DEVELOPMENT OF THE "GRAMMAR OF ACTION": AN ANALYSIS OF MOVEMENT SEQUENCES IN CHILDREN'S DRAWINGS OF GEOMETRIC FORMS

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ABSTRACT

DEVELOPMENT OF THE 'GRAMMAR OF ACTION': AN ANALYSIS OF MOVEMENT SEQUENCES IN CHILDREN'S DRAWINGS OF GEOMETRIC FORMS

By

Michael D. Petkovich

This research was designed to test some aspects of Goodnow and Levine's (1973) theory of the development of children's ability to copy forms. They contend that sequences and directions in copying can be considered to be a 'grammar' composed of 'motor rules'; these 'rules' determine, for example, where the starting point will be, which direction the first line will be drawn, and how many lines the copy will have. However, the analogy between language and copying is not clearly defined, and it was difficult to generate predictions from this conceptualization. It was decided that an important consequence of following Goodnow and Levine's 'rules' ought to be copies of superior quality.

A number of other theories about copying were reviewed, and a more comprehensive 'component' theory was developed. This component theory states that copying skill requires perceptual, cognitive, and sensorimotor abilities to act together as a system. Four predictions were generated from this theory: (1) for younger children, the organization of directionality is determined more by ease of execution of movements; in older children, directional organization (left-to-right)

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is more evident; (2) there is no association between any one of Goodnow and Levine's 'rules' and the quality of the copy; instead, consistency of use of movement sequences (that is, how often the same movements are used to construct repeated copies of the same figure) is correlated with the quality of reproduction; (3) children become more consistent in their movement sequences as they become older; and (4) movement sequences are more general (more nearly the same for both hands) for older children than for younger children.

These predictions were tested by having four- and five-year-old right-handed children make copies of three simple geometric forms--a square, a triangle, and a half cross. Each child made three copies of each with his right hand, and three copies with his left hand. The order and direction in which the lines of each figure were drawn was recorded, and all copies were rated for quality. All scores were inter-correlated to test the hypotheses. Ease of execution was measured by noting which direction the child drew a series of horizontal lines.

All the predictions were confirmed to some extent except for the first. The second prediction was supported; no single 'rule' correlated significantly with quality. However, consistency and quality were significantly correlated. This correlation made it difficult to assess the possibility that combinations of 'rules' used to construct a figure produced copies of superior quality. The third prediction was supported, but unusual sex differences were noted. The younger boys had significantly higher left-hand than right-hand scores, and the younger girls showed a tendency to have higher right-hand than left-hand consistency scores. The fourth prediction was supported to some extent, except that the younger girls' generality scores were as high as those of the five-year-old boys and girls.

Two alternative explanations were presented to account for the results found for the last two predictions. The first explanation was the addition of auxiliary hypotheses that did not significantly change the component theory. For example, the girls' superior generality scores were explained as a result of their faster rate of physical maturation; that is, their responses were more 'adult like' than the boys' responses. The second was based on Luria's (1966) theory of neuropsychological development and postulated that girls' early brain lateralization explained the sex and hand differences.

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To my Mother and Father

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INTRODUCTION

The idea that drawing ability can be developed by following a set of rules or patterns has a long history. Gombrich (1960) believes that one of the first books to reflect this view was Erhard Schön's *Unterweisung der Proporzion*, published in 1538. This was an ambitious effort, containing schemas for viewing the human head from different positions, and methods for imagining the human body as a composite of simple geometric forms. Schön apparently borrowed these ideas from Albrecht Dürer's *Dresden Sketchbook* (circa 1513), in which the geometric and stereometric structure of the human body was explored. The public's interest in books of this type has not diminished since the Renaissance, and in this century rigorous scientific methods have been used to see whether there are regularities in the development of drawing.

Contemporary psychologists have postulated a variety of theories to explain the development of drawing skills in normal children. The central problem most deal with is what Maccoby and Bee (1965) call the 'perception-performance lag.' Maccoby and Bee note that even a one-year-old can distinguish among a circle, square, and a triangle, but cannot copy a circle until four, and a triangle until the age of five. Each contemporary theorist hypothesizes some kind of perceptual, motor, or cognitive deficiency that prevents the child from translating his accurate perceptions of a figure or model into a copy. That is, an overcoming of some deficiency is presumed to be governing the transition from perception to performance. (All the theorists agree that the problem is not due to poor motor coordination.)[1] The distinction between perception and performance is linked to the more general problem of determining the relation between cognition and perception. That is, must one postulate separate cognitive and perceptual systems? Most theorists, however, do not explicitly deal with these problems.

An Outline of Some Major Theories of Copying Development

The major theories can be grouped into four categories. The theorists do not necessarily contradict one another; each focuses on an aspect of drawing skill, and many of their assertions are complementary.

Perceptual Organization

According to Werner (1948), the child's perceptual and perceptual-motor skills are organized poorly or 'diffusely.' Werner, however, does not recognize a perception-performance lag, but asserts that both abilities are deficient.

Conceptual Organization

Piaget and Inhelder (1956) and Rand (1973) focus on the conceptual deficiencies of the child to explain the perception-performance lag. Piaget and Inhelder postulate separate cognitive and perceptual

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[1]Children have difficulties with many spatial tasks that do not involve complex motor skills. Olson (1970) and Piaget and Inhelder (1956) probably give the most extensive treatments of this problem.

systems, and assert that the child must have adequate spatial concepts before he can copy accurately. Rand contends only that the child lacks the capacity to plan his visual-motor behavior.

Information from Perception

Maccoby and Bee (1965) and Olson (1970) hold that the child lacks the correct perceptual information to produce an adequate copy, even though he has enough information to discriminate differences among figures. Maccoby and Bee do not fully discuss how perceptual information is related to cognition. Olson theorizes that perceptual information must be organized by the 'infralogical operations' postulated by Piaget (1970a) before the child can copy. These operations allow the child to consider an object as a collection of parts. He then can perform the operation of combining the parts into the whole and the reverse operation of breaking the whole back into parts. Olson, however, contends that there are ". . . not two independent systems, perceptual and representational, as Piaget argued, but rather one system, a perceptual one, which is altered substantially by performatory acts in different media" (Olson, 1970, p. 187). This is a confusing notion, for if the infralogical operations are considered as concepts or cognitions, it is difficult to see how there can be only a perceptual system.

Motor Rules

Gesell and Ames (1946) and Goodnow and Levine (1973) suggest that children and adults follow motor sequences when copying. Gesell and Ames's normative study demonstrated that sequences of movement in copying show shifts with age. For example, 60% of five-and-a-half-year-olds and 25% of all adults used a single, continuous line to copy a square. Goodnow and Levine duplicated this study, and invoked Lashley's (1951) concept of 'syntax of behavior' in interpreting the results. Goodnow and Levine believe that the sequences of movement can be considered as a 'grammar of action' composed of 'motor rules.' The 'motor rules' determine, for example, which side of the copy the child will begin first, and in which direction the first line will be drawn, even if these 'rules' are incompatible with producing an adequate copy. Goodnow and Levine do not explicitly discuss how their 'grammar of action' is related to the perception-cognition problem, or how the concept of 'motor rules' is analogous to syntactic rules in language.

The Present Study

The present study extends and partly duplicates Goodnow and Levine's (1973) work, and contrasts it with a more comprehensive theory. Some 'functional' aspects of movement sequences were examined: Does the use of certain 'rules' produce better copies? Are the same 'rules' or movement sequences used for each limb and over a number of repeated copies? Before describing the study, assumptions about the development of copying skill, the nature of 'rules' and language, a description and evaluation of each theory, and an integration of these theories will be given in order to put the present work in a broader context.

Copying will be viewed as a complex ability requiring the integration of perceptual, cognitive, and sensorimotor processes. Bruner (1970a) suggests that copying makes the individual remember the entire orientation and shape of the figure and yet analyze it into parts permitting the execution of sequential movements that result in an accurate copy. The sensorimotor mechanisms involved in kinesthetic feedback play an important part in guiding movements so there is no deviation from the intended goal. In short, copying is a systemic process involving sensorimotor, perceptual, and cognitive processes. Note that with these assumptions different types of theories must be combined to explain the perception-performance lag. This viewpoint is the result of the present author's desire to create a theory of copying that is as comprehensive as possible; all other theories are evaluated according to this standard.

Goodnow and Levine's (1973) assertion that 'motor rules' can be considered as a 'grammar of action' needs considerable elaboration; Hesse (1963) notes that analogies in science must be stated carefully so it is clear what aspects of the disciplines are similar. Although sequences of movement in copying and syntax in language are superficially alike, other aspects seem incompatible: Is there a 'semantics' of copying? Does copying have a mathematical structure of a natural or artificial language? Bruner (1970b) observes that adults can substitute new motor movements in well-learned, coordinated actions, and still execute the action smoothly. For example, an adult can draw a square using four lines or one continuous line and produce very similar copies. This seems to be an important aspect of copying, but no obvious analogy exists in language. This discussion, however, does not imply that the concept of 'rule' is worthless in analyzing copying, but that a more thoughtful definition of 'rule' is needed to avoid logical absurdities.

Descriptions and Evaluations of Some Major Theories of Copying Development

Perceptual Organization: Werner (1948)

Description.--Werner (1948) hypothesized that the perceptual-motor skills of the young child are best described as 'diffusely organized.' He did not mean that these skills are disorganized as he asserts they would be in a retarded child, but rather that young children tend to focus on the 'qualities-of'the-whole' of the figure and to 'homogenize' it. Werner believes that these tendencies are reflected in the young child's preference for simple, primitive figures.

According to Werner (1948), children's copying can be characterized with three perceptual-motor rules: The first states that the child emphasizes the 'qualities-of-the-whole': Figure 1a illustrates how the model is transformed so it becomes more uniform and indivisible, and Figure 1b shows how open figures become closed. The second rule states that the parts of a figure and its directions become homogenized: Figure 1c shows how the parts become alike, Figure 1d how directions are simplified, and Figure 1e how figures become symmetrical. Werner's third rule describes the transformation of a figure into a 'chain type' of reproduction:

> The distinguishing sign of the chain type of drawing is the relative lack of definiteness in the relation of parts . . . the concatenation of pieces of the whole, an arrangement in which the distinguishing marks of higher geometric forms--the subordination of single parts, the presence of centers and so on--are lacking [pp. 123-124].

Figure 2 illustrates this rule with a six-year-old girl's copy of a cube (Werner, 1948, p. 124).[2] These observations were gathered from uncontrolled, informal testing situations.

Evaluation.--Graham, Berman, and Ernhart (1960) tested children three-and-a-half to five years of age to see whether their copies of geometric figures conformed to Werner's theory. The copies were also examined to see whether the older children's reproductions were more accurate. That is, did the copies become more opened or closed, curved or linear, have the same number of parts and intersections as the model? The 'accuracy' hypothesis best described the child's copying development. The only hypothesis of Werner's confirmed was that symmetrical productions are more common in younger children. Although one does find simplification and closure in children's copies, one also finds just as much complicating and opening of figures. Graham, Berman, and Ernhart did not test Werner's third rule because they felt it was indistinguishable from their own 'accuracy' hypothesis.

Perhaps the main problem with Werner's (1948) theory is that it does not recognize a perception-performance lag. The observation that a child prefers simple, primitive forms does not necessarily determine the kind of copies he is capable of producing. Furthermore, the child's preference for a certain kind of drawing does not mean he is incapable of discriminating among figures, or that his perceptions

---

[2]Note, however, that the child's copy in Figure 2 does seem to exhibit some structure that is present in the model. The juxtaposition of the three squares in the copy expresses the relations of the model's parts more than, say, three squares placed in a row.

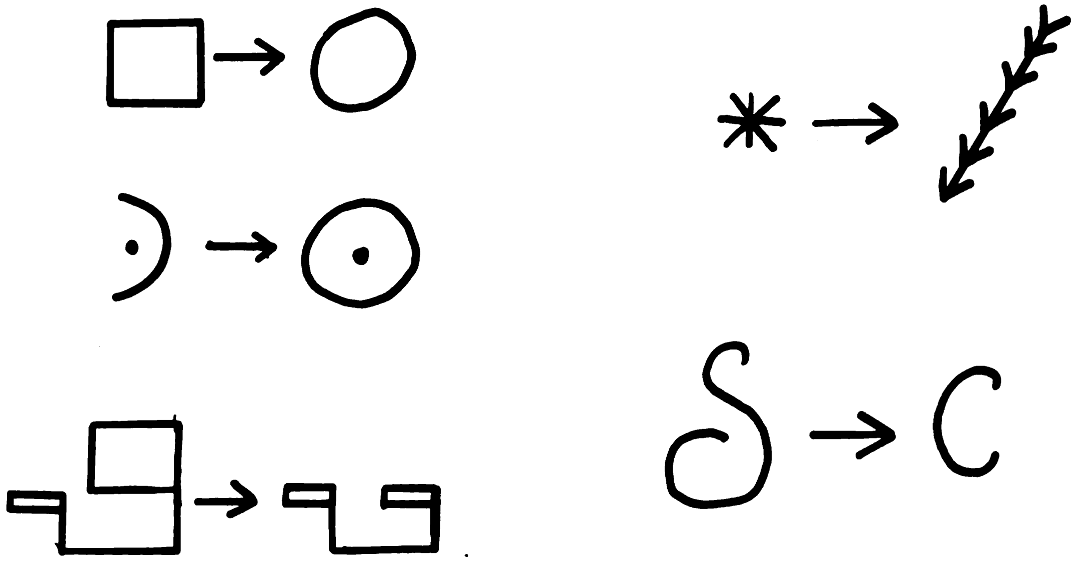

Figure 1. Copies of models that illustrate two of Werner's (1948) perceptual-motor rules.

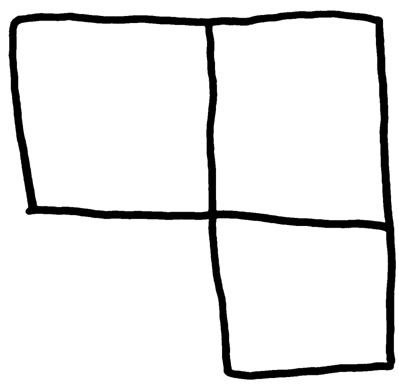

Figure 2. A six-year-old girl's copy of a cube that illustrates Werner's (1948) third perceptual-motor rule.

are 'diffusely organized.' Unfortunately, Graham, Berman, and Ernhart's (1960) conclusion that the child's copies become 'more accurate' is only a description of some, but not all, of the features found in children's copies. It is not an explanation of why a child becomes more accurate in copying, and is of little value in explaining the perception-performance lag.

Conceptual Organization: Piaget and Inhelder (1956) and Rand (1973)

Description.--Piaget and Inhelder's (1956) explanation of the perception-performance lag is rooted in Piaget's (1966, 1970a, 1970b) model of cognitive development and his solution of the cognitive and perception problem. Piaget relegates perception and cognition to separate but interrelated systems and asserts that each system is governed by different processes. Thus a child may be able to visually discriminate among figures but not be able to construct them because he lacks the requisite Euclidean and projective spatial concepts. These concepts allow the preservation of such features as angles, size, and straight lines (or 'metric properties') in copies of geometric forms. Euclidean and projective concepts act like a set of coordinates or a 'grid' which the child imposes on the outside world and uses to guide his constructions. These concepts, however, are not fully achieved until the period of Concrete Operations (about seven years of age); the preoperational child has 'primarily topological concepts of space.'

Piaget and Inhelder (1956) define the preoperational child's spatial concepts with five 'elementary topological relations' (Piaget and Inhelder, 1956, pp. 48-50):

1. Proximities are generally correct. A man is drawn so that his facial features are grouped near the top of the figure.
2. Separations are represented. Elements of a figure that are separated are generally separate in the copy.
3. The succession or order of elements in a representation are generally like that of the model. The distance between the elements of the copy, however, may be greatly expanded or contracted.
4. The relationship of surrounding is represented. For example, food in a man's stomach may be shown by means of a transparency (a transparent body wall).
5. Continuity in a form is represented. A hat is drawn on the head and not some distance above it.

Support for these assertions comes from Piaget and Inhelder's (1956) study of children's copies of geometric forms. Realizing that the inadequacies in the children's copies could come from poor muscle coordination, Piaget and Inhelder performed more experiments. (They do not discuss whether the child's 'poor muscle coordination' is from peripheral factors such as muscle weakness, or central factors such as an inability to sequence actions.) Reasoning that a child with primarily topological concepts of space should show deficiencies in any task requiring the construction of geometric forms,[3] they asked children to copy geometric forms with sticks, and found that the stick constructions were about as accurate as the drawings. Piaget and Inhelder

[3]The Soviet physiologist Nicolai Bernstein (1967) has also described human movements as 'topological' in form.

concluded that the child's copying difficulties were not from poor muscle coordination.

Evaluation.--There are, however, still a number of theoretical and empirical problems with Piaget and Inhelder's (1956) theory. Their description of the child's spatial concepts as 'primarily topological' is unclear because the term 'primarily' is undefined; a comparison of Piaget and Inhelder's geometry to a formal description may resolve this.[4] The mathematician Felix Klein in his 'Erlange Programme' (see Lietzman, 1965, and Barr, 1964) defines different geometries by their invariant properties and transformations that preserve these properties. A familiar example is the property of congruence in elementary geometry (i.e., metric or Euclidean geometry). A square can be rotated or translated on Cartesian coordinates, but it remains the 'same' square. Such transformations do not change distance relations or the number of degrees in an angle; these are invariant properties in metric geometry. In topology we are restricted to one invariant property. Any deformation is allowed so long as the connectivity of the form is maintained. A line can be stretched or bent, or disconnected and moved about and then reconnected, and the resulting figure is still equivalent to the original. In topology equivalent figures are 'homeomorphic.' Because connectivity is the only invariant property, squares, circles, triangles, and ellipses are homeomorphic. Note, however, that a figure 8 and a circle are not homeomorphic; the figure 8 has an extra 'connection.'

[4]Piaget and Inhelder's (1956) description of the child's spatial concepts will be referred to as the 'elementary topological relations' or the 'primarily topological concepts of space'; the mathematician's formal conception of topology will be referred to as 'topology.'

The elementary topological relations of discontinuity-continuity, separation, and enclosure are easily related to formal conceptions of topology. Order and proximity, however, require some further explanations.[5] The topological invariant of connectedness makes the continuity-discontinuity and separation topological properties. Because the connectedness of a form is invariant, lines remain intact even though they may be shortened or lengthened, and separations are maintained because no new connections are formed. The elementary topological relation of enclosure is also topological. For example, a circle has one 'inside' and one 'outside' and any other form with this relationship is homeomorphic to the circle. The elementary topological relations of order and proximity, however, have an ambiguous relation to topology. Order is related to the primitive 'between' in formal topology. To have 'betweenness' one needs a minimum of three points on a line so one point can be between the other two. More complex ideas of order can then be built on this foundation.[6] Obviously, the child's concepts of order could not be so precise, but there does seem to be a similarity between the two ideas. The elementary topological relation of proximity poses a more serious problem. The topologist works with a primitive of 'neighborhood' in his axiomatic system. That is, there is some notion of 'nearby' for any point, but this is not a distance (metric) concept. The child's ability to copy

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[5] I wish to thank Dr. Leroy Kelly, Professor of Mathematics, Michigan State University, for his suggestions on this problem.

[6] These more complex ideas do not include notions of 'left' and 'right.'

a circle at three years of age and a square at four years indicates that he has metric concepts to preserve straight lines, angles, and distances.

Other studies also demonstrate that children have metric concepts. Lovell (1959) repeated Piaget and Inhelder's (1956) copying tasks in a carefully controlled experiment with 145 children ranging in age from two years and eleven months to five years and eight months. He found that Piaget and Inhelder's elementary topological relations were preserved better than Euclidean properties for the 21 figures each child copied. However, for only the figures with curves, Euclidean and topological properties were preserved equally well. Piaget and Inhelder contend that metric properties are ignored by three-and-a-half to four-year-old children, while Lovell found a large number of metric properties in their copies. Lovell also found the children's stick constructions to be advanced by six months over their copies. These findings reduce the generality and accuracy of Piaget and Inhelder's principle of elementary topological relations. Children's copies seem to exhibit a mixture of metric and topological properties, and the preponderance of either type of property changes depending on the kind of figure copied.

A more serious objection to Piaget and Inhelder's (1956) theory and to Piaget's (1970a, 1970b) structural model is the assertion that concepts and perceptions can be separated into two systems.[7] In an informal study by the present author, 15 four-year-olds and 30 five-year-olds were shown eight different geometric forms. Each form had

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[7]The psychologist Garner (1966) and the philosopher Wittgenstein (1971) have also discussed the difficulty in separating perception from cognition.

two 'copies' constructed by the experimenter, and the child was asked to select the 'best' copy. For all eight forms, 73% of the four-year-olds' responses and 92% of the five-year-olds' responses indicated a preference for copies of forms that preserved more metric properties than topological properties. For example, the children judged copies of triangles and squares having the same angles, size, and straight lines as the model but a large gap as 'better' than rounded copies without a gap. Although most children simply pointed to the copy they thought best, some children justified their choices by saying that even though the metric copy 'had a hole in it,' it was better than the topological copy which looked 'punched in.' These results suggest that the child not only evaluates his perceptions, but relies also on perceptual processes to guide his motor movements so they conform to his intentions. This interpretation may indicate that the child intends to produce a copy that preserves metric characteristics, and that perception and cognition are acting so closely that they are inseparable.[8]

Perhaps a better way to interpret these findings is to use Piaget's distinction between 'sensorimotor intelligence' and 'operational intelligence' (see Piaget, 1966, and Piaget and Inhelder, 1969). Copying, for the preoperational child, could be considered a sensorimotor activity; operational thought has not developed enough to guide

[8]The initial assumptions about copying skill seem to make this viewpoint necessary. In other areas of study, however, these assumptions would be superfluous. Gibson (1966), for example, has studied perception without theorizing about cognition. He contends that perceptual phenomena can be viewed as being a function of the information available in the stimuli.

the child's movements. Flavell (1963) has described the sensorimotor period as a time when

> the infant moves from a neonatal, reflex level of complete self-world undifferentiation to a relatively coherent organization of sensory-motor actions vis-à-vis his immediate environment. The organization is entirely a 'practical' one, however, in the sense that it involves simple perceptual and motor adjustments to things rather than symbolic manipulations of them [p. 86].

Olson (1970) has noted that the preoperational child is still developing the cognitive operations that will allow him to remember the entire contour of the figure and to analyze it into segments. According to Piaget, sensorimotor intelligence is organized by the child's activities and experiences, and most of the preoperational child's life has been spent walking, eating, grasping, feeling, looking, and playing. Consequently, the type of spatial understanding developed from these experiences is the mixture of metric and topological concepts discussed previously in this section. This type of spatial understanding, however, is not well suited for cultural skills such as drawing and copying. For example, Olson notes that a preoperational child attempting to copy a diagonal by placing checkers on a checker board may construct a horizontal line at the top of the board. The child is using the topological cue of 'proximity' to guide his construction. To successfully copy, the child must use cognitive processes that allow him to analyze the entire figure and to break it down into segments. He cannot rely totally on sensorimotor intelligence, even though it plays an essential part in guiding and executing all constructions. Note, however, that this conceptualization, unlike Piaget and Inhelder's, places great emphasis on 'muscle coordination' as a central process that controls the sequencing of actions.

Description.--Rand's (1973) explanation of the perception-performance lag emphasizes the child's ability to develop visual-motor plans to organize his behavior. Although the child does not need superior visual-analytic ability, it is a necessary component in copying. Rand found that children's copying was not improved by practicing line orientation discriminations, tracing geometric figures, or discriminating between geometric figures. Copying, however, did improve when the children learned a strategy to organize their visual-motor behaviors. The children were taught to draw a dot where each corner of the copy was to be placed, and then to connect the dots. This same strategy also was learned by having children watch another person use it. Although this strategy resulted in improved copying, the children's ability to discriminate between various figures did not improve. Furthermore, the improvement in copying was maintained only if the dot strategy was used, and the strategy generalized only when a similar type of task was presented to the child. Rand concluded that the strategy improved the child's copying because it helped him to complete a task using skills he already possessed. The strategy enabled the child to plan his movements (e.g., where to start a line and when to stop) while preserving the outline of the figure.

Evaluation.--Rand's (1973) study focuses on the aspect of Bruner's (1970a) assumption that deals with the child's ability to analyze a figure into segments and yet to remain aware of the contour of the whole figure. Although Rand demonstrated the effectiveness of the dot strategy over discrimination training, she does not explain exactly what skills or mechanisms the child develops that enables him to copy without using the strategy. Olson's (1970) theory (see pages 18 to 22 of this text) provides such an explanation, and is therefore a necessary complement to Rand's study.

Information from Perception: Maccoby and Bee (1965) and Olson (1970)

Description.--Maccoby and Bee (1965, p. 375) state, "to reproduce a figure, the subject must make use of more attributes of the model than are required for most perceptual discriminations of this same model from other figures." For example, to distinguish a triangle from a square, one must note only that the triangle has three sides, and the square four. To copy the figure one must keep in mind the length of the lines, their intersections, angles, and spatial relationships. That is, more attributes of the figure must be known before the figure can be copied correctly. Although the term 'attribute' is not clearly defined, there is some support for their idea; Graham, Berman, and Ernhart (1960) found that children's accuracy in copying figures increases with age, and Lovell (1959) found that difficulty in reproducing a figure was related directly to the number of parts in the figure.

Evaluation.--Olson (1970), however, has identified three major problems with Maccoby and Bee's (1965) hypothesis. First, there is no quantitative difference between perceiving and performing. Piaget and Inhelder (1956) note that a child can copy a square at five years of age, and a diamond by seven, though the difference between the two figures is not great. Second, 'distinguishing features' derived from visual cues are not the same as 'attributes' built up from a cognitive system. Third, once the attributes are formed, there must be some system that determines how they will be organized so a figure can be copied. Finally, Maccoby and Bee's hypothesis is disconfirmed by Olson's and Rand's (1973) findings that training in recognizing figures does not improve copying ability. Olson's theory attempts to resolve these various difficulties in Maccoby and Bee's hypothesis.

Description.--Olson (1970) has approached the question of the perception-performance lag by focusing on the child's perceptual, conceptual, and constructional difficulties with the diagonal. Children are unable to construct a diagonal in any type of media (drawing with a pencil or construction on a checkerboard) until they are five years of age. Olson hypothesizes that the child's perceptual knowledge must be reorganized into a system before he can construct the diagonal. This system can be outlined as follows (Olson, 1970, pp. 61-75):

1. A child who cannot construct a diagonal (a 'prediagonal child') knows the diagonal only as a unitary, unanalyzed configuration. He does not know it in terms of its parts, properties, attributes, or segments.

   This assertion is supported by two findings. First, children who cannot construct a diagonal can recognize a diagonal consistently. Second, a prediagonal child can learn to sort cards with pictures of diagonals and non-diagonals, but this does not improve his ability to construct a diagonal. The child, moreover, cannot explain what is wrong with the non-diagonal figure on the card. For example, one card shows an oblique line starting at the upper left-hand corner that suddenly becomes a vertical line in the center of the card and drops to the bottom edge. Although the child knows the figure is not a diagonal, he can verbally neither describe nor point to the error.

2. At the same time the prediagonal child knows the parts in isolation when they are removed from the context of the configuration.

   Olson observed prediagonal children as they attempted to construct a diagonal using a board with rows of holes cut in it and checkers. The prediagonal child could not construct a diagonal if a model board with checkers in a diagonal pattern was shown to him, though he did so when the board was covered so that only one checker at a time was visible.

3. During the transition to diagonality, the child develops a system that relates parts to the whole, that is, the attributes to the concept. It is the system and not any specific element or mediator that accounts for the transition. The system has the following properties:

   a. The system specifies as elements both the whole and the parts, as well as the relations that hold between them (sometimes called 'structure'). Olson believes this part-whole relation is directly analogous to Piaget's (1970b) notions of logical and infralogical operations and reversible class-object relations. For Olson, the prediagonal child is also a preoperational child.

Most of the prediagonal children tested knew the concepts of 'corner' and 'crisscross' (diagonal), but apparently could not relate the terms. For example, one child began his construction from the middle of the board even though he knew both concepts.

b. The system makes possible the translation of perceptual knowledge into a temporal sequence necessary for reproduction. If the media does not demand temporal sequencing, the prediagonal child is better able to reproduce the diagonal. Olson found little difference between diagonal and prediagonal children in their ability to reposition a rod set on a rotating wheel to a diagonal position.

c. The system is stable and general. All the children Olson taught to construct a diagonal retained the ability when retested three weeks later. Once the ability is acquired, it transfers to diagonals on a larger board, the opposite diagonal, and other media such as drawing.

d. The system is reversible. The diagonal child can shift from attending to the whole to the attending to a part, and back again. He can make these reversals without destroying the integrity of either the part or the whole. The child can construct the diagonal after looking at the static model and correct errors in nondiagonal arrays.

e. The system is conceptual in nature. As such, it resembles a theory which is imposed on objects or events. The system is different from perceptual knowledge because it leads to performance. That is, perceptual knowledge is transformed into conceptual categories. The system is an interpretation of reality, not a copy of it.

f. The system is invented by the child, or communicated by an adult; it is not given, or even inherent in the stimulus array or in perceptual recognition. Children can learn to construct a diagonal through verbal instruction or non-verbal techniques such as an educational toy.

Basically, Olson suggests that the child's perceptual knowledge must be reorganized; not only must the child develop a conceptual system, but he must also learn to attend to new information in the media through his performances. Olson's studies of eye movements have shown that this information is rarely attended to otherwise. As noted in the section reviewing Piaget and Inhelder's (1956) work, most of the child's activities require only a 'primarily topological' understanding of space that is inadequate for drawing and copying.

