constructed so that their spatial properties were defined in terms of topological space, Euclidean space, the horizontal-vertical reference axes and three-dimensional space (Figure 1). Forms 1-9, 14 and 15 were based upon those presented by Piaget and Inhelder (The Child's Concept of Space, p. 54). Forms 10-13 were constructed in order to extend the examination of the hypothesis as it pertains to the use of a horizontal-vertical reference system and perspective. The spatial properties and the forms defined by these properties were the following:

1. Topological Space
 - a. Open-Closed, Forms 1-5
 - b. Boundaries, Forms 14-15
2. Euclidean Space, Forms 1-11
 - a. Preoperational, Forms 1-5
 - b. Transition to Concrete Operations, Forms 6-7
 - c. Concrete Operational, Forms 8-9

3. Horizontal-Vertical Axes, Forms 10-11

4. Perspective, Forms 12-13

In the test booklet, each form was located in the upper center of a 5 1/2" x 8 1/2" sheet of white paper. On the front page, the child's age, date of birth, sex and hand with which s/he wrote was identified. Anonymity with respect to name was preserved.

Procedure

The test was given to control subjects by group administration in each classroom. Children were instructed to copy each drawing anywhere on the page, to complete the test at their own pace, to copy all forms, and to do their best. Erasures and recopying were permitted. LD subjects were administered the drawing task individually by their resource room teachers.

Results

Qualitative Scoring of the Drawing Task

In order to analyze the results, a priori qualitative criteria were formulated, which were based on theoretical considerations (Appendix 1). The qualitative criteria were then applied to each protocol, and every form was assigned to one of three categories: (1) fail, at least a one error criterion was met (e.g., form 9) or the drawing did not illustrate the stated characteristic (e.g., form 4), (2) pass, no error criterion was met and all stated characteristics were drawn, or (3) poor, same as "pass," but the drawing appeared to be a poor replica of the model. After all drawings were assigned to the categories, within subjects and across ages and grades, data analyses were undertaken.

Within Subject Analyses

To examine the major hypothesis concerning the orderly development of drawing skills, Guttman scalogram analyses were performed. Specifically, this type of analysis was used to determine whether performance on the drawing test was indicative of a unidimensional developmental phenomenon--the growth and change of geometric drawing

skills. It was argued that a within subject analysis would be the most powerful tool to examine this question, since each child would serve as his/her own control. The degree to which successive items are cumulative is demonstrated by the finding that an individual's score on one form is associated with all of his/her scores on the other forms. For example, a pass on one form should be associated with passes on all previous forms (ranked as less difficult), while a failure on another form should be associated with failures on all forms ranked as more difficult. If this test were unidimensional and cumulative, then each subject should demonstrate such a pattern of functioning. These results should be demonstrated by the coefficient of reproducibility and the coefficient of scalability, i.e., the success of the Guttman analysis. For these analyses only, qualitative criteria were used. Forms were recorded as correct if they were assigned to the "pass" category, or incorrect if they were assigned to the "fail" or "poor" category.

The first Guttman analysis (Table 4) included all forms except for 12-15. Results from forms 14 and 15 were not used because, while they were ranked as the easiest forms a priori, the number of errors was inordinately high--5 on form 14 and 29 on form 15. Although these forms were ranked as the simplest, they clearly were not and would interfere with any developmental phenomenon that

might exist within the remaining set of figures. Results from forms 12 and 13 were not used because the number of subjects who copied them correctly was very small: 51 subjects on form 12 and 46 on form 13.

Results from the first Guttman analysis (Table 4) indicated the presence of a developmental aspect within the test since the coefficient of reproducibility was .9214. The results, however, also indicated that the measure might not be indicative of a unidimensional phenomenon, since the coefficient of scalability was only .5641. Several aspects of the data were determined to be contributory to this low coefficient. Forms 1-6 were not ranked initially according to their actual or empirically derived difficulty, but according to a priori rules. They were reranked by the Guttman from easy to hard in the following order: 4, 1, 5, 3, 2, 6. Since subjects in this sample made so few errors on these forms (total number of errors = 30), this ranking may not be accurate either. Further, the developmental aspects of these forms may have been masked because these forms appear to have been too easy for the youngest age group within this sample. Thus, it was decided to pool the results of these figures under one variable, which was labeled "Low." Next, it was noted that form 8 had a relatively lower point-biserial correlation with the other forms (.5445). As a result, it was decided to remove this form from the

analysis and use only form 9. This latter form had been placed in the test to measure the same Euclidean characteristics as form 8.

Using these changes, a second Guttman analysis was completed (Table 5). Specifically, forms 14, 15, 8, 12 and 13 were omitted from the analysis and results from forms 1-6 were pooled under the single variable Low. With these alterations, the new coefficient of reproducibility was .9073 and the new coefficient of scalability was .6900. Thus, there appeared to be a developmental progression in the representation of this set of forms. These coefficients are indicative of a valid Guttman scale. The intercorrelations of the following forms: Low, 7, 9 and 10 ranged from .6228-.6975. The intercorrelation dropped to .4211 on form 11, suggesting that it was least well associated with the other forms.

Effects of Grade, Age and Sex on Drawing Performance

Overall accuracy

The percentage of forms correct was examined for all subjects combined. The number of forms correct was calculated using the qualitative criteria and thus all forms were included in the analyses. The percent correct for each grade and each age was calculated for each school.

As shown in Table 6 and Figure 2, the overall performance on forms 14, 15 and 1-6 was excellent. These results indicate that subjects of all ages had little difficulty copying these eight forms accurately.

The first major decline in performance occurred on form 7. Further systematic decrements in performance were found for forms 8-13. Only half of the subjects drew forms 8 and 9 accurately. Fewer subjects drew form 10 correctly, slightly less than a quarter of the subjects drew form 11 accurately and few subjects (1.5-7.5%) drew forms 12 or 13 accurately.

As is clear from Table 6 and Figure 2, the same decremental patterns in performance were found in both schools. However, a significant difference in the percentage correct for forms 15, 9, 10 and 11 was also present. School 1 performed significantly better than School 2 on the latter three forms. These significant differences between schools did not emerge, however, when the forms were analyzed by age or grade within each school. In summary, as the forms increased in complexity, the number of children who copied them correctly decreased.

Changes with grade level

Performance on individual forms was evaluated further by examining the percentage of passes on each form within

each grade. Functioning within each school was evaluated separately (Tables 6 and 7 and Figures 3-9).

In the kindergarten classes in both schools (Tables 7 and 8 and Figure 3), performance on the easier forms (14, 15 and 1-6) was excellent. Performance dropped precipitously on form 7 (19.5% correct). This form was a priori identified as the one marking the transition from the preoperational to the concrete operational stage of development. There were few correct responses on forms 8-13, indicating that most kindergarten subjects incorrectly copied the more complex forms.

In both first grade classes, performance was again excellent on forms 14, 15, and 1-6 (Tables 7 and 8 and Figure 4). Accuracy again dropped on form 7 (41.3% correct), although not as abruptly. Accuracy on form 8 also improved (39.1% correct). There were few correct responses on form 9 and few first grade students copied the more complex forms accurately.

Second grade students had no difficulty copying forms 14, 15, and 1-6 (Tables 7 and 8 and Figure 5). The decrement in performance on form 7 was again less sharp than in the previous grade (70.4% correct). Half of these students copied form 8 accurately. Performance dropped again on form 9. For the first time, several subjects were able to copy form 10, the first complex form, accurately. Few subjects drew forms 11-13 accurately.

Third grade students in both schools drew forms 14, 15 and 1-6 accurately (Tables 7 and 8 and Figure 6). Form 7 was drawn correctly by the majority of students as well (84.0% correct). About half of the subjects in both schools drew forms 8 and 9 accurately. Performance declined on the first complex form, form 10 (34.0% correct). Nevertheless, functioning was becoming more proficient on these more difficult Euclidean forms. Most subjects continued to copy forms 11-13 incorrectly.

Grade 4 subjects in both schools (Tables 7 and 8 and Figure 7) demonstrated perfect copying skills on forms 14, 15 and 1-6. Nearly all subjects copied form 7 accurately as well. There was a decrement in performance on forms 8, 9 and 10, since only a little more than half of the subjects in both schools drew these forms accurately. Performance continued to decline on form 11 (29.3% correct). Almost no fourth graders copied the forms in perspective correctly.

Nearly all Grade 5 students copied forms 14, 15, and 1-7 correctly (Tables 7 and 8 and Figure 8). Performances on forms 8-11 were indicative of increasing skill, since about half of the subjects in this group drew these forms accurately. Performance remained poor on the two forms in perspective.

The performance of the Grade 6 subjects (Tables 7 and 8 and Figure 9) was almost flawless on forms 14, 15 and 1-

7. Performance remained proficient on form 8. Accuracy on forms 9 and 10 was also high. Performance dropped precipitously on form 11 (36.7% correct) and continued to fall on forms 12 and 13.

Changes with age

Next, performance on individual forms was evaluated by examining the percentage of passes on each form within each age group (5.0-5.11, ...12.0-12.11). Functioning within each school was evaluated separately (Tables 9 and 10 and Figures 10-17).

The performance of the 5.0- to 5.11-year-olds in both schools was excellent on forms 14, 15 and 1-6. The first major decrement occurred on form 7 (20.0% correct) and performance remained low on form 8. Almost none of the 5-year-olds accurately copied forms 9-13.

Performance by the 6.0- to 6.11-year-olds was similar to that of the 5-year-old group because they, too, performed well on forms 14, 15 and 1-6 and because the first major decrement again occurred on form 7 (35.4% correct). A few more 6-year-old subjects drew form 8 accurately. Almost none accurately copied forms 9-13.

Subjects in the 7.0-7.11 age group drew the first eight forms accurately. More than half of the subjects in each school copied form 7 correctly. Performance on form 8 was also substantially better than at previous ages (47.1% correct). Accuracy dropped precipitously on form 9

(21.6% correct) and few 7-year-old children drew the remaining forms correctly.

The 8.0-8.11 age groups in both schools again did well on forms 14, 15 and 1-6. Performance on form 7 was also proficient. Performance on forms 8 and 9, while somewhat lower, was also good. A little less than half of the 8-year-olds copied form 10 accurately. Performance declined again on form 11 (17.0% correct) and almost none of these subjects copied forms 12 or 13 accurately.

The 9.0-9.11 and the 10.0-10.11 age groups performed proficiently on forms 14, 15 and 1-7. A substantial number of these subjects (51-73%) also demonstrated accurate copying skills on forms 8-10. In general, performance declined on form 11 (.08-.18% correct). Few subjects drew forms 12 or 13 correctly.

The 11.0- to 11.11- and 12.0- to 12.11-year-old groups drew forms 14, 15 and 1-7 excellently. Performance on forms 8-10 was also strong. Accuracy decreased substantially on form 11 (38-40% correct); subjects had more difficulty on this form than on previous ones. Performance on forms 12 and 13 remained poor in this group.

Comparison of schools

The mean number of forms correct within each grade in both schools was examined. All forms were included in these analyses as well (Table 11 and Figure 18).

Subjects in kindergarten and first grade in both schools, on the average, drew the topological and most of the simple Euclidean forms accurately. Children in second grade drew the topological forms, the simplest Euclidean forms and one more complex Euclidean form accurately. Third and fourth grade subjects copied the topological, the simple Euclidean and at least one of the more complex Euclidean forms accurately. Fifth and sixth grade children drew the topological figures, Euclidean forms and one of the horizontal-vertical axes forms correctly. As the grade level increased, the mean number of forms correct also increased. No significant differences in the mean number of forms correct was found when the corresponding grades in the two schools were compared.

The same analysis was completed for the eight age groups within each school. Specifically, the mean number of forms correct for each age group was calculated (Table 12 and Figure 19).

The 5.0-5.11 group usually copied the topological and simple Euclidean forms accurately. Subjects in the 6.0-6.11 group copied the topological forms, the simple Euclidean forms and an overlapping form accurately. The 7.0-7.11 group drew the topological forms, simple Euclidean forms and a more complex Euclidean form accurately. The subjects in the 8.0-8.11 and the 9.0-9.11 groups usually copied all the simpler Euclidean forms

accurately. The three oldest groups drew all of the easier Euclidean forms and a horizontal-vertical axes form accurately. No significant differences were found between the corresponding age groups in the two schools.

Number of consecutive forms drawn accurately

Finally, the mean number of consecutive forms drawn correctly was examined first by grade (Table 13 and Figure 20) and then by age (Table 14 and Figure 21) within each school. No significant differences were found when subjects in the corresponding grades or with the same ages were compared in the two schools.

The average number of consecutive forms drawn correctly by kindergartners included the topological forms and most of the simple Euclidean forms. The first graders copied all forms through the first overlapping form correctly. Second grade subjects copied all forms correctly through the overlapping forms. Third graders copied all forms including one more complex Euclidean form correctly. Fourth and fifth graders drew all forms accurately through the more complex Euclidean forms. Sixth grade subjects copied all forms including the first horizontal-vertical axes form correctly. As is clear as grade increased, the mean number of accurate consecutive forms increased as well.

The mean number of consecutive forms drawn correctly was examined by age. Five-year-olds drew the topological

forms and a few of the simple Euclidean forms accurately. Six- and 7-year-old subjects copied forms accurately through one or both of the overlapping forms. Eight-year-olds drew forms correctly through the overlapping forms and, at times, copied the first more complex Euclidean form correctly. Nine-, 10-, 11- and 12-year-olds drew all forms correctly, including one or both of the more complex Euclidean forms. Thus, as age increased, the number of forms drawn correctly increased as well.

No significant differences in performance were found when functioning was examined by sex.

The Development of Quantitative Scoring Criteria

Quantitative criteria were developed using subjects' actual constructions so that the adequacy of the drawings could be examined in a more objective manner. Specifically, measurements of individual lines, angles and distances were taken for forms 8, 9, 10, 11, 12, and 13. (A list of these measurements is found in Appendix 2.) Only forms falling into categories 2 and 3 ("passes" and "poors") were used to develop the quantitative scoring criteria; protocols in category 1, "fail," had already been eliminated by the qualitative criteria. Data from the "pass" and "poor" categories were subjected to discriminant analyses. The actual number of protocols used in the analysis of each form is found in Table 15. This type of analysis was chosen using these two groups

because it was suspected that what appeared correct perceptually to a rater in some way might be significantly different from that which appeared to be a failure, despite the figure's correctness based on qualitative criteria. It was expected that the discriminant analyses would distinguish between the two groups, "pass" and "poor," because of differences in measurements. This type of analysis was used for two purposes: (1) to determine which measurements were important for establishing the correctness of a form and (2) to find out whether the "passes" were significantly different from the "measure fails."

Quantitative Criteria

Quantitative criteria were derived for only forms 9, 10 and 11 for several reasons. When the protocols for form 8 were sorted into the three categories using the qualitative criteria and were then subjected to a Guttman analysis, the diamond was not found to be a useful form for predicting success or failure on forms 9, 10 or 11. The number of subjects able to draw the three-dimensional forms (12 and 13) well enough to pass the qualitative criteria was small--51 subjects for the former and 46 subjects for the latter. It was decided that reliable quantitative criteria could not be derived from this small subject sample. Analysis of forms 9, 10, and 11 revealed

measurements that discriminated between protocols labeled as "passes" and "poors" for forms 9, 10 and 11.

Form 9. Angle size proved to be the variable that differentiated between the two groups for form 9. Specifically, the absolute value of the difference between angles A and A' was removed at the first step of the discriminant analysis (Wilks lambda: .79), then the size of angle A (Wilks lambda: .71) and finally the size of angle A' (Wilks lambda: .67). Using these variables, 93.5% of the "passes" were correctly classified and 51.0% of the "poors" were correctly classified. The overall correct classification using this discriminant function was 84.02%.

Figure 10. Four discriminating variables were found for form 10. The most powerful discriminator was the size of angle 2 (Wilks lambda: .86), then the absolute value of the difference between B and B' (Wilks lambda: .79), then the size of angle 4 (Wilks lambda: .74) and finally the size of angle 1 (Wilks lambda: .72). Using these variables, 86% of the "passes" were correctly classified and 57.8% of the "poors" were correctly classified, yielding an overall correct classification of 77.83%.

Figure 11. Three variables were identified that best differentiated between the two groups. The most powerful discriminator was the absolute value of the difference between distances A and A' (Wilks lambda: .78), then the

absolute value of the difference between distances B and B' (Wilks lambda: .70) and finally distance R (Wilks lambda: .68). These variables correctly classified 86.1% of the "passes," 70.2% of the "poors," and thus 77.46% of the data.

These quantitative criteria can now be used to differentiate between drawing protocols that are true "passes" versus those that meet all qualitative criteria, yet still appear to be inaccurate replicas of the forms.

Error Patterns

Error patterns were examined to determine whether children of different ages committed different types of errors. The ages examined were 5.0-5.11, 8.0-8.11 and 11.0-11.11. The specific question posed was whether the number of distortions in basic shape (qualitative errors) decreased over age while errors of precise measurement remained (quantitative errors). The results, shown in Table 16, suggest that basic shape reproduction became more accurate as age increased, while the number of measurement errors increased. These findings were suggested by the drop in the percentage of qualitative errors on form 9 from ages five (96%) to eight (71%); the drop in the percentage of qualitative errors on form 10 from ages five (94%) to eight (61%); and the drop in the percentage of qualitative errors on form 11 from ages five (98%) to eight (54%). The relationship between the

decrease in qualitative errors and the increase in quantitative errors is not surprising, because when a qualitative error was identified in a form, it was withdrawn from any further analysis. Consequently, the constructions with qualitative errors were not, and at times could not have been, examined for errors of measurement.