Evaluation.--Although Olson (1970) stresses the perceptual and cognitive aspects of the perception-performance lag, he deals with nearly all of this author's assumptions. Olson also incorporates a large number of observations into his theory, but empirical and theoretical problems remain. For example, in some of his experiments there were fewer than ten subjects, and these subjects had been exposed to many different treatments. The procedures in other experiments is unclear; this is illustrated in the task that required children to explain what was wrong with pictures of nondiagonals (see page 19 of this text). It is not reported whether the nondiagonals are the kind that prediagonal children would make, or whether the pictures were constructed by the experimenter. Theoretical problems, such as the relation of perception and cognition (discussed on page 3 of this text) and the nature of the infralogical operations, also need clarification. The infralogical operations used in copying presumably would be spatial abilities, but Olson does not discuss how one would test a child to determine their presence. Another major problem is Olson's brief treatment of sensorimotor processes; this matter is considered on pages 28 to 30 of this text.

Motor 'Rules': Gesell and Ames (1946) and Goodnow and Levine (1973)

Description.--Gesell and Ames's (1946) normative study of children's and adults' copying revealed developmental shifts in the sequence and directionality of movements. Children one-and-one-half to seven years of age (N not given) and twelve adults were required to copy a horizontal line, vertical line, circle, square, cross and triangle. The motor movements used to copy the figures were found to be quite regular. For example, 95% or more of all subjects drew the horizontal lines from left to right, except at 18 months when 20% drew from right to left. One continuous line was used to copy the square by 3% of the four-year-olds, 23% of the five-year-olds, 50% of the five-and-a-half year-olds, 37% of the six-year-olds, and 25% of the adults.

The authors speculated that these trends are the result of motor predispositions to move limbs in certain directions. They observed, for example, that one-year-old infants have a tendency to move their arms up and down, while later there is a greater tendency to move the arms in a horizontal plane. Gesell and Ames, however, did not specify how these predispositions determine copying sequences. Because the study was essentially normative, no evaluation of it is presented.

Description.--Goodnow and Levine's (1973) study is largely a duplication of Gesell and Ames (1946) work. The major difference is Goodnow and Levine's interpretation of the results using Lashley's (1951) concept of the 'syntax of behavior,' that is, the notion that all skilled behaviors have a characteristic pattern or sequence. By explaining copying with rules similar to those found in linguistics, Goodnow and Levine hope to develop a general theory of behavior not tied to concepts such as 'motoric skill,' 'cognition,' or 'perception.' The search for sequences and patterns in copying, however, actually leads to an emphasis on the sensorimotor aspects of copying. Their 'syntactic rules' determine the sequence of paths followed in copying, the errors made, and describe developmental changes in terms of shifts in rule usage.

Goodnow and Levine (1973) describe their copying 'grammar' in terms of seven 'principles.' Most of these principles, or 'rules,' are in the form of a binary choice. Two 'rules' deal with starting points: start at the topmost and leftmost point. Two 'rules' deal with starting strokes: start with a vertical line and, in any figure with an apex, start at the top and come down the left oblique line. Three 'rules' deal with progressions: draw all horizontals left-to-right, draw all verticals top-to-bottom, and 'thread,' that is, draw continuous lines when possible. Goodnow and Levine assert that these 'rules' are very general and apply to a large number of figures. In some cases agreement between subjects on 'rule' use reaches 90% over a number of figures within an age group. In other cases a number of 'rules' are in direct conflict. For example, in copying a square one cannot thread and at the same time draw all verticals top-to-bottom, and all horizontals left-to-right. Although these 'rules' account for many regularities seen in copying, they emphasize its sequential aspects.

Evaluation.--Neuropsychological research has revealed that there is also a 'wholistic' component to drawing and copying skill. Studies by Warrington (1969), Warrington, James, and Kinsbourne (1966), and Gazzaniga, Bogen, and Sperry (1965) demonstrate that each cerebral hemisphere contributes different components to drawing and copying ability. The right hemisphere appears to have a 'wholistic' or 'spatial' function that is responsible for overall organization of the figure, while the left hemisphere determines sequences of movements.[9]

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[9]The distinction between 'wholistic' and 'sequential' functioning of the hemispheres also appears in the work of Ingram (1973) and Levy (1969). The generalizations hold only for right-handed individuals and some left-handed individuals (see Zangwill, 1960). These studies are reviewed in Harris (1974).

Patients with right hemisphere lesions and split-brain patients using their right hand[10] tend to produce copies of geometric figures that have many lines but little resemblance to the model in terms of overall organization. Patients with left hemisphere lesions and split-brain patients using their left hand copy slowly and laboriously, but their copies retain a basic, though simplified outline of the model. Goodnow and Levine's (1973) rules focus mainly on the sequential or 'left hemisphere' aspects of copying.

Because Goodnow and Levine's (1973) rules deal with sequences of movement, they can be used to explain overall organization only in a limited fashion. For example, a child may produce a copy of Figure 3a that looks like Figure 3b. This could result from the child following the rules to start at the topmost, leftmost point, to draw all verticals first, and to draw all horizontals left-to-right. The child may have begun his drawing with a vertical line and considered it as the "left-most point.' His second line would be the horizontal line drawn in a left-to-right direction to the right of the vertical line.[11] However, this type of explanation cannot explain how a child is able to plan the entire organization of a copy and then execute sequences of movement.

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[10] Because the motor nerves to the distal parts of the arm are largely connected contralaterally (to the opposite hemisphere), the split-brain patients would be using their left hemisphere for this task, and their right hemisphere when using their left hand (see Gazzaniga, 1970).

[11] Other interpretations must not be excluded even if this sequence of reproduction is seen. One child observed during the experiment drew Figure 3b to the left of Figure 3a and said he made an 'H.' His class was learning the alphabet, and 'Mr. H' was "letter of the day' the previous week.

Figure 3. Copy (a) of a model (b) that can be explained by using Goodnow and Levine's (1973) copying 'grammar.'

Serious problems are also encountered when one tries to use the grammar analogy to generate predictions about copying. For example, it would seem that an extremely important prediction from the grammar analogy would be that the use of the 'rules' described by Goodnow and Levine would be associated with copies of superior quality. Copies of poor quality not produced by these 'rules' would be 'just like' a violation of syntax in language that results in nonsense. However, it might also be the case that copies produced by different 'rules' are of equal quality. This is 'just like' paraphrasing in language where the same idea is conveyed by a different sentence. Of course, Goodnow and Levine even have the option of stating that there is nothing in language that is analogous to the quality of a copy, and that the analogy only includes the sequencing of behavior. Perhaps this is a misrepresentation of what Goodnow and Levine mean by a 'grammar of action,' but it is incumbent upon them to state precisely how language and copying are similar. It will simply be assumed in this study that the use of Goodnow and Levine's 'rules' will be associated with copies of superior quality, and no further attempts will be made to generate predictions from the analogy. In short, Goodnow and Levine's 'rules' describe how many children and adults copy, but their interpretation of the phenomenon is inadequate. A more comprehensive theory of copying that attempts to integrate the previously discussed theories and findings is presented below.

A 'Component' Theory of the Development of Copying Skill

The processes that enable the child to copy geometric forms can be conceptualized as a system of components that organize perceptual knowledge and create the sequences of movements ('rules') described by Goodnow and Levine (1973). The preoperational child's constructional ability is largely at a sensorimotor level. Because his previous experience and abilities did not lead to a complete Euclidean or metric understanding of space, the child's spatial knowledge can be described by the elementary topological relations and some metric relations. According to Olson (1970), the child's perceptual knowledge must be organized into a system before he can successfully copy. This system is capable of performing the infralogical operations described by Piaget (1970a, 1970b), and enables the child to analyze a figure into segments while keeping in mind the entire contour of the figure. This segmentation leads to 'performance.' The child is now able to execute sequences of movement that produce an adequate copy, and these sequences of movements correspond to Goodnow and Levine's 'motor rules.' The movement sequences may be centrally encoded as 'directional engrams' or 'motor memories' described by Bernstein (1967).

Bernstein (1967) has suggested that motor memories determine the sequence and directionality of movements for any coordinated action, and that the same sequences and directions would result whichever limb is used to execute the action. Bernstein came to this conclusion after studying skilled rhythmical movements such as hammering. He noted that the 'same' actions involve different groups of muscles because the total forces acting on the limb are different for each of the periodic actions. This change in forces may be due to slight changes in the initial starting positions for each action or differences in how the hammer is held. Bernstein argued that there must be a central representation of the actions because of their similar trajectories despite the innervation of different muscles. (His research disconfirmed the theory that the same movements resulted from the innervation of the same muscles.) The central representation and muscles act together as a cybernetic system; the muscles are controlled by the central representations via a negative feedback loop. This conceptualization of the system leads to some predictions about the use of 'motor rules,' and the quality of the copies produced from various movement sequences. These predictions were tested in the present study.

According to Bernstein (1967), the movement sequences should be 'general' in the sense that they are roughly the same regardless of the limb used to produce the copy. This prediction, however, should hold only for older children. Perceptual knowledge in a child who has recently acquired the spatial-infralogical operations is not sufficiently organized to produce motor memories that will determine sequences and directions of movements for all limbs. Instead, the movement sequences for each limb would be determined more by how easily movements can be executed. Reed and Smith's (1961) and Harris' (1973) studies of direction of hand movements in drawing horizontal lines indicate that adults and children prefer movements outward from midline (tensor) to movements inward to midline (flexor), regardless of the hand used to execute the task. It is predicted that the starting points and directions that figures are copied by children will be determined by 'ease of execution' (as measured by their drawing of horizontal lines); this effect should be stronger for younger children.

The consistency with which movement sequences are used and the quality of the reproductions are predicted by the system outlined above. Piaget (1970a, 1970b) discovered that operational thought is initially unstable; it is a new skill for the child, and he must 'practice' this skill before he can use it with ease. Because of the crucial role of operational thought in copying, the consistency of use of a movement sequence over a number of repeated copies should be less for young children. It is also predicted that children who use the same movement sequences over repeated copies will produce copies of better quality than children who are inconsistent in their use of movement sequences. The more automatized copying indicates that the child has a 'complete' and stable system that enables consistent movement sequences to be produced. Unlike Goodnow and Levine's (1973) theory, this conceptualization does not predict that certain 'rule' use will result in copies of superior quality. Because the movement sequences are produced by processes that organize the entire copy, no particular movement sequence should be associated with copies of superior quality.

The current study tested the above hypotheses and collected normative data on Goodnow and Levine's (1973) rules. Four- and five-year-olds were instructed to copy a number of geometric forms with their preferred and nonpreferred hand. With each hand the subject had to make three copies each of the forms shown in Figures 4, 5, and 6. To determine which kind of movement (right-to-left or left-to-right) was 'dominant,' or motorically easier, the children also were shown a ladder-like figure and a second figure lacking the rungs, and were asked to draw in the rungs. The direction in which the horizontal lines were drawn was recorded and used as a measure of preferred, and presumably easier, direction of movement where no figure copying task is involved. This was done using the Reed and Smith test shown in Figure 7.

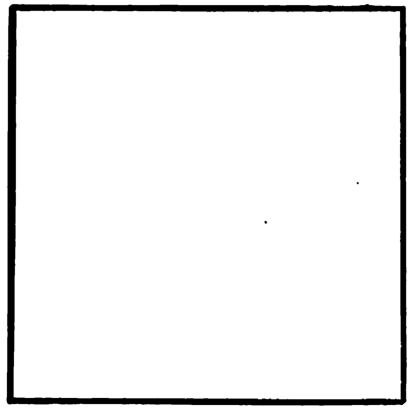


Figure 4. One of the geometric forms the children were required to copy (actual size).

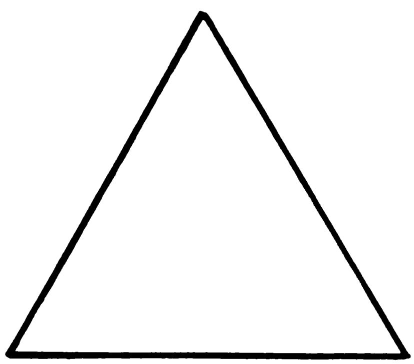


Figure 5. One of the geometric forms the children were required to copy (actual size).

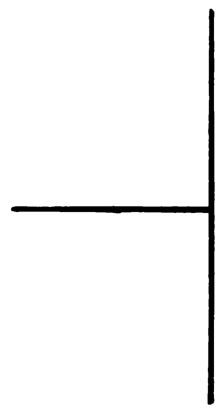


Figure 6. One of the geometric forms the children were required to copy (actual size).

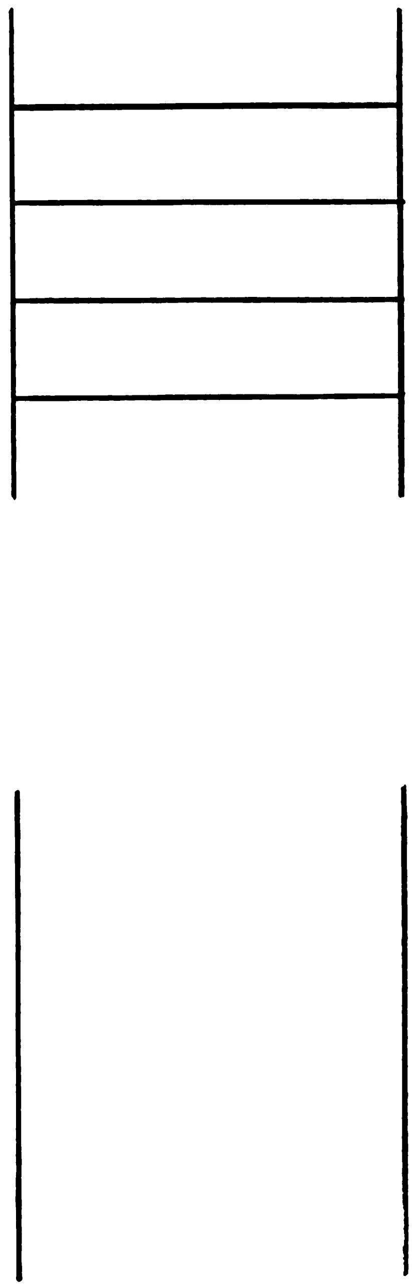


Figure 7. The Reed and Smith (1961) test of tensor and flexor movements.

METHOD

Subjects

Subjects were 30 four-year-olds and 30 five-year-olds, with 15 boys and 15 girls in each age group. Two four-year-old boys and one five-year-old boy and one five-year-old girl were left-handed for copying.

Procedure

The children were tested individually at a small table in a quiet room. The four-year-olds were tested by two experimenters. One sat to the child's right and gave instructions, and the other sat slightly behind the child on the side that gave the best view of the copy and recorded the sequences and directions of his copying. The procedure was the same for five-year-olds, except that only one experimenter was needed to give instructions and record movement sequences. The five-year-olds needed less prompting and were able to do small tasks such as putting their completed copies on a corner of the table.

The child was instructed to make a copy that looked 'just like' the model, or, with the Reed and Smith test, to make the bottom figure 'look just like the top one.' The child was permitted to make another copy on the same sheet of paper if he made a mistake, and he was also allowed to rest if he was tired of copying. All drawing was done with a black felt-tipped pen on 8 1/2 x 11 inch (21.6 x 27.9 cm.) paper. All papers were held to the table so that the paper's 8 1/2 inch edge was parallel to and one inch from the edge of the table. Each child was randomly assigned to one of the twelve counterbalanced orders that controlled for the order in which the geometric forms were copied and which hand was used first. The complete list of counterbalanced orders is presented in Appendix A, and the complete protocol of instructions is presented in Appendix B.

Sequences and directions in copying were recorded on a scoring sheet hidden from the child's view. The direction a line was drawn was indicated with an arrow, and the sequences of movement were indicated by placing numbers beside each line. The experimenter also tried to reproduce the general contours of the child's copy. For example, Figure 8a shows a copy of a square that was begun at the upper left hand corner with a vertical line. A new sequence line was begun at the lower right hand corner because the child 'hesitated,' that is, he lifted the pen from the paper. This copy, however, is considered to have one line and one hesitation; a different path must be followed if the copy is to have two lines. Figure 8b illustrates the scoring of a copy with two lines.

The number of lines, sequences and directions of movements, hesitations and quality score of a copy were punched onto computer cards using the codebook presented in Appendix C. Because some of the variables coded are not included in Goodnow and Levine's (1973) 'rules,' all of the variables are referred to as 'movement sequences.' The variables for each copy the child completed were intercorrelated for

Figure 8. Examples of how sequences and directions of movement in copying were recorded.

all possible combinations of the six copies. A high positive correlation for a variable indicated that many children did (or did not) use the movement sequence in constructing the two copies of the figure.

The copies were scored for quality using the scoring systems and techniques presented in Appendix D. The three scoring systems were very similar. Each copy received a score from 1 (poorest quality) to 7 (highest quality) depending on how well proportioned it was and how many 'deviations' it had. The line lengths and angle sizes of the copy had to fall within certain limits to be defined as well-proportioned. Deviations were defined as gaps, lines crossing over other lines, wavy and curved lines, and rotations. There were two categories of deviations: Type A deviations were larger than 3/16 of an inch, and Type B deviations were between 1/16 and 3/16 of an inch. Type A deviations lowered the score of a copy more than Type B deviations. Note that all tracings of a model received quality scores of 1. It was assumed that this response meant the child was incapable of copying the figure.

A copy could receive a low score for being either poorly proportioned, or for having too many deviations, or both. A copy could not, however, have more than four deviations from any one category. For example, a copy with two Type B gaps was scored as having one Type B deviation. A copy with two Type A gaps and three sides with Type A wavy lines was scored as having two Type A deviations. This procedure was followed so as not to overly penalize the children for a lack of fine motor control. It was thought that too great an emphasis on these features of the children's copies might obscure the contributions to the total score from features such as proportionality and angle sizes. The decision of how to weight the features must remain somewhat arbitrary; there is no theory of copying that clearly states how the quality of the reproduction should be conceptualized.

Examples of how some typical copies were scored using the three scoring systems are presented in Figures 9 through 15, 16 through 22, and 23 through 29. All copies are actual size. (Some copies that receive a score of 5 and all copes that received a score of 6 or 7 are from a separate study done with adults.) Inter-rater reliabilities for blind rating for three judges as determined by the Spearman-Brown prediction formula (see Winer, 1962) ranged from .90 to .96.

The Reed and Smith (1961) test was scored by recording which direction the horizontal lines were drawn. If the child drew lines both left-to-right and right-to-left, the direction with the largest number of lines was scored as his response. If the child drew an equal number of lines in both directions, his response was scored as 'mixed.' That is, there was no indication of a preferred direction.

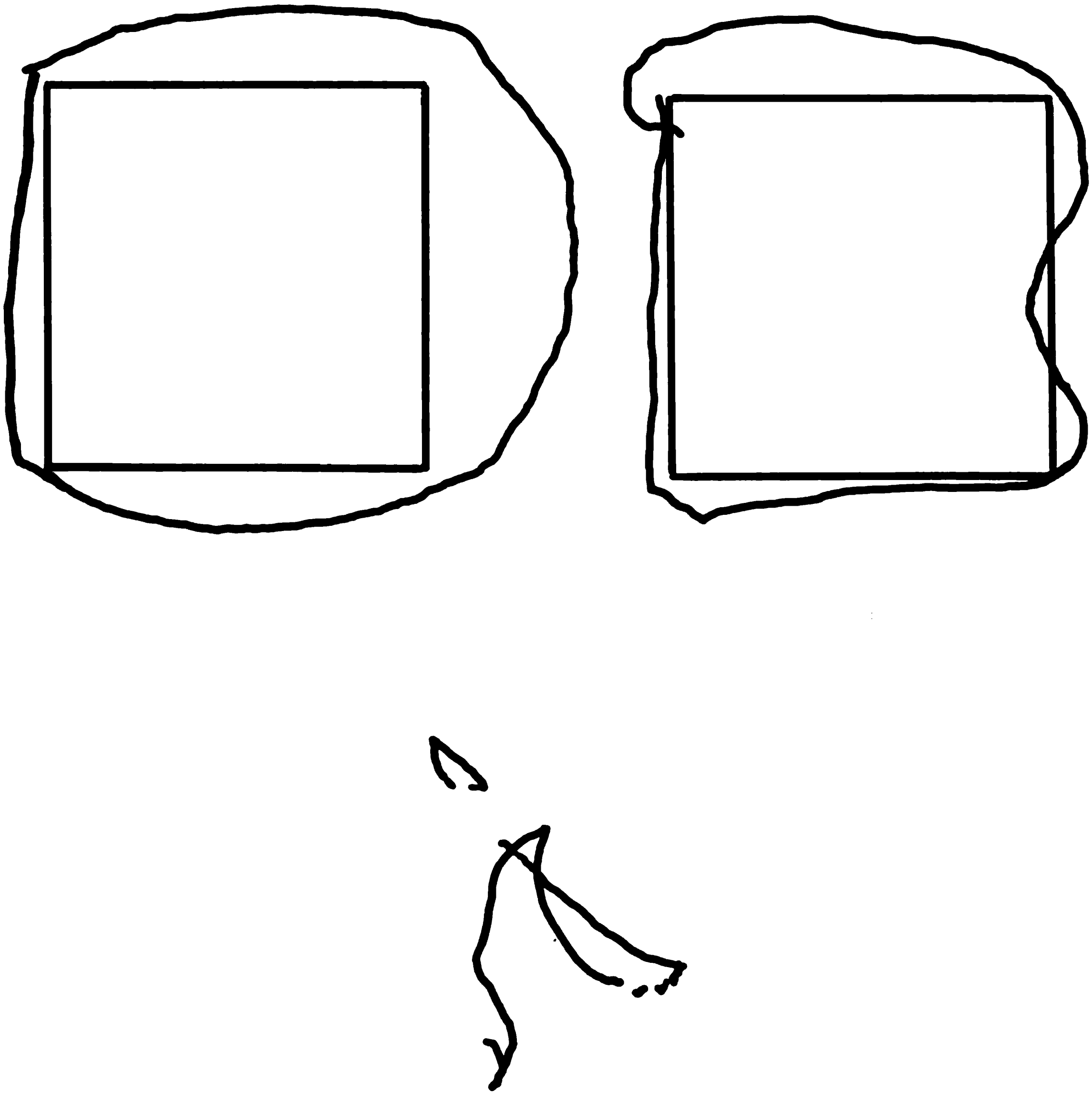


Figure 9. Examples of copies of a square (actual size) receiving quality scores of 1. (The two copies at the top of the page are tracings of the model; see page 38 of this text for an explanation.)

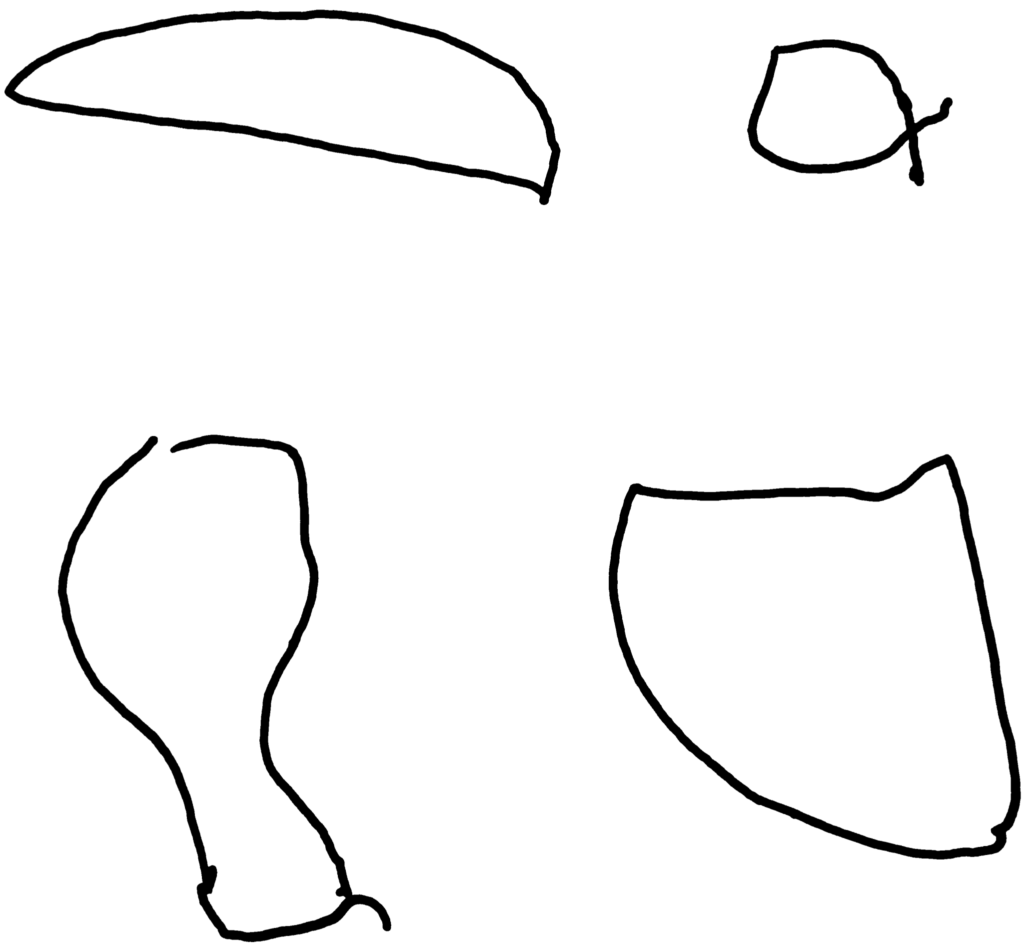


Figure 10. Examples of copies of a square (actual size) receiving quality scores of 2.

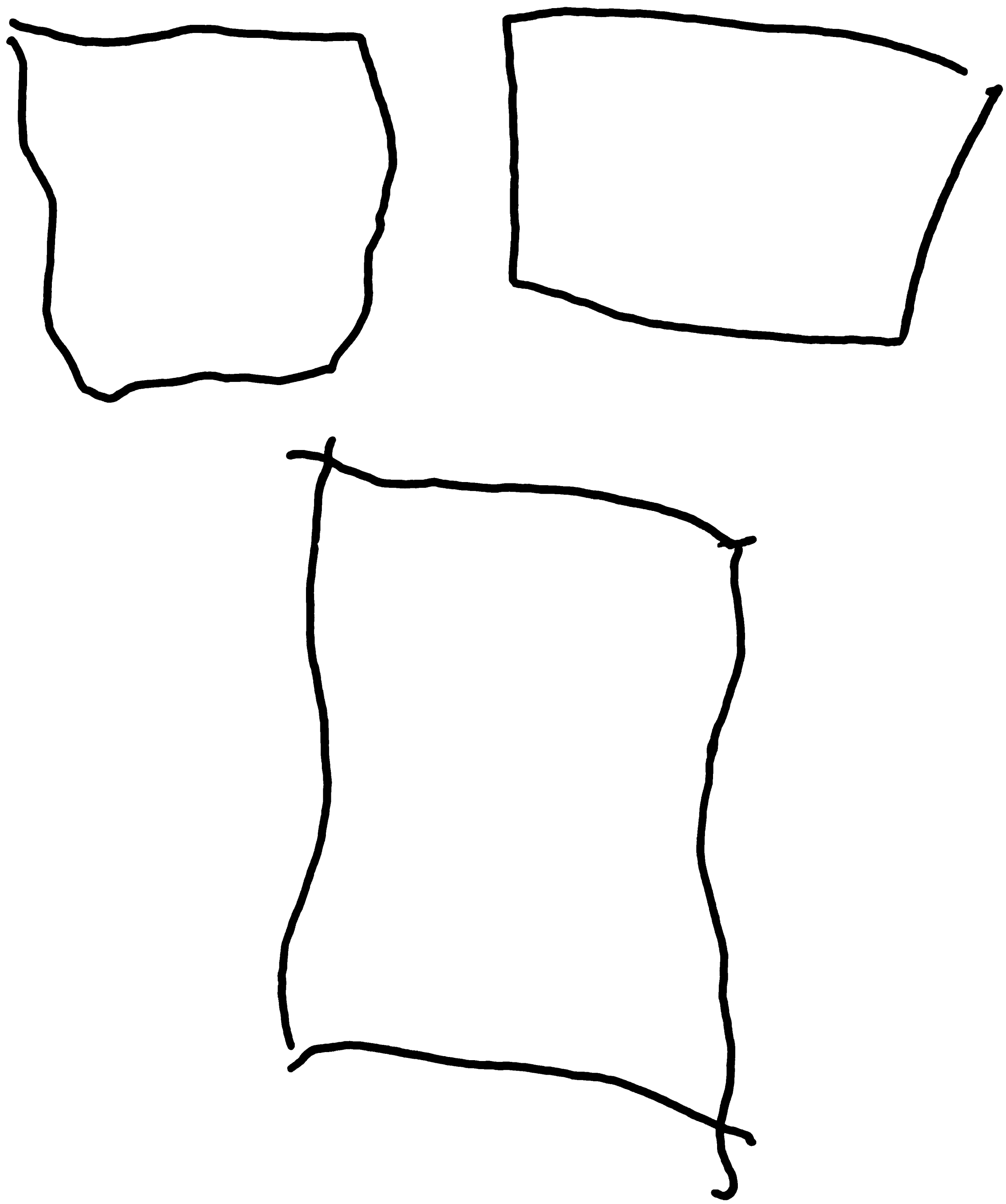


Figure 11. Examples of copies of a square (actual size) receiving quality scores of 3.