Performance of Learning Disabled Subjects

The performance of the learning disabled subjects was compared to that of the control subjects. The total number of forms drawn by the third grade LD group ($\bar{X}=8.31$, S.D.=1.11) was significantly lower ($t(61) = 4.67$, $p < .001$) than that of the Grade 3 control group ($\bar{X}=10.3$, S.D.=1.33). The total number of forms drawn by the sixth grade LD group ($\bar{X}=10.39$, S.D.=1.50) was significantly lower ($t(66) = 4.99$, $p < .001$) than that of the Grade 6 control group ($\bar{X}=12.07$, S.D.=1.41).

Further, as shown in Figures 22, 23, and 24, LD subjects copied fewer forms correctly and reached their best level of representation earlier than controls. Only 38% of the third grade LD subjects passed the sequence of forms 7-8 (an overlapping form and a diamond), while 86% of the third grade control subjects correctly drew these forms (Figure 22). No third grade LD students passed form 9 (a parallelogram), compared to half of the third grade control group (Figure 23). Form 10 (an obliquely oriented

form) was passed by 31% of the sixth grade LD students, as compared to 76% of the Grade 6 control subjects.

Discussion

The findings described in the Results section lend clear support to Piaget and Inhelder's theory of the development of form copying skills. The major findings emerged from the application of the Guttman analyses to the performance patterns of each individual subject. Specifically, the development of form copying skills occurs in the orderly progression described by Piaget and Inhelder. Children of different ages depicted geometric forms according to the rule based system in which they were operating. Young children were unable to conserve angles, distances and overall size of forms; however, they were able to copy the basic shape of forms. Thus they were successful in copying the easier forms (the preoperational forms); however, they were unable to copy the complex ones. Older children who were beginning to conserve these aspects of space copied the preoperational forms, the transitional overlapping form, the more complex Euclidean forms and an increasing number of the complex horizontal-vertical forms correctly.

The results from the Guttman analyses are so powerful because each subject served as his/her own control. Specifically, the degree to which all of the items were

related was evaluated within each of the 354 subjects and, as a result, the developmental phenomenon was tested within each subject. Individual variation could not be masked by group averages, as it could have been in a between subject analysis. However, not all forms could be used ultimately in the Guttman analyses because they detracted from the demonstration of the developmental phenomenon.

The two topological forms were not included because of the error rate on these two forms. The failures on these two forms often appeared to be the result of sloppiness and speed. The errors predominantly consisted of a lack of closure of one of the components of the form or the abutment of the two components of the form when they should not have been sharing a common boundary. In fact these were the two last forms administered, and the children may have been in a rush to complete the test or relieved following considerable difficulty on the three-dimensional forms. Without these two forms the first Guttman analysis demonstrated a developmental trend; however, the coefficient of scalability was low and suggested that the test may have been measuring more than one drawing phenomenon.

Consequently, further analyses were undertaken with a restructuring of the data base. Because of the age of this sample, all the preliminary forms were generally

drawn accurately and consequently were grouped under one factor indicative of simple Euclidean forms. Finally, form 8, the diamond, was discarded. Despite its presence on many tests of form copying ability such as the Stanford Binet and the Wechsler Preschool and Primary Scales of Intelligence, results indicated that it measured the developmental level less accurately than the parallelogram, even though the forms shared similar Euclidean characteristics. With these alterations, the second Guttman analysis indicated that this set of forms was examining a unidimensional developmental phenomenon. One could accurately describe subjects' levels of drawing ability from the overall number of forms drawn correctly. As a result the conclusion can be drawn that this set of forms may be used to delineate the different levels of form copying skill development present in children aged 5-12.

Results from the between subject analyses support the second and third hypotheses. A systematic developmental progression of forms passed by children of increasing age and grade level was found. Further, distinct markers were also found that separated children of different developmental stages. These points were represented by performance on pivotal forms.

It is not surprising that forms 15, 16 and 1-6 were drawn correctly by the majority of subjects because the

age of these children would place them all in at least the second stage of form copying development. As a result they should have been able to copy topological characteristics and simple Euclidean features accurately. The drop in percent correct on form 7, a pivotal form, was also expected since this form represents a transitional point marking the entry into concrete operational functioning. Not all subjects in this sample would be expected to be at that level of development.

Performance on forms 8 and 9 was also as expected; about half of the subjects were able to draw these forms correctly. To complete these forms accurately the child must be able to depict angles and lines in their precise relationships to each other. To do this, the children have to function within a fixed coordinate system. This skill occurs during the concrete operational period, roughly beginning at age seven, and thus many of the younger subjects in this sample were unable to complete these forms accurately. For forms 10 and 11 more complex skills are required; subjects must be able to hold constant external horizontal and vertical axes. As a result fewer subjects would be expected to depict these forms accurately. Forms 12 and 13, forms in perspective, are the most complex. Most subjects in this sample were unable to depict these two forms accurately. To test the

validity of a developmental aspect inherent in these two forms, an older subject sample would be required.

Performance on the drawing test was examined by grade as well as by age because of the overlap of ages in successive grades. Nonetheless, the basic findings were the same and are summarized by examining performance by kindergartners and 5-year-olds, third graders and 8-year-olds and sixth graders and 11- and 12-year-olds. These groups were selected because they mark pivotal transitional points in development and the differing stages can be clearly seen. Kindergartners and 5-year-olds drew the topological and the simple Euclidean forms well. Their performance declined precipitously on form 7, the pivotal form for entering concrete operational skills.

Third graders and 8-year-olds performed well through form 9, indicating that they were all functioning within a concrete operational frame of reference. Their performance dropped on forms 10 and 11, for which they needed a more sophisticated level of development--the ability to use a fixed external reference frame (the horizontal and vertical axes) in order to draw the oblique and straight lines in proper relation to each other and the page.

The sixth graders and 11- and 12-year-olds performed well through form 11, but were unable to complete the

forms in perspective, indicating they had not yet reached the culmination of the formal operational period.

When the mean number of forms drawn correctly was examined, the results were in accordance with the previous findings. The average number of forms drawn correctly by the youngest subjects included the preoperational forms, those drawn by the middle age group including the more complex Euclidean forms and those drawn correctly by the oldest group included the forms requiring external reference axes.

The average number of consecutive forms drawn correctly was slightly lower because when a subject failed a form, any form drawn accurately after that one was not included. The results generally did coincide with previous findings from the successive grades and age groups. They were also suggestive of a developmental phenomenon inherent in the test.

The significant difference found between the two schools on forms 9, 10 and 11 is interesting. However, comparisons between the schools by age and by grade revealed no significant differences. These results suggest then that, overall, School 1 may have performed slightly better than School 2.

The scoring methods developed to evaluate the forms appear to be useful. When quantitative criteria, chosen through the discriminative analyses, were applied to the

forms already sorted according to qualitative criteria, there was a high level of agreement as to which drawings were accurate representations of the forms.

Interestingly, angle size was usually the most important variable in discriminating between the two groups. This result is consistent with Piaget and Inhelder's comment that Euclidean space is defined when children become aware of angle size and not when they are able to simply draw straight lines.

With regard to the error analysis, Piaget and Inhelder had argued that there were distinct and qualitative differences between the ways in which younger and older children depict copies of geometric forms. Indeed, when the three different age levels were examined, qualitative differences were found. Specifically, when younger and older children failed on some of the same forms, the errors made by the older children were inaccuracies in measurement and not impaired shape reproduction. Thus, for Grades 3 and 6 difficulty with the actual size of component parts of the forms suggests incomplete attainment of the use of an overall Euclidean reference system. Further evidence of the lack of a complete reference system was demonstrated by the oldest subjects' inaccurate copies of the most complex geometric forms on the test.

While the LD subjects showed the same developmental sequence as the control subjects, both the third and the sixth grade LD subjects were clearly deficient compared to grade-matched controls. Both LD groups made errors on forms that would correspond to transitional points in Piaget and Inhelder's proposed operational stages of development.

These results suggest that this group of LD subjects had greater difficulty developing the more complex form representational skills than did their grade-matched controls. It is significant that the performance of the LD group declined on the critical transitional forms, suggesting that these forms may serve a useful diagnostic purpose. Failure on these forms could be indicative of an immature representational system or could be reflective of an underlying conceptual or organizational problem that pervades other areas of cognitive functioning as well. In fact, these subjects were often described by their special education teachers as having difficulty with the organization and integration of linguistic material. This possible difficulty in forming an overall conceptual entity out of bits of information, whether linguistic or visual perceptual, may be an underlying problem for these subjects. It is important to recall that these subjects were not typically described as having visual perceptual or graphomotor problems.

Implications of this Research for Prior Models

The Guttman analysis technique has been used in several studies to examine hypotheses generated from Piagetian theory. As mentioned previously, Peel (1959) examined the development of form copying skills of children aged 2.9-7.9. The forms were scored on an 11-point scale (based on the stages and substages found in Piaget's theory). The scores for each form were the average grade from two raters. Results analyzed according to the Guttman technique verified the developmental nature of the forms. Peel also found, however, that he had to collapse several stages and substages in order to demonstrate clear drawing skill improvement with age. As a result, stages 0, 1A and 1B were unified and subsequently called Stage 1; Stage 2A became Stage 2; Stage 2B became Stage 3 and Stage 3 became Stage 4. Peel concluded that while the sequence of stages was accurate, Piaget's age norms were not. Results from the current experimental measure are similar in that they demonstrate the predicted developmental sequence and several forms in this measure representing developmental stages had to be combined as well. Thus these two studies provide additional support for Piaget's views of the developmental nature of form copying skills.

Learning disabled youngsters have been found to operate at lower levels of cognitive development than

control subjects on other types of Piagetian tasks as well. Derr (1985) found that when children aged 9-12 with severe mathematics disabilities were examined on Piaget's concept of conservation, they had not yet reached the level of concrete operations. In contrast, 90% of the control group had an understanding of these concepts. It was suggested that this lag in basic cognitive development may have been interfering with their ability to understand the math concepts.

While results from the study by Derr and the present one can be interpreted as support for a developmental lag theory as opposed to a developmental disorder theory in learning disabilities, neither hypothesis can be proven with the current data because of the cross-sectional design of this study. In order to determine whether children "outgrow" these problems or whether the deficits remain with them for life, longitudinal studies of groups of learning disabled youngsters using these measures are necessary.

Implications of this Research for an Understanding of Cognitive Functioning

The ability to copy geometric forms is one type of problem solving task. The development of this skill is based on the acquisition of systems of rules that are integrated into increasingly complex structural units. The results from this study suggest that the ontogeny of

this ability is not completed through the accretion of piecemeal skills such as the increasingly precise ability to copy lines in specific orientations. Instead, this ability develops because of the child's burgeoning understanding of increasingly complex structural rules.

The significantly lower performance demonstrated by the LD subjects suggests that there are cognitive demands other than the graphomotor and perceptual ones that operate in the development of form copying skills. The processes of systematic analysis of visual or auditory input, and integration of the component parts into a mental schema, and planning of the response are basic and vital skills. The impaired form copying skill detected in the LD students in this study may reflect impairment in one or more of these processes.

Further support for this view comes from Cromer (1983) who examined hierarchical planning skills in language disordered children. The subjects included 12 aphasic children (5 receptively impaired and 7 expressively impaired) and 12 profoundly deaf and 12 normal children as two control groups. The subjects were required to copy a line drawing and a three dimensional model in two ways. Initially they were allowed to reproduce the models in any sequence they wanted to. Subsequently, however, they were required to use a hierarchical structure. The model to be reproduced was a tree structure and thus for the second

reconstruction the subjects had to copy all lines on the lowest level and then proceed up to the next level.

Cromer argued that if lack of auditory input were the cause of the hierarchical planning problems, both receptive aphasics and deaf subjects should do poorly. However, if a central hierarchical planning mechanism were the cause of the subjects' problems, then the two control groups should perform significantly better than the language disordered children when they were required to use the second method for reconstruction. Results from the study indicated that receptive and expressive aphasic subjects performed similarly on the planning aspect of the tasks and that they performed in a deficient manner compared to the deaf and normal subjects. Cromer concluded that a primary hierarchical planning disability in some aphasic children was the cause of their difficulties completing the tasks in a hierarchical manner as well as of some of their difficulties with language tasks. He emphasized that none of these children demonstrated a drawing or constructional deficit per se, but that it was when they were required to complete the tasks in the second manner that they had difficulties.

Results from the current study may allow investigators to examine drawing protocols from any drawing test and place the child's current level of functioning within the framework of a competency model instead of a deficiency

model. This alternative will be possible because children's protocols may be examined not only with empirical norms, but also with a theory of form copying development. As a result errors may be placed in a developmental framework. This will allow professionals to understand more completely the nature of the errors and decide whether and what type of remediation might be necessary. Indeed, Shilkret and Friedland (1974) observed that with this method one can more accurately depict the world in which the child is functioning. As a result a deficit model is now not the only description available. When a child is not functioning at age level expectations, the stage in which he is operating will be evident.

Limitations of the Current Research and Suggestions for Future Research






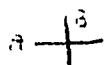


Results from this dissertation form the basis for an elaboration of Piaget and Inhelder's theory of the development of form copying skills. Further work in this area may include an extension of the age ranges of the subject sample studied to 4- and 5-year-olds and 13- to 15-year-olds. A larger LD sample would aid in the understanding of the performance of children with learning problems. It would also be useful to have identical intelligence test data for all LD subjects so that Performance and Verbal IQ differences in these subjects could be examined in relation to the drawing test results.

The scoring methods for this measure need to be refined as well. Additional raters are needed to classify the forms using the current qualitative criteria to verify the interrater reliability of the criteria.

Finally, errors made by preschoolers on forms 14 and 15 need to be closely examined so that a decision can be made as to whether these forms should remain in this test or they, like form 8, should be discarded. It is unclear whether the errors made by older children on these forms were due to haste or difficulty with the forms. If the young children make different types of mistakes on these forms, more thought should be given to the fate of these forms--whether to create different topological forms or to retain the original ones.

A final suggestion for future research would be to examine how the level of form copying development correlates with the level of conservation development in Piaget's general scheme of cognitive development.

Appendix 1
Qualitative Criteria used to
Score the Experimental Measure

<u>Form #</u>	<u>Form</u>	<u>Criteria</u>
14		two non-intersecting closed forms
15		smaller closed form completely enclosed within larger closed form
1		closed, curved form
2		closed four-sided form whose corners make clear angles
3		closed three-sided form whose corners make clear angles
4		line A and line B intersect and do not deviate from the horizontal or vertical respectively by more than 20 degrees
5		lines A and B intersect and do not deviate from the oblique orientation by more than 20 degrees
6		the rectangles overlap similarly and all corners of rectangle B lie outside of rectangle A

7



the triangle overlaps the rectangle similarly, such that all of its vertices lie outside of the rectangle

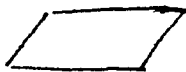
8



Errors:

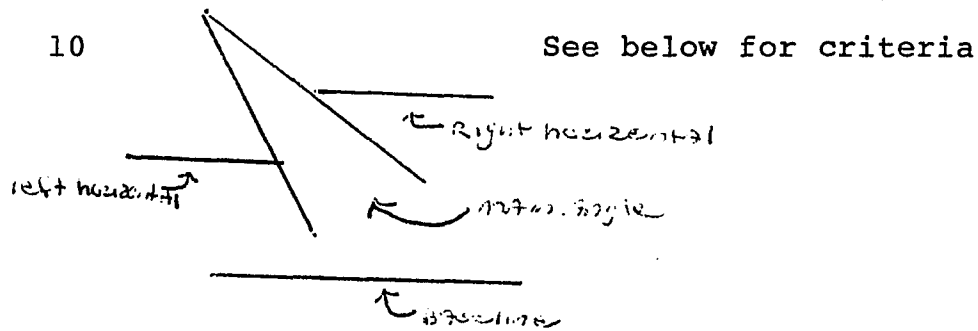
- 1 corners:
 - missing
 - pinched
 - rounded
- 2 lines:
 - extra lines
 - broken lines
- 3 figure resembles a square

9



Errors:

- 1 angles:
 - round
 - pinched
 - absent
- 2 lines:
 - curved or wavy
 - broken with alteration in angle
- 3 base:
 - rotation 20 degrees or more from horizontal baseline
- 4 shape:
 - resembles a trapezoid



Error Criteria:

1 lines:

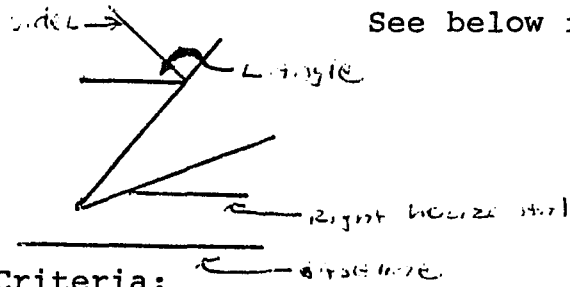
- broken with direction change
- horizontal line at endpoint of side, at vertex of main angle or extends into main angle
- horizontal line or baseline rotated 20 degrees or more
- horizontal line is separated 4 mm. or more from main angle
- left horizontal is at same level or above right horizontal
- absent lines
- additional lines

2 angles:

- main angle is constructed as a whole rather than as including a horizontal line
- projection of sides the main angle do not intersect
- right side of main angle is nearly or completely horizontal
- left side of main angle is nearly or completely vertical
- angle 2 is not 90 degrees or greater
- angle 4 is not 90 degrees or greater

 Acceptable: side of main angle touches baseline
 absent baseline

11 See below for criteria



Error Criteria:

1 lines:

- broken with direction change
- right horizontal
- displacement in relation to main angle: at endpoint of right side, at vertex, extends into angle rotated 20 degrees or more
- separated 4 mm. or more from the main angle
- omission of any line except baseline
- baseline rotated 20 degrees or more from horizontal
- additional lines

2 angles:

- main angle:
 - right side is nearly or completely horizontal
 - left side is nearly or completely vertical
 - left side is rotated to the left of vertical
- left angle:
 - side L is nearly or completely vertical
 - displaced to endpoint of left side or vertex of main angle
 - mirror image
 - located at or below level of right horizontal