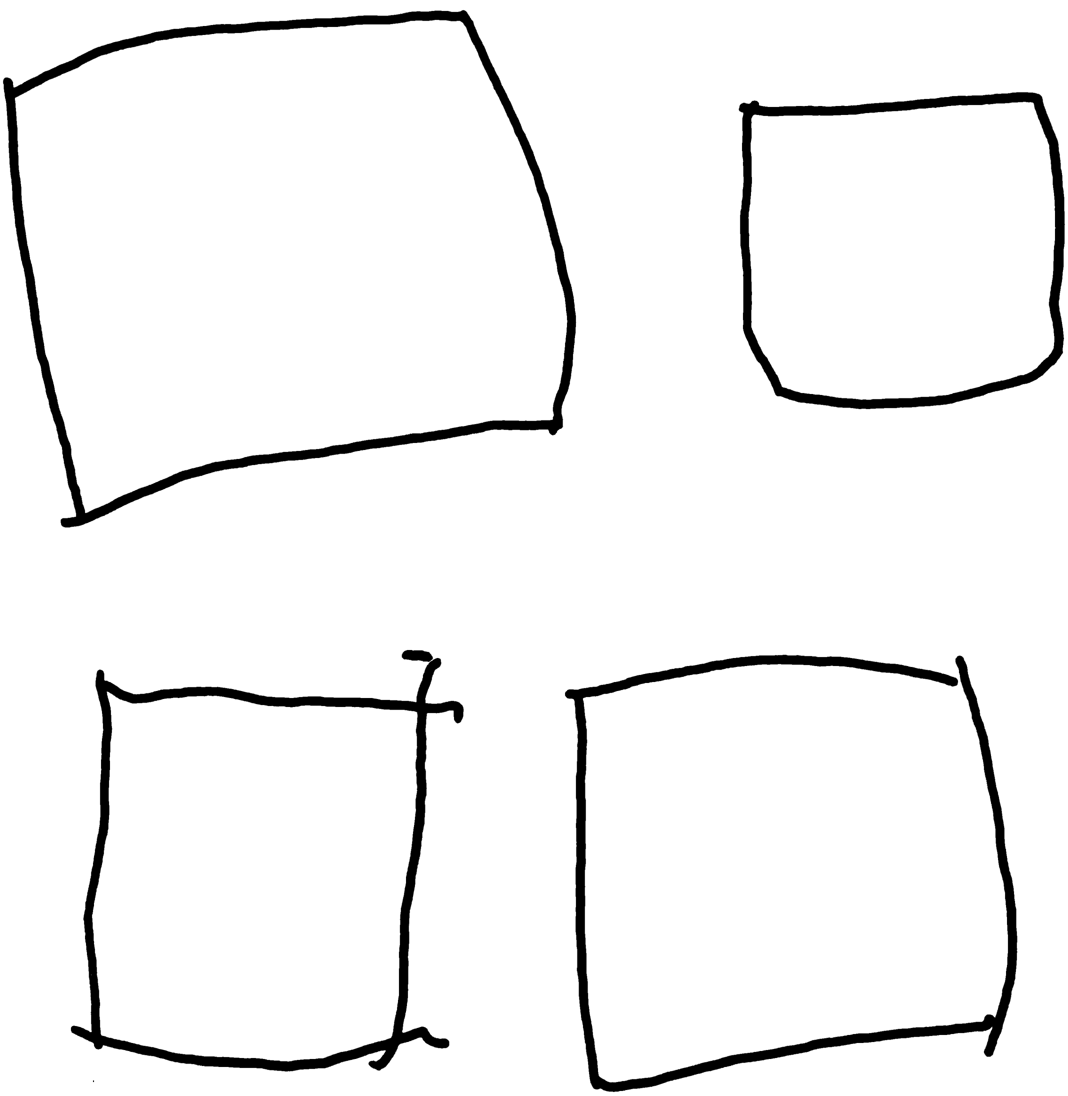


Figure 12. Examples of copies of a square (actual size) receiving quality scores of 4.

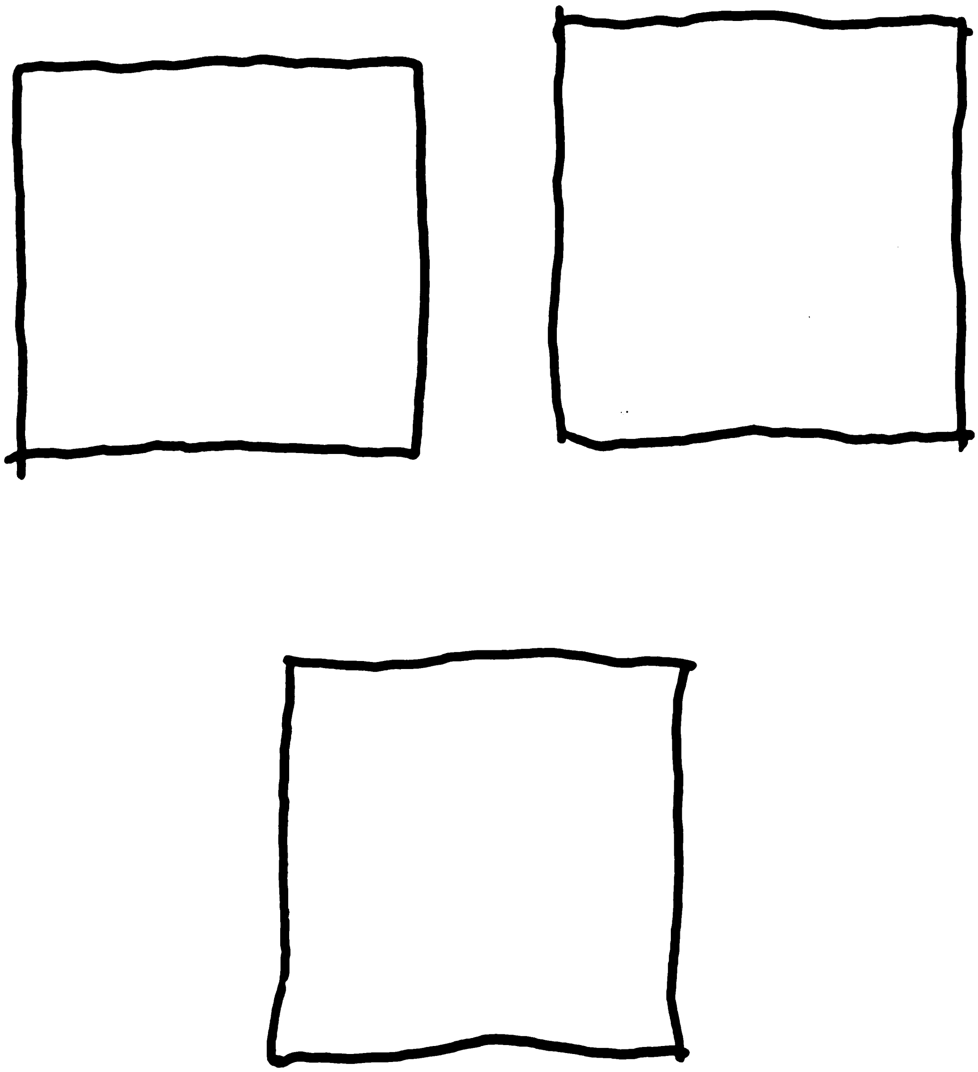


Figure 13. Examples of copies of a square (actual size) receiving quality scores of 5.

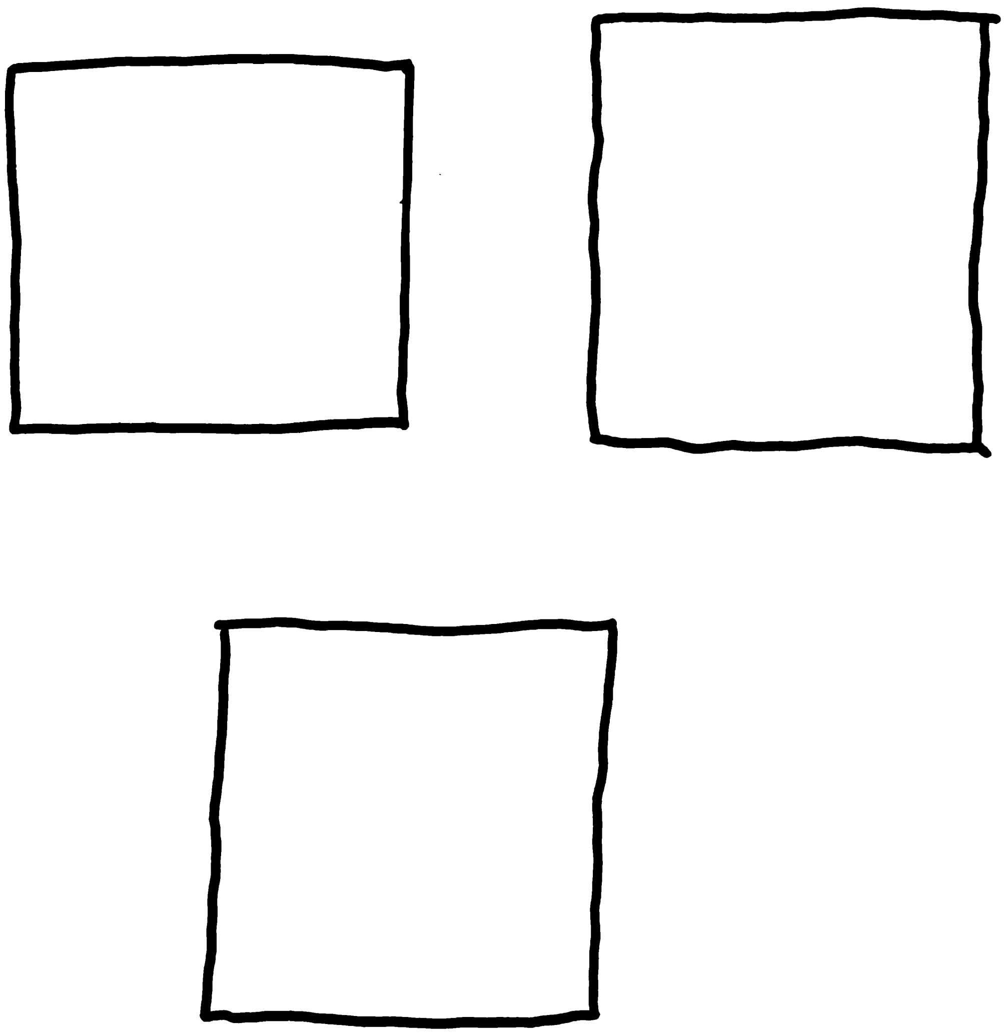


Figure 14. Examples of copies of a square (actual size) receiving quality scores of 6.

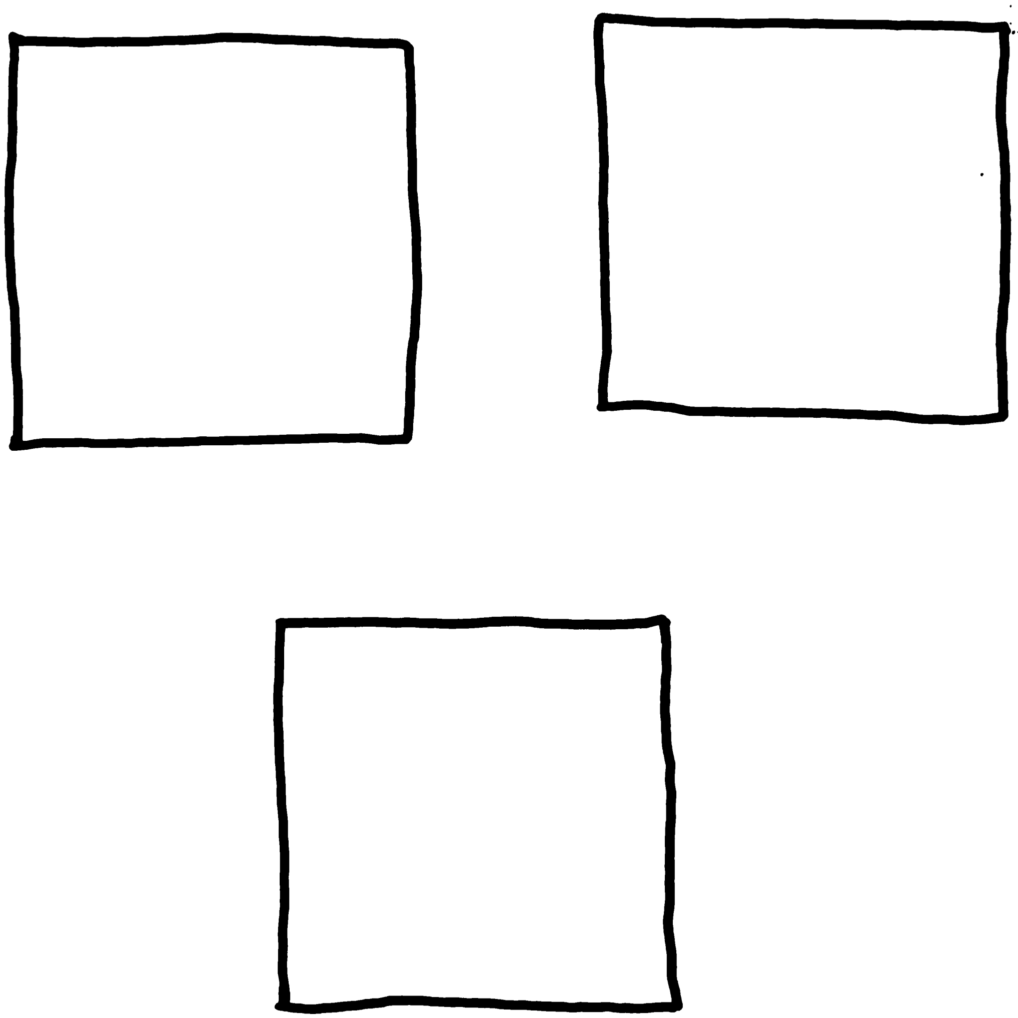


Figure 15. Examples of copies of a square (actual size) receiving quality scores of 7.

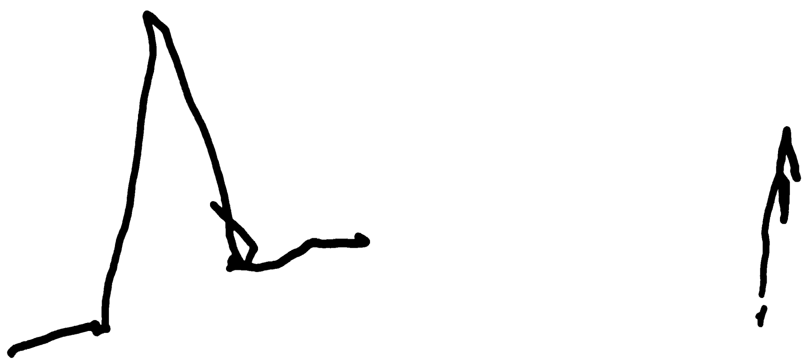


Figure 16. Examples of copies of a triangle (actual size) receiving quality scores of 1.

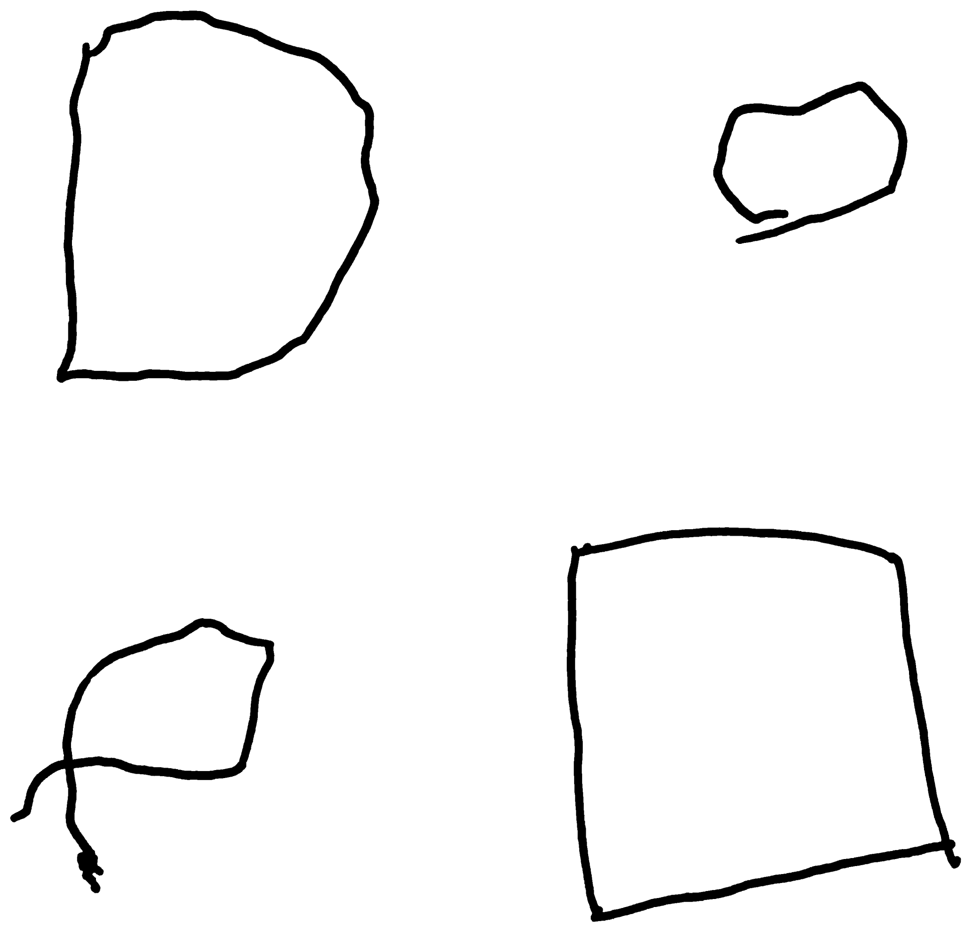


Figure 17. Examples of copies of a triangle (actual size) receiving quality scores of 2.

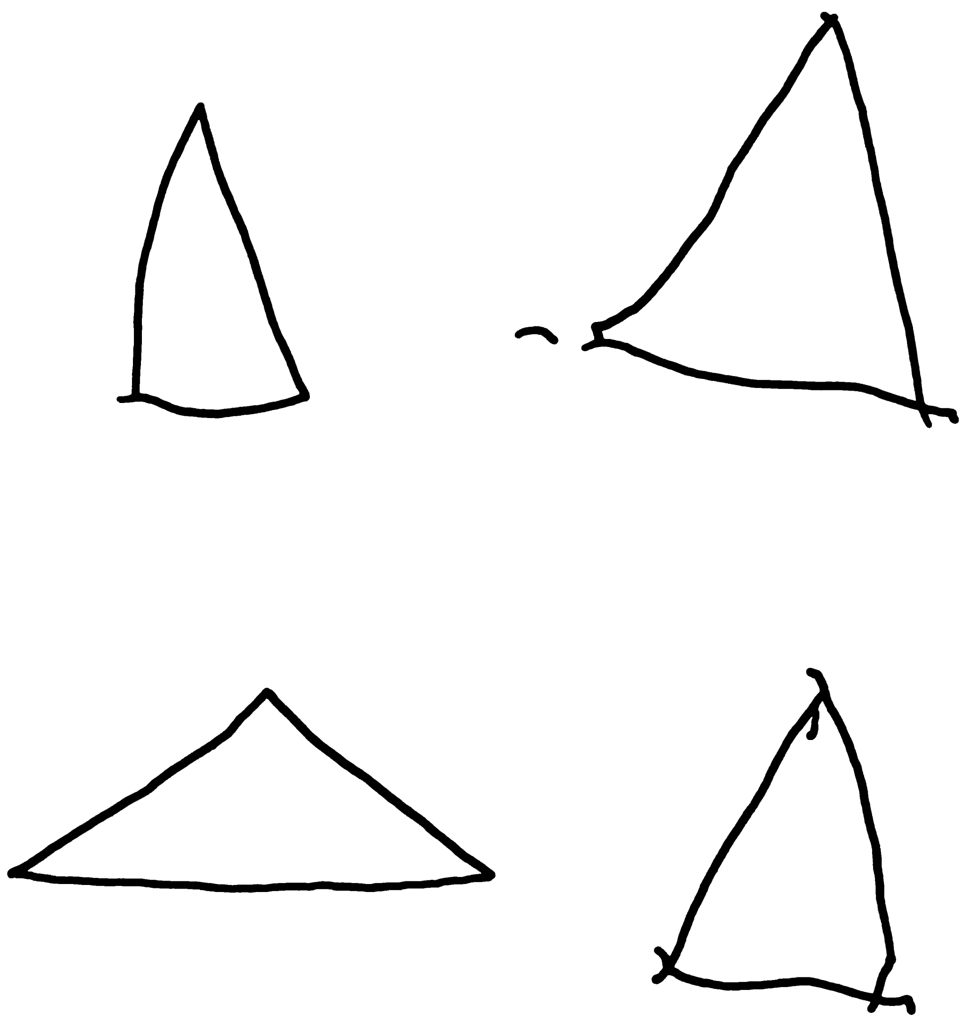


Figure 18. Examples of copies of a triangle (actual size) receiving quality scores of 3.

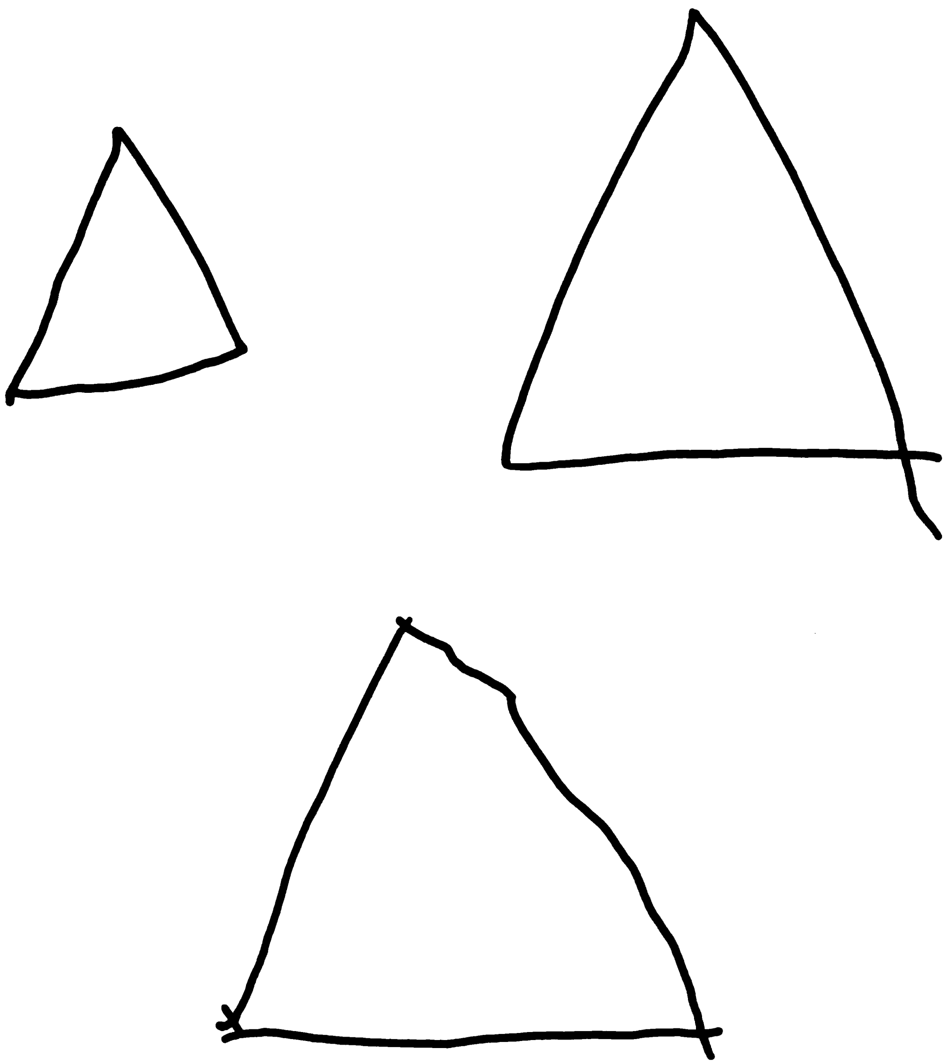


Figure 19. Examples of copies of a triangle (actual size) receiving quality scores of 4.

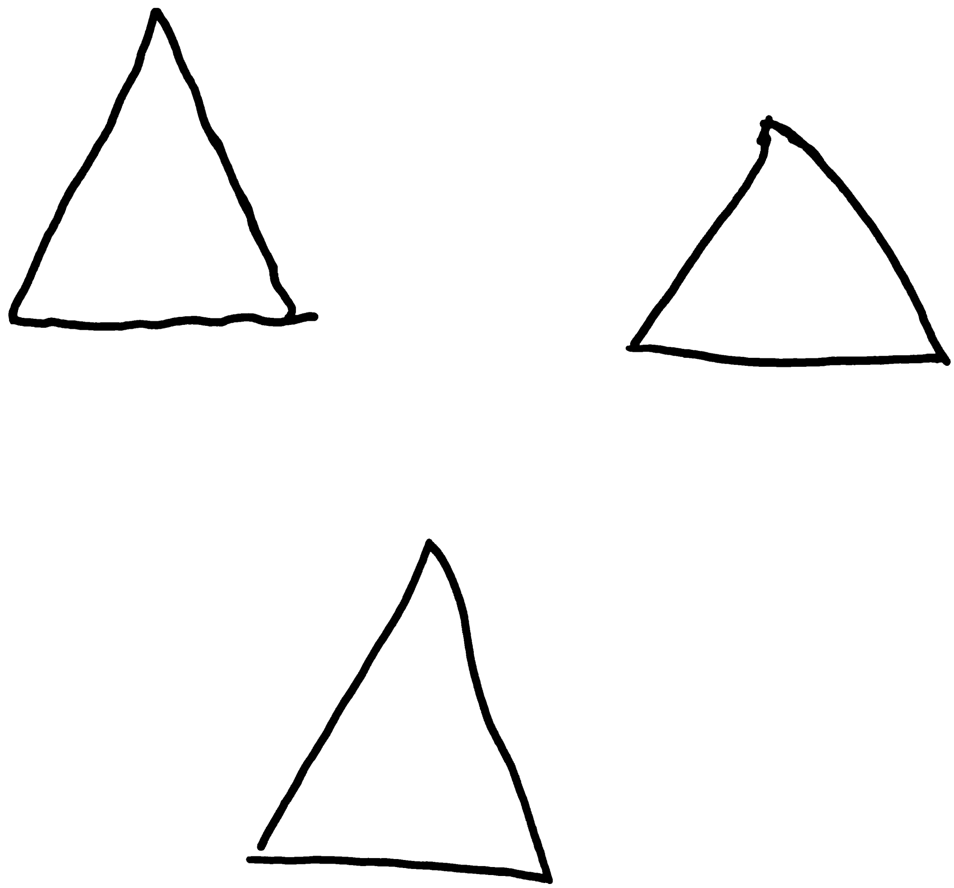


Figure 20. Examples of copies of a triangle (actual size) receiving quality scores of 5.

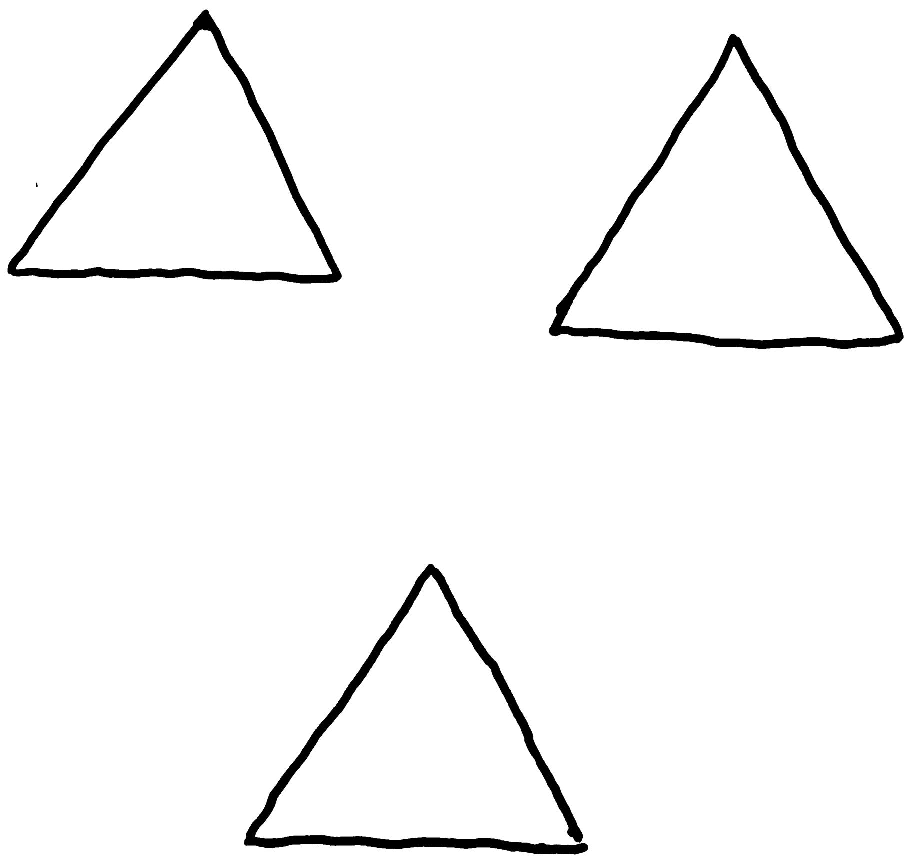


Figure 21. Examples of copies of a triangle (actual size) receiving quality scores of 6.