3 projection of sides of main angle and left angle do not intersect

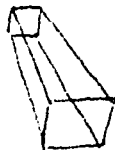
 Acceptable: vertex of main angle touches baseline
 absent baseline

12



all lines drawn to the appropriate corners
 correct orientation of the cube

13



all lines drawn to the appropriate corners
 side B is smaller than side A
 the figure is correctly oriented

Appendix 2

Measurements Used to Derive Quantitative Criteria

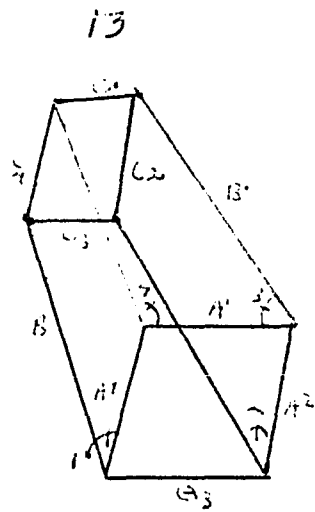
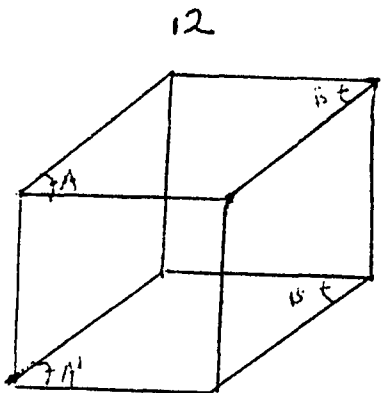
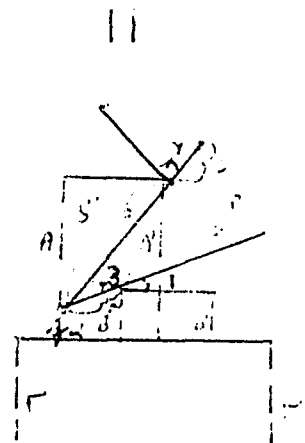
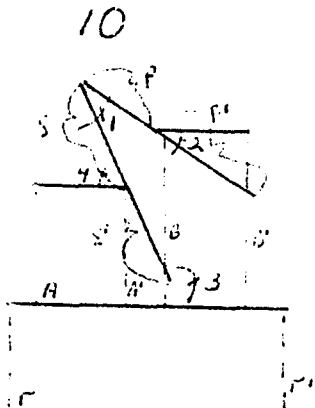
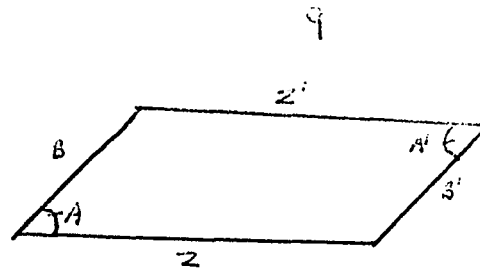
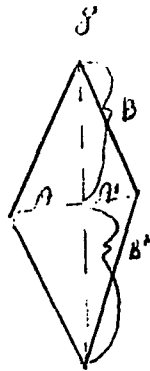


Table 1

Number of subjects within each 12 month interval

Age	School 1	School 2	Total across schools
5.0-5.11	15	15	30
6.0-6.11	26	22	48
7.0-7.11	31	20	51
8.0-8.11	30	23	53
9.0-9.11	31	20	51
10.0-10.11	27	21	48
11.0-11.11	32	26	58
12.0-12.11	7	8	15

Table 2

Number of subjects by grade in each school and
age range (AR) within each grade in each school

Grade	Total	School 1	School 2	AR	AR 1	AR 2
K	41	22	19	5.3-6.3	5.3-6.2	5.3-6.3
1	46	27	19	5.5-7.7	6.0-7.7	6.1-7.0
2	54	29	25	6.4-8.7	6.4-8.7	7.3-8.3
3	50	27	23	8.1-10.1	8.2-9.6	8.1-10.1
4	58	33	25	8.4-11.1	9.0-10.6	8.4-11.1
5	50	30	20	9.2-12.0	9.2-12.0	10.4-11.6
6	55	31	24	10.6-12.9	10.9-12.5	10.6-12.9

Table 3
Number of learning disabled subjects and their
age ranges in each grade

Grade	Subjects	Age Range
3	13	7.11-10.3
6	13	10.11-12.6

Table 4
Guttman Analysis Using Figures 1-11

0 = fail
1 = pass

Item	4		1		5		3		2		6		7		8		9		10		11		Total		
Response	0	1	0	1	0	1	0	1	0	1	0	1	0	1	0	1	0	1	0	1	0	1	0	1	
R	11	0	34	0	34	0	34	0	34	0	34	0	34	0	34	0	34	0	34	0	34	0	34	34	
O	10	0	71	0	71	1	70	0	71	0	71	0	71	1	70	8	63	0	65	8	63	47	24	71	
S	9	0	71	0	71	0	71	0	70	0	71	0	71	3	68	25	46	20	51	33	38	60	11	71	
E	8	0	58	0	58	1	57	0	58	0	58	0	58	8	50	27	31	43	15	44	14	51	7	58	
N	7	0	59	0	59	0	59	1	58	0	59	0	59	25	34	49	10	54	5	51	8	56	3	59	
	6	0	42	1	41	0	42	1	41	0	42	1	41	42	0	39	3	42	0	42	0	42	0	42	
	5	1	13	2	12	1	13	0	14	5	9	5	9	14	0	14	0	14	0	14	0	14	0	14	
	4	1	4	1	4	2	3	2	3	1	4	3	2	5	0	5	0	5	0	5	0	5	0	5	
	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
sums	2	352	4	350	5	349	5	349	6	348	9	345	98	256	167	187	184	170	197	157	275	79	354		
pcts	1	99	1	99	1	99	1	99	2	98	3	97	28	72	47	53	52	48	56	44	78	22			
errors	2	0	4	0	5	0	5	0	5	4	1	11	37	0	60	13	26	20	8	60	0	45	306		

Statistics:

coefficient of reproducibility = 0.9214
 minimum marginal reproducibility = 0.8197
 percent improvement = 0.1017
 coefficient of scalability = 0.5641

Table 4 (continued)

Yule's Q:

	1	2	3	4	5	6	7	8	9	10	11
1	1.0000	-1.0000	-1.0000	-1.0000	0.9330	-1.0000	1.0000	0.5457	1.0000	1.0000	1.0000
2	-1.0000	1.0000	-1.0000	-1.0000	-1.0000	0.7895	1.0000	1.0000	1.0000	1.0000	1.0000
3	-1.0000	-1.0000	1.0000	-1.0000	-1.0000	0.9404	0.8312	0.2571	0.1640	1.0000	-0.4039
4	-1.0000	-1.0000	-1.0000	1.0000	0.9773	-1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
5	0.9330	-1.0000	-1.0000	0.9773	1.0000	-1.0000	0.6008	0.6406	0.1640	0.0903	0.0703
6	-1.0000	0.7895	0.9404	-1.0000	-1.0000	1.0000	1.0000	0.8069	1.0000	1.0000	1.0000
7	1.0000	1.0000	0.8312	1.0000	0.6008	1.0000	1.0000	0.6877	0.8241	0.7673	0.6714
8	0.5475	1.0000	0.2571	1.0000	0.6406	0.8069	0.6877	1.0000	0.6614	0.5157	0.4858
9	1.0000	1.0000	0.1640	1.0000	0.1640	1.0000	0.8241	0.6614	1.0000	0.7394	0.6016
10	1.0000	1.0000	1.0000	1.0000	0.0903	1.0000	0.7673	0.5157	0.7394	1.0000	0.5404
11	1.0000	1.0000	-0.4039	1.0000	0.0703	1.0000	0.6714	0.4858	0.6016	0.5404	1.0000
Biserial Correla- tion Scale Item	0.5168	0.5908	0.3032	0.5739	0.2572	0.6509	0.7328	0.5445	0.6889	0.6065	0.4384

Table 5

Guttman analysis using Low and forms 7 and 9-11

1 = fail

0 = pass

Item	Low	7	9	10	11	Total
Response	0 1	0 1	0 1	0 1	0 1	
R 5	0 22	0 22	0 22	0 22	0 22	22
O 4	49 0	0 49	0 49	0 49	0 49	49
S 3	79 2	58 23	9 72	10 71	6 75	81
E 2	71 0	67 4	39 32	27 44	9 62	71
N 1	88 0	87 1	79 9	77 11	21 67	88
0	43 0	43 0	43 0	43 0	43 0	43
sums	330 24	255 99	170 184	157 197	79 275	354
pcts	93 7	72 28	48 52	44 56	22 78	
errors	0 2	0 28	9 41	37 11	36 0	164

Statistics:

coefficient of reproducibility = 0.9073
 minimum marginal reproducibility = 0.7011
 coefficient of scalability = 0.6900

Yule's Q:

	Low	7	9	10	11
Low	1.0000	1.0000	0.8388	1.0000	0.5400
7	1.0000	1.0000	0.8107	0.7715	0.6289
9	0.8388	0.8107	1.0000	0.7394	0.6016
10	1.0000	0.7715	0.7394	1.0000	0.5404
11	0.5400	0.6289	0.6016	0.5404	1.0000

Biserial
Correla-
tion
Scale
Item

0.6661 0.6975 0.6543 0.6228 0.4211

Table 6

Percent correct for each form in School 1 and School 2

Form	School 1	School 2	Chi-Square	P
14	98.99	98.06		
15*	87.94	96.77	9.05	.05
1	97.99	99.35		
2	96.98	98.06		
3	98.99	98.06		
4	99.50	100.00		
5	98.49	100.00		
6	98.99	94.84		
7	73.87	72.26		
8	55.30	49.70		
9*	53.77	40.60	5.57	.05
10*	51.30	35.50	9.19	.05
11*	26.10	17.40	4.23	.05
12	7.53	5.16		
13	1.51	3.23		

* indicates a significant difference in percent correct between School 1 and School 2

Table 7

Percent correct for each form by grade in School 1

Form	Grade						
	K (n=22)	1 (n=27)	2 (n=29)	3 (n=27)	4 (n=33)	5 (n=30)	6 (n=31)
14	95.5	100	100	100	96.97	100	100
15	90.9	88.9	89.7	88.9	84.9	90.0	83.9
1	90.9	96.3	96.6	100	100	100	100
2	81.8	100	100	92.6	100	100	100
3	100	100	93.1	100	100	100	100
4	95.5	100	100	100	100	100	100
5	86.4	100	100	100	100	100	100
6	90.9	100	100	100	100	100	100
7	27.3	48.1	62.1	88.9	90.9	86.7	96.8
8	13.6	40.7	62.1	59.3	57.6	56.7	83.9
9	4.5	22.2	31.0	55.6	75.8	76.7	90.3
10	4.5	22.2	44.4	44.8	60.6	76.7	87.1
11	0.0	3.7	27.6	22.2	33.3	46.7	38.7
12	0.0	0.0	0.0	0.0	9.1	20.0	19.4
13	0.0	0.0	0.0	0.0	0.0	3.3	6.5

Table 8

Percent correct for each form by grade in School 2

Form	Grade						
	K (n=19)	1 (n=19)	2 (n=25)	3 (n=23)	4 (n=25)	5 (n=20)	6 (n=24)
14	89.5	100	100	95.7	100	100	100
15	94.7	94.7	96.0	95.7	100	95.0	100
1	94.7	100	100	100	100	100	100
2	89.5	100	100	95.7	100	100	100
3	84.2	100	100	100	100	100	100
4	100	100	100	100	100	100	100
5	100	100	100	100	100	100	100
6	79.0	84.2	96.0	100	100	100	100
7	10.5	31.6	80.0	78.3	92.0	95.0	100
8	5.3	36.8	40.0	52.2	56.0	65.0	83.3
9	0.0	0.0	20.0	47.8	60.0	70.0	75.0
10	0.0	15.8	24.0	21.7	52.0	65.0	62.5
11	0.0	0.0	8.0	13.0	24.0	40.0	33.3
12	0.0	0.0	0.0	4.4	4.0	15.0	12.5
13	0.0	0.0	0.0	0.0	0.0	10.0	12.5

Table 9

Percent correct for each form by age in School 1

Form	Age							
	5 (n= 15)	6 (n= 26)	7 (n= 31)	8 (n= 30)	9 (n= 31)	10 (n= 27)	11 (n= 32)	12 (n=7)
14	93.3	100	100	100	96.8	100	100	100
15	86.7	100	80.7	90.0	80.7	96.3	81.3	100
1	86.7	100	93.6	100	100	100	100	100
2	73.3	100	100	93.3	100	100	100	100
3	100	100	93.6	100	100	100	100	100
4	93.3	100	100	100	100	100	100	100
5	86.7	96.2	100	100	100	100	100	100
6	86.7	100	100	100	100	100	100	100
7	26.7	42.3	58.1	86.7	90.3	81.5	96.9	100
8	26.7	30.8	48.4	66.7	58.1	55.6	81.3	57.1
9	6.7	15.4	22.6	60.0	74.2	77.8	84.4	85.7
10	6.7	19.2	32.3	50.0	64.5	66.7	87.5	71.4
11	0.0	3.8	22.6	20.0	29.0	48.1	40.6	42.9
12	0.0	0.0	0.0	0.0	6.5	18.5	21.9	14.3
13	0.0	0.0	0.0	0.0	0.0	0.0	9.4	0.0

Table 10

Percent correct for each form by age in School 2

Form	Age							
	5 (n= 15)	6 (n= 22)	7 (n= 20)	8 (n= 23)	9 (n= 20)	10 (n= 21)	11 (n= 26)	12 (n=8)
14	86.7	100	100	95.7	100	100	100	100
15	93.3	95.5	95.0	95.7	100	100	100	100
1	93.3	100	100	100	100	100	100	100
2	93.3	95.5	100	95.7	100	100	100	100
3	80.0	95.5	100	100	100	100	100	100
4	100	100	100	100	100	100	100	100
5	100	95.5	100	100	100	100	100	100
6	80.0	90.9	90.0	100	100	100	100	100
7	13.3	27.3	80.0	78.3	80.0	100	100	87.5
8	6.7	27.3	45.0	47.8	40.0	71.4	76.9	87.5
9	0.0	0.0	20.0	34.8	70.0	61.9	76.9	50.0
10	0.0	13.6	30.0	26.1	40.0	52.4	65.4	50.4
11	0.0	0.0	10.0	13.0	25.0	23.8	34.6	37.5
12	0.0	0.0	0.0	0.0	5.0	19.1	11.5	0.0
13	0.0	0.0	0.0	0.0	0.0	9.5	7.7	12.5

Table 11
Mean number of forms correct within each grade
in School 1 and School 2

Grade	School 1 (n=199)	N	School 2 (n=155)	N
K	7.05	22	7.47	19
1	7.33	27	8.53	19
2	10.07	29	9.64	25
3	10.56	27	10.04	23
4	11.15	33	10.84	25
5	11.67	30	11.55	20
6	12.26	31	11.83	24

Table 12

Mean number of forms correct within each age group
in School 1 and School 2

Age group	School 1	N	School 2	N
5.0-5.11	7.73	15	7.47	15
6.0-6.11	9.04	26	8.36	22
7.0-7.11	9.58	31	9.20	20
8.0-8.11	10.70	30	10.26	23
9.0-9.11	11.03	31	10.60	20
10.0-10.11	11.52	27	11.45	21
11.0-11.11	12.21	32	12.23	26
12.0-12.11	11.86	7	11.37	8

Table 13

Mean number of consecutive forms correct within
each grade in School 1 and School 2

Grade	School 1	N	School 2	N
K	6.86	22	6.53	19
1	8.93	27	7.95	19
2	8.90	29	9.28	25
3	9.96	27	9.39	23
4	10.45	33	10.12	25
5	10.37	30	10.85	20
6	11.39	31	11.46	24

Table 14

Mean number of consecutive forms correct within each
age group in School 1 and School 2

Age group	School 1	N	School 2	N
5.0-5.11	6.40	15	6.60	15
6.0-6.11	8.88	26	7.68	22
7.0-7.11	8.61	31	9.20	20
8.0-8.11	9.83	30	9.30	23
9.0-9.11	10.45	31	9.80	20
10.0-10.11	10.30	27	10.32	21
11.0-11.11	11.25	32	10.96	26
12.0-12.11	11.00	7	10.63	8

Table 15

Number of protocols used for the discriminant analysis

Form	Total	Passes	Poors
8	250	187	63
9	219	170	49
10	221	157	64
11	173	79	94

Table 16

Percentage of qualitative (Q) and quantitative (M) errors
 made by 5.0-5.11 year olds (1), 8.0-8.11 year olds (2),
 and 11.0-11.11 year olds (3)

Form	Error type	Age 1	Age 2	Age 3
9	Q	96	71	64
	M	4	29	36
10	Q	94	61	54
	M	6	39	46
11	Q	98	54	58
	M	2	46	42

Figure 1

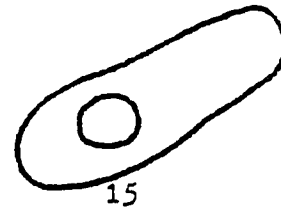
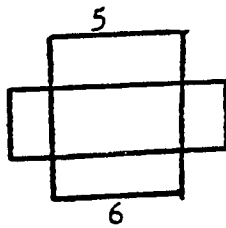
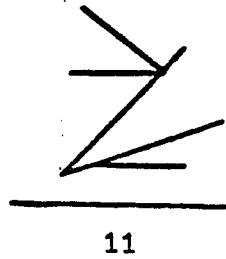
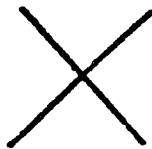
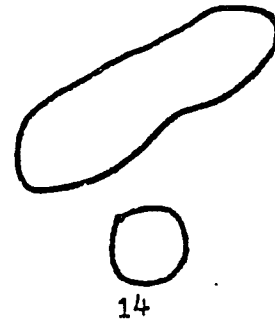
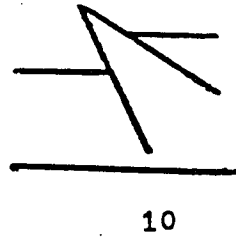
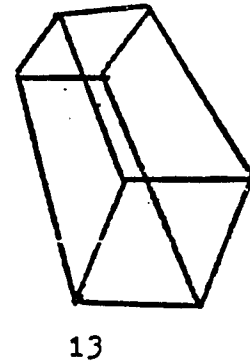
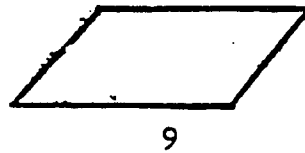
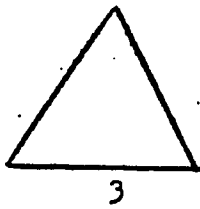
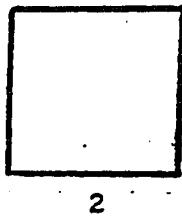
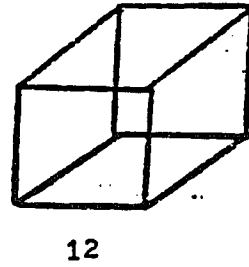
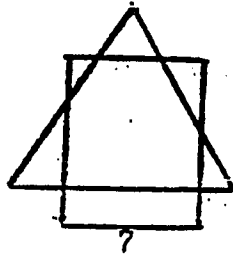
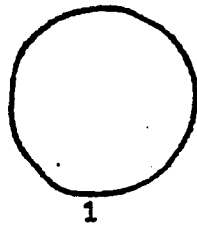