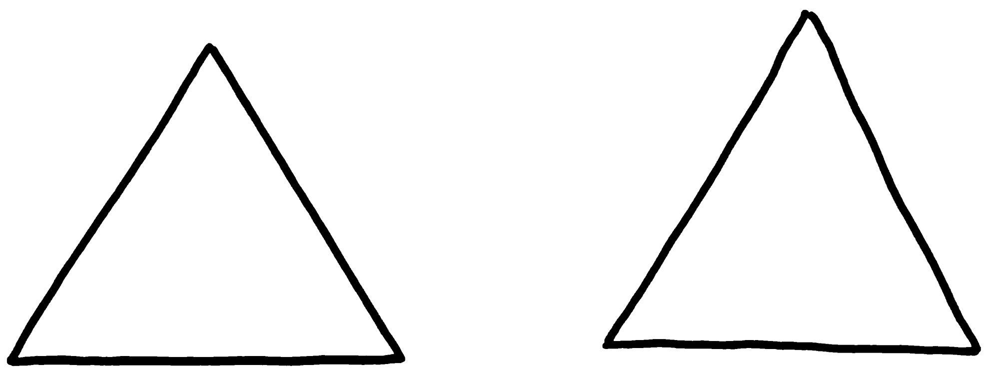


Figure 22. Examples of copies of a triangle (actual size) receiving quality scores of 7.

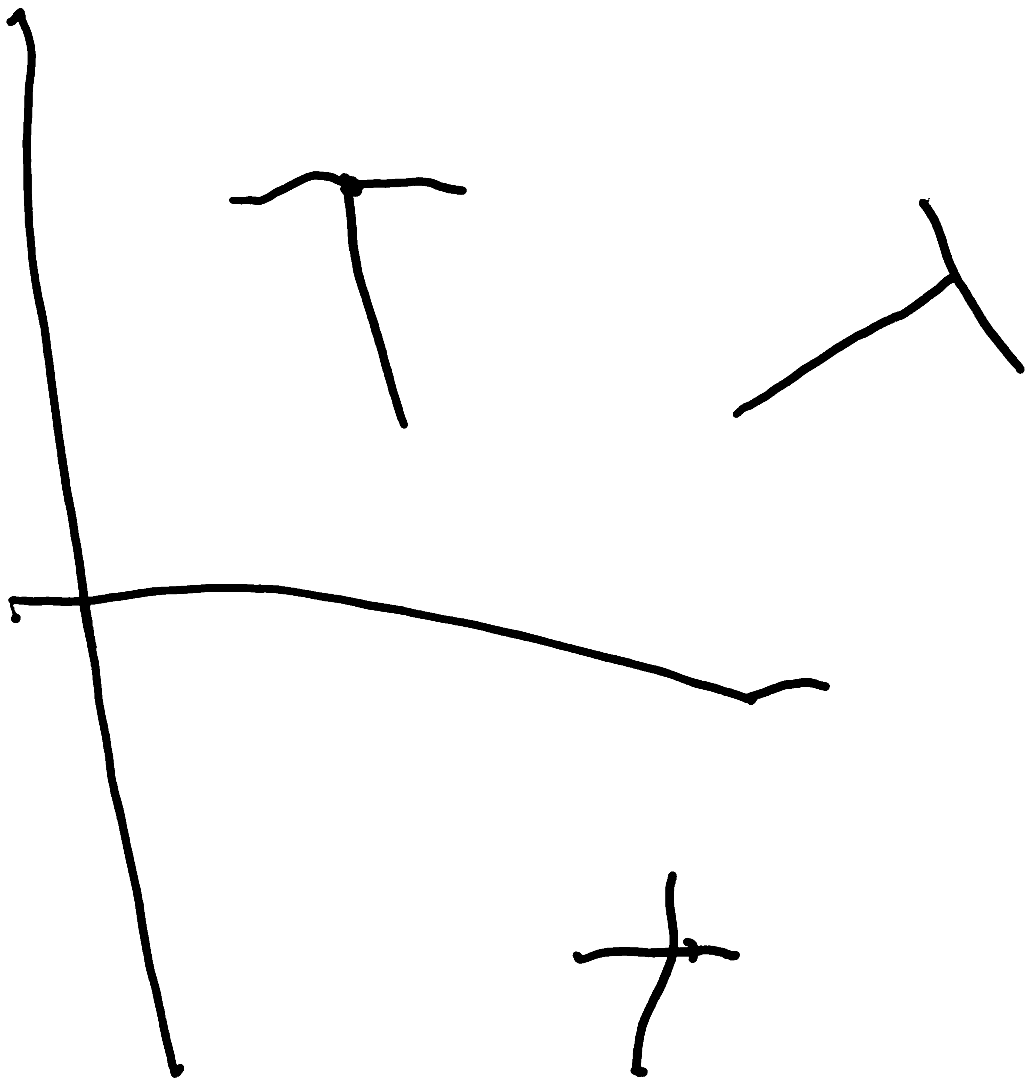


Figure 23. Examples of copies of a half cross (actual size) receiving quality scores of 1.

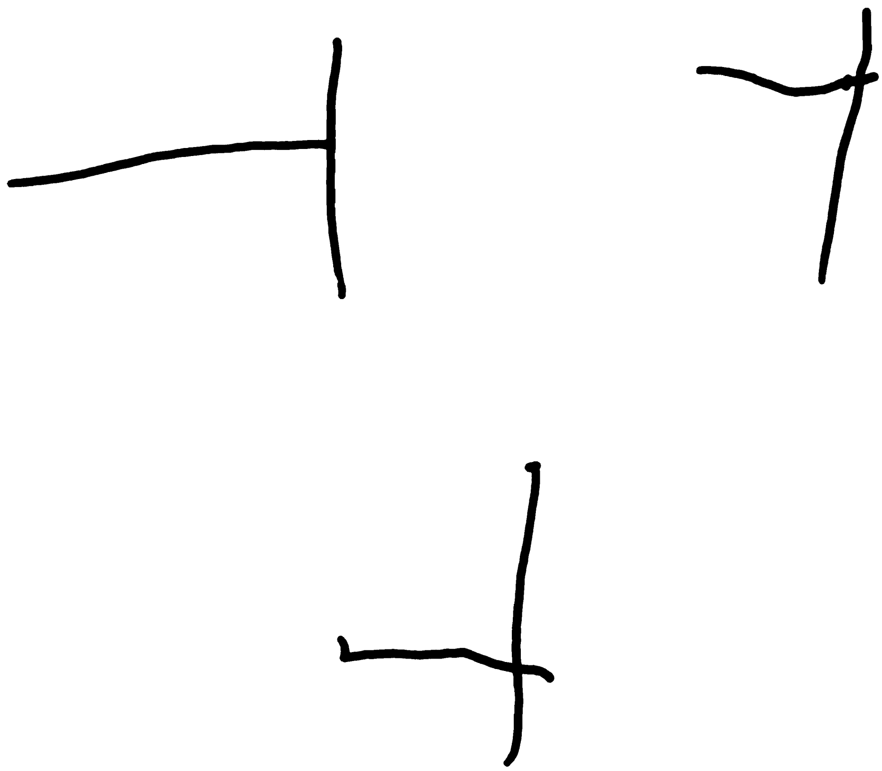


Figure 24. Examples of copies of a half cross (actual size) receiving quality scores of 2.

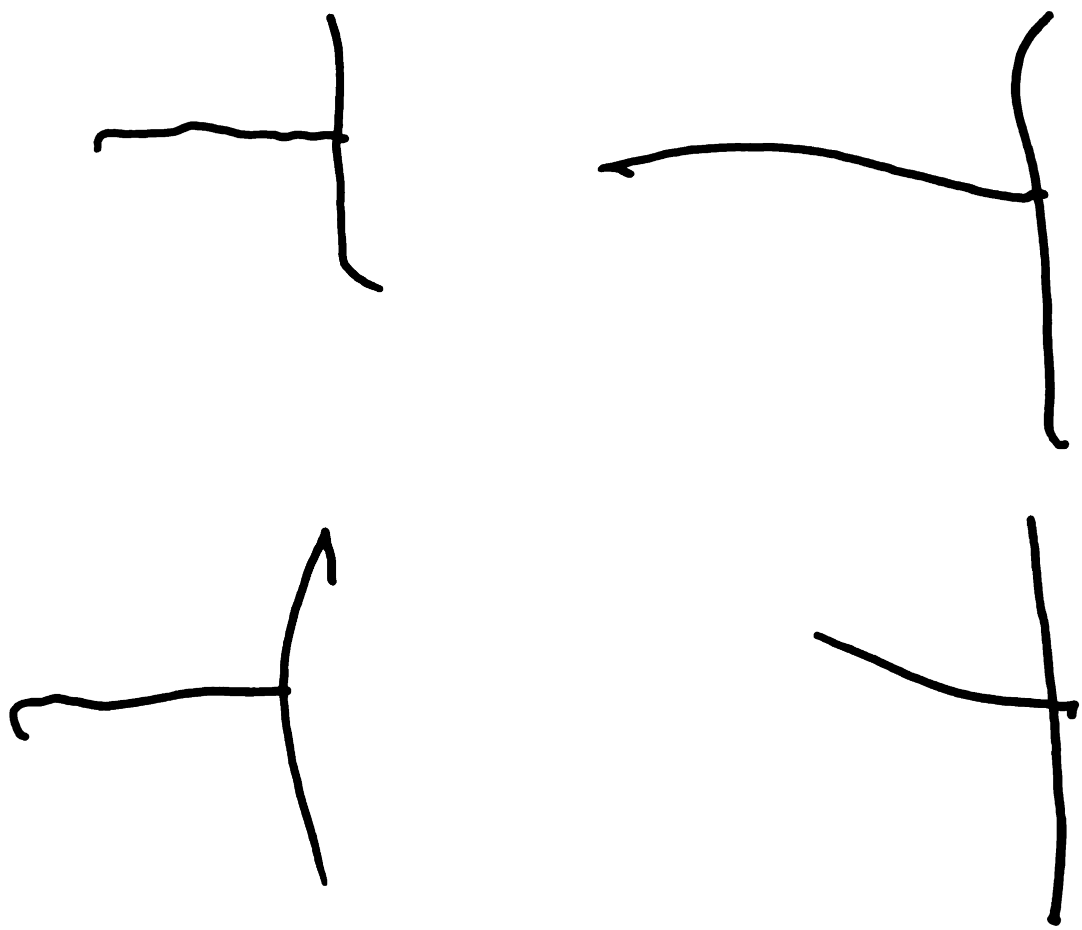


Figure 25. Examples of copies of a half cross (actual size) receiving quality scores of 3.

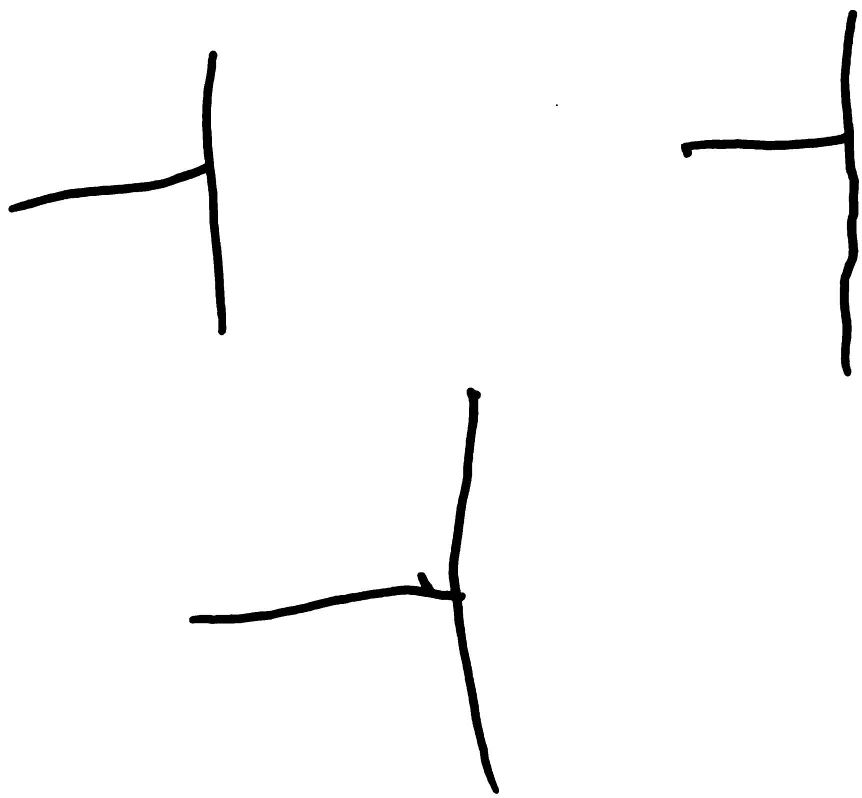


Figure 26. Examples of copies of a half cross (actual size) receiving quality scores of 4.

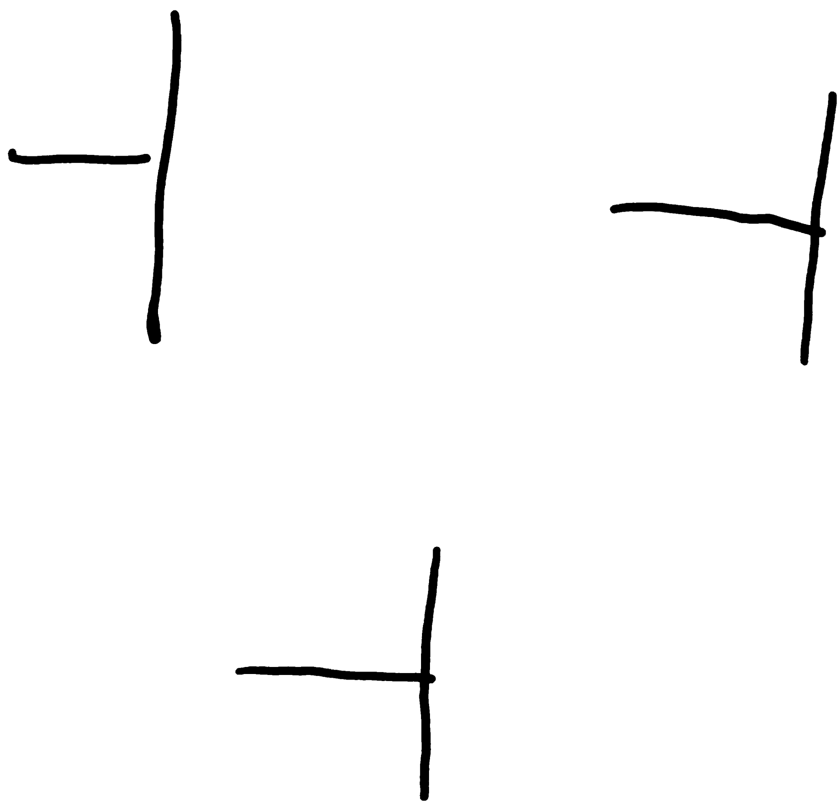


Figure 27. Examples of copies of a half cross (actual size) receiving quality scores of 5.

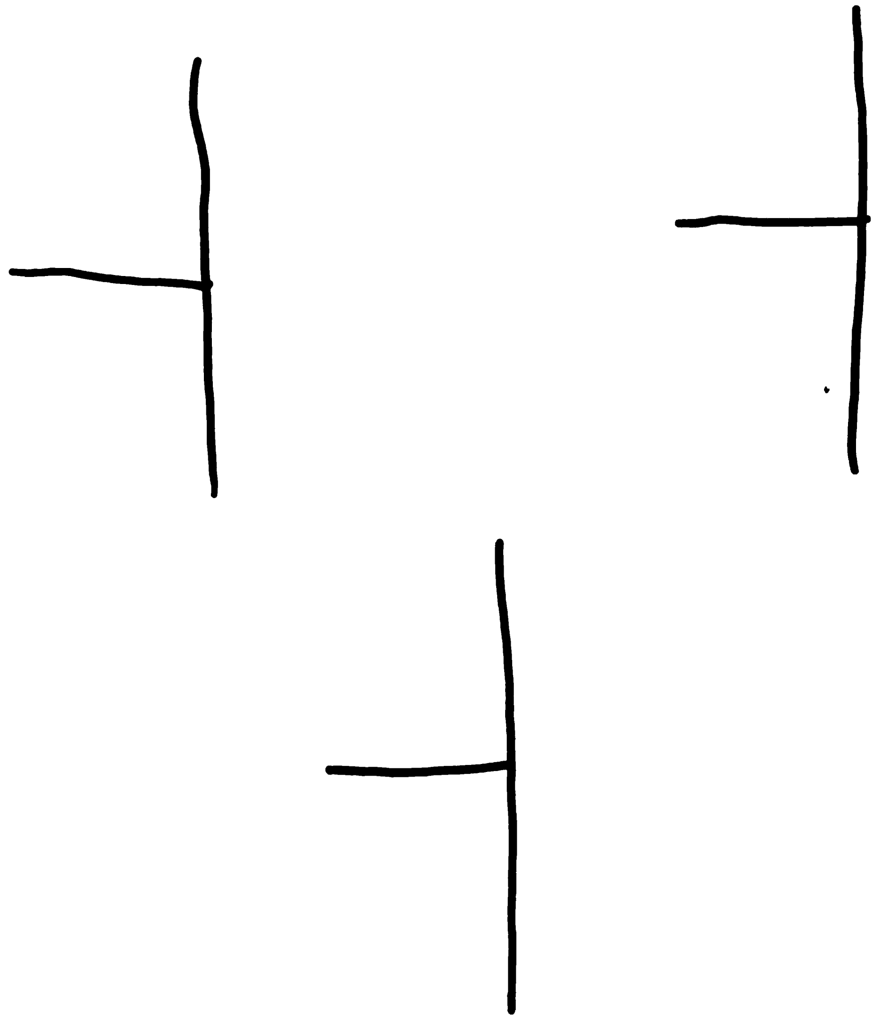


Figure 28. Examples of copies of a half cross (actual size) receiving quality scores of 6.

Figure 29. Examples of copies of a half cross (actual size) receiving scores of 7.

RESULTS AND DISCUSSION

The Results and Discussion section is divided into four parts. The first part presents an analysis of the quality scoring systems to determine their validity; the validity criteria can also be considered as an explanation of the quality score results. The second part is an analysis of the results to determine whether the four predictions made in the Introduction were confirmed. The results are interpreted using auxiliary hypotheses that do not significantly change the component theory. The third part is an interpretation of the results based on findings from differential psychology and neuropsychology that significantly enlarges the component theory. The fourth part is an attempt to answer the question 'Is there a grammar of copying?' by drawing upon previously discussed findings and theories.

Analyses of the Quality Scoring Systems

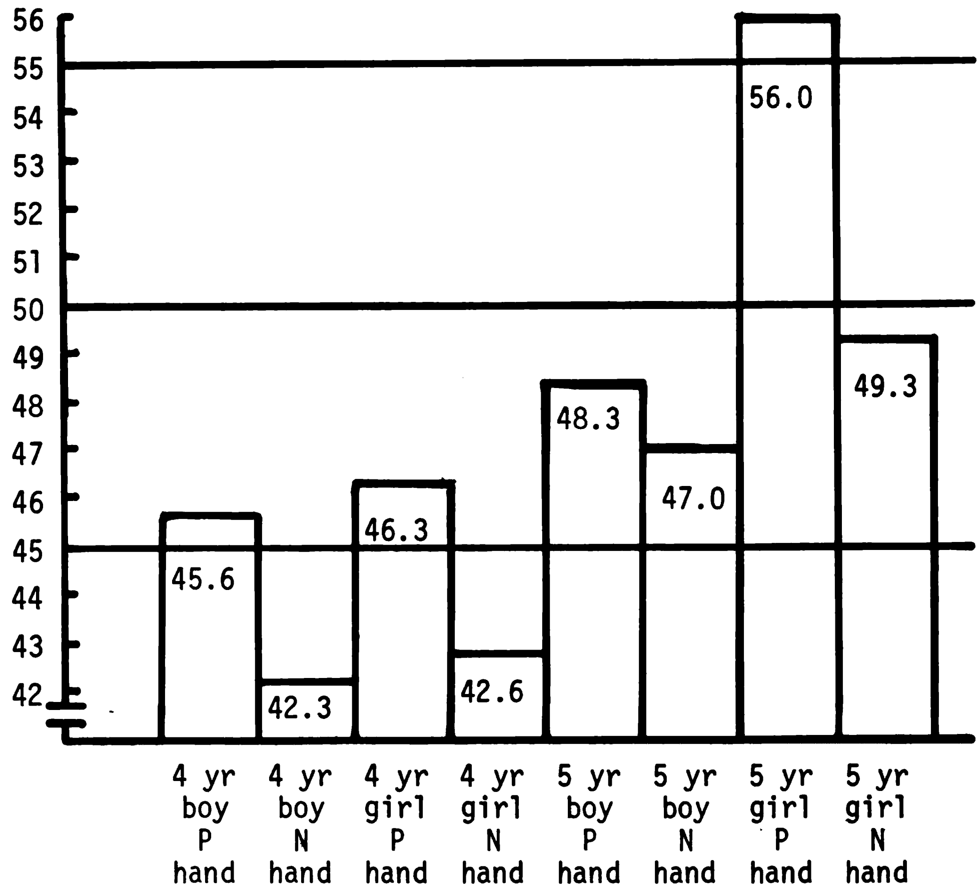
Five kinds of criteria were used to determine the external validity of the scoring systems. First, the scores would be expected to be higher for older children in as much as copying skills are known to improve as the child matures. Second, scores should be higher for copies made with the preferred hand. This result may not hold for younger children who lack adquate motor control for either hand. Third, the girls' scores should be higher than the boys' scores in as much as girls until and through adolescence mature faster than boys (see Tuddenham and Snyder, 1954). Fourth, because girls mature faster than boys, girls should also show a preferred hand superiority before the boys. A preferred hand superiority is a more 'adult-like' response. Again, young children who lack adequate motor control for either hand would show no hand differences. Fifth, scores for the triangle should be lower than those for the square, since the triangle is known to be a more difficult figure to copy than the square. Maccoby and Bee (1965) note that while the square is copied accurately by the fourth year, the triangle is not copied accurately until the fifth year. It is not absolutely necessary, however, to meet the fifth criterion. Both scoring systems could be internally consistent but not comparable in this manner. It should be noted that the five validity criteria are also predictions and explanations of the age, sex, and hand differences found in the quality scores. These criteria are similar to the auxiliary hypotheses used to interpret the results.

The Square

The results of a 2 x 2 x 2 (age, sex, hand) repeated measures analysis of variance ($N = 60$) are shown in Table 1. Treatments, age, and hand were significant at the .01 level, and sex differences were significant at the .05 level. Figure 30 is a summary of a Newman-Keuls comparison test and a histogram of treatment scores. The five-year-old girls' preferred hand scores were significantly ($p < .05$) higher than the scores for any other cell. No other comparisons disclosed significant differences. These results largely satisfy the first four criteria for

Table 1. Results of a 2 x 2 x 2 (age, sex, hand) repeated measures analysis of variance for quality scores of copies of the square

Source	Sum of squares	d.f.	Mean squares	F	p
Treatment	8.2	7	1.2	4.0	.01
Age	4.3	1	4.3	14.3	.01
Sex	0.8	1	0.8	2.7	.05
Hand	1.7	1	1.7	5.7	.01
Age x sex	0.6	1	0.6	2.0	
Age x hand	0.0	1	0.0	0.0	
Sex x hand	0.5	1	0.5	1.7	
Age x sex x hand	0.3	1	0.3	1.0	
Error	31.0	112	0.3		
Total	41.1	119			



(5 yr girl P) (4 girl N)
(5 yr girl P) (4 boy N)
(5 yr girl P) (4 boy P)
(5 yr girl P) (4 girl P)
(5 yr girl P) (5 boy N)
(5 yr girl P) (5 boy P)
(5 yr girl P) (5 girl N)

Figure 30. Histogram of quality scores for each cell and pairs of means found to be significantly different using a Newman-Keuls test for the square.

validity outlined above; the fifth is discussed with the analysis of the triangle quality score.

The scores for the square were also examined to determine whether children whose total preferred and nonpreferred hand quality scores were above the median showed superior preferred hand quality scores. This is another way of assessing the second and fourth validity criteria. If higher scores are an indication of a more mature response, then a preferred hand superiority should be associated with higher scores. This should be true regardless of the sex of the child. Table 2 is a summary of such an analysis of the scores for the square; the Chi-square test in Table 3 demonstrates that children whose total scores were above the median had superior preferred hand scores.

Table 2. Differences in quality scores for the preferred and nonpreferred hands of children whose total scores were above or below the median for the square

	No difference between hands	Preferred hand scores greater	Nonpreferred hand scores greater
Above the median	2	17	5
Below the median	14	16	6

Table 3. Chi-square comparison of preferred and nonpreferred hands of children whose total quality scores were above or below the median for the square

	Total score above the median	Total score below the median
Nonpreferred hand scores greater or equal	17	16
Preferred hand scores greater	7	20

$\chi^2 = 4.05$

$p < .05$

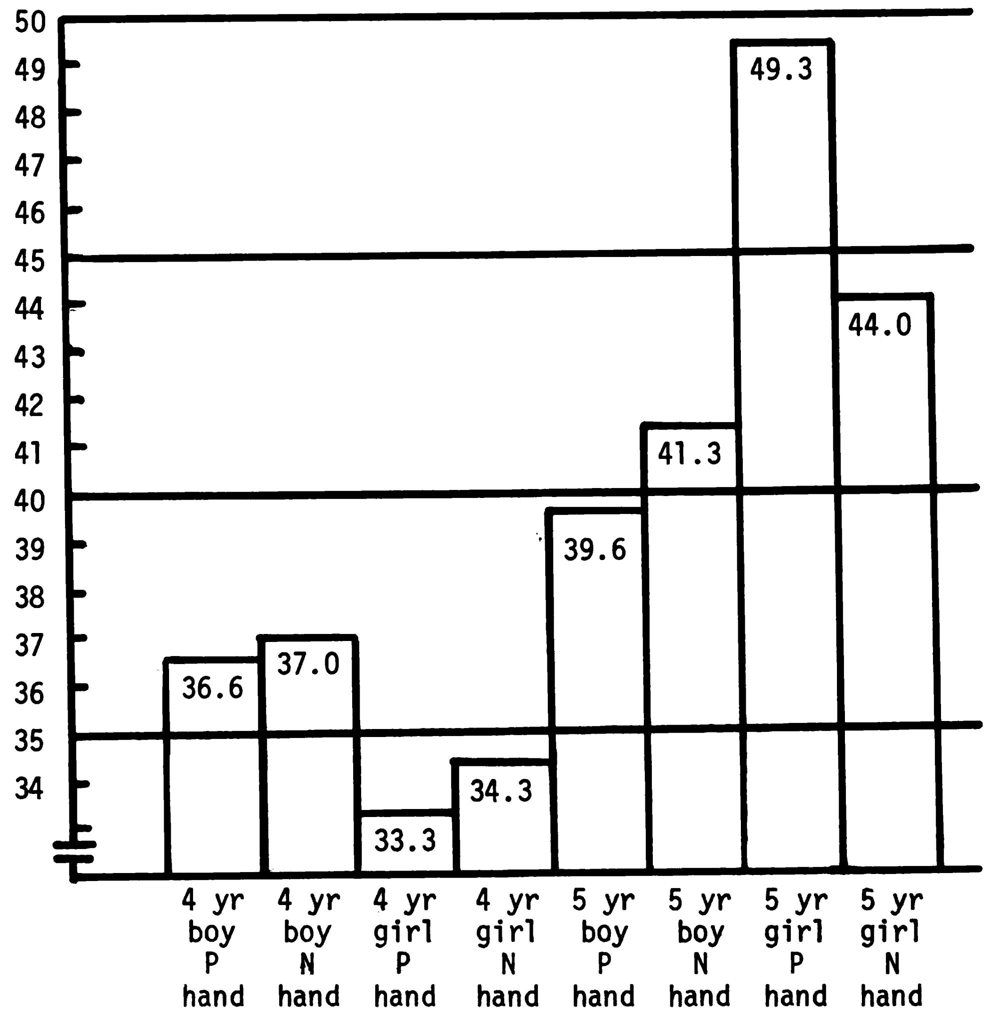
The Triangle

The results of the 2 x 2 x 2 (age, sex, hand) repeated measures analysis of variance ($N = 60$) of the triangle quality scores are shown in Table 4. Treatments, age, and age x sex interactions were significant at the .01 level. Figure 31 is a summary of the Newman-Keuls comparisons and a histogram of treatment scores. The five-year-old girls' preferred hand scores were significantly ($p < .05$) higher than the five-year-old boys' preferred hand scores and all of the four-year-olds' scores. No other comparisons disclosed significant differences. These results largely satisfy the first four criteria listed above.

The triangle scores, like the scores for the square, were examined to determine whether children whose total preferred and nonpreferred hand quality scores were above the median showed superior preferred hand scores. Table 5 contains a summary of this analysis for the triangle. The Chi-square test in Table 6 demonstrates that

Table 4. Results of a 2 x 2 x 2 (age, sex, hand) repeated measures analysis of variance for quality scores of the triangle

Source	Sum of squares	d.f.	Mean squares	F	p
Treatment	13.0	7	1.9	3.8	.01
Age	8.6	1	8.6	17.2	.01
Sex	0.2	1	0.2	0.4	
Hand	0.1	1	0.1	0.2	
Age x sex	2.6	1	2.6	5.2	.01
Age x hand	0.4	1	0.4	0.8	
Hand x sex	0.4	1	0.4	0.8	
Age x hand x sex	0.7	1	0.7	1.4	
Error	50.6	112	0.5		
Total	63.6				



(5 girl P) (4 girl P)
(5 girl P) (4 girl N)
(5 girl P) (4 boy P)
(5 girl P) (4 boy N)
(5 girl P) (5 boy P)

Figure 31. Histogram of quality scores for each cell and pairs of means found to be significantly different using a Newman-Keuls test for the triangle.