FIGURE 2

Percent correct for each figure in school 1 and school 2

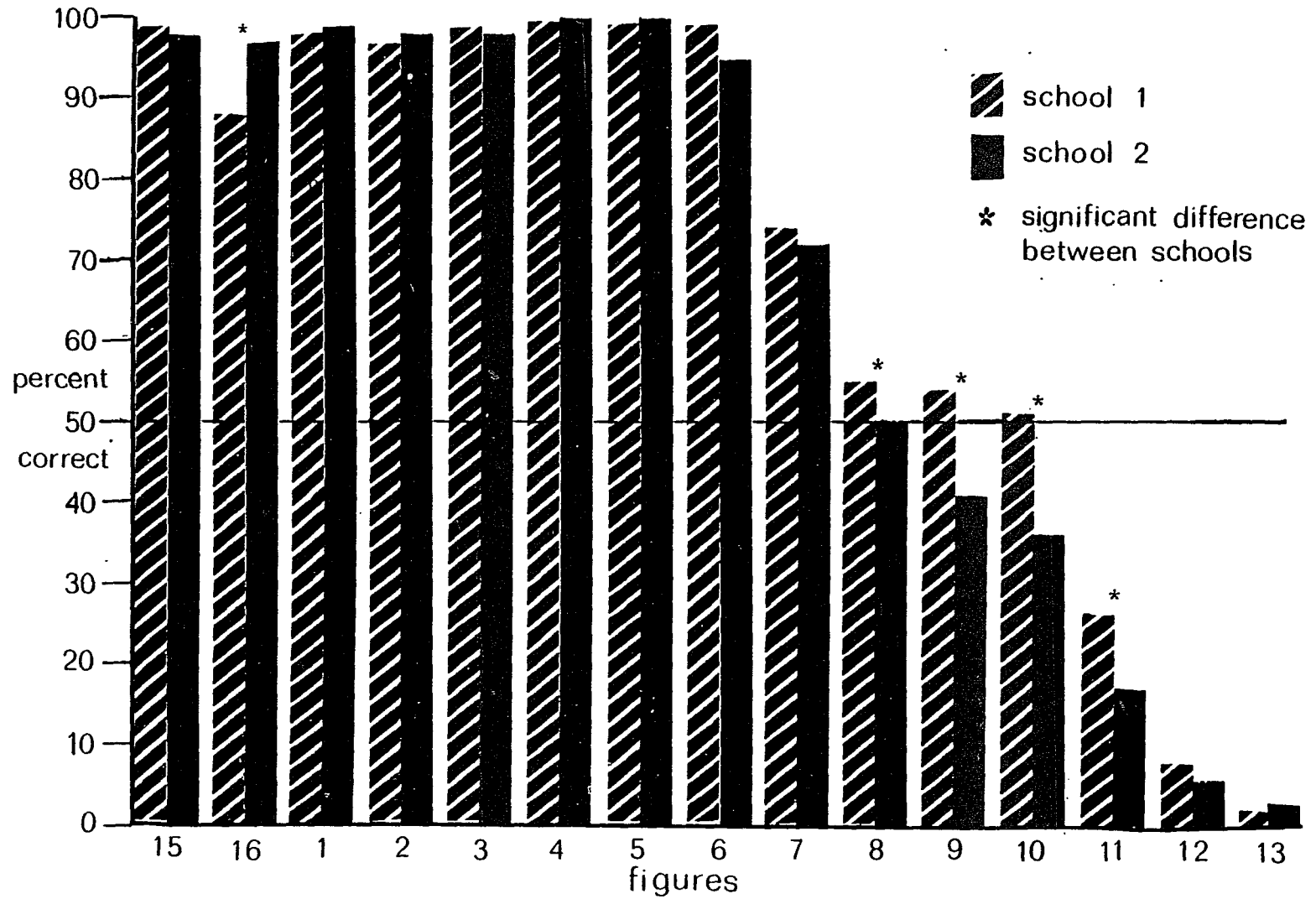


FIGURE 3

Kindergarten: percent correct for each figure

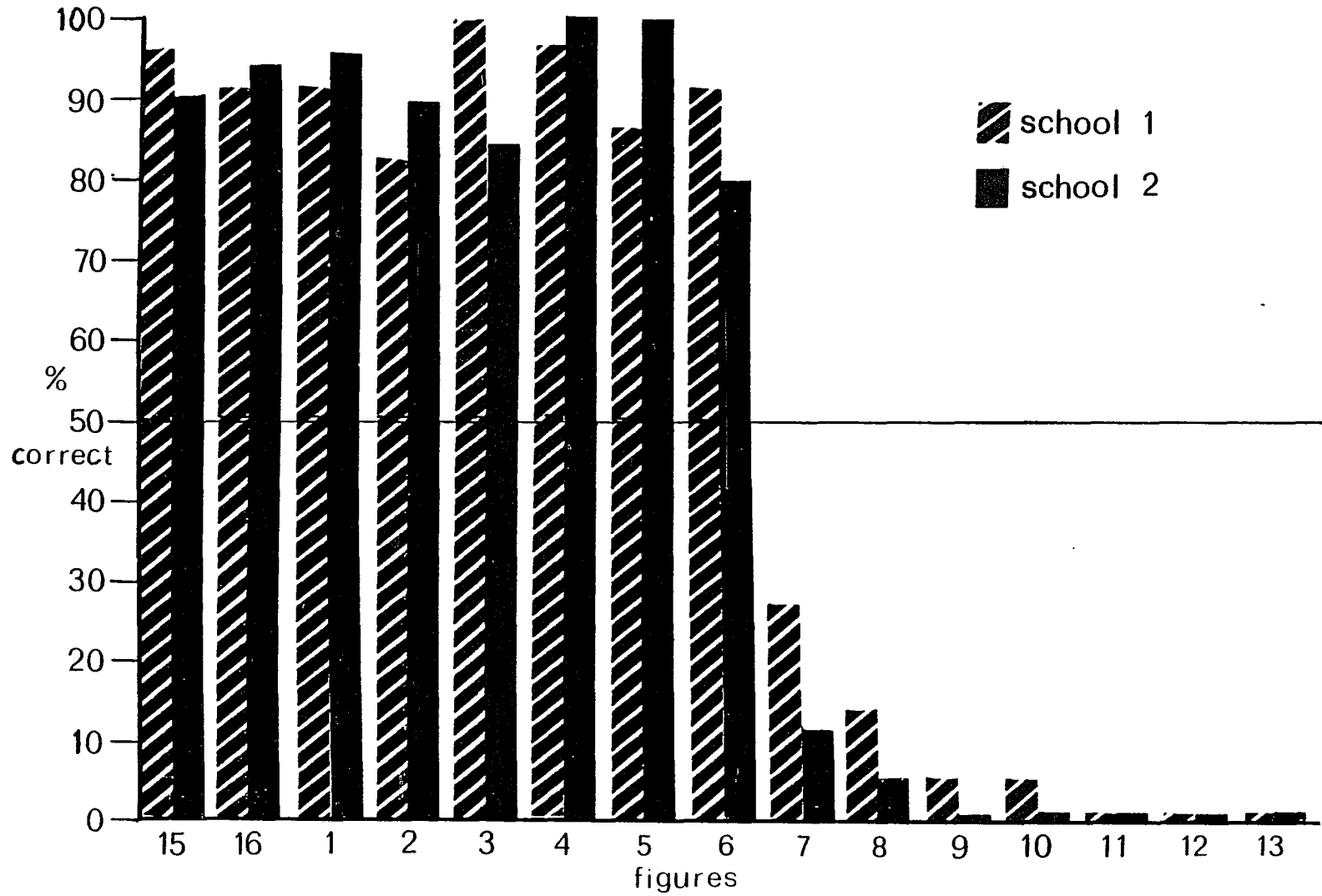


FIGURE 4

Grade 1: percent correct for each figure

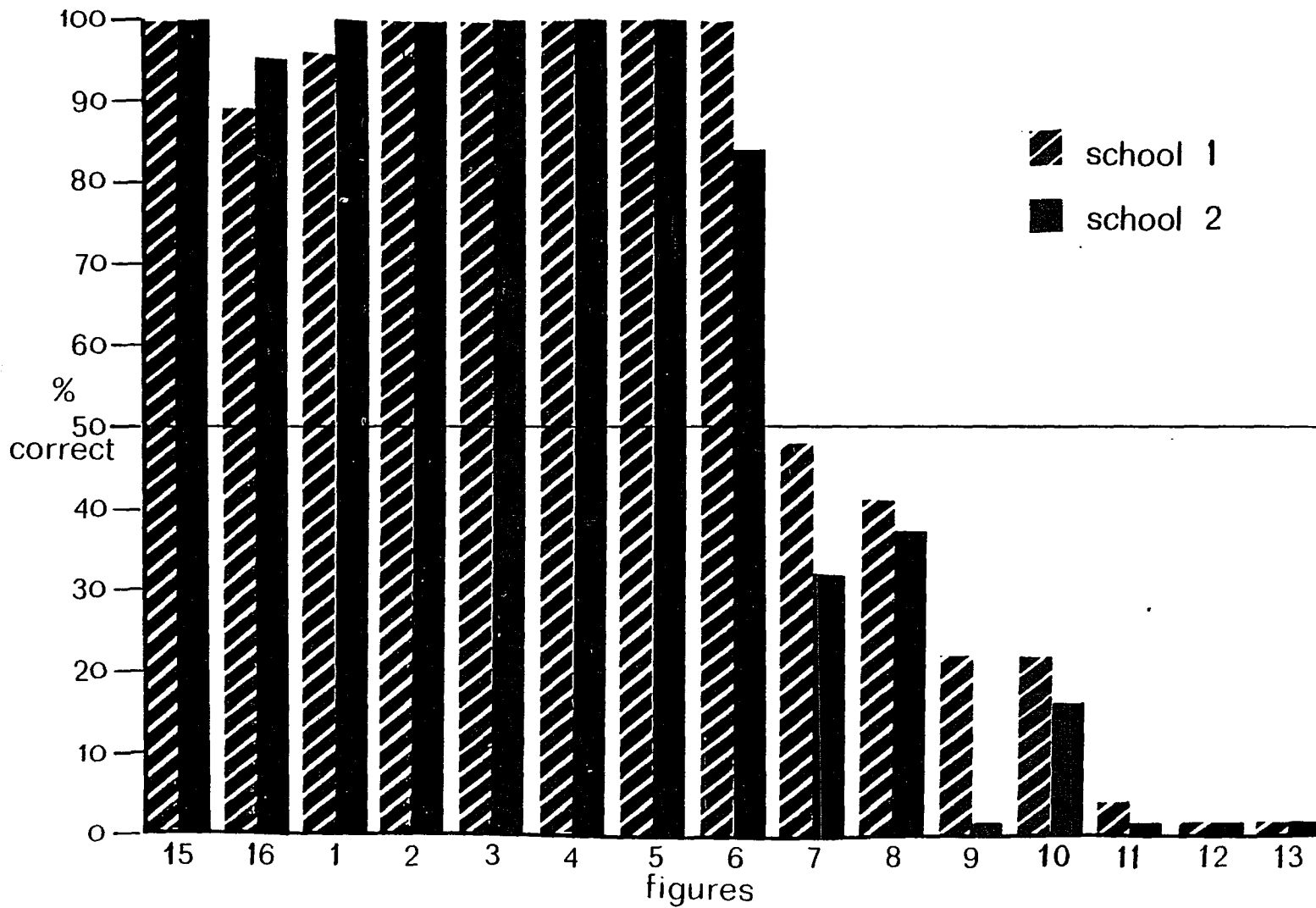


FIGURE 5

Grade 2: Percent correct for each figure

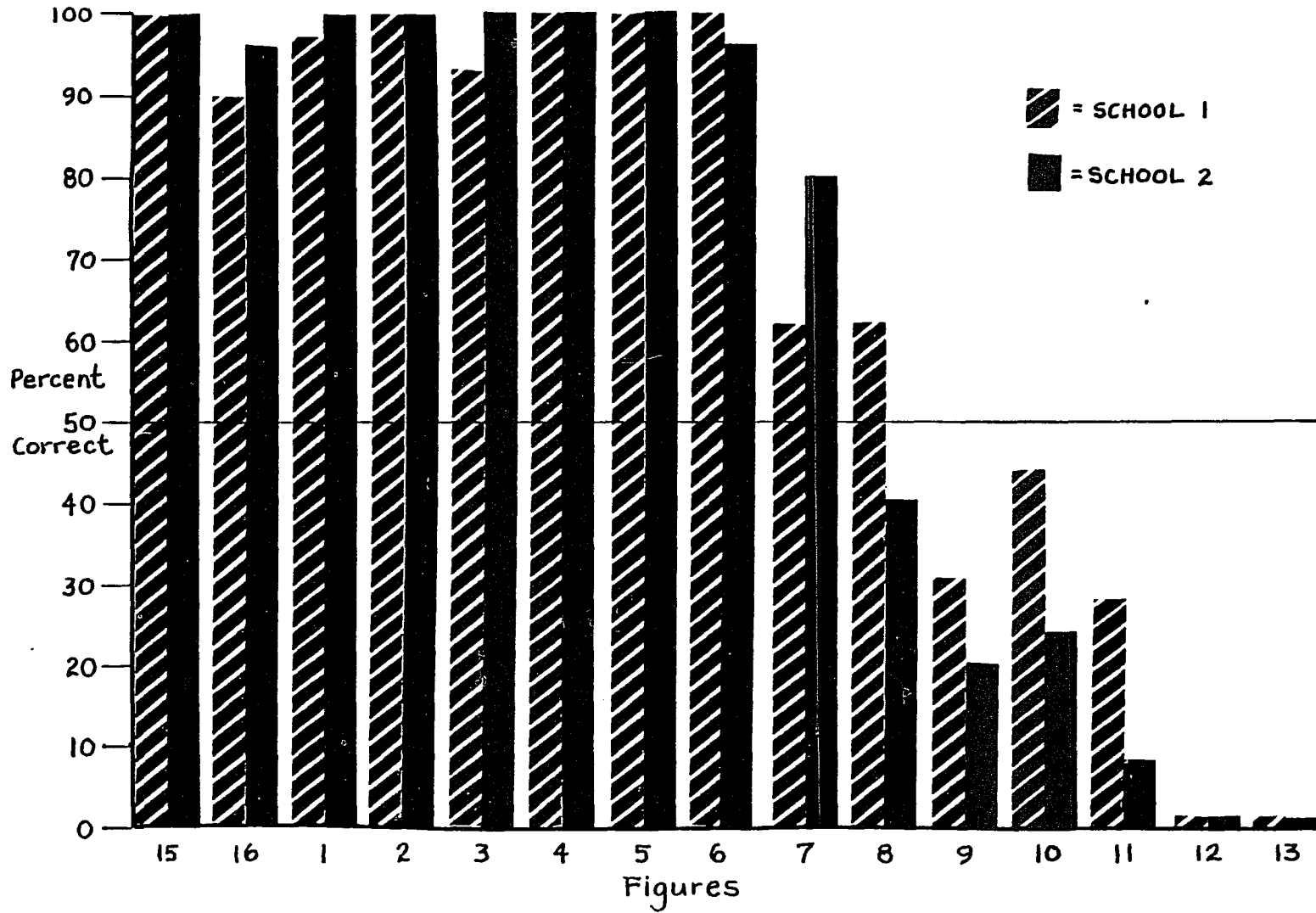


FIGURE 6

Grade 3: Percent correct for each figure

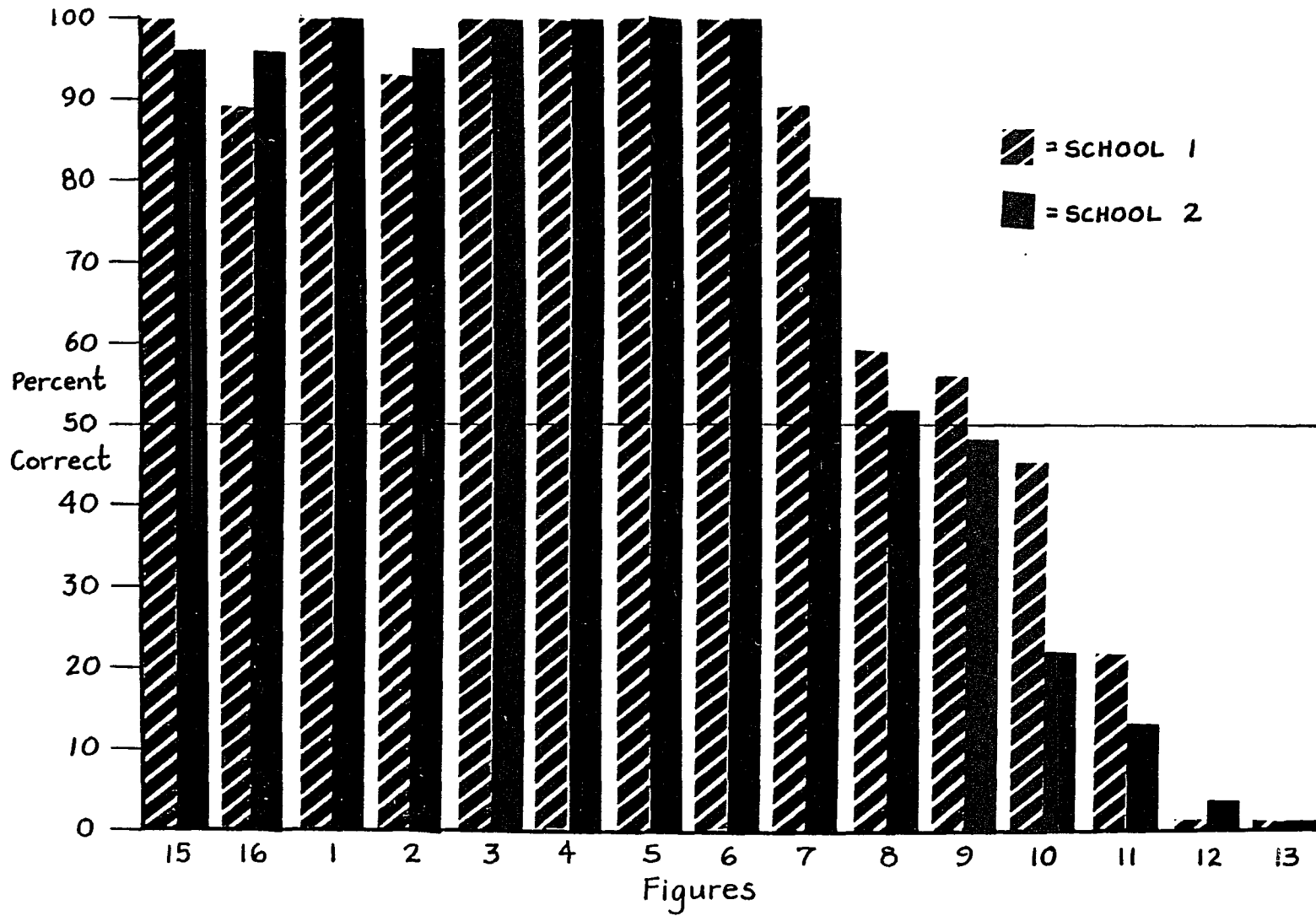


FIGURE 7

Grade 4: Percent correct for each figure