Table 5. Differences in quality scores for the preferred and nonpreferred hands of children whose total scores were above or below the median for the triangle

	No differences between hands	Preferred hand scores greater	Nonpreferred hand scores greater
Above the median	8	13	8
Below the median	12	6	13

Table 6. Chi-square comparison of preferred and nonpreferred hands of children whose total scores were above or below the median for the triangle

	Total score above the median	Total score below the median
Nonpreferred hand scores greater or equal	13	6
Preferred hand scores greater	16	25

$\chi^2 = 4.45$

$p < .05$

children whose total scores are above the median have superior preferred hand scores.

The fifth criterion was tested by comparing each child's combined scores for the square and triangle for each hand. Table 7 summarizes the results of the sign tests for each treatment group. All groups indicated a tendency for the triangle scores to be lower; this trend was weaker in the preferred and nonpreferred hands of the five-year-old girls and the nonpreferred hands of the four-year-old boys. These results largely satisfy the fifth criterion. According to the five criteria presented, the square and triangle scores are valid.

Table 7. Results of sign tests comparing total square and triangle scores of individual children in each cell[a]

				p					p
Four-year-old boys	P	11+	2-	.011	Four-year-old girls	P	12+	2-	.019
	N	9+	3-	.254		N	10+	2-	.055
Five-year-old boys	P	10+	2-	.019	Five-year-old girls	P	10+	5-	.151
	N	10+	2-	.046		N	9+	3-	.254

[a]A + score indicates that the child's total square scores are greater than his total triangle scores; a - score indicates his total triangle scores are greater than his total square scores.

The Half Cross

The results of the 2 x 2 x 2 (age, sex, hand) repeated measures analysis of variance of the half cross quality scores are shown in Table 8. Treatments, age, and hand were significant at the .05 level, and the age x sex interaction was significant at the .01 level. Figure 32 is a summary of the Newman-Keuls comparisons and a histogram of treatment scores. No comparisons disclosed significant differences. These results do not satisfy the first four criteria.[12]

The scores were also examined to determine whether children whose total preferred and nonpreferred hand scores were above the median showed superior preferred hand quality scores. Table 9 is a summary of such an analysis of the scores for the half cross; the Chi-square test in Table 10 shows no difference between children whose scores were above or below the median.

These negative results can be partly explained by examining the kinds of errors frequently made by the children. Table 11 is a summary of these errors for each treatment group. Five kinds of errors were noted: half crosses with the horizontal line on the right side of the figure, inverted L-shaped figures, T-shaped figures, enclosed figures, and full crosses. The errors are interesting because they seem to indicate more left-right confusions for the younger girls and more errors for the younger girls and older boys that appear to be either a rotation of the figure or a transformation of the model into a letter of the

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[12] The Newman-Keuls test, however, may not be sensitive enough to demonstrate differences. If so, it appears that the four-year-old boys' scores are anomalous; the other groups seem to conform to the criteria.

Table 8. Results of a 2 x 2 x 2 (age, sex, hand) repeated measures analysis of variance for quality scores of the half cross

Source	Sum of squares	d.f.	Mean squares	F	p
Treatment	22.1	7	3.2	2.1	.05
Age	4.1	1	4.1	2.7	.05
Sex	2.5	1	2.5	1.7	
Hand	3.5	1	3.5	2.3	.05
Age x sex	11.6	1	11.6	7.7	.01
Age x hand	0.1	1	0.1	0	
Sex x hand	0.1	1	0.1	0	
Age x sex x hand	0.2	1	0.2	0.1	
Error	173.3	112	1.5		
Total	195.4	119			

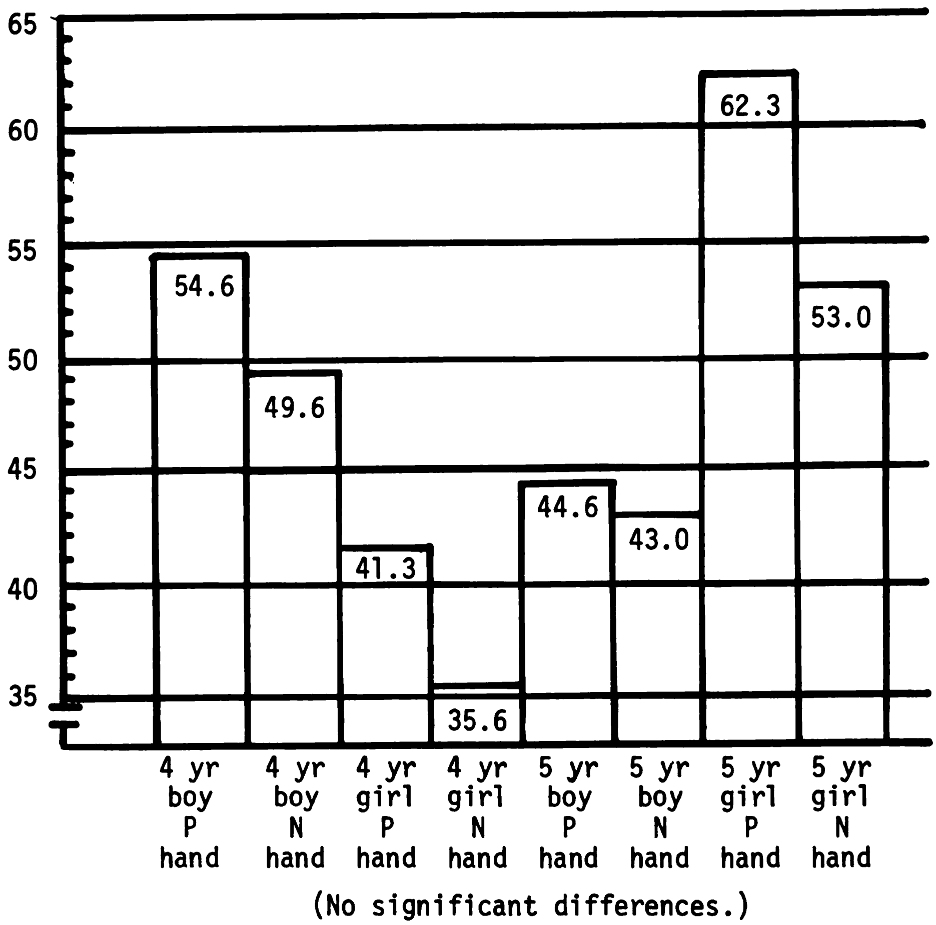


Figure 32. Histogram of quality scores for each cell and pairs of means found to be significantly different using a Newman-Keuls test for the half cross.

Table 9. Differences in quality scores for the preferred and non-preferred hands of children whose total scores were above or below the median for the half cross

	No difference between hands	Preferred hand scores greater	Nonpreferred hand scores greater
Above the median	4	18	6
Below the median	9	17	6

Table 10. Chi-square comparison of preferred and nonpreferred hands of children whose total quality scores were above or below the median for the half cross

	Total score above the median	Total score below the median
Nonpreferred hand scores greater or equal	10	15
Preferred hand scores greater	18	17

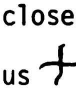
$\chi^2 = 0.81$

not significant

Table 11. Types of errors made by children attempting to copy the half cross

Age and sex of subject	Hand used	Type of figure[a]	Age and sex of subject	Hand used	Type of figure[a]
4 yrs, boy	P1	R	5 yrs, boy	P1	T
	N2	R		P2	T
				P3	T
4 yrs, boy	P3	R		N1	T
	N2	R		N2	T
	N3	R		N3	T
4 yrs, boy	P1	T	5 yrs, boy	P1	T
	P2	T		P2	T
	P3	T		P3	T
	N1	T		N1	T
	N2	R		N2	T
	N3	E		N3	T
4 yrs, girl	P1	T	5 yrs, boy	P1	T
	P2	T		P2	T
	P3	T		P3	T
	N1	T		N1	T
	N2	E		N2	T
	N3	T		N3	T
4 yrs, girl	P1	I	5 yrs, boy	N3	P
	P2	I			
	P3	I	5 yrs, girl	P1	T
	N1	I		P2	T
	N2	I			
	N3	E			
4 yrs, girl	N1	R			
	N2	R			
4 yrs, girl	P1	R			
	P2	R			
	P3	R			

[a]R = reversed  E = enclosed 

I = inverted 'L'  P = plus .

T = 'T' 

alphabet. Some children would spontaneously remark that their copy was "a 'T,' just like Tammie's name," (a girl in class), while others would draw a 'T' but not respond to the experimenter's inquiries about the reproduction. Although removal of these anomalous copies from the treatment groups does not appreciably change the groups' averages, the changes that result are in the right direction and proportions to make the overall scores more nearly valid. That is, the four-year-old girls' and five-year-old boys' scores would increase more than the other groups. (Also note that there are about an equal number of errors made by the preferred and nonpreferred hands for each group.)

Not all of the errors made may have been identified because the errors were not fully expressed in the copy. For example, a child might not have been able to decide whether to copy a half cross or to draw a 'T.' He therefore might have compromised by placing the horizontal line close to the top of the vertical line; this copy would receive a low quality score (see Appendix C). These speculations, however, require further testing.

Analyses of the Results and Discussion of the Predictions

The results are analyzed in this section using correlational and nonparametric techniques to test the predictions made in the Introduction. Four predictions were made: (1) the directionality of young children's copies will be determined more by ease of execution (tensor movements), while the copies of older children will exhibit an absolute left-to-right organization; (2) Goodnow and Levine's (1973) 'rules' (topmost, leftmost start, vertical line first, and 'thread') will not be associated with high quality copies of the square, but quality of copy and consistency of movement sequence use (or how often the same movement sequences are used for repeated copies done by the same hand) will show a positive correlation; (3) consistency of movement sequence use will be greater for older children; and (4) movement sequence use will be more general (more nearly the same for both hands) for older children. Although the results generally support all of the predictions except the first, some unexpected sex differences and hand differences necessitated two alternative explanations. The first, presented with the results and discussion of the predictions, is the addition of auxiliary hypotheses to the component theory presented in the Introduction.

Before analyzing the results and predictions, two methodological problems are discussed. First, were copies done by some children or the copies of a particular figure unsuitable for analyses? Second, was order of presentation (that is, which hand the child used first to copy) correlated with quality and the use of certain movement sequences?

One of three problems made copies unsuitable for analysis. First, the child was unable to complete all six copies of the figure. Second, the copies were done by left-handed children. Third, analyses could not be performed on quality scores of poor validity.

The copying skill of children who were unable to complete all six copies might differ qualitatively from children who could complete all six. Therefore, to assure that homogeneous groups of children were being tested in the correlational analyses, only children who completed all six copies were used. The triangle was a difficult figure to copy; only six four-year-olds and 17 five-year-olds were able to complete all six copies. (Of these subjects, two of the four-year-olds and six of the five-year-olds were boys.) No attempt was made to analyze the triangle data using correlations because the small number of subjects reduced the variance of many variables to zero. A zero variance may truly represent consistent rule use (as it could if a larger number of subjects were available), or it could result by chance from the small number of subjects. Less sensitive methods were used to analyze the triangle data to test the third and fourth predictions.

All left-handed children were excluded from the analyses. Left handers are known to show difference patterns of hand dominance compared with right handers (see Zangwill, 1960, and Harris, 1974). Two four-year-old boys, one five-year-old boy and one five-year-old girl were left-handed for copying. They were eliminated from all analyses whether or not they completed all six copies.

Quality scores of the half cross were not used because of poor validity. Because many unusual errors were noted in the half cross copies, this figure was eliminated entirely from the analyses except for the testing of the first prediction. Other unusual properties of the figure were noted also in this context.

No significant tendencies were found to indicate a relation between order of presentation ('PN' and 'NP') and quality and movement sequence use for the square. The correlation matrices are presented in Appendix E, Tables E1, E2, E3, and E4. Only ten correlations were significant out of 384.

To summarize, the data from the square appear to be the most nearly complete and valid.[13] The half cross and triangle data will not be emphasized for the reasons discussed above.

Ease of Execution and the Organization of Directionality of the Copies

The prediction that directionality in the younger children's copies would be determined more by ease of execution, and that an absolute left-to-right organization would be found in older children's copies, was not confirmed. The four-year-old boys used significantly more tensor movements (right-to-left movements with the left hand), and the four-year-old girls and the five-year-old boys and girls showed tendencies in this direction. The analyses and discussion of the results are presented below.

To use the Reed and Smith (1961) test to test whether the organization of the children's copies was determined by an absolute left-to-right rule or ease of execution, three prerequisites had to be met. First, only copies that showed a clear left-to-right or right-to-left organization could be used. With a copy that exhibits a more

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[13] The number and type of movement sequences the children used to construct the square were similar to those found by Gesell and Ames (1946). For children's copies of the square, they noted the number of lines used, the direction in which the horizontal and vertical lines were drawn, and the percentage of children who used one of four predominant patterns of movement sequences. The present data were compared by using all right-hand copies done by right-handed children who completed all three copies. The results were similar to those found by Gesell and Ames for children of the same age.

ambiguous left-right organization it is difficult to determine the relative contribution of cognitive (central) factors and ease of execution (peripheral) factors. For example, a square drawn with one line by starting at the leftmost, topmost point and a vertical line first was horizontal lines drawn in opposite directions. Although the copy was started on the left and the bottom horizontal was drawn left-to-right, the copy was completed by drawing the top horizontal line from right-to-left. Second, it must be determined what combination of results on the Reed and Smith test and which copies definitively test the two hypotheses. There are some outcomes that are predicted by both hypotheses; these outcomes cannot be used if the two hypotheses are to be distinguished. Third, there must be enough children who satisfy the first two prerequisites so the hypotheses can be adequately tested. The three prerequisites are discussed below.

1. Figure 33 illustrates the types of copies that show a clear left-to-right or right-to-left organization. Note that four sided squares and all the half crosses must be copied in a particular sequence to exhibit a clear directional organization. All figures without numbers in Figure 33 indicate that the sequence the lines are drawn is unimportant, and all lines without arrows indicate that the directionality of these lines does not affect the directional organization of the copy.

2. Table 12 shows the outcomes on the Reed and Smith test and directional organization of the copy for each child needed to confirm or disconfirm the two hypotheses. Any copy organized left-to-right confirms the absolute left-to-right directionality hypothesis, whatever the

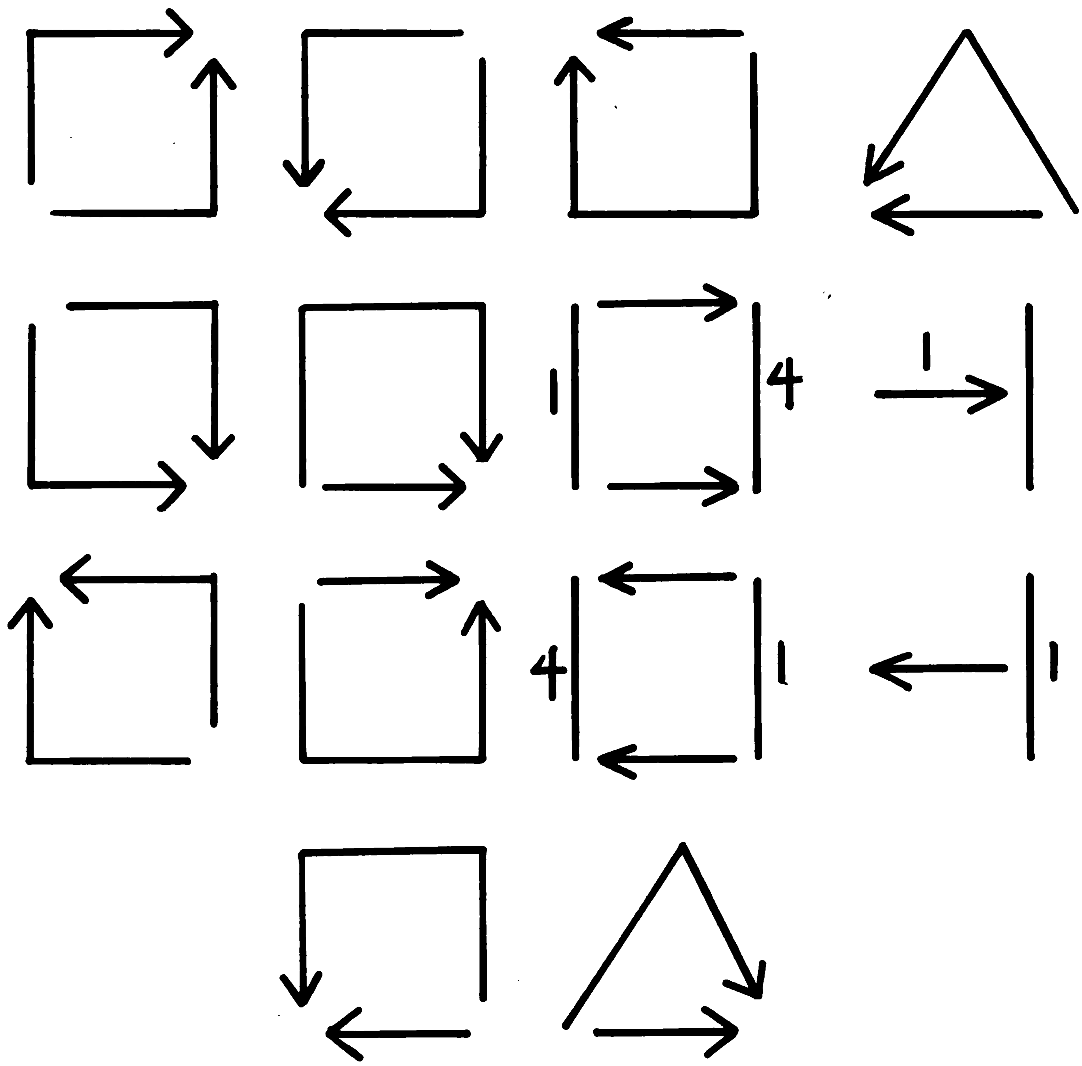

Figure 33. Copies that show a clear directional organization. (A line without an arrow indicates that the directionality of the line is not crucial; a line without a number indicates that the sequence of the line is not crucial.)

Table 12. Outcomes needed on the Reed and Smith test and directional organization of copies to confirm or disconfirm the 'ease of execution' or 'absolute left-to-right' hypotheses

	Absolute left-to-right hypothesis	Ease of execution hypothesis
Confirm:		
Reed and Smith	→	→
Copy	→	→
Reed and Smith	←	←
Copy	→	←
Disconfirm:		
Reed and Smith	→	→
Copy	←	←
Reed and Smith	←	←
Copy	←	→

outcome on the Reed and Smith test; all copies organized right-to-left disconfirm the hypothesis. Only copies organized in the same direction as the results on the Reed and Smith test confirm the ease of execution hypothesis; all other cases disconfirm the hypothesis. Note in Table 12, however, that the same cases can confirm or disconfirm both hypotheses. Thus, if the two hypotheses are to be distinguished from each other and tested, these outcomes cannot be used. The usable cases are presented in Table 13.

Table 13. Outcomes on the Reed and Smith test and directional organization of the copy that definitively test the 'ease of execution' and 'absolute left-to-right' hypotheses

	Absolute left-to-right hypothesis	Ease of execution hypothesis
<u>Confirm</u>:		
Reed and Smith	←	←
Copy	→	←
<u>Disconfirm</u>:		
Reed and Smith	←	←
Copy	←	→

3. Table 14 presents the number of cases that fulfill both of the preceding prerequisites. Because one child could have as many as 18 testable responses, Table 15 presents the number of children who made the responses for each cell in Table 14. The number of children who made responses that supported both of the hypotheses is shown in parentheses for each age x sex group. Because only a small number of children produced the necessary responses, no attempt was made to test the hypotheses using this method. Furthermore, there is reason to believe that the Reed and Smith test did not accurately measure how easily movements were executed.

Table 14. Number of responses that confirm the 'absolute left-to-right' or 'ease of execution' hypotheses for each age x sex group

	Confirm absolute left-to-right	Confirm ease of execution
Four-year-old boys	3	13
Four-year-old girls	5	9
Five-year-old boys	0	10
Five-year-old girls	2	12

Table 15. Number of children who made responses that would test the 'absolute left-to-right' or 'ease of execution' hypotheses[a]

	Confirm absolute left-to-right		Confirm ease of execution
Four-year-old boys	2	(1)	3
Four-year-old girls	3	(2)	3
Five-year-old boys	0		3
Five-year-old-girls	1		4

[a]The number of children who made responses that confirm both hypotheses are in parentheses.

Table 16 presents a summary of the Reed and Smith (1961) test results. The only significant finding was that five-year-old girls show significantly ($p < .05$) more tensor movements than five-year-old boys. Note that nine of the twelve nontensor movements for the five-year-old boys (or 60% of their total responses) were left-to-right movements for both hands. Reed and Smith tested 50 right-handed children and 50 left handed children nine to thirteen years old and found that 13% of the right-handed and 4% of the left-handed children made left-to-right movements with both hands.

A possible explanation of the five-year-olds' results can be based on their learning experiences and sex differences in maturation. Elkind and Weiss (1967) found that six-year-old children who were just learning to read and write used a left-to-right rule when naming pictures arranged in a triangular outline. Five-, seven-, and eight-year-olds usually named the pictures by following the outline of the triangle. The authors speculated that there is a tendency for children to spontaneously practice new skills on any possible occasion and task until they achieve mastery; thus the six-year-olds imposed a 'left-to-right' rule acquired in reading on another perceptual task. The Elkind and Weiss' hypothesis was also supported by the observation that slow readers in the second grade used a left-to-right rule on the picture naming task. Although the authors do not report sex differences, a similar argument can be used for the present data. Because the five-year-olds were learning to read and write at the time of testing, there may have been more of a tendency for them to organize their perceptual

Table 16. Chi-square tests comparing the number of tensor and nontensor movements in four- and five-year-old boys' and girls' completion of the Reed and Smith test using either their right or left hand

	4-year-old boys	4-year-old girls	5-year-old boys	5-year-old girls
Tensor movements, both hands	3	5	3	11
Left-to-right movements, both hands	2	5	9	3
Right-to-left movements, both hands	2	0	3	1
	$\chi^2 = 3.55$		$\chi^2 = 8.60$ $p < .05$	
	Comparison of tensor and nontensor movements in four-year-old boys and girls.		Comparison of tensor and nontensor movements in five-year-old boys and girls.	

	4-year-old boys	5-year old boys	4-year-old girls	5-year-old girls
Tensor movements, both hands	3	3	5	11
Left-to-right movements, both hands	2	9	5	3
Right-to-left movements, both hands	2	3	0	1
	$\chi^2 = 1.95$		$\chi^2 = 2.90$	
	Comparison of tensor and nontensor movements in four- and five-year-old boys.		Comparison of tensor and nontensor movements in four- and five-year-old girls.	

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and motor behaviors in an absolute left-to-right direction. This effect would be stronger for boys who mature less quickly than girls, and may need more experience to master these spatial skills.

Since the Reed and Smith (1961) test may not be an accurate measure of tensor movements, the prediction was tested by assuming that the human body is structured to make tensor movements easier than flexor movements (see Reed and Smith, 1961). All copies that fulfilled the first prerequisite were used; right-hand copies do not distinguish between the two hypotheses because both predict left-to-right movements. Table 17 is a summary and analysis of the results using a sign test. The four-year-old boys and four- and five-year-old girls used more tensor movements than nontensor movements. The difference was significant, however, at only the $p < .10$ level. The five-year-old boys showed the same but still weaker trends.

These results are probably best interpreted by noting that of all the 113 copies that could be used to test the hypotheses, 97 were half crosses. The half cross may be such a simple figure to copy that it constitutes another version of the Reed and Smith test for tensor movements, while the triangle and square are so complex that other factors (presumably cognitive) are more important.[14] This explanation, however, cannot account for the five-year-old boys' greater use of absolute left-to-right movements with either hand in the Reed and Smith

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[14] Piaget and Inhelder (1956) note that the first figures the child can copy are the circle and the full cross. The half cross is very similar to the full cross, and this may make it an easy figure to copy.

Table

Four-year-old boys

Table 17. Summary of data and results of sign tests on the number of children who used tensor and nontensor direction of organization for copies done with the left hand

Four-year-old boys

Copies constructed using:		
Tensor movements	Nontensor movements	
3	0	+
3	0	+
4	0	+
3	0	+
0	2	-
0	1	-
3	0	+
3	0	+
3	0	+
3	0	+
3	0	+

$p = 0.033$

Four-year-old girls

Copies constructed using:		
Tensor movements	Nontensor movements	
3	0	+
1	2	-
3	1	+
3	0	+
3	3	0
3	0	+
3	0	+
3	0	+
3	0	+
3	1	-

$p = 0.090$

Five-year-old boys

Copies constructed using:		
Tensor movements	Nontensor movements	
3	0	+
3	0	+
3	3	0
0	3	-
2	0	+
3	0	+

$p = 0.188$

Five-year-old girls

Copies constructed using:		
Tensor movements	Nontensor movements	
3	0	+
3	0	+
3	0	+
3	0	+
3	0	+
0	3	-
3	0	+
0	2	-
3	0	+
3	0	+

$p = 0.055$

test. It is possible that some configurational properties of the half cross elicited greater tensor movements. But what these properties might be cannot be determined without a theory that predicts the relative contribution of ease of movement and the configuration of the model to directionality of movements in copying.

The Correlation of Quality Scores with (1) Goodnow and Levine's (1973) 'Rules' and (2) Consistency Scores

Goodnow and Levine's (1973) 'rules' (topmost, leftmost start, vertical line first, and thread) were not correlated with high quality copies of the square. The correlation matrices of 'rule' (and movement sequence) with quality are presented in Appendix E, Tables E5, E6, E7, and E8. The proportion of children who used each 'rule' and movement sequence are presented in Appendix E, Tables E9 and E10. Ten four-year-old boys, 11 four-year-old girls, 13 five-year-old boys, and 13 five-year-old girls completed all six copies and were used as subjects. Only five positive correlations were significant ($p < .05$) out of 168. All five of these were found in the four-year-old girls' copies, but these correlations did not exhibit a strong relation between 'rule' use and quality. For example, 'horizontal line first' and quality were correlated at 0.67 ($p < .05$) for the first and third copies done with the right hand, and at -0.26 for the second copy done with the right hand. These results suggest that Goodnow and Levine's 'rules' may only be an indication that some children find certain movement sequences more efficient than others for copying. The 'rules' need not be followed to produce a copy of high quality.

One might object to this conclusion on three gounds. First, the quality scoring system used in this study may have focused on features of the copy that are unrelated to 'rule' use. For example, if the quality scoring system had strongly emphasized features such as the proportions of the copy or its size in relation to the model, then the relationship between quality and 'rule' use would appear. Second, group data may obscure different 'rules' for individual children that produce copies of high quality. Third, high quality would be associated only with copies constructed using all four 'rules' (topmost, leftmost start, vertical line first, and 'thread').

The first two objections are conceptually inadequate. In the first case, the grammar theory does not unambiguously predict what features would be critically dependent on rule use. The first objection, therefore, has no force unless a clear prediction can be made. As for the second objection, if it were true, a 'universal' grammar theory of copying would be impossible because no general rules could be found. There would be a 'grammar' for each individual child.

The third objection is far more substantial because it suggests that the data presented so far are an inadequate test of the second prediction. Children who copied the square by starting at the topmost, leftmost point, drew a vertical line first and 'threaded' would produce copies of superior quality; the data presented test only whether one of the rules is correlated with copies of high quality. Unfortunately, the data available to test this objection are difficult to interpret. Table 18 presents the number of children who copied the square using all four

Table 18. Number of children who copied the square using the topmost, leftmost start, vertical line first, and 'thread' rules

Age and sex of subject	Hand used	Number of copies where 4 rules used
4 yrs, boy	P	3
4 yrs, boy	P	2
	N	1
4 yrs, boy	N	1
4 yrs, boy	P	1
4 yrs, boy	N	2
4 yrs, boy	N	2
4 yrs, boy	P	2
	N	3
4 yrs, boy	P	1
	N	1
4 yrs, boy	N	2
4 yrs, girl	P	2
	N	3
4 yrs, girl	N	2
4 yrs, girl	P	3
	N	3
4 yrs, girl	N	3
4 yrs, girl	P	3
	N	3
4 yrs, girl	P	1
	N	3
4 yrs, girl	P	1
	N	1
5 yrs, boy	P	3
	N	3
5 yrs, boy	P	2
	N	2
5 yrs, boy	P	3
	N	3
5 yrs, boy	P	3
	N	2
5 yrs, boy	P	1
	N	2
5 yrs, boy	P	3
	N	3
5 yrs, boy	P	1
5 yrs, boy	P	3
	N	3
5 yrs, boy	N	3
5 yrs, girl	P	2
5 yrs, girl	P	3
	N	3
5 yrs, girl	P	2
	N	3
5 yrs, girl	P	3
	N	3
5 yrs, girl	P	3
	N	2
5 yrs, girl	P	3
	N	3
5 yrs, girl	P	3
	N	3
5 yrs, girl	P	3
	N	3
5 yrs, girl	P	3

rules; this shows that the use of all four rules is confounded with consistency. Since the component theory predicts that the more consistently 'rules' are used, the higher the quality of the copy, it is difficult to distinguish between the grammar theory and the component theory with these data. The theories could be compared within age groups only by finding other children who constructed copies using a different combination of four 'rules' just as consistently as the children described in Table 18. Unfortunately, no other combination of 'rules' was used so much or so consistently as the combination topmost, leftmost start, vertical line first, and 'thread.'

Because the present data do not solidly confirm the component theory, it must be demonstrated that the copies a child makes by using different 'rules' would be of equal quality. This could be tested by forcing the child to use various starting points for each copy. The child would be required to begin his copies near different edges of the paper so his constructions would be organized a different direction each time. A circular piece of paper would be used to eliminate any possible visual cues that might come from the straight edges, and a dot near the edge of the paper would indicate the starting point.[15]

Although 'rule' use and quality were not related, consistency and quality were correlated, but not highly. Table 19 presents the

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[15]This result would be seen only after the children had an opportunity to practice the task. Bernstein (1967) postulates recoding mechanisms that translate the information contained in the motor memory into muscle movements. Some practice would be necessary before adequate control would be achieved so smooth actions would result.

Table 19. Results of a Spearman rank order correlation between consistency and quality of copy for four- and five-year-old boys' and girls' copies of a square

Consistency scores		Quality scores	
5-year-old girls: right	39	5-year-old girls: right	3.74
5-year-old girls: left	35	5-year-old girls: left	3.36
5-year-old boys: left	31	4-year-old girls: right	3.30
4-year-old girls: right	25	4-year-old boys: right	3.23
5-year-old boys: right	24	5-year-old boys: right	3.18
4-year-old boys: left	22	5-year-old boys: left	3.13
4-year-old girls: left	16	4-year-old girls: left	3.09
4-year-old boys: right	11	4-year-old boys: left	2.87

$r_s = 0.64$; $p < .10$

results of a Spearman rank order correlation between consistency and quality scores; $r_s = 0.64$, which is significant at the $< .10$ level. The same subjects used to test Goodnow and Levine's (1973) hypothesis were used here. (Note that these quality score averages are computed from the copies of children who could complete all six copies.) These findings support the component theory; consistency in copying the square indicates that the child has a more nearly 'complete' system for copying the figure.

The Relation of Consistency of Use of Movement Sequences with Age

The prediction that older children will exhibit more consistency than younger children was confirmed. This is another indication of a more complete and stable system for older children. However, some unusual findings were also noted. Four-year-old boys were significantly more consistent with their left hand, while four-year-old girls were more consistent with their right hand; the girls' right hand consistency scores were also significantly higher than the boys' right hand scores. Similar tendencies were also present in the five-year-olds' scores. The same subjects used for prediction 2 were used here.

Consistency of movement sequence use for each hand was determined by first examining the intercorrelations of movement sequences for all copies made with the same hand ('intra-hand' correlations). Hypotheses were tested by comparing the number of significant correlations ($p < .05$) found in each age x sex group with Chi-square tests. The correlation matrices are presented in Appendix E, Tables E11, E12, E13, and E14.

The Chi-square tests are presented in Table 20. These results indicate that the four-year-old boys' right hand copies were significantly less consistent than their own left-hand copies, whereas the four-year-old girls' right hand scores were more consistent than their own left-hand scores. The four-year-old boys' right hand scores were significantly less consistent than the four-year-old girls' right hand scores. The five-year-old boys' right-hand copies were significantly less consistent than the five-year-old girls' right-hand copies, and

Table 20. Chi-square tests comparing the consistency scores of right-handed four- and five-year-old boys' and girls' right and left hand copies of a square

	Right	Left	Right	Left
Significant[a]	11	21	25	16
Not significant[b]	34	24	20	29
	$\chi^2 = 4.84$ $p < .05$		$\chi^2 = 3.68$	
	Comparison of right and left hand scores of four-year-old boys.		Comparison of right and left hand scores of four-year-old girls.	

	Boys	Girls	Boys	Girls
Significant[a]	11	25	21	16
Not significant[b]	34	20	24	29
	$\chi^2 = 9.06$ $p < .05$		$\chi^2 = 1.16$	
	Comparison of right hand scores of four-year-old boys and girls.		Comparison of left hand scores of four-year-old boys and girls.	

	Right	Left	Right	Left
Significant[a]	24	31	39	35
Not significant[b]	21	14	6	10
	$\chi^2 = 2.30$		$\chi^2 = 1.22$	
	Comparison of right and left hand scores of five-year-old boys.		Comparison of right and left hand scores of five-year-old girls.	

Table 20 (cont'd.)

	Boys	Girls	Boys	Girls
Significant[a]	24	39	31	35
Not significant[b]	21	6	14	10
	$\chi^2 = 11.92$ $p < .05$		$\chi^2 = 0.90$	
	Comparison of right hand scores of five-year-old boys and girls.		Comparison of left hand scores of five-year-old boys and girls.	

	Four	Five	Four	Five
Significant[a]	11	24	21	31
Not significant[b]	34	21	24	14
	$\chi^2 = 7.90$ $p < .05$		$\chi^2 = 4.56$ $p < .05$	
	Comparison of right hand scores of four- and five-year-old boys.		Comparison of left hand scores of four- and five-year-old boys.	

	Four	Five	Four	Five
Significant[a]	25	39	16	35
Not significant[b]	20	6	29	10
	$\chi^2 = 10.60$ $p < .05$		$\chi^2 = 16.34$ $p < .05$	
	Comparison of right hand scores of four- and five-year-old girls.		Comparison of left hand scores of four- and five-year-old girls.	

[a]The number of correlations significant at the .05 level.

[b]The number of correlations not significant.

the five-year-old boys and girls were significantly more consistent than the four-year-olds of the same sex using the same hand. In summary, the boys' right hand appears to be less consistent, and the girls' right hand more consistent than the other groups; these differences diminish with age as both hands in both sexes become more consistent.

Again, these differences may be accounted for by sex differences in rate of maturation. A comparison of the present scores with those of three- and six-year-olds would test this hypothesis. The boys may show superior left-hand scores because they lack confidence using this hand; They may impose more order on their movements as a strategy to ensure that they produce an adequate copy each time.[16] A similar situation would be found in examining a person's behavior when he is visiting a relatively unfamiliar neighborhood. The same routes are taken for a period of time so he doesn't get lost, and only after the area becomes familiar are alternate routes explored.

Because of the small number of subjects able to complete all six copies, consistency in copying the triangle was tested with a simpler and less sensitive method than correlations. There is some reason to believe that nontriangular copies were produced with less consistent movement sequence use than triangular copies; thus a comparison of the proportion of triangular and nontriangular copies completed in each cell could be a measure of consistency. With this

[16] This hypothesis would be a serious threat to the component theory if it implied that the higher scores were not due to difference in motivation, and that the child could voluntarily raise his consistency scores without first developing certain processes.

method the data from all of the children could be used, except the left handers. Many of the nontriangular copies looked very disorganized and differed greatly from each other. Figures 34, 35, 36, and 37 present some examples of the sequences and directionality of lines in four children's attempts to copy a triangle with their preferred and non-preferred hands. Observations of children whose triangle drawings were nontriangular suggested that they were searching for a way to organize their copies on each trial. These children would hesitate and look at the model more frequently than children who were able to copy the figure. This is not to say that children who were able to copy the triangles used the same rules to produce each figure, but rather that their responses were more consistent than those made by children who produced nontriangular figures. The latter children generally used new movement sequences on each attempt.

Table 21 presents the Chi-square test used for determining consistency of movement sequence use in copying the triangle. A child's score was determined by whether or not he could complete all three copies for each hand. The five-year-old girls' right hand was significantly more consistent than the four-year-old girls' right hand; no other significant differences were found. These results are not much different from those for the square if one assumes that these methods are less sensitive than correlational techniques.

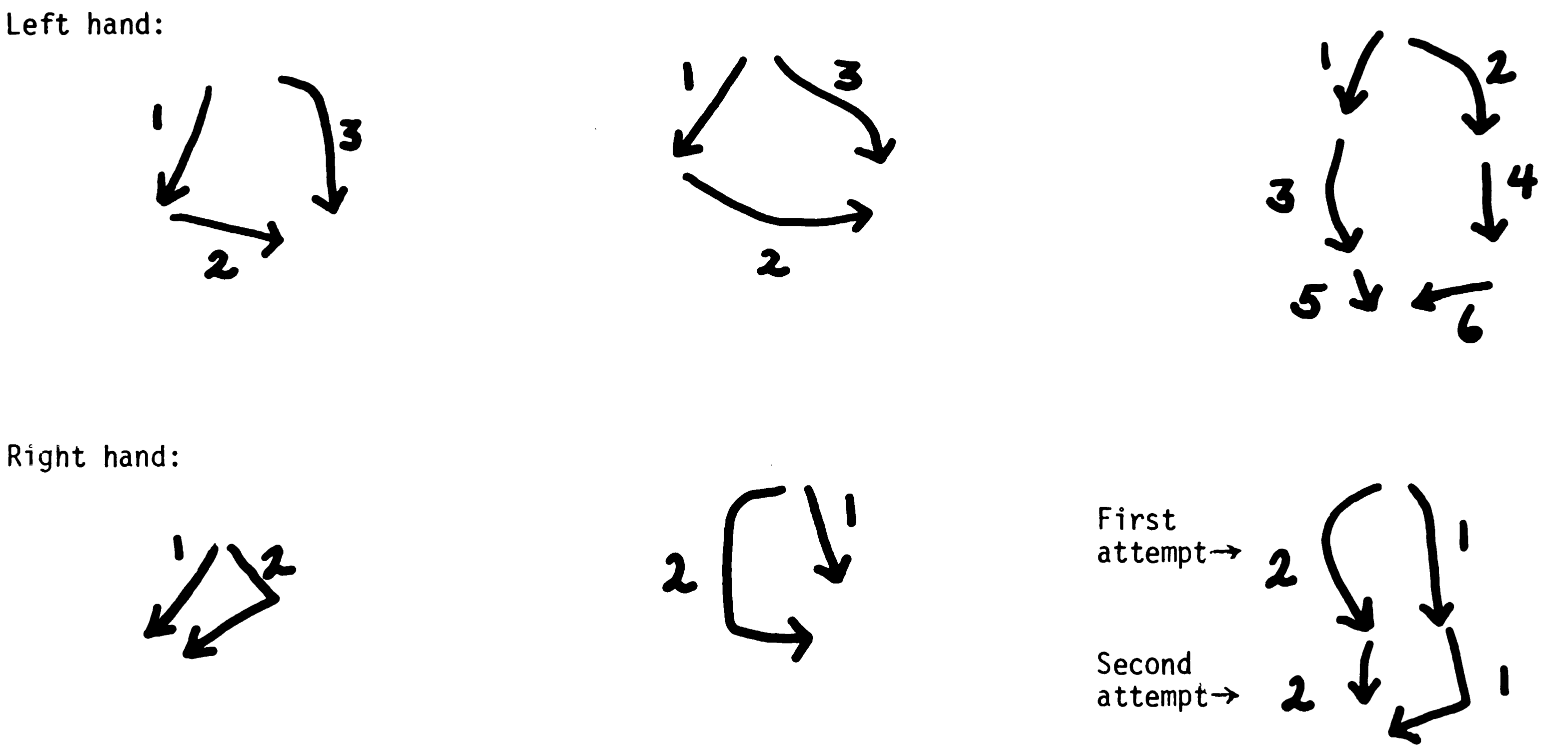

Figure 34. Attempts of a right-handed four-year-old boy to copy a triangle using his left and right hand ('NP' order).

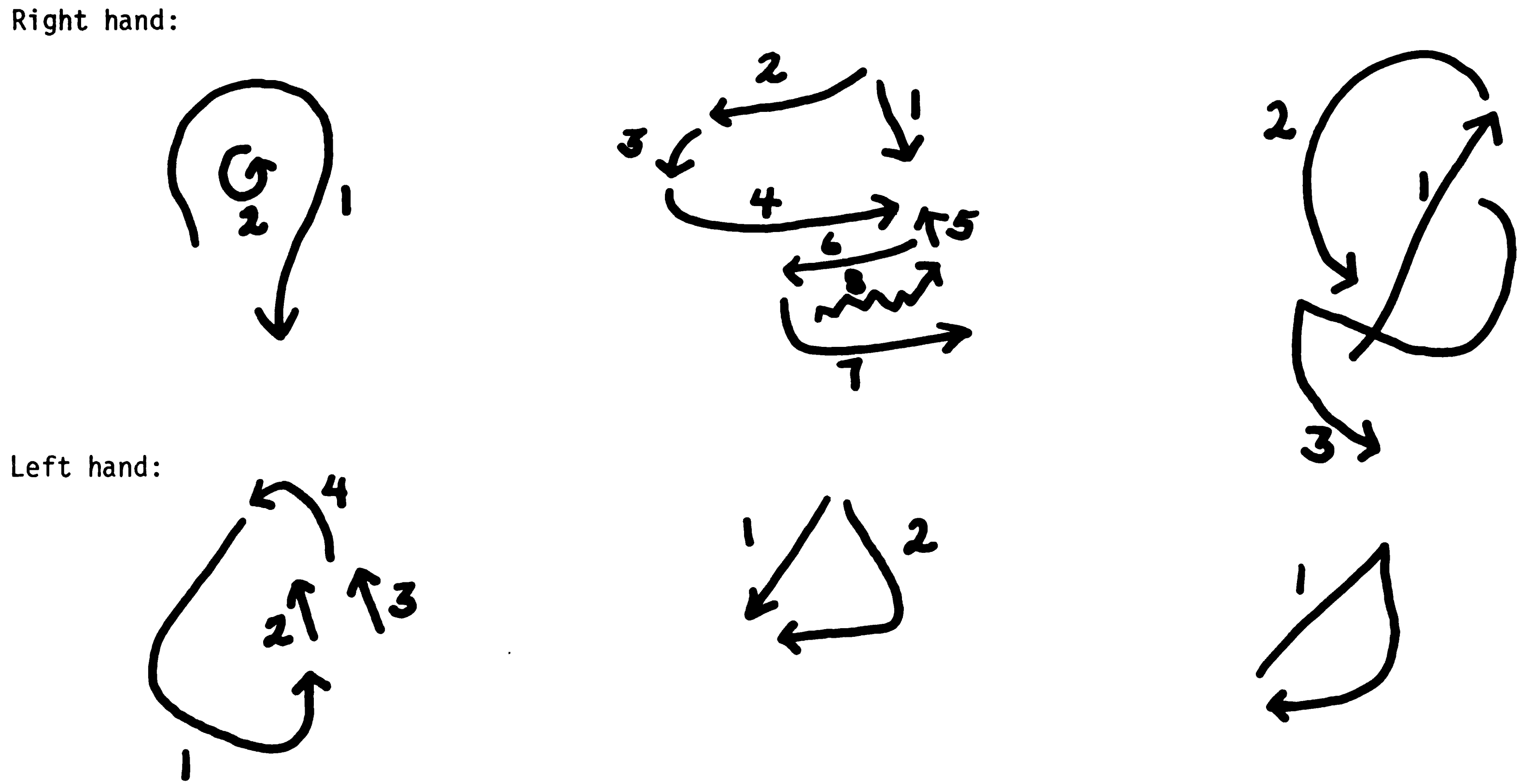

Figure 35. Attempts of a right-handed four-year-old boy to copy a triangle using his right and left hand ('PN' order).

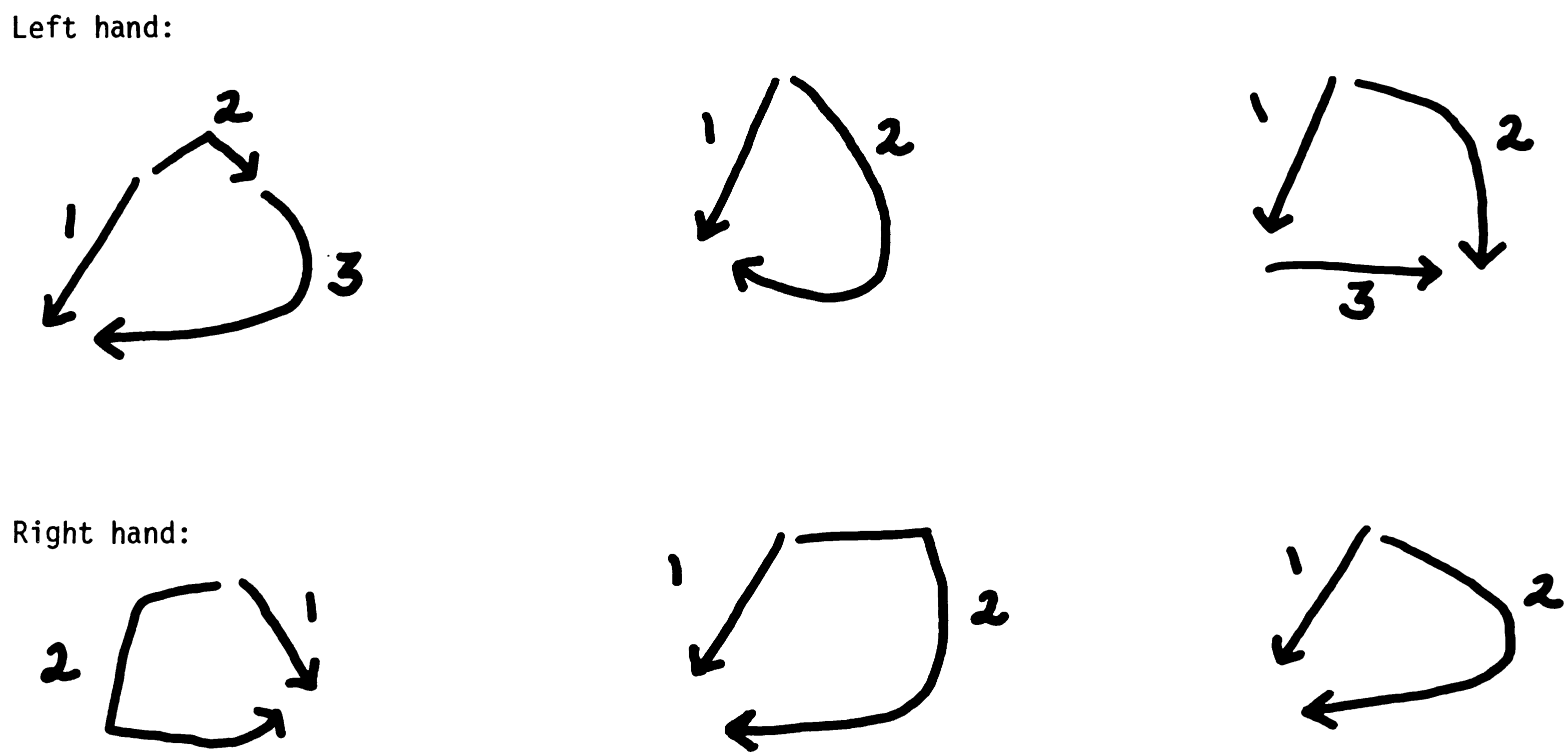

Figure 36. Attempts of a right handed four-year-old girl to copy a triangle using her left and right hand ('NP' order).

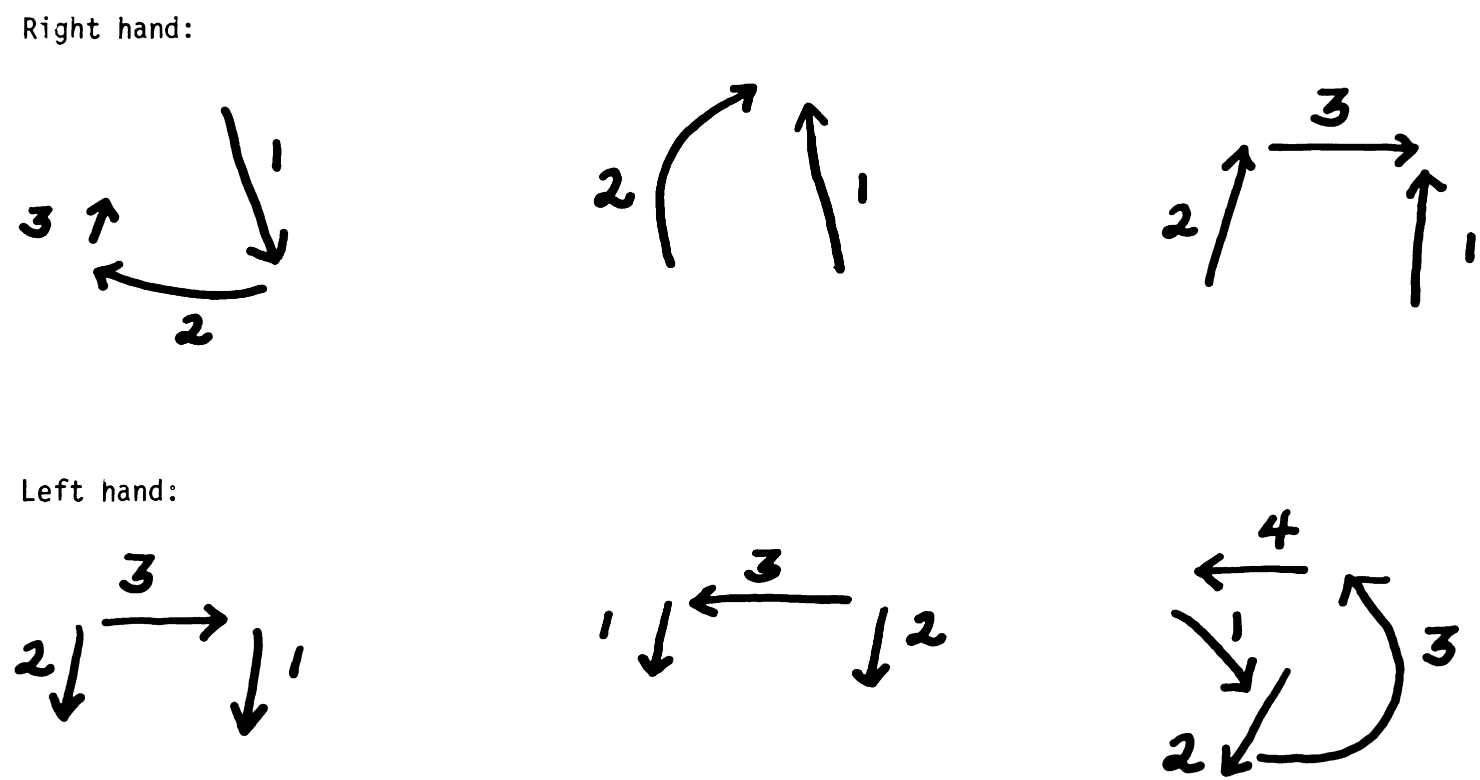

Figure 37. Attempts of a right-handed four-year-old girl to copy a triangle using her right and left hand ('PN' order).

Table 21. Chi-square tests comparing the consistency scores of right-handed four- and five-year-old boys' and girls' right and left hand copies of a triangle

	Right	Left	Right	Left
Three copies[a]	5	4	4	7
Less than three[b]	8	9	11	8
	$\chi^2 = 0.14$		$\chi^2 = 1.26$	
	Comparison of right and left hands of four-year-old boys.		Comparison of right and left hands of four-year-old girls.	

	Boys	Girls	Boys	Girls
Three copies[a]	5	4	4	7
Less than three[b]	8	11	9	8
	$\chi^2 = 1.83$		$\chi^2 = 0.73$	
	Comparison of right hand scores for four-year-old boys and girls.		Comparison of left hand scores for four-year-old boys and girls.	

	Right	Left	Right	Left
Three copies[a]	9	4	11	11
Less than three[b]	5	7	3	3
	$\chi^2 = 0.72$		$\chi^2 = 0.00$	
	Comparison of right and left hands of five-year-old boys.		Comparison of right and left hands of five-year-old girls.	

Table 21 (cont'd.)

	Boys	Girls	Boys	Girls
Three copies[a]	9	11	7	11
Less than three[b]	5	3	7	3
	$\chi^2 = 0.70$		$\chi^2 = 2.48$	
	Comparison of right hand scores of five-year old boys and girls.		Comparison of left hand scores of five-year-old boys and girls.	
	Four	Five	Four	Five
Three copies[a]	5	9	4	7
Less than three[b]	8	5	9	7
	$\chi^2 = 1.80$		$\chi^2 = 1.04$	
	Comparison of right hand scores of four- and five-year-old boys.		Comparison of left hand scores of four- and five-year-old boys.	
	Four	Five	Four	Five
Three copies[a]	4	11	7	11
Less than three[b]	11	3	8	3
	$\chi^2 = 7.99$	$p < .05$	$\chi^2 = 3.11$	
	Comparison of right hand scores of four- and five-year-old girls.		Comparison of left hand scores of four- and five-year-old girls.	

[a]Number of children who completed all three copies of a triangle.

[b]Number of children who completed less than three copies of a triangle.

Generality of Use of Movement Sequences and Age of Child

The generality of movement sequence use prediction was partially confirmed. Boys exhibited the predicted patterns, while girls showed high scores at both ages. The same subjects used in prediction 2 were used here. Generality of movement sequence use for the square was tested using procedures similar to those used to test consistency, except that the correlations were from the pairing of copies done with the right and left hands. (Note that this eliminates hand differences.) The correlations matrices are presented in Appendix E, Tables E15, E16, E17, and E18.

Table 22 shows the results of Chi-square comparisons for generality of movement sequence for each age x sex group. Four-year-old boys show significantly less general rule use than any other group; no other comparisons are significant.

The sex differences may be explained by boys' slower maturation rate. The girls could be considered as more 'advanced' than the boys.

Generality of rule use for the triangle was measured by comparing the number of children in each group who could complete all six copies. All the right-handed children were used as subjects. Table 23 shows the results of Chi-square comparisons. Five-year-old girls were significantly more general than four-year-old girls; the five-year-old girls also show a trend to be more general than the five-year-old boys. No other significant differences were found. These results are similar to those found for the square.

Table 22. Chi-square tests comparing the generality scores of right-handed four- and five-year-old boys' and girls' copies of a square

	Boys	Girls	Boys	Girls
Significant[a]	12	55	55	58
Not significant[b]	123	80	80	77
	$\chi^2 = 36.70$ $p < .05$		$\chi^2 = 0.14$	
	Comparison of scores of four-year-old boys and girls.		Comparison of scores of five-year-old boys and girls.	

	Four	Five	Four	Five
Significant[a]	12	55	55	58
Not significant[b]	123	80	80	77
	$\chi^2 = 36.70$ $p < .05$		$\chi^2 = 0.14$	
	Comparison of scores of four- and five-year-old boys.		Comparison of scores of four- and five-year-old girls.	

[a]Number of correlations significant at the .05 level.

[b]Number of correlations not significant.

Table 23. Chi-square tests comparing the generality scores of right-handed four- and five-year-old boys' and girls' copies of a triangle

	Boys	Girls	Boys	Girls
Six copies[a]	2	4	7	11
Less than six[b]	11	11	8	3
	$\chi^2 = 0.56$		$\chi^2 = 3.72$	
	Comparison of four-year-old boys and girls.		Comparison of five-year-old boys and girls.	

	Four	Five	Four	Five
Six copies[a]	2	6	4	11
Less than six[b]	11	8	11	3
	$\chi^2 = 2.43$		$\chi^2 = 7.82$ $p < .05$	
	Comparison of four- and five-year-old boys.		Comparison of four- and five-year-old girls.	

[a]Number of children who could complete all six copies of a triangle.

[b]Number of children who completed less than six copies of a triangle.

In summary, there is some support for all the predictions except the first. However, unusual hand differences and sex differences made necessary the addition of auxiliary hypotheses to explain the results.

A Neuropsychological Interpretation of the Results

A more complex explanation of the results using the component theory is based on Luria's (1966) principles that describe the development of 'higher mental functions' such as copying. Luria states that many different abilities work together as a system to make up a complex skill, and that at different stages of development one or more of these abilities will be of greater importance than the others. For example, when a child first learns to write from dictation, the sound analysis of the word and the search for the appropriate grapheme is of greater importance than recoding the word into a visual image and kinesthetic movements. In studying the development of copying skill, one must add another principle; not only do the relations of the component abilities change, but the abilities also undergo qualitative changes. For example, Piaget and Inhelder (1956) and Olson (1970) contend that the child must possess operational thought to successfully copy. This type of thinking represents a qualitatively different way of dealing with the environment than found in the sensorimotor stage. It will be argued here that the sequencing of movements plays a crucial role in the development of copying skills in children from three to seven years of age. This does not imply that the role of spatial-infralogical operations should be de-emphasized, but that the working of the operations and sequencing of movements as a system should be the proper focus of our attention.

Copying skill is the result of perceptual, cognitive, and sensorimotor abilities acting together as a system; the shift from sensorimotor functioning to operational thought represents a qualitative change in the child's cognitive abilities. The operations reorganize the sensorimotor abilities enabling the child to produce copies that preserve metric features found in the model. To say that a child is functioning at a preoperational level implies the absence of the operations which reorganize the sensorimotor abilities, that is, the preoperational child lacks the adequate cognitions to guide his constructions. Note that the sensorimotor abilities are considered here as a separate component in the system. It is postulated that this component has its own representation of space, and that this spatial organization is largely topological when it is not reorganized or influenced by the operations. Bernstein (1967) concluded, after studying the paths of movements used by adults performing sensorimotor tasks such as hammering and walking, that the central representations of movements are organized in a manner that can be generally described as topological. His description of this spatial organization corresponds very closely to Piaget and Inhelder's (1956) description of the preoperational child's spatial concepts. In copying, it appears that the child must develop concepts of space (i.e., operations) that will reorganize a sensorimotor component that is predisposed to have a largely topological organization.

This conceptualization of copying skill can also be used to explain the perception-performance lag. Each component has its own representation of space, and various tasks will reveal the spatial representation of each. Olson (1970) notes that children 'know' (that is, recognize perceptually) the diagonal as a 'unitary, unanalyzed configuration' even though they are unable to copy it. Maccoby and Bee (1965) also note that children can discriminate among figures before they can copy them. This is an indication that the perceptual component has the capacity to recognize metric features of objects, but this knowledge cannot be used to reorganize the sensorimotor component. The cognitive component must possess operational thought before the sensorimotor component can be reorganized for successful copying. Once operational thought is achieved, it may or may not be used to organize actions. For example, adults' actions are 'metric' in nature for cultural skills such as copying, but 'topological' for skills such as tennis playing. This conceptualization can also be used to explain individual differences in copying. Strengths or weaknesses in certain component abilities will produce various changes in the quality of the reproduction and how it is executed.

It is hypothesized that at four- and five-years of age, girls are better copiers than boys because girls have better ability to execute sequences of fine movements--an ability also reflected in their greater expressive language skill (see Harris, 1975b). Although boys may possess superior spatial-infralogical ability, their copies are of poor quality because they have inferior motor sequencing abilities.