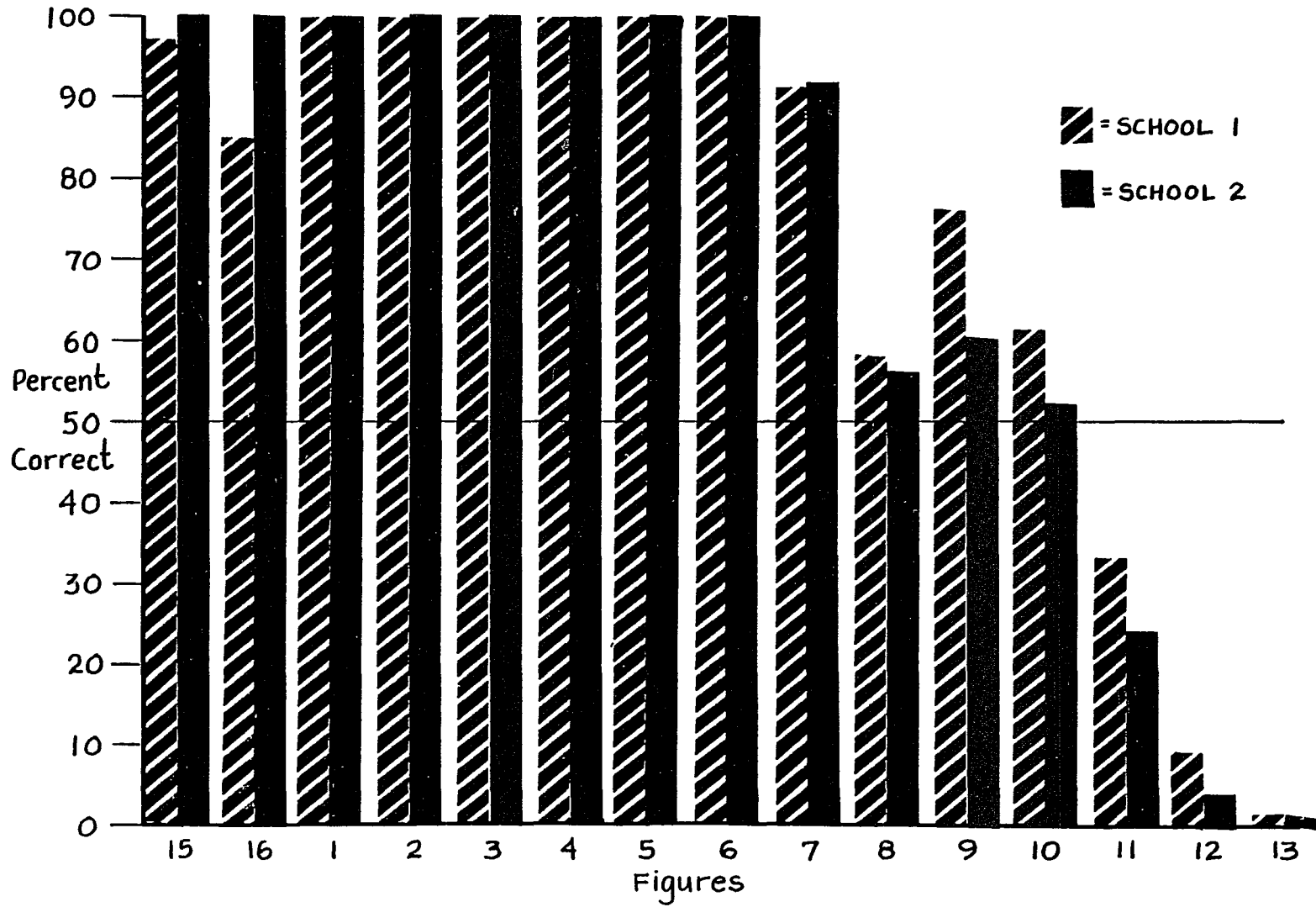


FIGURE 8

Grade 5: Percent correct for each figure

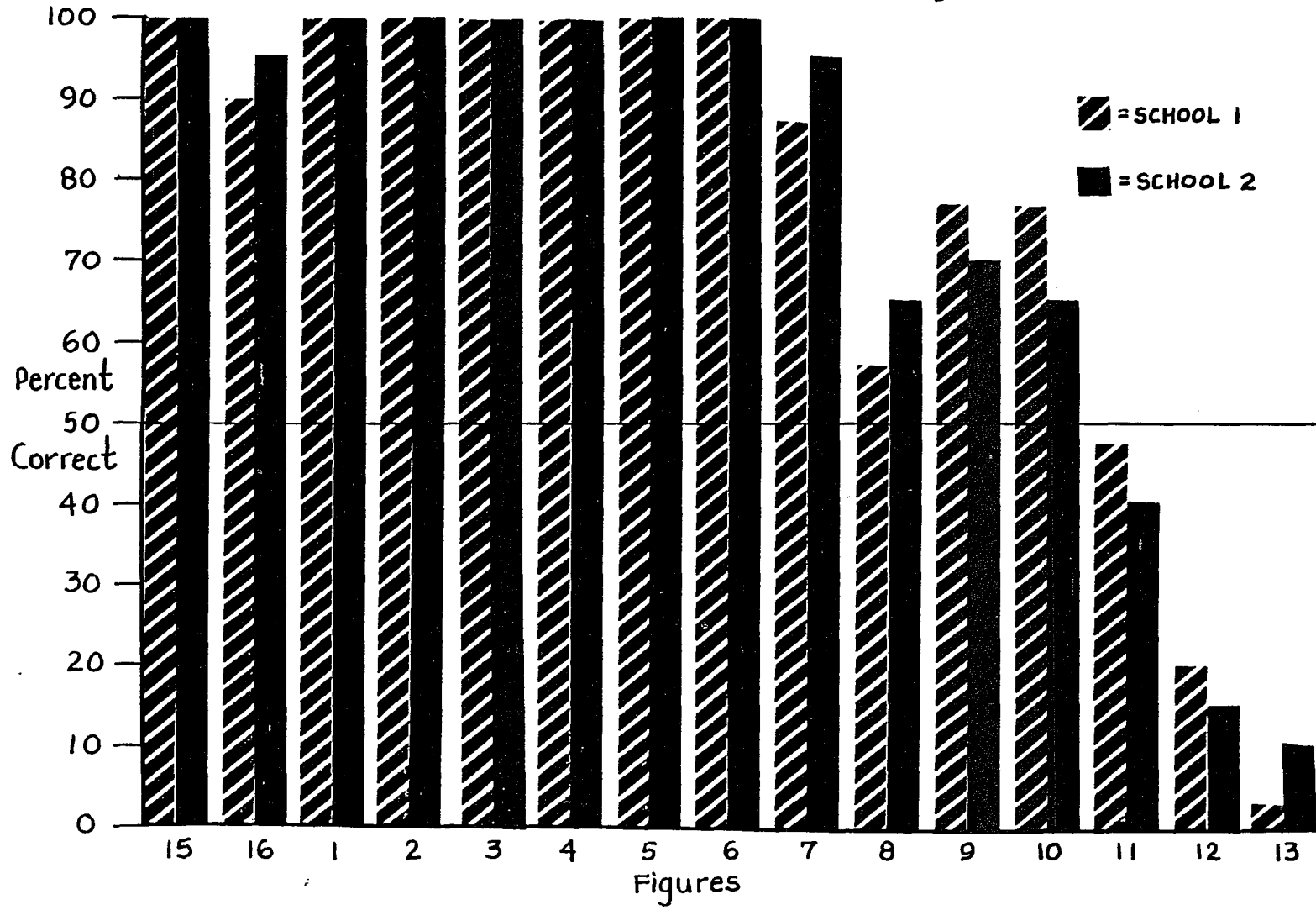


FIGURE 9

Grade 6: Percent correct for each figure

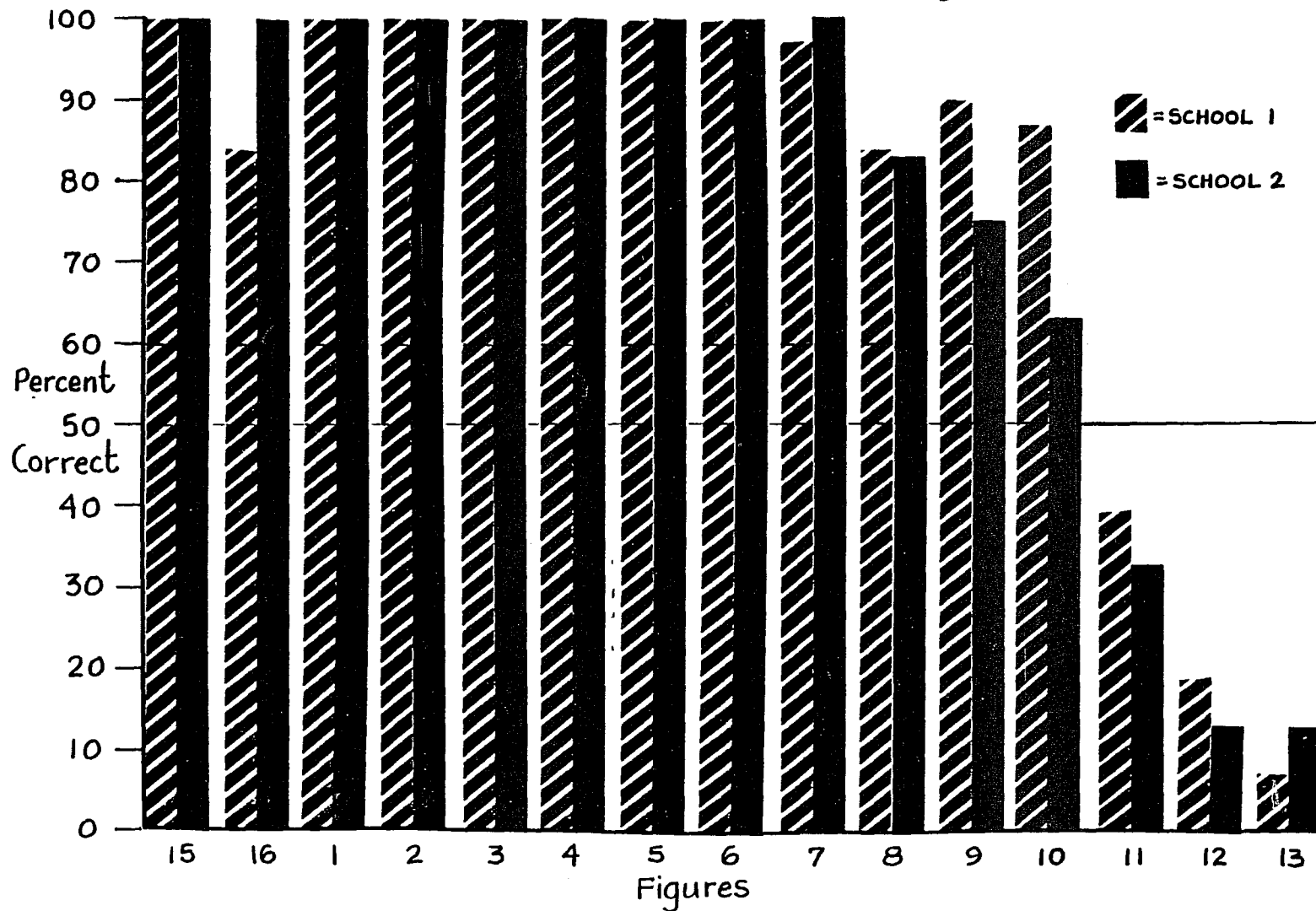


FIGURE 10

Age 5: Percent correct for each figure

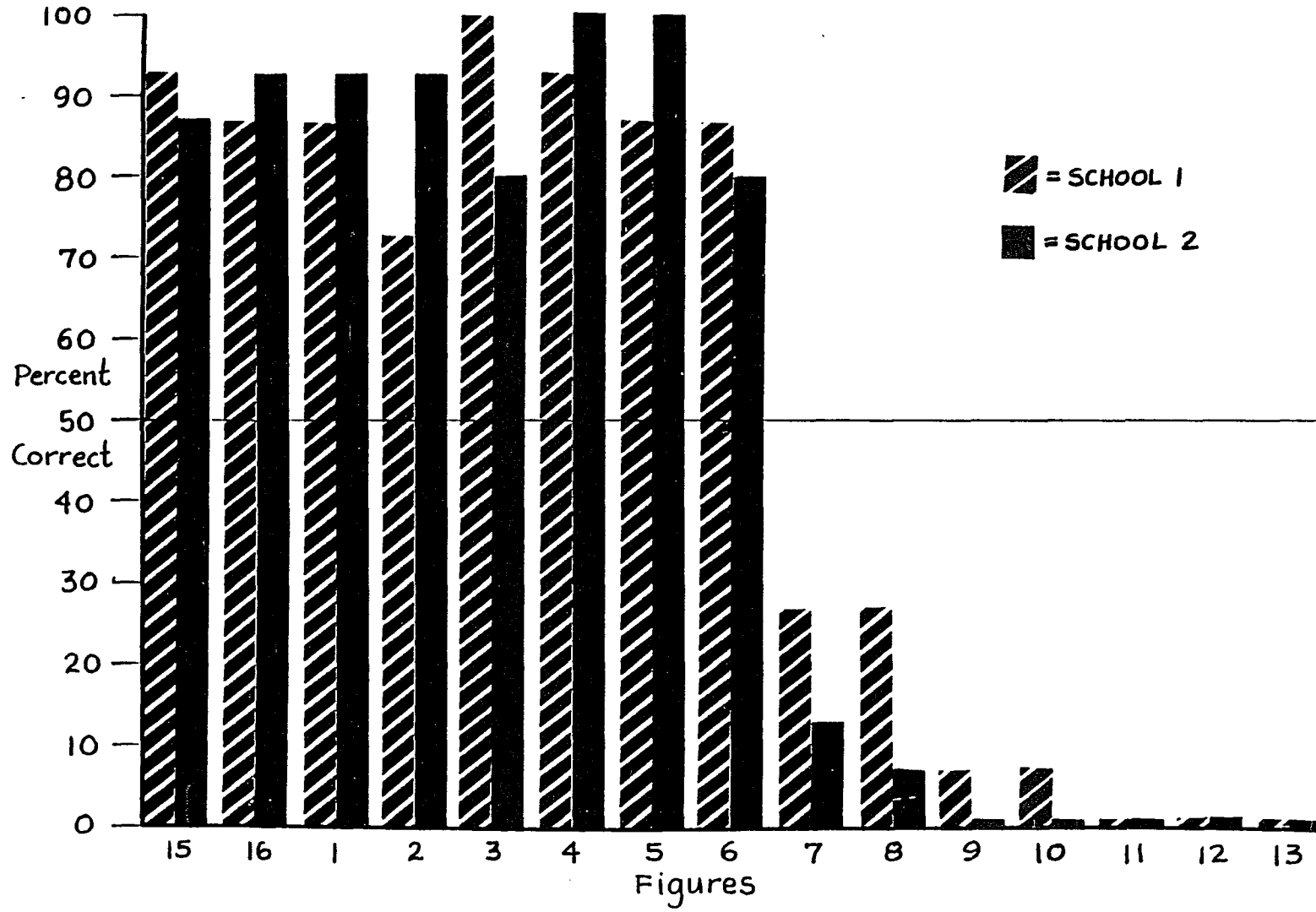


FIGURE 11

Age 6: Percent correct for each figure

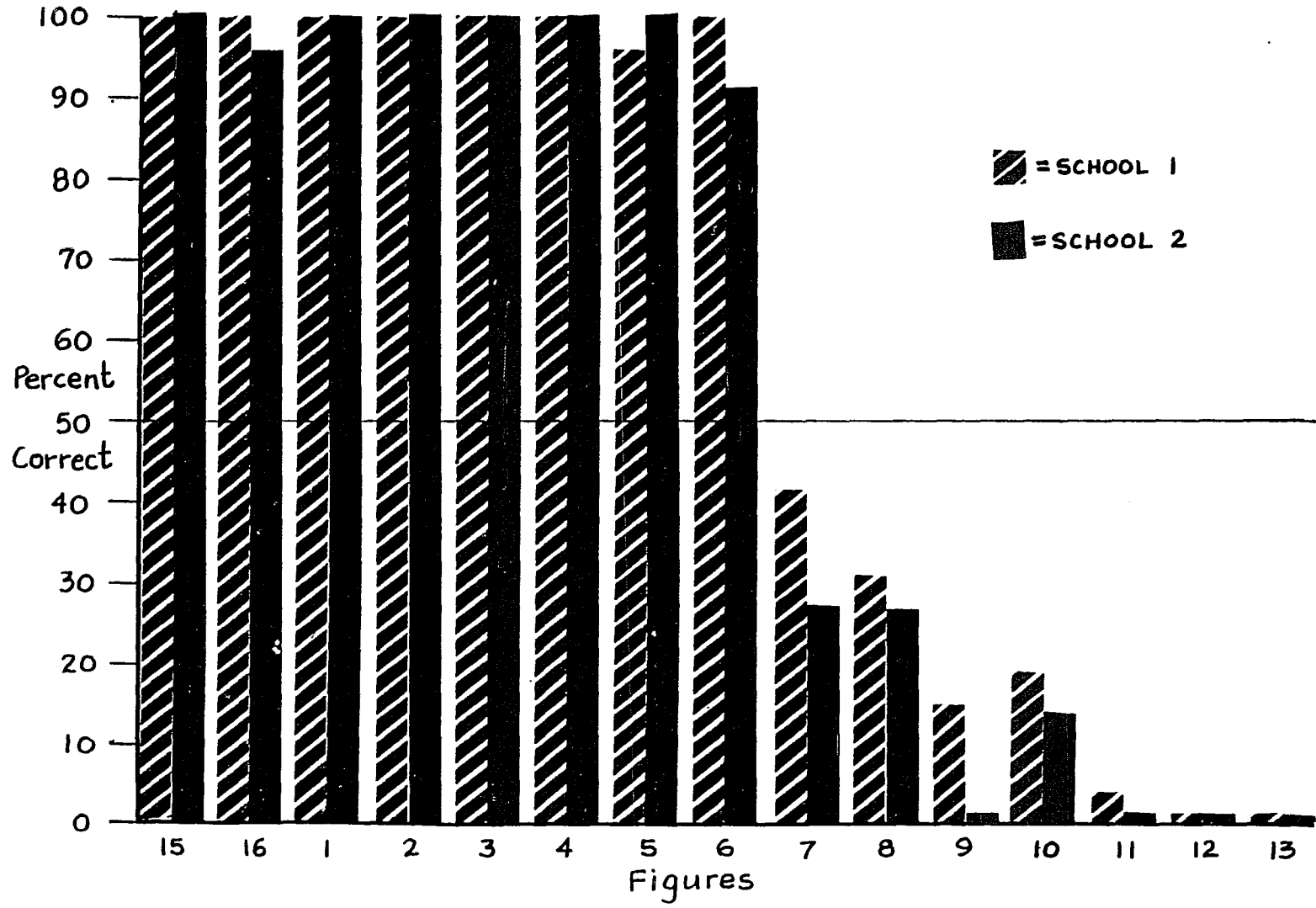


FIGURE 12

Age 7: Percent correct for each figure

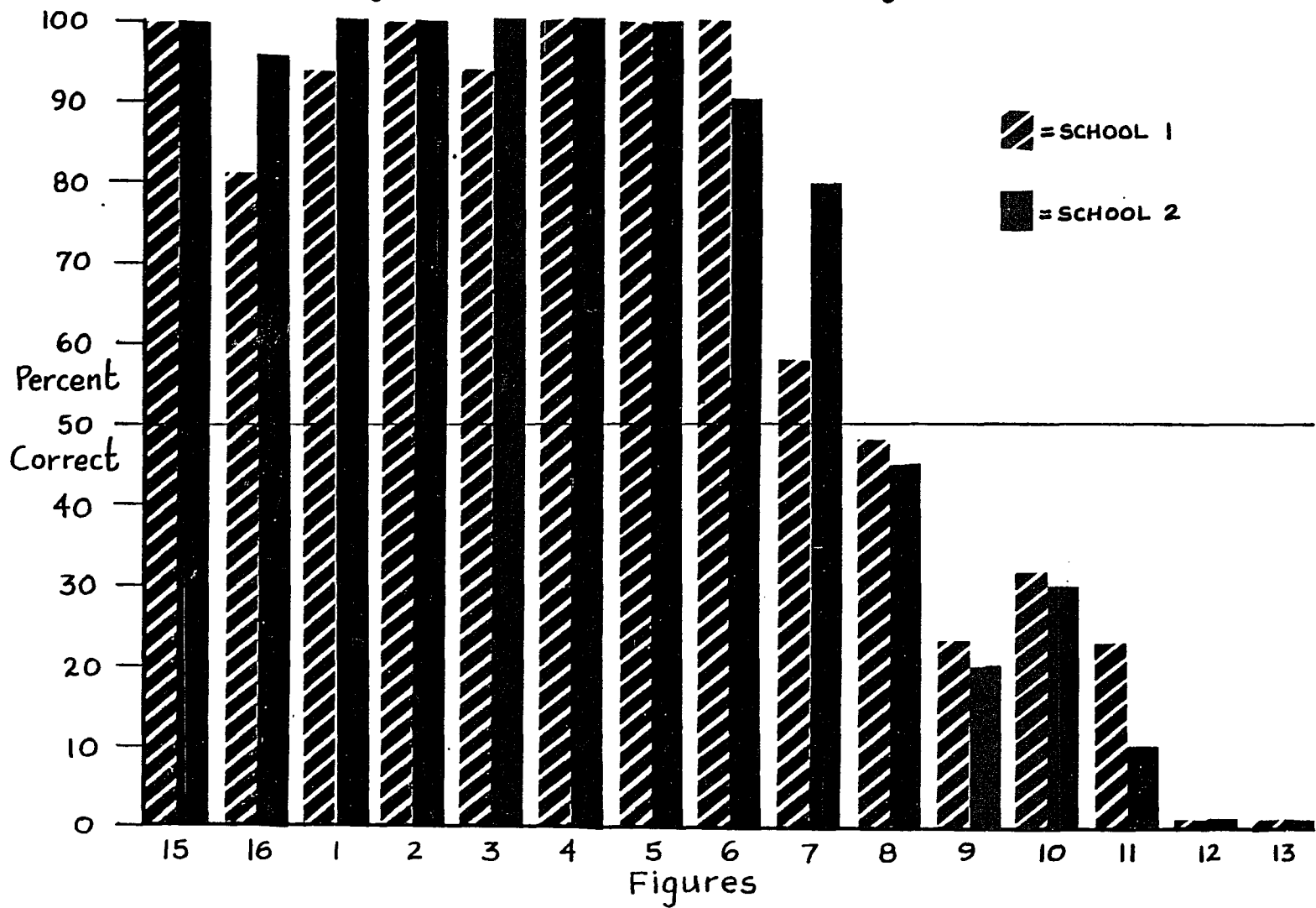


FIGURE 13

Age 8: Percent correct for each figure