Copying for boys may be more of a sensorimotor task. They would rely more on external cues such as the edges of the table, paper, or model to guide their movements in copying a square. These skills seem to depend largely on a 'wholistic' type of functioning that is subserved by the right hemisphere. This is what may make the boys' left hand 'dominant' for consistency in copying. The quality of the copy would not necessarily be superior, however, since there is no central process that determines overall organization.

An important test of this theorizing would be a demonstration of a positive correlation between the quality of the copies produced and language ability. Verbal fluency would be an appropriate skill to examine because it seems to require a great deal of motor sequencing. In this context, tasks such as throwing an object at a target and the pursuit rotor task would not be considered as adequate measures of motor sequencing ability. These two tasks appear to require sensorimotor abilities, that is, they require the subject to coordinate his movements to objects and events in the external environment. Copying and speaking, however, are more determined by internal processes. One must also demonstrate that the absence of any spatial-infralogical ability and the presence of some motor ability results in copies of poor quality, and that a high degree of competence in both abilities is associated with copies of superior quality.

Demonstrating the presence and degree of the spatial-infralogical abilities presumed to be important in copying is far more difficult because it is not clear what kinds of tasks adequately measure these abilities. For example, Goldschmid (1967) tested six- and seven-year-olds on a variety of Piagetian conservation tasks and found that boys were significantly better than girls on two tasks that involved spatial factors. Whether these tasks are related to the spatial abilities in copying is unknown. A study by Nebes (1971) of intermodal matching in adults seems a closer test of the spatial-infralogical operations. The subjects were required to touch arcs made of plexiglass that were hidden from view with one hand and determine which arc could have come from a full circle of plexiglass presented visually. For right-handed subjects, Nebes found better left-hand performance for this task; no sex differences were reported. This task seems to test spatial-infralogical abilities; the subject must remember the entire shape of the figure and yet break it down into segments to determine which arc is part of the circle. A visual, intramodal presentation of this task could be used to test children.

An important prediction from this theorizing is that sex differences in quality scores should change when copying becomes more automatized for both boys and girls. That is, when the children's copying skill is developed to the point where stereotyped sequences of movement are possible, boys' superior spatial skills should become apparent (see Harris, 1975a) and their quality scores should be higher than those of girls.[17] Consistency should be an adequate measure of

[17] The prediction of male superiority in copying is an inference from many other studies where males are shown to excel in spatial skills (see Harris, 1975a). No attempt is made here to use one of the various neurological models (see Harris, 1975a) to explain the sex differences; this is a complex issue that deserves far more space than is available here. Note, however, that viewing copying (or any other skill) as a

automatized or stereotyped functioning. According to the component theory, high consistency scores are an indication of a stable, efficient system for copying.[18] (Note in the present data that the five-year-old girls' right hand consistency scores show 39 significant correlations out of a possible 45.) Preliminary findings from a study by Harris and Petkovich (1974, in preparation) support the hypotheses presented above. Right-handed male college students show higher overall quality scores than right-handed women, and show a greater right hand superiority.

The boys' inferior quality, generality, and consistency scores may result from their greater dependence on sensorimotor skills in copying. That is, external, visual cues such as the edge of the table, paper, and the model itself may provide enough information so the boys can use the topological concept of proximity to guide their constructions. The low scores result because there is less reliance on internal processes that could organize the entire construction of the copy and produce consistent motor sequences. This hypothesis could be tested by having four- and five-year-olds copy squares and triangles on triangular

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system of components complicates any investigation of neurological functioning.

[18] Buffery's (1971) and Taylor's (1969) neuropsychological studies indicate that girls become lateralized for language before boys, and that boys are not well lateralized for language until seven years of age. This neurological event may be responsible for a new stage in copying. Warrington (1969) notes that the hemispheres in adults are responsible for different components of copying skills. The right hemisphere is responsible for the overall organization of the copy, while the left hemisphere determines the sequences of movements. Lateralization may make this 'division of labor' possible.

and square pieces of paper. If the child relies on sensorimotor processes to guide his copying, then copying a figure on paper of a different shape from the figure should disrupt his performance; this should have little effect on the performance of a child who relies on internal processes. All of the children should be able to copy figures on paper with the same shape as the figure.

The boys' high left-hand consistency scores may be better understood if one interprets 'topological concepts' as visual-spatial processes; note that the topological concepts are actually statements about how children use visual information to guide their motor behavior. If we assume that these processes are subserved by the right hemisphere as they are in adults (see Harris, 1974), and that the right hemisphere better controls sensorimotor functions of the left hand as in adults (see Semmes, 1967), we can understand why the boys' left hand is 'dominant' for consistency. Unlike the functional hypothesis presented earlier, one would predict that practice with the left hand would result in little or no increase in consistency. One should also find left hand superiority in consistency in children who function at a sensorimotor level on other copying tasks.

To summarize, two alternative explanations are presented to account for the results. The first is the addition of auxiliary hypotheses to the component theory, while the second enlarges the component theory by postulating sex differences in functioning and the relative importance of motor and spatial-infralogical abilities.

Is There a Grammar of Copying?

In creating a comprehensive theory that explained a number of facts about copying, Goodnow and Levine's (1973) grammar theory has been radically reinterpreted and integrated with other theories and ideas. That is, there is some truth and some nonsense in their theory, and this can be seen only when one has an adequate understanding of the underlying processes in copying and in language.

Both copying and language involve the sequencing of motor behavior, but other components in the skills are very different. In language a set of rules (a grammar) determines the overall organization of a sentence, and the rules must be followed if a certain idea is to be expressed. Although paraphrasing is possible, too many changes in wording result in a change in meaning, and a violation of grammatical rules results in nonsense. There also must be mechanisms that recode the grammatical knowledge into motor behavior for speaking and writing. In copying, however there is no grammar available. The individual must analyze the entire shape of the model and invent the sequences of movement and their overall organization. The final goal is a copy that resembles the model. The present study lends some support to the hypothesis that the sequences and directions of movements used to obtain this are largely irrelevant. Copying may resemble other motor tasks in that the substitution of new movements in various parts of the task do not disrupt overall performance.

If these characterizations of copying and language are accurate, explanations of these two skills can be achieved only with theories that deal with the unique combinations of underlying process in each. Facile generalizations about a 'grammar of copying' are inadequate; not only is it difficult to generate predictions from such a vague analogy, but it also emphasizes only one aspect of copying. The theorizing presented earlier in this section and the Introduction indicates that copying skill is a system of various processes, and the proper functioning of one or more of the processes may be crucial in a particular developmental stage. Thus a motor sequencing process that is common to both language and copying may be of great importance for children between the ages of three and seven. This theory eliminates the analogy between language and copying, and creates a parallel between copying and neuropsychological models of brain functioning and cybernetics.

The distinction between an 'analogy' and a 'parallel' can be better understood by referring to Piaget's (1968) classification of psychological theories. Goodnow and Levine's (1973) 'grammar of copying' is an example of 'psychological reductionism' where different phenomena are explained by principles that remain unchanged throughout development. The development of new behavior is explained by shifts in 'rule' usage. The component theory is an example of a 'constructivist' explanation. The child's behavior is viewed as 'innovatory,' that is, there are constructive processes in development that are not simply the result of past experiences. It is also postulated that there are underlying physiological mechanisms that are responsible for changes in the psychological sphere.

APPENDICES

APPENDIX A

COUNTERBALANCED ORDERS OF PRESENTATION

The children were required to draw the geometric forms in one of the following orders. 'P' is the child's preferred hand, or the one he uses to copy. 'N' is the child's nonpreferred hand. Each child was randomly assigned to one of these orders, and approximately an equal number of children in each age group did one of the orders.

P[123123123, Reed and Smith test] N[repeat 'P' order]
N[123123123, Reed and Smith test] P[repeat 'N' order]
P[132132132, Reed and Smith test] N[repeat 'P' order]
N[132132132, Reed and Smith test] P[repeat 'N' order]
P[213213213, Reed and Smith test] N[repeat 'P' order]
N[213213213, Reed and Smith test] P[repeat 'N' order]
P[231231231, Reed and Smith test] N[repeat 'P' order]
N[231231231, Reed and Smith test] P[repeat 'N' order]
P[312312312, Reed and Smith test] N[repeat 'P' order]
N[312312312, Reed and Smith test] P[repeat 'N' order]
P[321321321, Reed and Smith test] N[repeat 'P' order]
N[321321321, Reed and Smith test] P[repeat 'N' order]

where

1 = the square
2 = the triangle
3 = the half cross.

APPENDIX B

PROTOCOL

Steps 2 through 6, 12, 13, 15 and 17 were followed exactly for each child.

1. "Hello (child's name). I'd like you to draw some pictures for me today." (The experimenters continue to talk to the child to make him feel comfortable.)
2. Move the chair to the correct orientation; it should be placed so that the child is right next to the table and the front of the seat of the chair is parallel to the edge of the table. Don't let the child sit on his knees.
3. "Let's draw now. I'll hold the page down so it doesn't move around on the table."
4. Make sure the page is always at the same place and orientation on the table. It should be parallel to the edge of the table and one inch away from the edge.
5. "Make a picture just like this one (the experimenter points to the geometric figure) down here (the experimenter uses his hand with fingers extended, palm down, to indicate the area of the page)."
6. "Here's a pen." (The pen is placed vertically in the center of the page with the point towards the top.)

7. Let the child pick up the pen and draw. If the child is in the NP order, place the pen in his other hand and let him draw.
8. "Are you done now?" (If yes, take the page and go on, if no, wait until the child is done and ask him again.)
9. "Are you done now?"
10. Go on to the next drawing.
11. "Let's do another one." (Or, "How about another one?" etc.)
12. Hold down the page.
13. Repeat step 5.
14. Repeat from step 8 for the remaining 'P' or 'N' drawings.
15. "See this drawing?" (The experimenter points to the completed figure at the top of the Reed and Smith test.) "Someone started one just like it down here (the experimenter points to the incomplete figure at the bottom) but didn't finish it. Can you finish it?"
16. If the child seems tired here or anywhere through the procedure, allow him to get out of the chair and walk around. Be sure to talk to the child.
17. "Now I'd like you to make some drawings with this hand." (The experimenter puts the pen in the child's other hand.)
18. Repeat as in previous drawings for all nine 'N' (or 'P') copies and repeat the Reed and Smith test.

APPENDIX C

CODEBOOK FOR TRANSFERRING DATA TO COMPUTER CARDS

Variables 1 through 3, 19 through 36, 45, 55 through 66, 73, 75, and 80 were not used in the correlations.

1. and 2. ID number
3. card number
4., 5., and 6. age in months
7. sex: male = 1 female = 2
8. handedness: right = 1 left = 2
9. order: PN = 1 NP = 2
10. limb used: right hand = 1 left hand = 2
11. Reed and Smith test: left to right = 1 right to left = 2

<u>Variables for the Square</u>

12. number of lines (1 to 5 where 5 = 5 or more)
13. first line top start
14. first line bottom start
15. first line left start
16. first line right start
17. first line horizontal
18. first line vertical
19. second line top start
20. second line bottom start
21. second line left start
22. second line right start
23. second line horizontal
24. second line vertical
25. third line top start
26. third line bottom start
27. third line left start
28. third line right start
29. third line horizontal
30. third line vertical
31. fourth line top start
32. fourth line bottom start
33. fourth line left start
34. fourth line right start
35. fourth line horizontal
36. fourth line vertical
37. ↑↑
38. ↓↓
39. ↑↓
40. ↓↑
41. {⇉
42. {⇇
43. {⇄
44. {⇆
45. number of hesitations (1 to 4)
46. quality (1 to 7)
47. uncodable

Variables for the Triangle

48. number of lines (1 to 4 where 4 = 4 or more)
49. apex start first
50. left corner start first
51. right corner start first
52. left oblique first
53. right oblique first
54. base first
55. apex start first
56. left corner start second
57. right corner start second
58. left oblique second
59. right oblique second
60. base second
61. apex start third
62. left corner start third
63. right corner start third
64. left oblique third
65. right oblique third
66. base third
67. ↗ ↖
68. ↙ ↘
69. ↗ ↘
70. ↙ ↖
71. →
72. ←
73. number of hesitations (1 to 3)
74. quality (1 to 7)
75. uncodable

Variables for the Half Cross

76. horizontal (0) or vertical (1) first
77. vertical: top to bottom (0) or bottom to top (1)
78. horizontal: left to right (0) or right to left (1)
79. quality (1 to 7)
80. uncodable

APPENDIX D

QUALITY SCORING SYSTEMS FOR THE SQUARE, TRIANGLE, AND HALF CROSS

The quality of the copies was scored according to the systems below. Each figure has a scoring system based on a scale from 1 (poorest quality) to 7 (superior quality).

The Square: Scoring System

A square is defined as having four angles, each between 80 and 100 degrees. The longest side is not longer than 1 1/4 times the shortest side; if the longest side exceeds this limit, the figure is a rectangle. Each figure is also scored on the basis of how many deviations are found. There are two types of deviations:

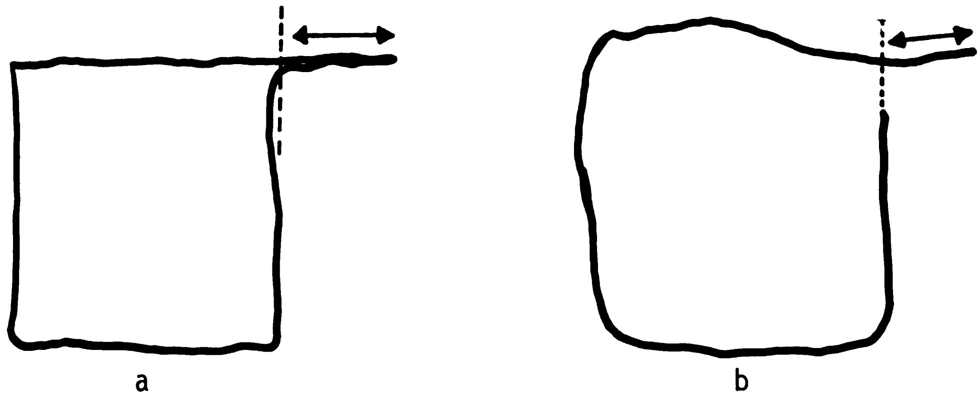
Type A Deviations:

1. The copy has a gap longer than or equal to 3/16 of an inch. A gap is measured by taking the shortest distance between the end points of the two lines.

2. The copy has a crossover, i.e., a line that runs beyond the boundaries of the figure and is longer than or equal to 3/16 of an inch. The cases illustrated in Figure D1 are measured from the dotted line to the endpoint of the line that is outside the figure. The crossover in Figure D2 is measured as the greatest distance from the corner to the end of the loop.

3. The copy has a curved or wavy line. This is measured as a deviation from a straight line connecting the two endpoints of the line drawn that is 3/16 of an inch or more.

4. A 'rotated' copy has a horizontal side that deviates from the horizontal edge of the paper by 15 degrees or more, and a vertical side deviating from the vertical edge of the paper by 15 degrees or more.



a b

Figure D1. Examples of how 'crossovers' are measured.

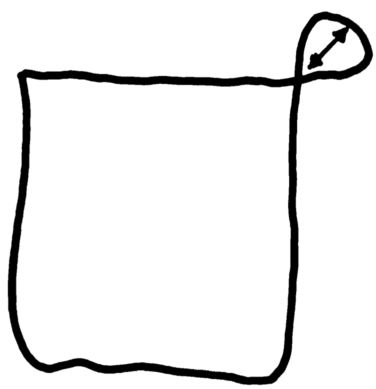


Figure D2. Example of how a 'crossover' is measured.

Type B deviations are smaller than Type A deviations.

Type B Deviations:

1. The copy has a gap between 1/16 and 3/16 of an inch.

2. The copy has a crossover between 1/16 and 3/16 of an inch.

3. The copy has a side with a deviation from a straight line between 1/16 and 3/16 of an inch.

4. A 'rotated' copy has a horizontal side and a vertical side that deviate between 5 and 15 degrees from the edges of the paper.

A copy cannot have more than four deviations from any one category. For example, a copy with two Type B gaps is scored as having one Type B deviation. A copy with two Type A gaps and three sides with Type A wavy lines is scored as having two Type A deviations. The following methods were used to score the copies.

Deviations were measured by using the template shown in Figure D3; this pattern was transferred to a Kodak transparency. The vertical and horizontal lines are perpendicular, and the lines radiating around each of these four lines subtends ten degrees. The vertex of the template was placed on a corner of the copy; if the copy had a rounded corner, the midpoint of the curved portion of the line was considered as the 'corner.' The horizontal line on the template was adjusted so that the endpoints of the copy's line fell on it. The right vertical line of the copy was then examined to see if any part of it fell outside the radiating lines. If it did, this was considered a deviation from 'squareness.' Figure D4 illustrates how the template was used to measure angles.

The parallel lines at the bottom of Figure D3 were used to determine gaps and wavy lines. Figure D5 illustrates how the template was used to measure gaps. The line marked X in Figure D5 was placed over the copy so it touched the endpoint of one line. The template was then adjusted so that a straight line connecting the endpoints of the two lines was perpendicular to the parallel lines on the template. A type A deviation occurred if the endpoint of the second line fell beyond the last parallel line marked Z in Figure D5, and a Type B deviation was recorded if the endpoints fell between the two outer lines marked Y and Z on Figure D5.

Wavy and curved lines were measured by placing the template over the copy so the endpoints of the line measured fell on the central line of the template; this is shown in Figure D6. If any portion of the line extended to the area between Y and Z, a Type B error was recorded. If

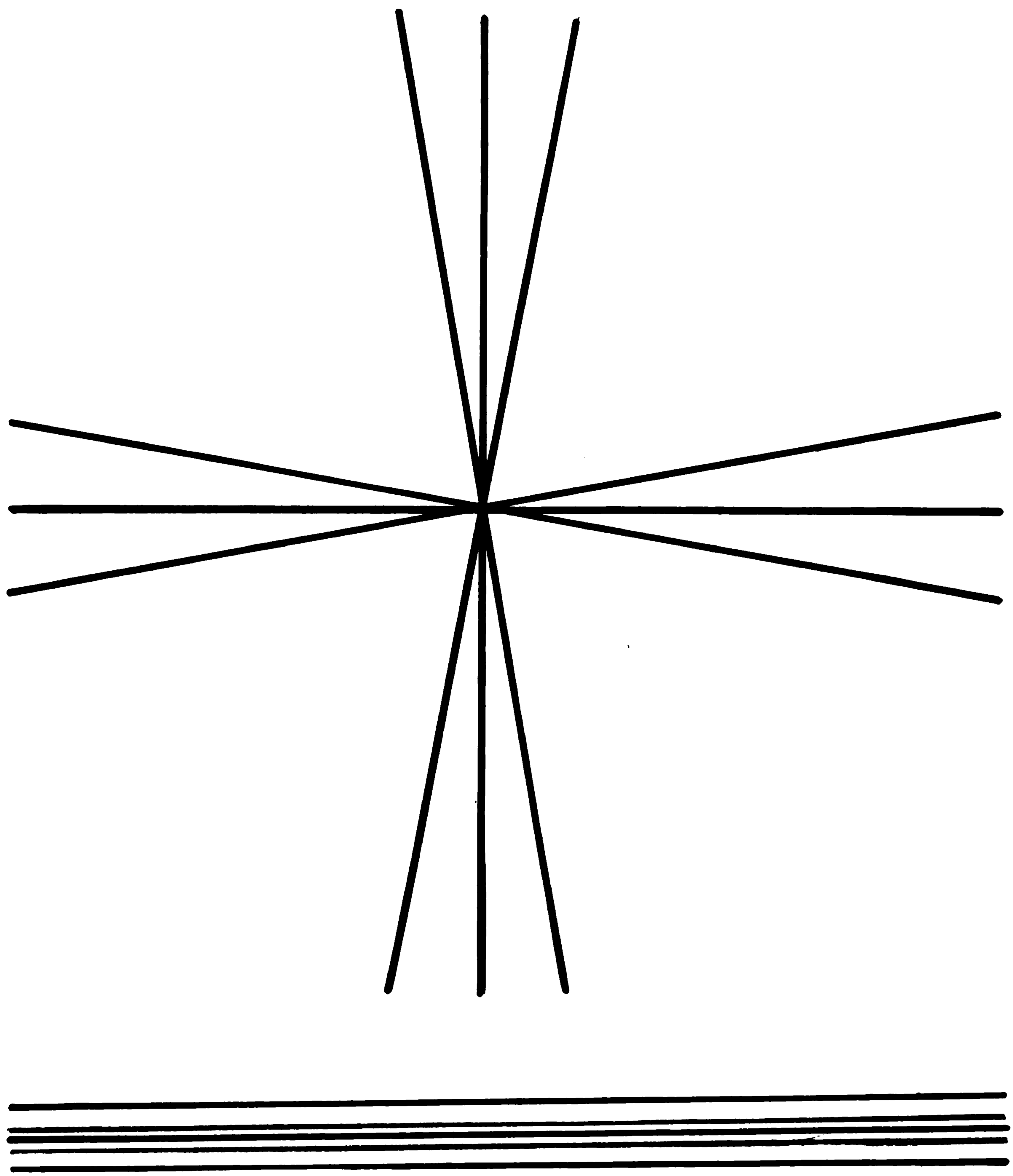


Figure D3. Template used to measure how well proportioned and what type of deviations are present in copies of the square and half cross.

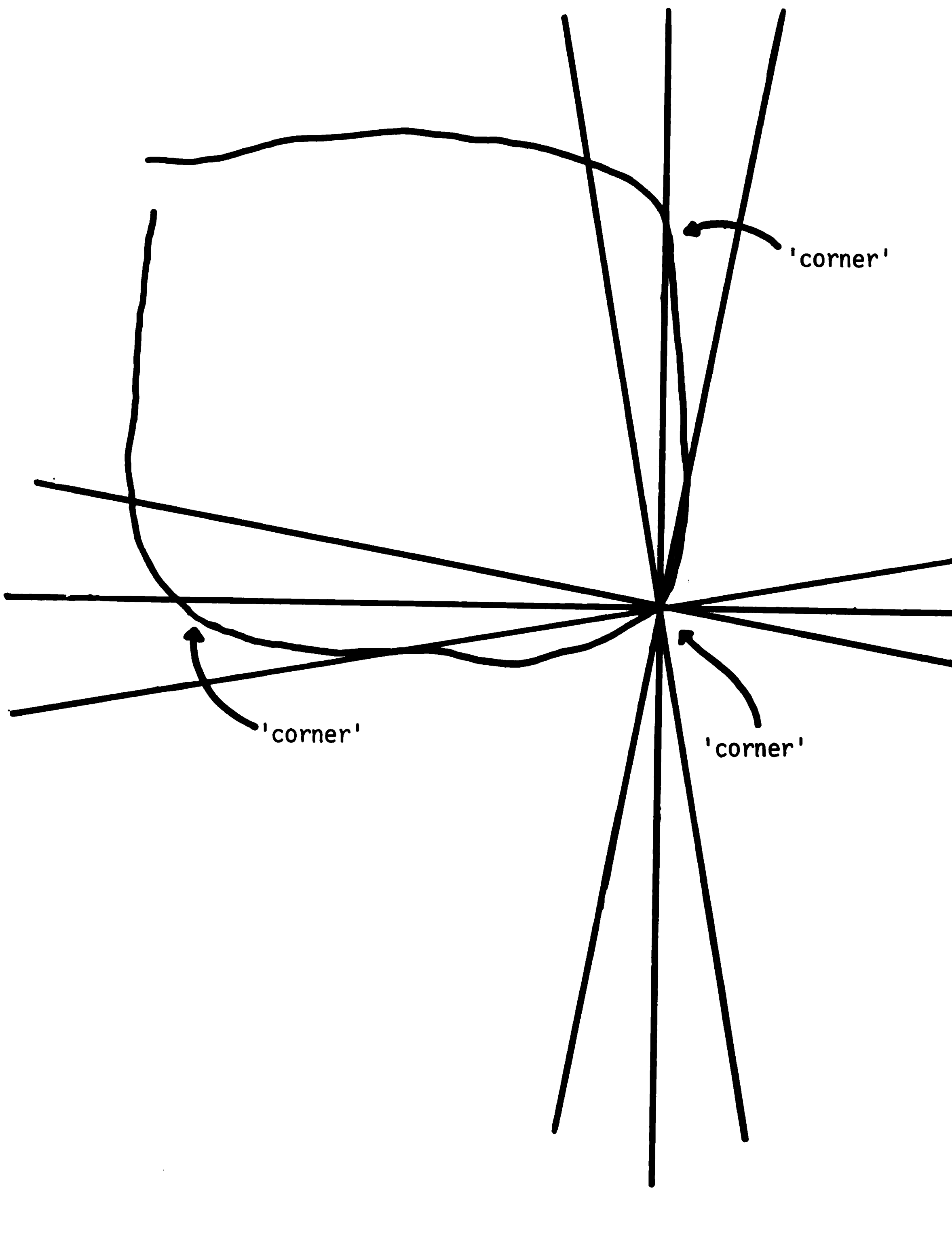


Figure D4. Example of how the template (of Figure D3) is used to measure angles in copies of the square.

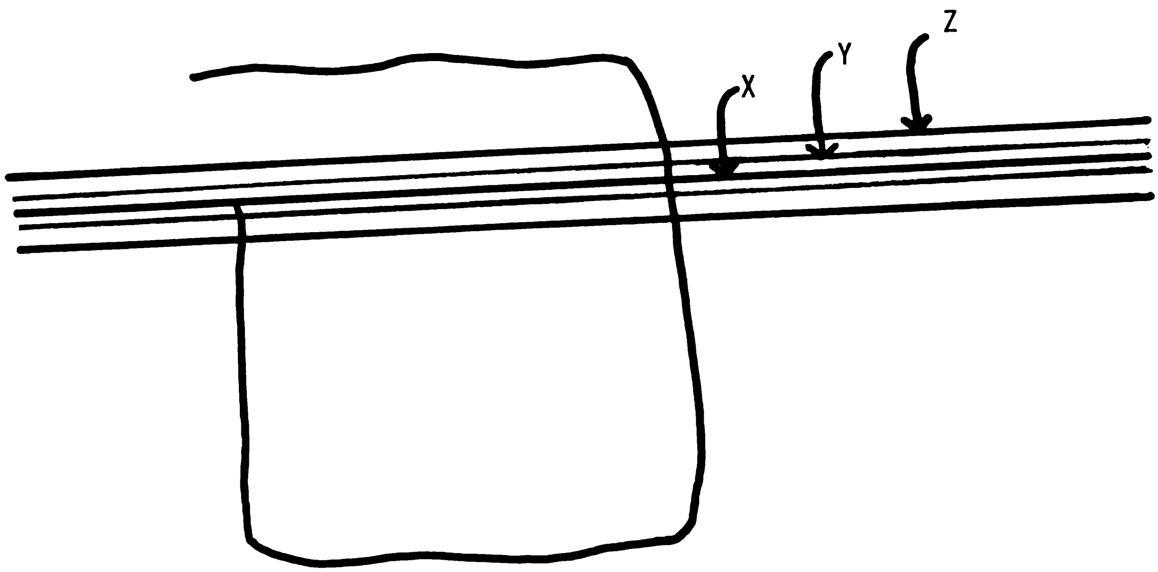


Figure D5. Example of how the template (of Figure D3) is used to measure gaps in copies of the square.

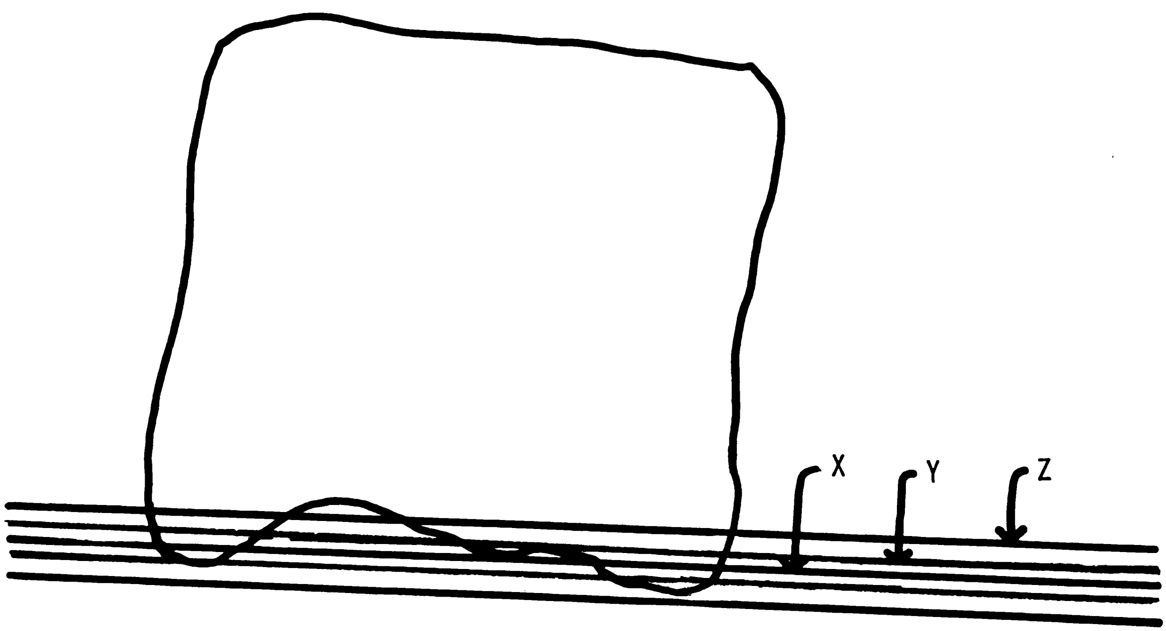


Figure D6. Example of how the template (of Figure D3) is used to measure wavy lines in copies of the square.

the line extended past Z, a Type A error was recorded. No distinction was made between curved and wavy lines. The endpoint of a line in a copy with rounded corners was considered the midpoints of the rounded portion of the corner.