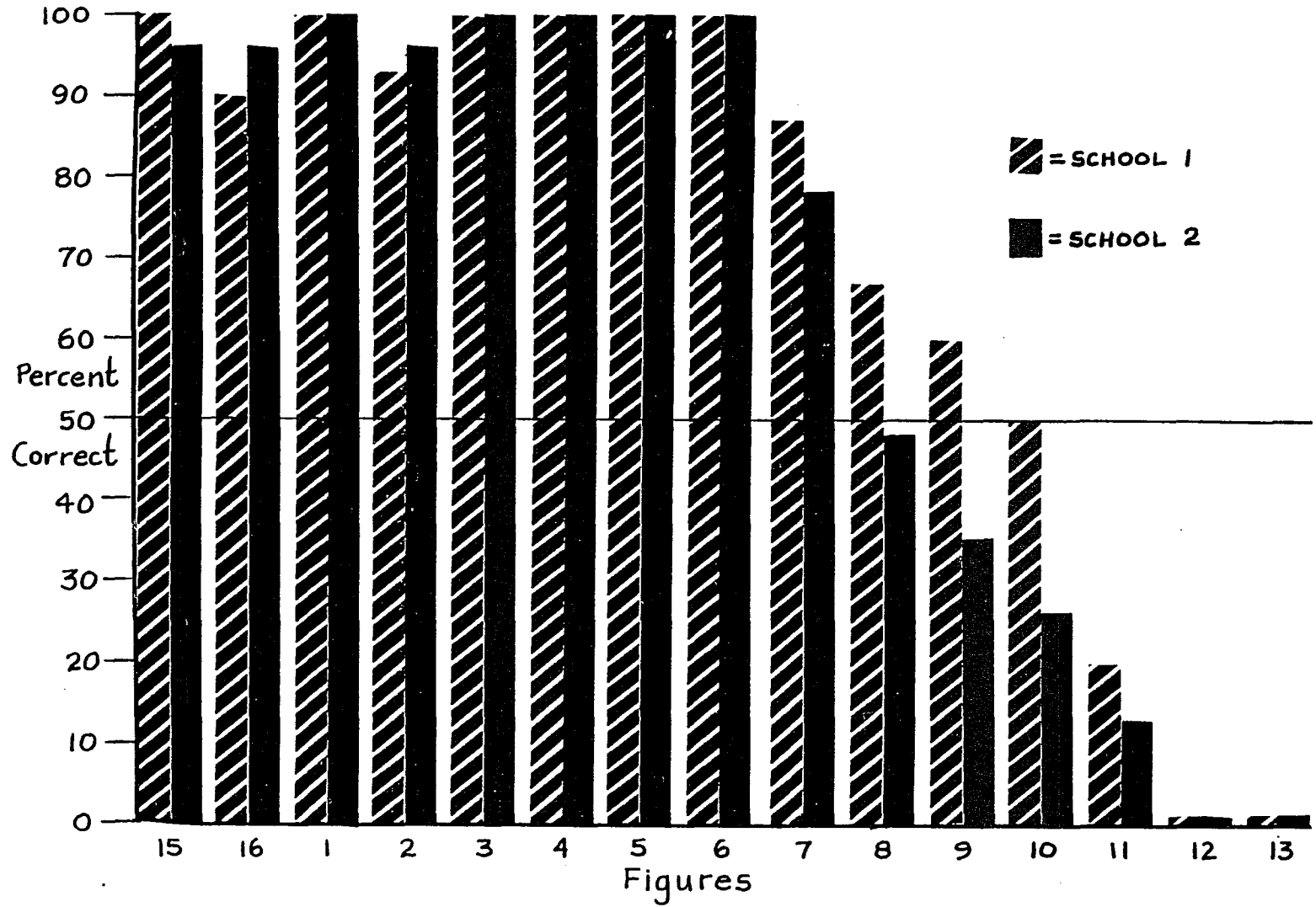


FIGURE 14

Age 9: Percent correct for each figure

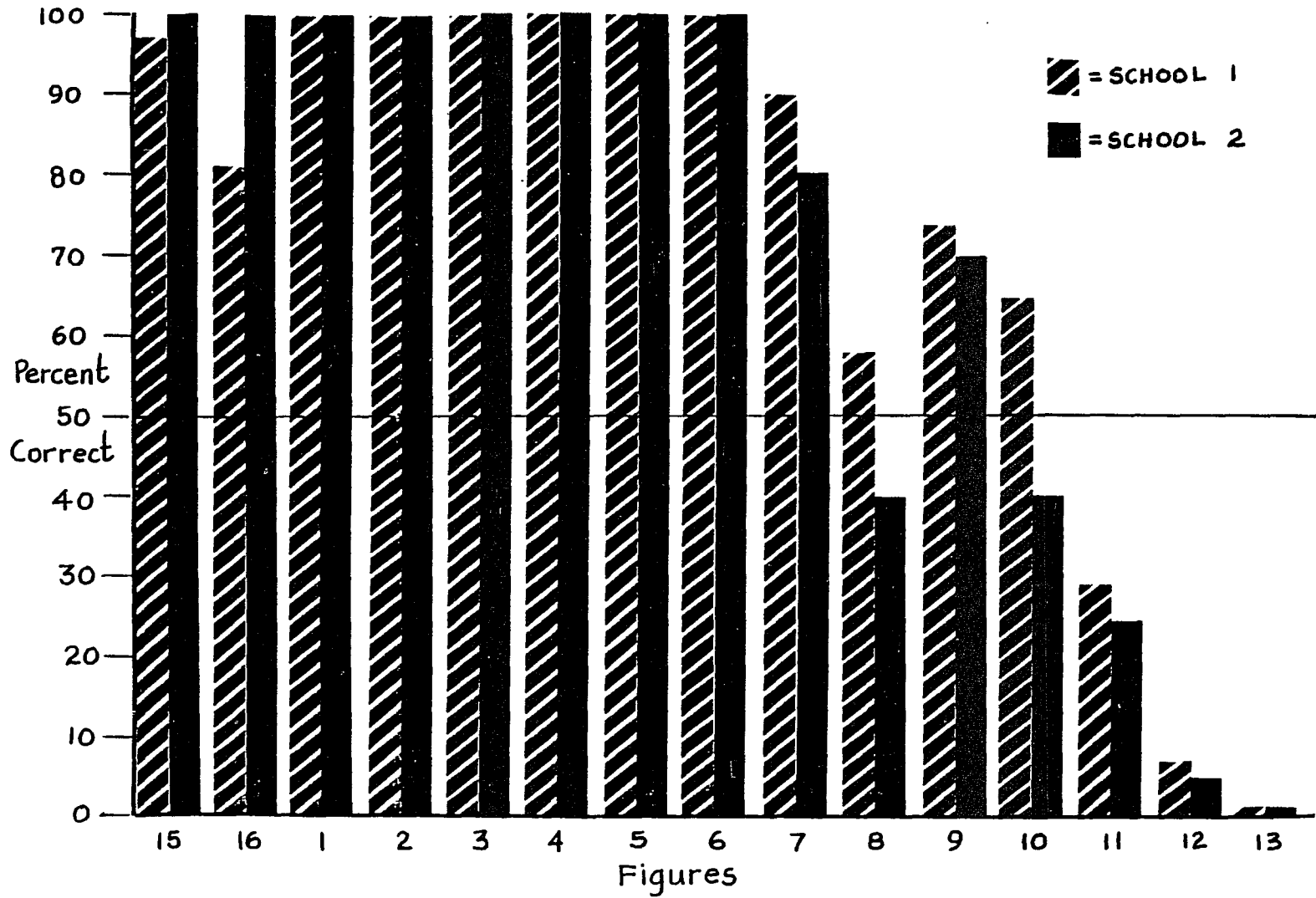


FIGURE 15

Age 10: Percent correct for each figure

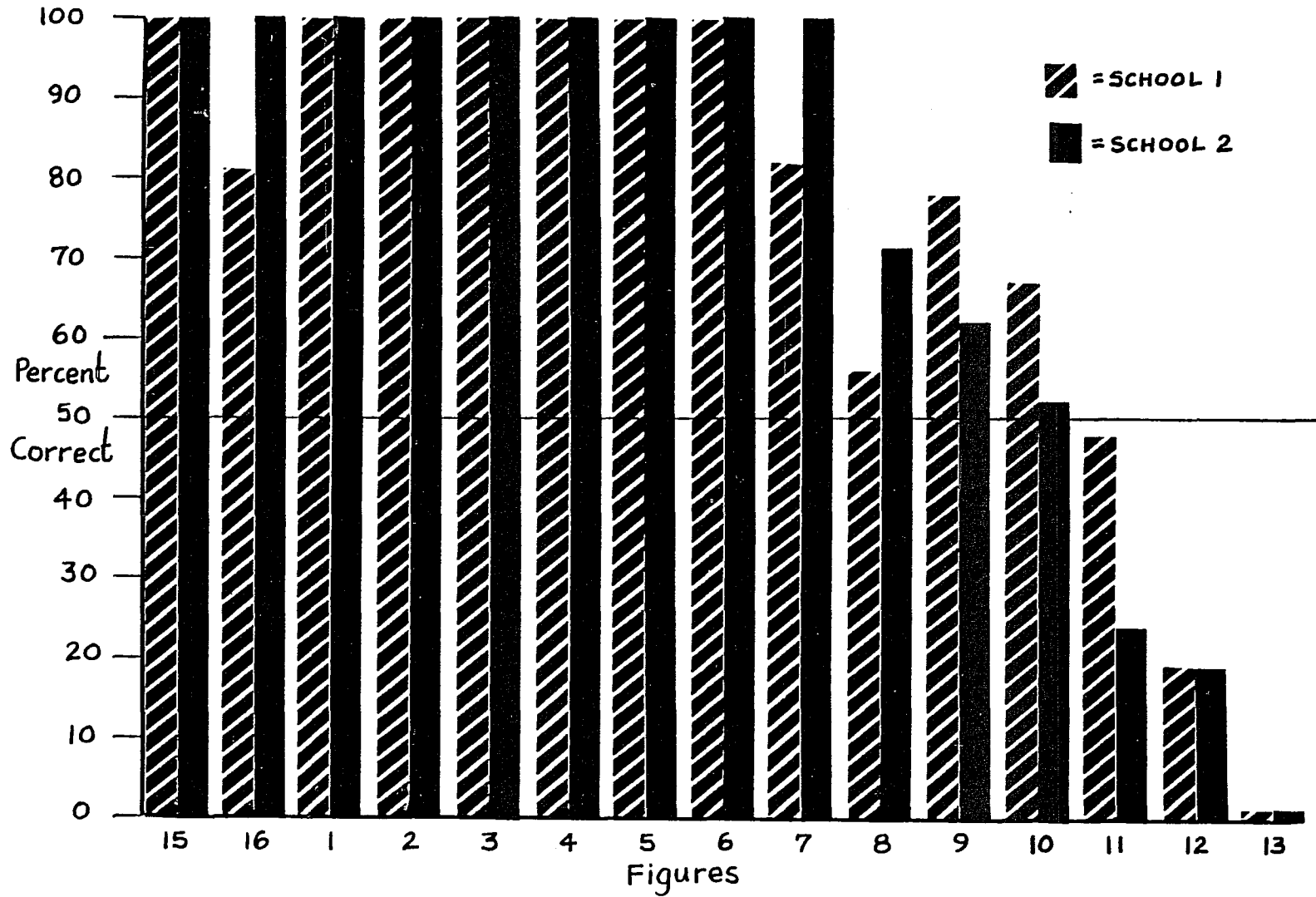


FIGURE 16

Age 11: Percent correct for each figure

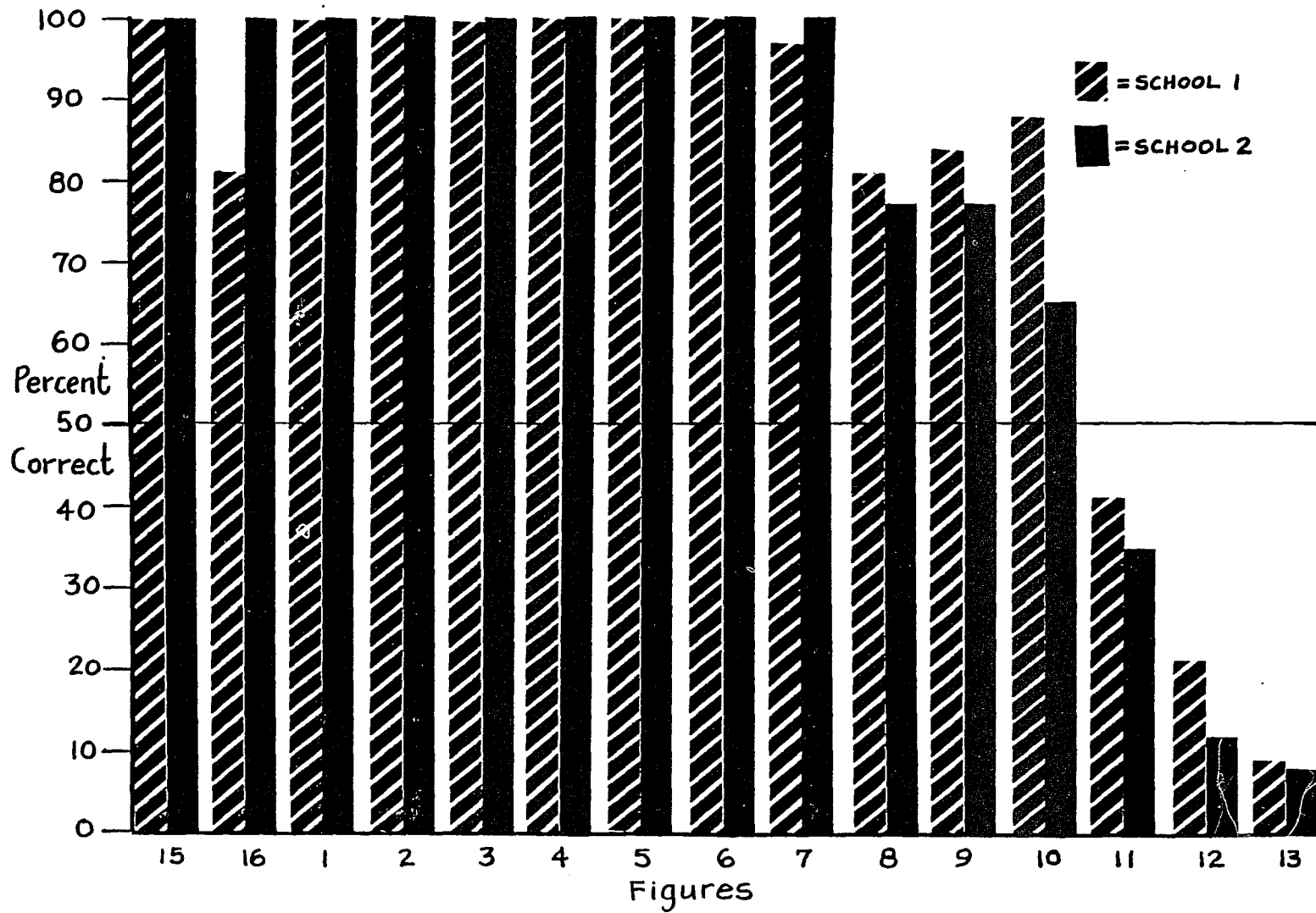


FIGURE 17

Age 12: Percent correct for each figure

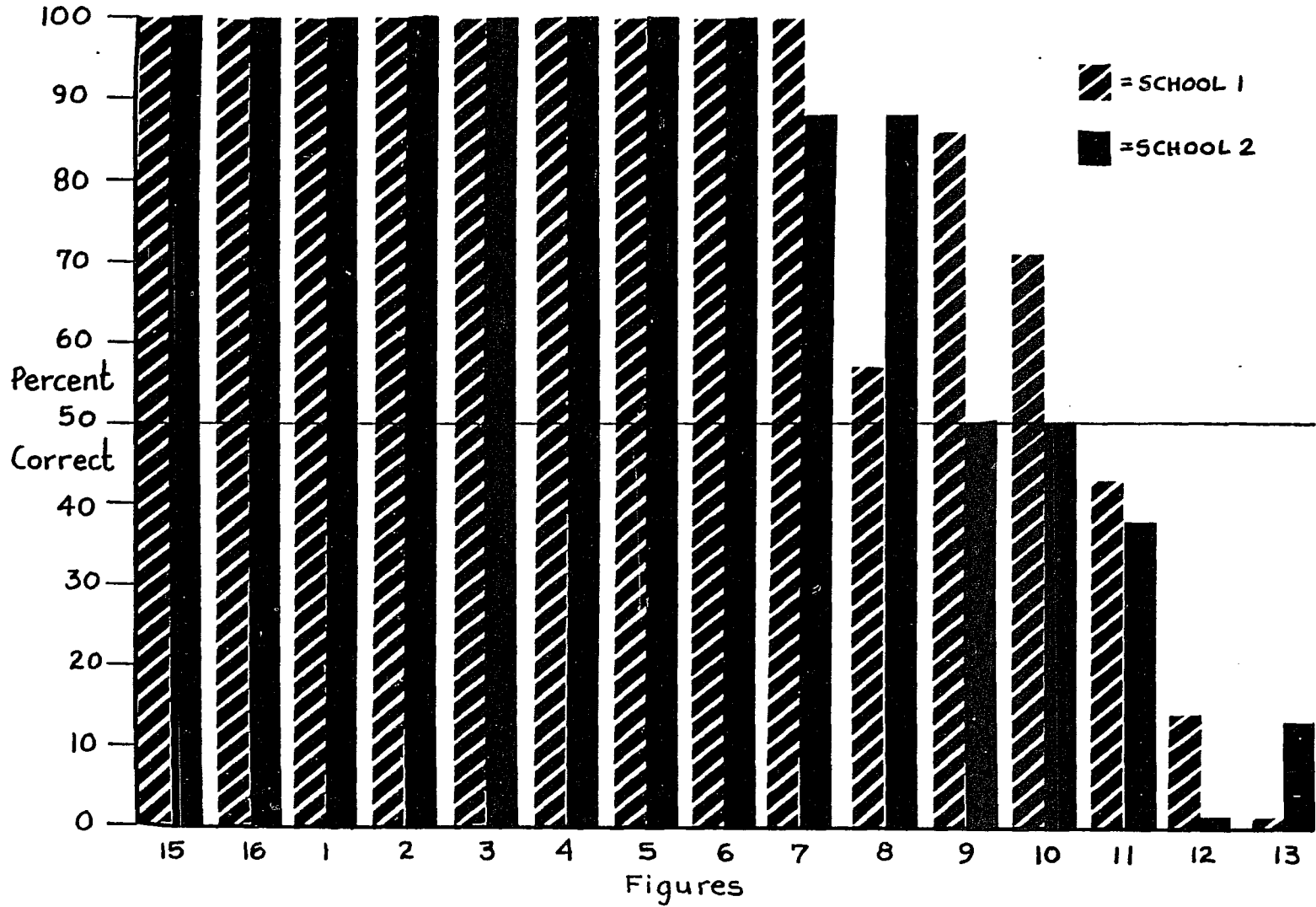


FIGURE 18
Mean Number of Figures Correct by Grade

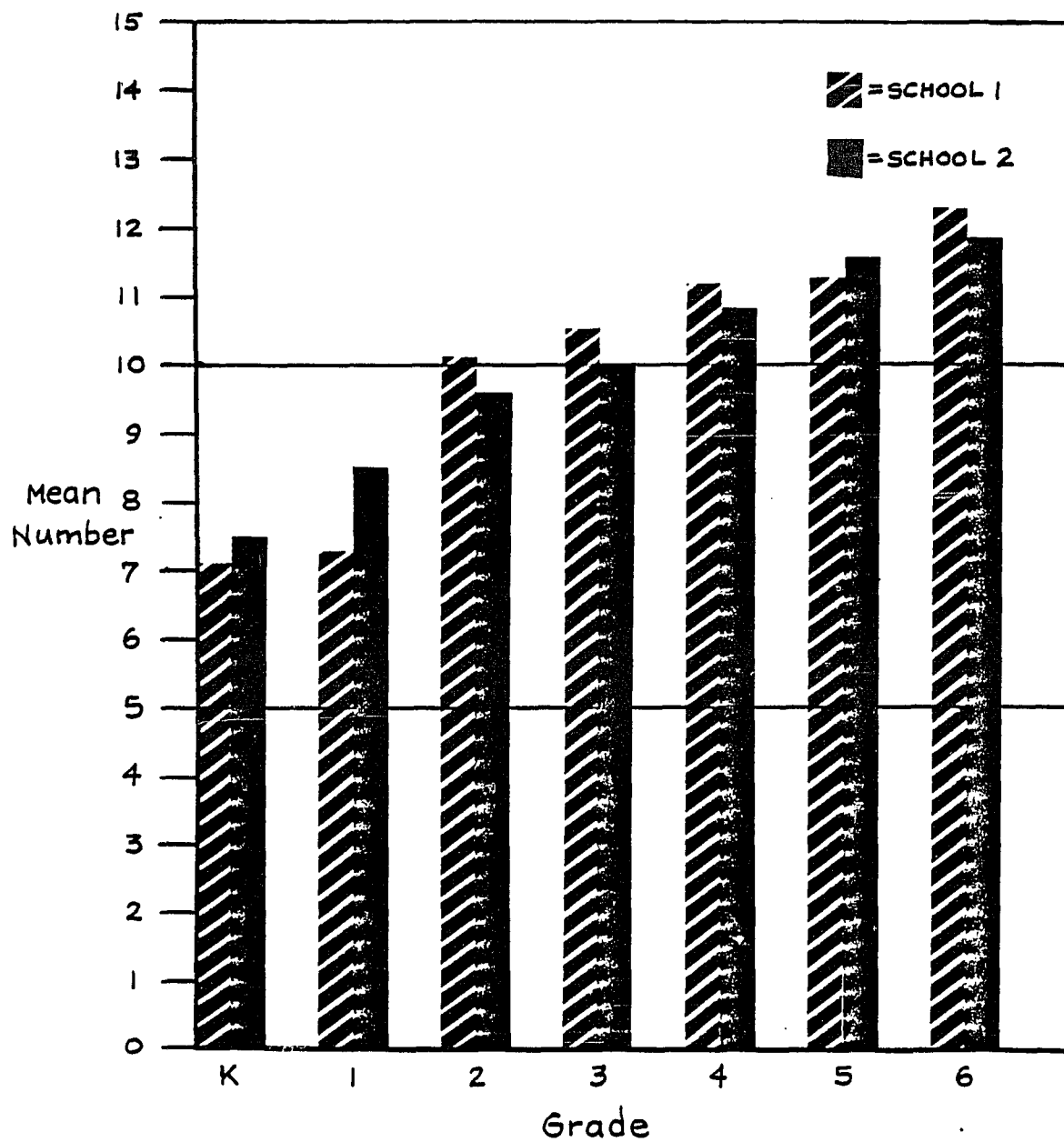


FIGURE 19
Mean Number of Figures Correct by Age

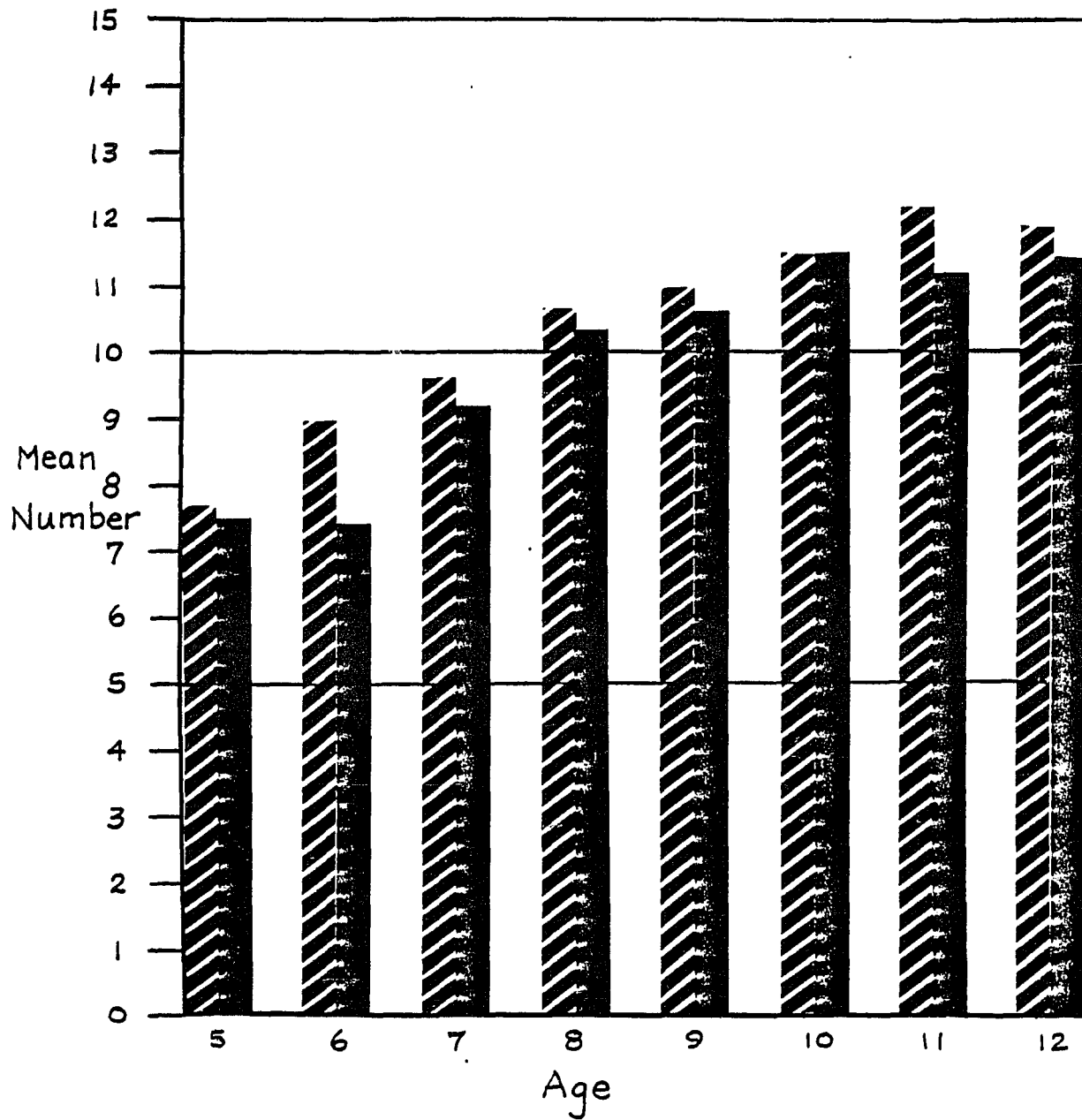


FIGURE 20
Mean Number of Consecutive Figures Correct
by Grade

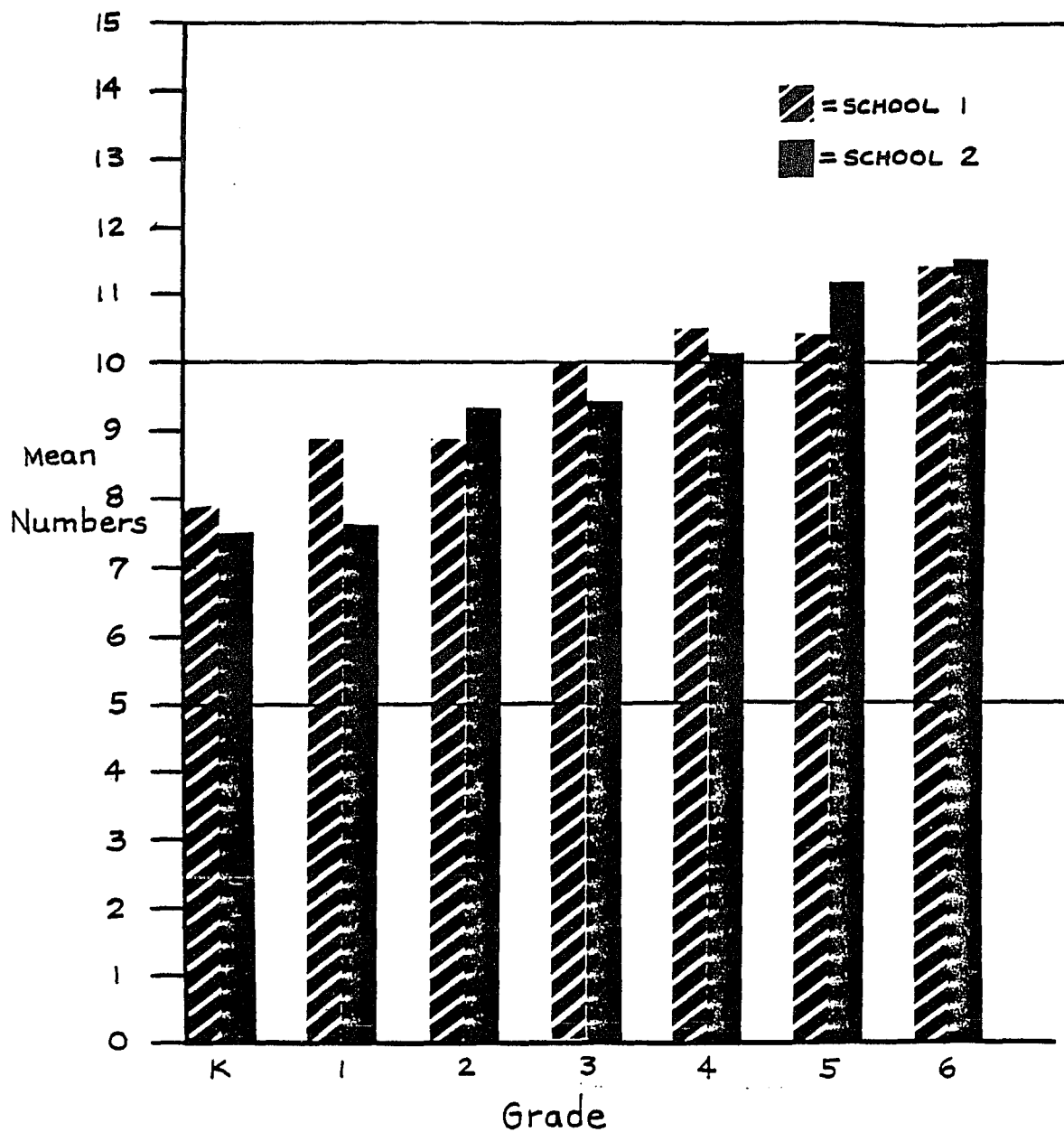


FIGURE 21
Mean Number of Consecutive Figures Correct
by Age

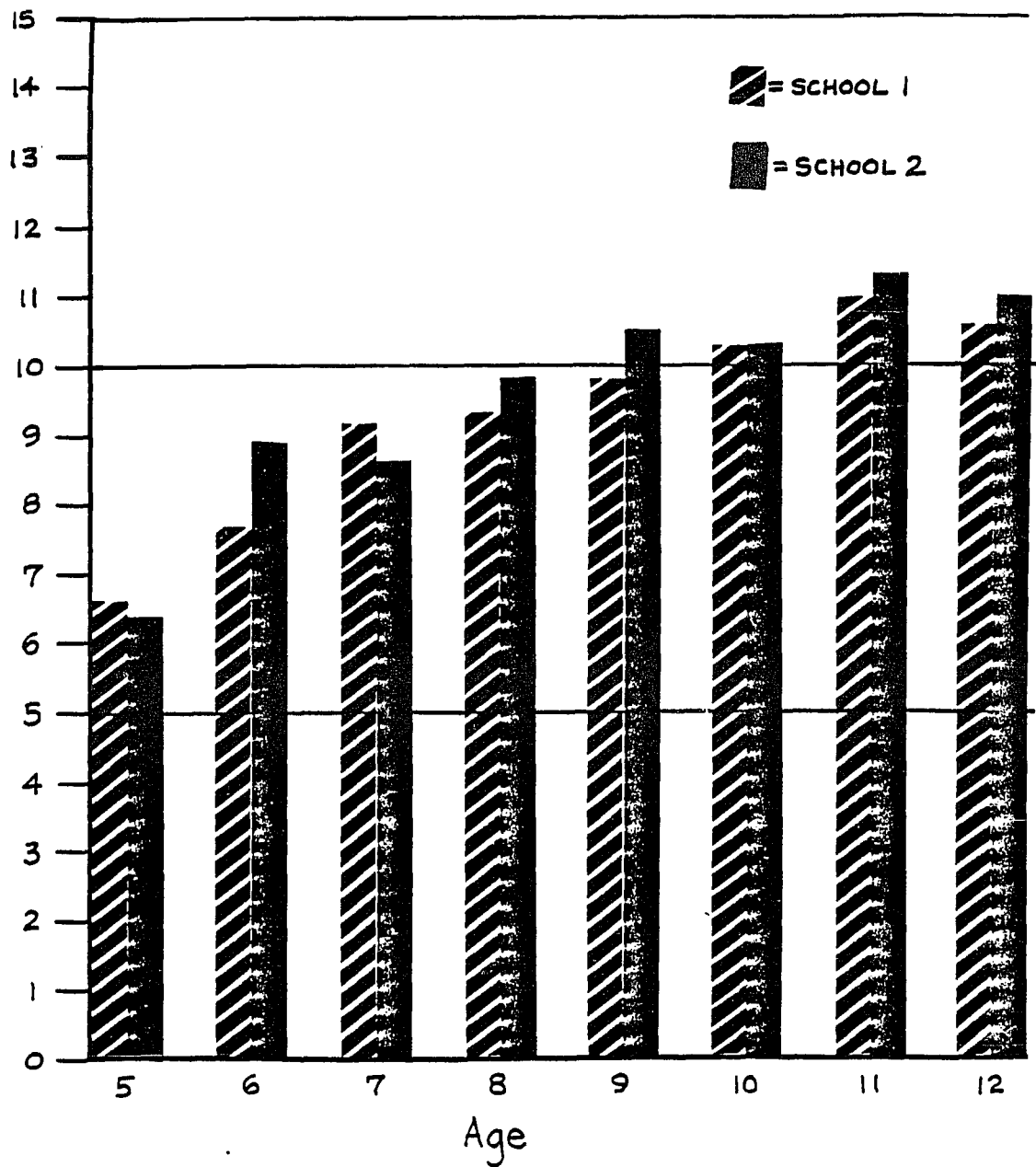


Figure 22

Forms 7-8 (Pre Operational to Concrete Operational)

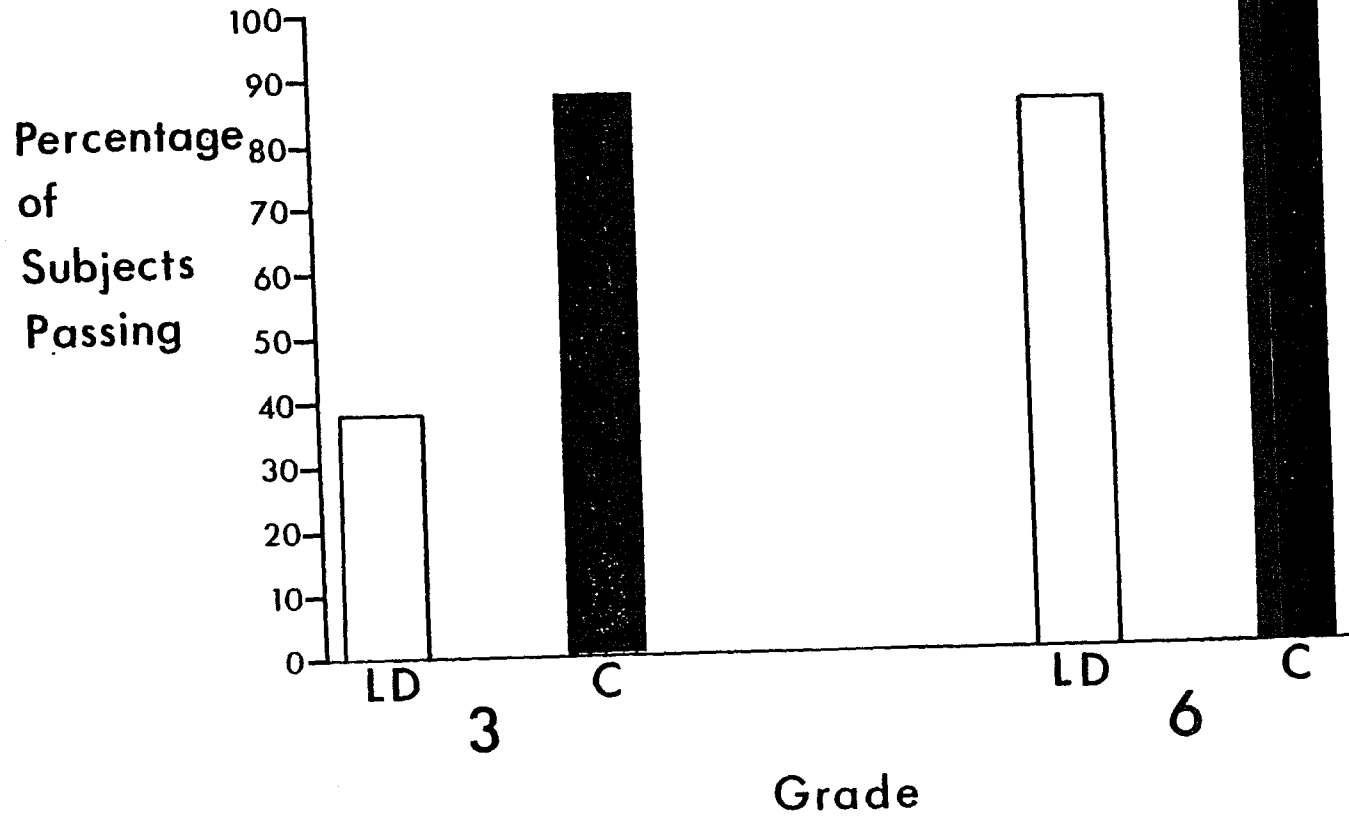


Figure 23
Form 9 (Parallelogram)

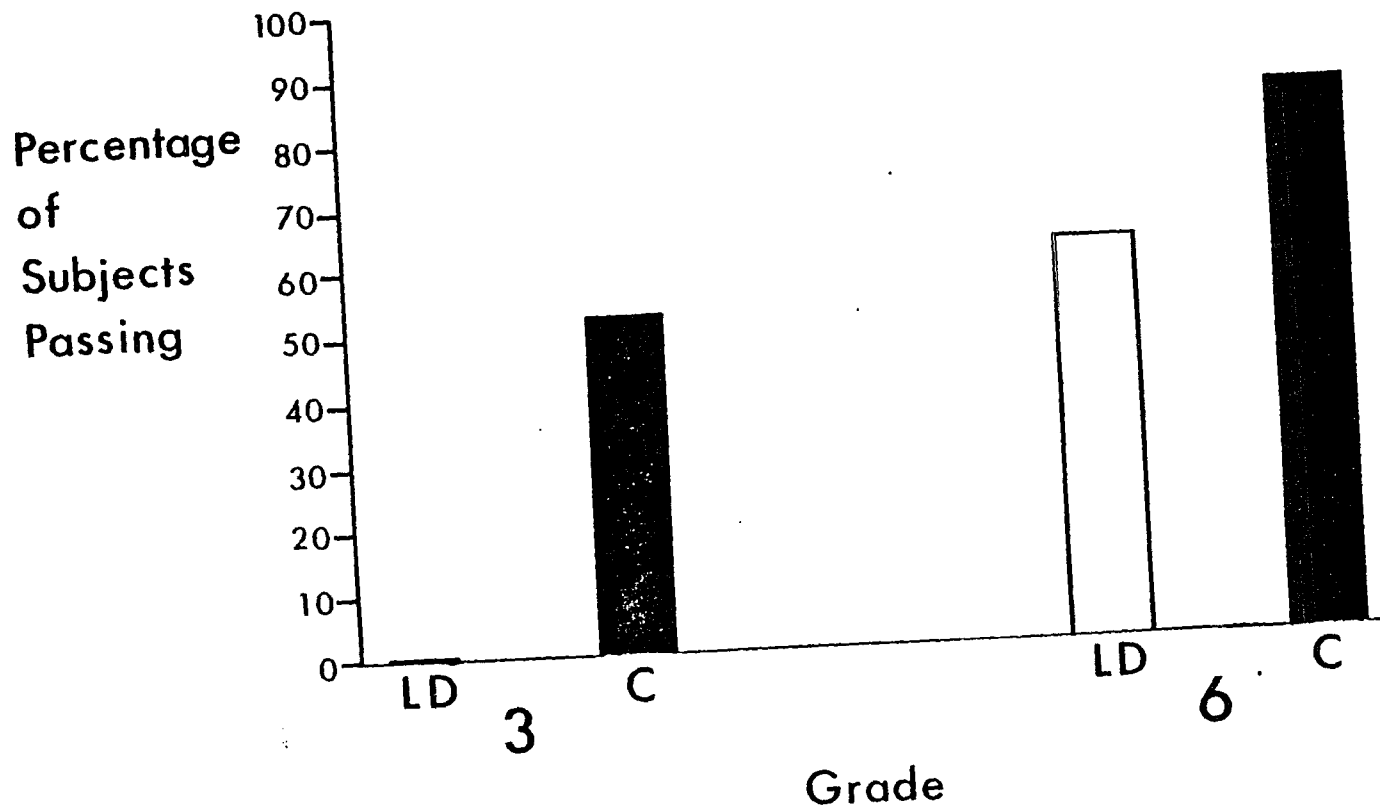
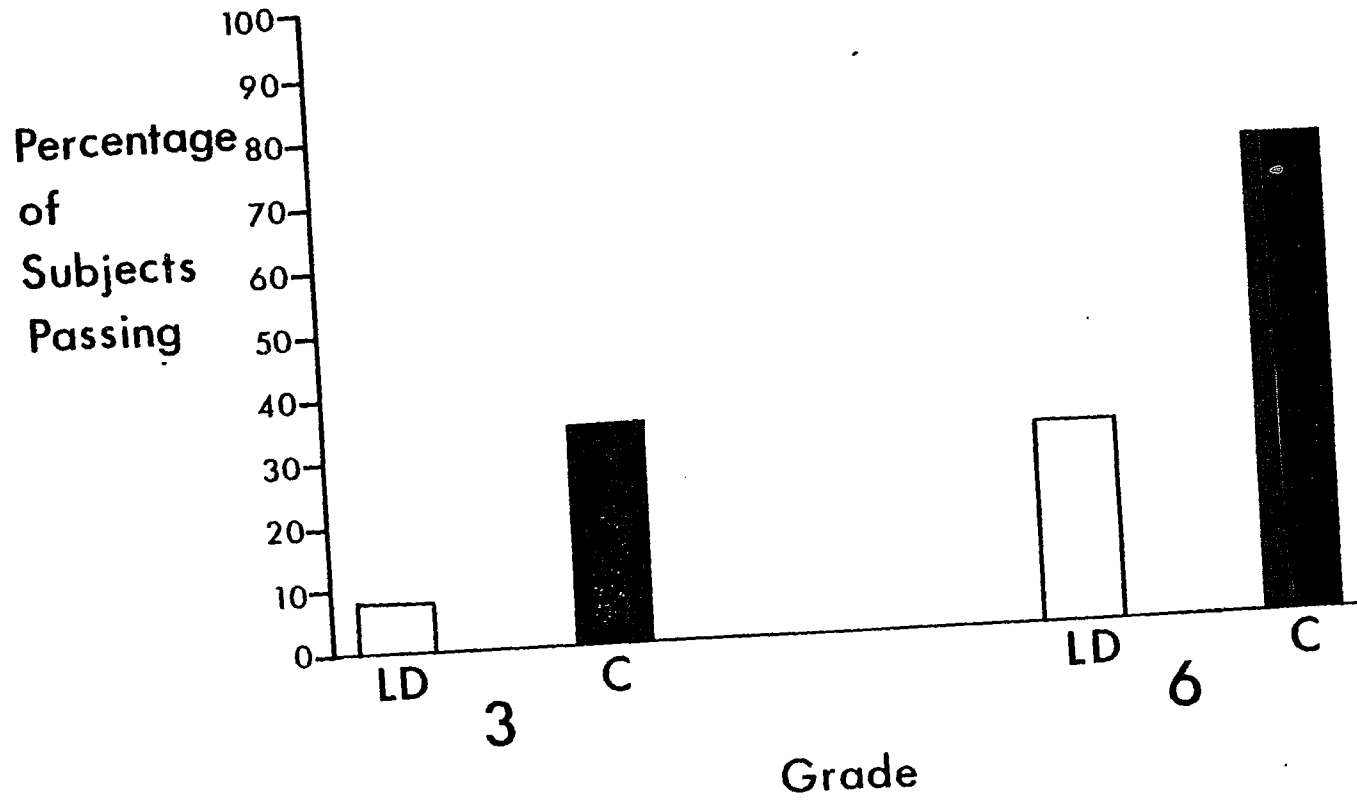


Figure 24

Form 10 (Obliquely Oriented)



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