Rotations were also measured using the template. The template's edge was kept parallel to the paper's vertical or horizontal edge, and the deviation of the copy's lines were estimated.

The largest deviation in any category was scored. For example, if a copy had a Type A gap and a Type B gap, the Type A gap was recorded.

The following system was used to rate the copies:

1
The copy has no form: it may be a scribble, angular line, or a tracing of the model.

2
The copy is a closed form, but it has no resemblance to the model; the copy may be circular, pear-shaped, or a greatly deformed angular shape.

3
The copy is one of the following:

a. A trapezoid or rhomboid shape; the presence of one or more angles greater than or equal to 100 degrees or less than or equal to 80 degrees.
b. A figure with three angles.
c. A rectangle (see the definition of a 'square').
d. A square with three or more A deviations.

4
A square with one or two Type A deviations, or three or four Type B deviations.

5
A square with one or two Type B deviations, or a poorly proportioned 6.

6
The copy is very much like the model; it is between 1 1/2 to 2 inches in height and width. Crossovers, gaps, and wavy lines are equal to or less than 1/16 of an inch. Any rotation is 5 degrees or less.

7
The copy is almost identical to the model.

Inter-rater reliability for three judges as determined by the Spearman-Brown prediction formula (see Winer, 1962) was 0.92 on a sample of 50 copies before rating began. The reliability coefficient was 0.95 on 25 copies after each judge had scored 70 copies.

The Triangle: Scoring System

An equilateral triangle is defined as having three angles between 53 and 67 degrees; the longest side is not longer than 1 1/4 times the shortest side. A copy with a side 1 1/4 times the shortest side is not an equilateral triangle. The same deviation Types as in the square were used. The template used for the triangle is shown in Figure D7. The procedures for measuring deviations are the same as in the square, except that the model of the triangle on the transparency was used to determine how well proportioned the copy was.

The following system was used to rate the copies:

1

The copy has no form; it may be a line that is not closed, a scribble, an angular line, or a tracing of the model.

2

The copy is a closed form, but it has no resemblance to the model; it may be circular, rectangular, or partially opened.

3

The copy is not an equilateral triangle or it is an equilateral triangle with three or four Type A deviations.

4

The copy is an equilateral triangle with one or two Type A deviations or three or four Type B deviations.

5

The copy is an equilateral triangle with one or two Type B deviations or a poorly proportioned 6.

6

The copy is very much like the model; the sides are 1 1/2 to 2 1/2 inches in length, and any rotation is five degrees or less.

7

The copy is almost identical to the model.

Inter-rater reliability for three judges as determined by the Spearman-Brown prediction formula (see Winer, 1962) was 0.93 on a sample of 50 copies before rating began. The reliability coefficient was 0.92 on 25 copies after each judge had scored 70 copies.

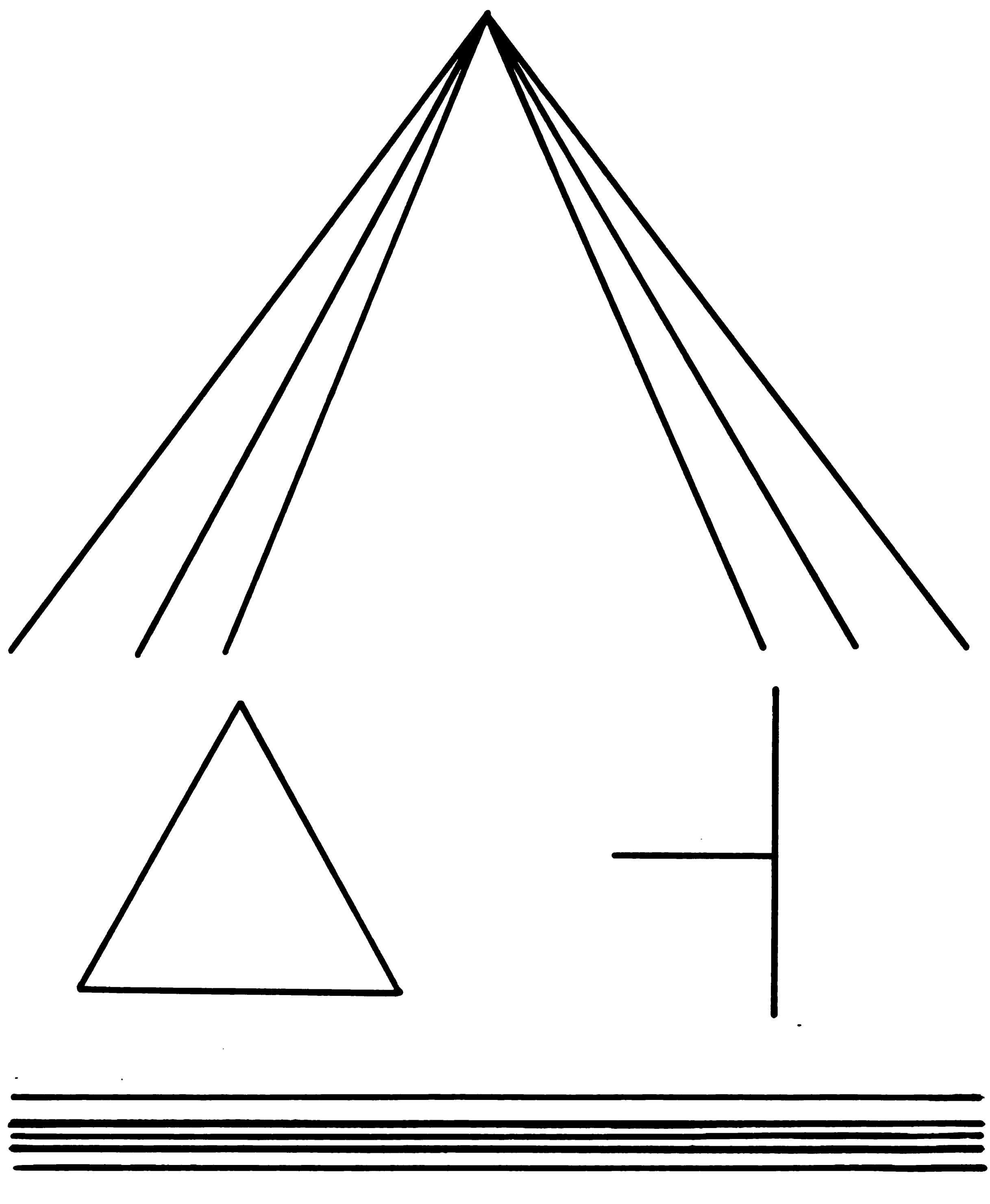


Figure D7. Template used to measure how well proportioned and what type of deviations are present in copies of the triangle, and models of the half cross and triangle.

The Half Cross: Scoring System

The figure is considered to have three lines: a horizontal line and two vertical lines that are formed by the intersection of the horizontal line. The longest line of the half cross is not more than 2 1/2 times longer than the shortest line, and any horizontal line crossing over the vertical line does not exceed 1/2 of the length of the horizontal line to the left of the vertical line. There are two types of deviations; these are similar to those for the square and triangle.

Type A Deviations:

1. The copy has a crossover between 1/2 and 1/4 times as long as the left horizontal line. If the copy's vertical line is less than one inch, the crossover then must exceed 3/16 of an inch.

2. The copy has two angles (where the horizontal and vertical lines intersect) where one exceeds 100 degrees and the other is less than 80 degrees.

3. The copy has a gap greater than or equal to 3/16 of an inch.

4. The copy has a curved or wavy line that deviates from a straight line connecting the endpoints by 3/16 of an inch.

5. The horizontal line is not centered on the vertical line. The center is defined as 1/4 of the vertical line's distance on either side of the center of the vertical line.

6. One line is 2 to 2 1/2 times longer than the shortest side.

7. The vertical line is rotated greater than 100 or less than 80 degrees from the vertical of the edge of the page.

Type B Deviations

1. The copy has crossovers between 1/16 and 3/16 of an inch.

2. The copy is noticeably rotated, but not beyond 80 to 100 degrees of the vertical of the page.

3. The copy has gaps between 1/16 and 3/16 of an inch.

4. The copy has a curved line that deviates from a straight line connecting the endpoints by 1/16 to 3/16 of an inch.

5. The copy's longest side is 1 1/2 to 2 times longer than the shortest side.

6. The copy has one angle that is greater than 100 degrees or less than 80 degrees.

The following categories were used:

1

The copy is an enclosed figure, or one of the forms illustrated in Figure D8. Figure D8a may be considered a 'rotation.' In this case the horizontal line (now a vertical line) must fall outside boundaries of 150 to 210 degrees. Figure D8b has a right horizontal line that is 1/2 as long or longer than the left horizontal line. Figure D8c is a 'reversal' of the horizontal line. All copies that do not conform to the definition of the half cross on page 133 are in this category.

2

The copy is a half-cross in basic form, but the longest line is 2 1/2 to 2 times the shortest line.

3

The copy is a half cross, but has two or more Type A deviations or the second deviation listed in the Type A deviations.

4

The copy may have one Type A deviation, two or more Type B deviations, or one Type A and one Type B deviation.

5

The copy has one Type B deviation.

6

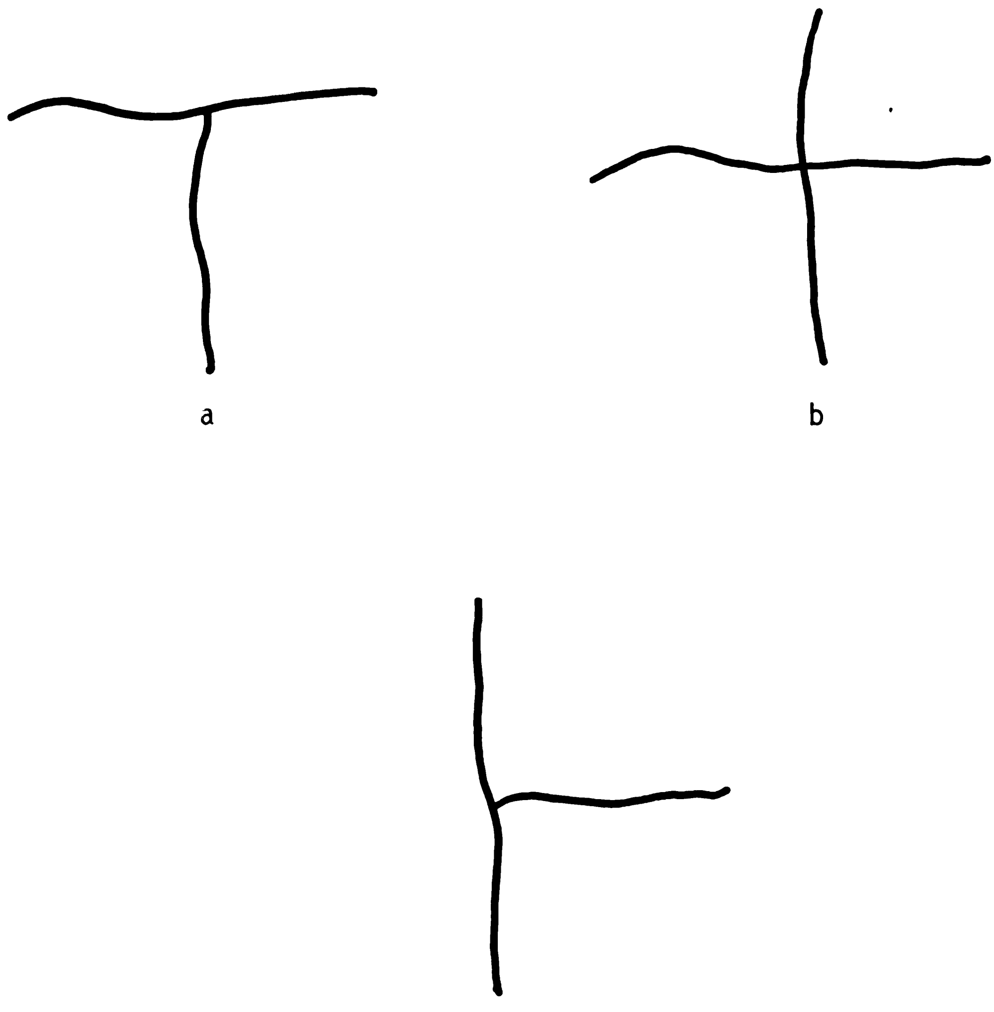
The copy has deviations, but all are below the limits set in the Type B deviations.

7

The copy is almost identical to the model.

The template used for the square and the half cross model on Figure D7 were used to score the half cross. The procedures for the square were used for the half cross.

Inter-rater reliability for three judges as determined by the Spearman-Brown prediction formula (see Winer, 1962) was 0.90 on a sample of 50 copies before coding began. The reliability coefficient was 0.96 on a sample of 25 copies after each judge had scored 70 copies.



a b c

Figure D8. Copies of the half cross that receive quality scores of 1.

APPENDIX E

TABLES OF MEANS AND CORRELATIONS

The following abbreviations were used:

1 = first copy done with the right hand
2 = second copy done with the right hand
3 = third copy done with the right hand
4 = first copy done with the left hand
5 = second copy done with the left hand
6 = third copy done with the left hand

r_{xy} indicates which copies were correlated, where x and y are the copy number.

Movement sequences

# = number of lines
t = topstart
b = bottom start
l = left start
r = right start
h = horizontal line first
v = vertical line first

NS = number of subjects
r = correlation significant at .05 level
* = significant correlation

A '900' correlation indicates that one, or both, of the variables correlated had a variance of zero. A '900' was considered significant at the .05 level if one of the variables had a mean of 1.00, and the other a mean between 0.80 and 1.00.

Table E1. Correlations of movement sequences and quality with order of presentation (where 'PN' = 1 and 'NP' = 2) for the four-year-old boys' copies of a square

	1	2	3	4	5	6
#	0.20	-0.15	00	00	0.22	0.22
t	0.82*	0.60	0.41	0.22	0.41	0.22
b	-0.82*	-0.60	-0.41	-0.22	-0.41	-0.22
l	00	-0.22	-0.50	-0.22	-0.22	-0.20
r	00	0.22	0.50	0.22	0.22	0.20
h	00	-0.50	-0.33	-0.50	-0.22	-0.22
v	00	0.50	0.33	0.50	0.22	0.22
↑↑	-0.33	-0.33	00	900	0.33	0.33
↓↓	0.65*	00	00	00	00	-0.22
↑↓	-0.41	-0.50	-0.65*	00	00	0.33
↓↑	900	0.65*	0.65*	00	-0.22	-0.20
⇉	-0.33	-0.33	-0.22	900	900	900
⇇	-0.33	00	900	900	0.33	0.50
⇄	0.22	-0.22	-0.65*	00	00	00
⇆	0.33	0.41	0.82*	00	-0.22	-0.41
Q	-0.22	0.33	900	00	0.19	0.22

NS = 10, r = 0.64.

Table E2. Correlations of movement sequences and quality with order of presentation (where 'PN' = 1 and 'NP' = 2) for the four-year-old girls' copies of a square

	1	2	3	4	5	6
#	0.33	0.33	0.30	0.03	0.04	0.42
t	0.13	-0.18	-0.04	-0.18	-0.36	-0.04
b	-0.13	0.18	0.04	0.18	0.36	0.04
l	-0.24	0.13	-0.04	900	-0.24	-0.24
r	0.24	-0.13	0.04	900	0.24	0.24
h	0.36	0.24	0.24	0.36	0.36	0.36
v	-0.36	-0.24	-0.24	-0.36	-0.36	-0.36
↑↑	900	900	900	0.24	0.24	0.24
↓↓	0.36	0.24	0.18	-0.13	-0.13	0.36
↑↓	0.31	-0.07	0.18	0.18	900	-0.42
↓↑	-0.61	-0.07	-0.39	-0.21	-0.04	-0.18
⇉	0.24	0.24	0.24	-0.13	-0.13	0.24
⇇	900	900	900	0.24	0.24	0.24
⇄	0.45	0.07	0.07	0.18	900	-0.13
⇆	-0.61*	-0.21	-0.21	-0.21	-0.04	-0.18
Q	0.24	-0.36	0.36	00	0.24	-0.44

NS = 11, r = 0.61.

Table E3. Correlations of movement sequences and quality with order of presentation (where 'PN' = 1 and 'NP' = 2) for the five-year-old boys' copies of a square

	1	2	3	4	5	6
#	-0.14	-0.28	0.17	0.48	0.17	0.17
t	0.39	0.39	900	0.39	0.27	0.27
b	-0.39	-0.39	900	-0.39	-0.27	-0.27
l	-0.22	0.39	-0.03	0.27	0.27	0.27
r	0.22	-0.39	0.03	-0.27	-0.27	-0.27
h	-0.27	-0.27	900	-0.27	-0.27	-0.27
v	0.27	0.27	900	0.27	0.27	0.27
↑↑	-0.27	-0.27	900	900	900	900
↓↓	0.23	0.23	0.23	0.38	0.05	0.05
↑↓	0.46	-0.27	0.03	900	-0.27	-0.27
↓↑	-0.38	0.10	-0.22	-0.38	0.10	0.10
⇉	-0.27	-0.27	-0.27	0.31	0.31	0.31
⇇	0.27	-0.27	900	900	900	900
⇄	0.39*	0.23	0.22	0.05	-0.28	-0.28
⇆	-0.22	0.10	-0.07	-0.22	0.10	0.10
Q	0.16	-0.15	0.12	0.02	-0.14	0.23

NS = 13, r = 0.56.

Table E4. Correlations of movement sequences and quality with order of presentation (where 'PN' = 1 and 'NP' = 2) for the five-year-old girls' copies of a square

	1	2	3	4	5	6
#	-0.23	-0.40	-0.39	-0.10	0.13	0.24
t	0.23	0.23	0.23	0.23	0.23	0.34
b	-0.23	-0.23	-0.23	-0.23	-0.23	-0.34
l	-0.54	-0.37	-0.37	0.23	0.23	0.23
r	0.54	0.37	0.37	-0.23	-0.23	-0.23
h	-0.23	-0.23	-0.23	-0.23	-0.23	-0.34
v	0.23	0.23	0.23	0.23	0.23	0.34
↑↑	-0.23	-0.23	-0.23	-0.23	-0.23	-0.23
↓↓	-0.23	0.10	0.10	0.03	0.35	0.50
↑↓	-0.54	0.37	0.37	900	900	900
↓↑	-0.16	-0.16	-0.16	0.10	-0.22	-0.35
⇉	0.10	-0.34	-0.43	-0.43	-0.06	0.10
⇇	900	900	900	900	900	900
⇄	0.32	0.32	0.54	0.32	0.32	0.32
⇆	-0.35	-0.02	-0.02	0.10	-0.22	-0.35
Q	00	0.20	-0.05	0.15	0.38	0.38

NS = 13, r = 0.56.

Table E5. Correlations of 'rules' (and movement sequences) with quality for the four-year-old boys' copies of a square

	1	2	3	4	5	6
#	-0.22	-0.25	900	-0.37	-0.12	-0.05
t	-0.36	0.33	900	0.22	0.15	0.05
b	0.36	-0.33	900	-0.22	-0.15	-0.05
l	0.53	0.22	900	0.22	0.12	-0.22
r	-0.53	-0.22	900	-0.22	-0.12	0.22
h	-0.33	-0.17	900	0.25	-0.12	0.43
v	0.33	0.17	900	-0.25	0.12	-0.43
↑↑	-0.22	-0.11	900	900	-0.06	0.22
↓↓	0.05	-0.27	900	-0.37	-0.09	-0.52
↑↓	0.09	-0.17	900	0.25	-0.15	0.22
↓↑	900	0.51	900	0.10	0.28	0.22
⇉	-0.22	-0.11	900	900	900	900
⇇	-0.22	-0.17	900	900	-0.06	0.33
⇄	0.43	-0.22	900	-0.10	-0.23	-0.22
⇆	-0.22	0.41	900	0.10	0.28	-0.09

NS = 10, r = 0.64.

Table E6. Correlations of 'rules' (and movement sequences) with quality for the four-year-old girls' copies of a square

	1	2	3	4	5	6
#	-0.14	0.02	0.90*	00	0.52	00
t	0.15	0.38	0.29	00	-0.67	-0.48
b	-0.15	-0.38	-0.29	00	0.67*	0.48
l	0.10	-0.83	-0.24	900	0.10	00
r	-0.10	0.83*	0.24	900	-0.10	00
h	0.67*	-0.26	0.67*	00	-0.15	00
v	-0.67	0.26	-0.67	00	0.15	00
↑↑	-0.10	0.15	0.67	00	-0.15	00
↓↓	900	900	900	00	1.00	00
↑↓	0.29	0.28	-0.52	00	900	0.55
↓↑	-0.24	-0.38	0.13	00	-0.52	-0.44
⇉	900	900	900	00	1.00	00
⇇	-0.15	-0.26	0.62	00	-0.15	00
⇄	0.35	0.43	-0.36	00	900	-0.74
⇆	-0.24	-0.28	-0.29	00	-0.52	-0.44

NS = 11, r = 0.61.

Table E7. Correlations of 'rules' (and movement sequences) with quality for the five-year-old boys' copies of a square

	1	2	3	4	5	6
#	-0.22	-0.46	-0.18	-0.19	-0.04	-0.18
t	0.17	0.07	900	0.10	0.16	00
b	-0.17	-0.07	900	-0.10	-0.16	00
l	0.32	0.52	0.39	0.07	0.16	00
r	-0.32	-0.52	-0.39	-0.07	-0.16	00
h	-0.12	-0.05	900	-0.07	-0.16	00
v	0.12	0.05	900	0.07	0.16	00
↑↑	-0.12	-0.05	900	900	900	900
↓↓	-0.22	-0.09	-0.16	0.02	0.03	-0.25
↑↓	-0.17	-0.66	-0.39	900	-0.16	00
↓↑	0.37	0.46	0.43	-0.02	0.06	0.23
⇉	-0.12	-0.05	-0.08	-0.30	-0.16	00
⇇	-0.12	-0.66	900	900	900	900
⇄	-0.22	-0.09	-0.43	0.35	0.03	-0.25
⇆	0.32	0.46	0.46	-0.06	0.06	0.23

NS = 13, r = 0.56.

Table E8. Correlations of 'rules' (and movement sequences) with quality for the five-year-old girls' copies of a square

	1	2	3	4	5	6
#	-0.31	-0.44	-0.25	-0.33	-0.43	-0.15
t	0.25	0.25	0.14	0.18	0.15	0.22
b	-0.25	-0.25	-0.14	-0.18	-0.15	-0.22
l	00	-0.07	0.14	0.18	0.15	0.15
r	00	0.07	-0.14	-0.18	-0.15	-0.15
h	-0.25	-0.25	-0.14	-0.18	-0.15	-0.22
v	0.25	0.25	0.14	0.18	0.15	0.22
↑↑	-0.25	-0.25	-0.14	-0.18	-0.15	-0.15
↓↓	-0.25	0.11	-0.21	-0.28	-0.40	-0.06
↑↓	00	0.07	-0.14	900	900	900
↓↑	0.28	0.01	0.33	0.37	0.47	0.14
⇉	00	-0.37	-0.27	-0.09	-0.28	0.14
⇇	900	900	900	900	900	900
⇄	-0.16	0.14	-0.21	-0.34	-0.28	-0.28
⇆	0.13	0.15	0.39	0.37	0.47	0.14

NS = 13, r = 0.56.

Table E9. Proportions of movement sequences used by four-year-old boys and girls for each hand and order of presentation

	Four-year-old boys			Four-year-old girls			Four-year-old 'PN'			Four-year-old 'NP'		
	Right	Left	Total	Right	Left	Total	Right	Left	Total	Right	Left	Total
#	1.467	1.267	1.367	1.394	1.545	1.470	1.296	1.259	1.278	1.528	1.528	1.528
t	0.500	0.667	0.584	0.727	0.727	0.727	0.444	0.667	0.556	0.750	0.722	0.736
b	0.500	0.333	0.417	0.273	0.273	0.273	0.556	0.333	0.445	0.250	0.278	0.264
l	0.700	0.633	0.667	0.818	0.939	0.879	0.815	0.852	0.834	0.722	0.750	0.736
r	0.300	0.367	0.333	0.182	0.061	0.122	0.185	0.148	0.167	0.278	0.250	0.264
h	0.167	0.267	0.217	0.121	0.182	0.152	0.148	0.222	0.185	0.139	0.222	0.181
v	0.833	0.733	0.783	0.879	0.818	0.849	0.852	0.778	0.815	0.861	0.778	0.819
↑↑	0.394	0.067	0.231	0.000	0.091	0.046	0.111	0.000	0.056	0.028	0.139	0.084
↓↓	0.300	0.233	0.533	0.212	0.182	0.197	0.148	0.222	0.185	0.333	0.195	0.264
↑↓	0.367	0.233	0.300	0.425	0.152	0.289	0.481	0.185	0.333	0.333	0.194	0.264
↓↑	0.200	0.467	0.334	0.364	0.576	0.470	0.259	0.593	0.426	0.305	0.472	0.389
⇉	0.167	0.000	0.084	0.091	0.152	0.122	0.148	0.074	0.111	0.111	0.083	0.097
⇇	0.100	0.100	0.100	0.000	0.091	0.046	0.074	0.000	0.037	0.028	0.167	0.098
⇄	0.433	0.400	0.417	0.545	0.182	0.364	0.185	0.296	0.241	0.500	0.278	0.289
⇆	0.300	0.500	0.400	0.364	0.576	0.466	0.296	0.630	0.463	0.361	0.472	0.417

NS = 21.

Table E10. Proportions of movement sequences used by five-year-old boys and girls for each hand and order of presentation

	Five-year-old boys			Five-year-old girls			Five-year-old 'PN'			Five-year-old 'NP'		
	Right	Left	Total	Right	Left	Total	Right	Left	Total	Right	Left	Total
#	1.487	1.462	1.475	1.385	2.000	1.693	1.578	1.622	1.600	1.243	1.879	1.561
t	0.897	0.897	0.897	0.923	0.897	0.910	0.844	0.822	0.833	1.000	1.000	1.000
b	0.099	0.099	0.099	0.077	0.099	0.088	0.156	0.178	0.167	0.000	0.000	0.000
l	0.769	0.923	0.846	0.897	0.923	0.910	0.889	0.867	0.878	0.757	1.000	0.879
r	0.231	0.077	0.154	0.103	0.077	0.090	0.111	0.133	0.122	0.243	0.000	0.122
h	0.048	0.077	0.063	0.077	0.149	0.113	0.089	0.155	0.045	0.000	0.000	0.000
v	0.952	0.923	0.938	0.923	0.851	0.887	0.911	0.845	0.955	1.000	1.000	1.000
↑↑	0.048	0.000	0.024	0.077	0.077	0.077	0.111	0.067	0.089	0.000	0.000	0.000
↓↓	0.231	0.359	0.295	0.128	0.359	0.244	0.133	0.267	0.200	0.243	0.485	0.364
↑↓	0.128	0.048	0.088	0.149	0.000	0.075	0.045	0.045	0.045	0.212	0.000	0.106
↓↑	0.619	0.619	0.619	0.692	0.564	0.628	0.711	0.622	0.667	0.545	0.515	0.530
⇉	0.077	0.077	0.077	0.180	0.205	0.195	0.200	0.133	0.107	0.030	0.152	0.091
⇇	0.048	0.000	0.024	0.000	0.000	0.000	0.045	0.000	0.023	0.000	0.000	0.000
⇄	0.282	0.308	0.245	0.205	0.231	0.218	0.111	0.245	0.123	0.425	0.303	0.369
⇆	0.604	0.615	0.610	0.615	0.564	0.540	0.644	0.622	0.633	0.545	0.545	0.545

NS = 26.

Table E11. Intra-hand correlations ('consistency') of movement sequences used by four-year-old boys copying a square[a]

	#	t	b	l	r	h	v	↑↑	↓↓	↑↓	↓↑	→→	←←	→←	←→
r_{12}	0.15	0.41	0.41	0.36	0.36	0.38	0.38	1.00*	0.36	0.41	900	-0.11	0.67*	0.05	0.27
r_{13}	0.41	0.25	0.25	0.10	0.10	0.67*	0.67*	0.67*	0.22	0.53	900	-0.22	900	-0.05	0.41
r_{23}	0.30	0.41	0.41	0.76*	0.76*	0.67*	0.67*	0.67*	0.10	0.22	1.00*	-0.22	900	-0.05	0.58
r_{45}	0.76*	0.80*	0.80*	1.00*	1.00*	0.76*	0.76*	900	1.00*	0.61	0.53	900	900	0.67*	0.53
r_{46}	0.22	1.00*	1.00*	0.65*	0.65*	0.22	0.22	900	0.22	0.67*	0.41	900	900	0.61	0.17
r_{56}	0.52	0.80*	0.80*	0.65*	0.65*	0.52	0.52	1.00*	0.22	0.41	0.65*	900	0.67*	0.41	0.53

NS = 10, r = 0.64.

[a]There are some unusual trends in Tables E11 and E12. For the four-year-old boys' right hand and the four-year-old girls' left hand, the first copy does not correlate highly with the second and third copies. For the four-year-old girls' right hand, the third copy coes not correlate highly with the second and first copies. Whether these findings represent 'learning' and 'boredom' effects is difficult to ascertain with the present data. Each child would have to make more copies of the square with each hand to determine if the trends would continue.

Table E12. Intra-hand correlations ('consistency') of movement sequences used by four-year-old girls copying a square

	#	t	b	l	r	h	v	↑↑	↓↓	↑↓	↓↑	→→	←←	→←	←→
r_{12}	1.00*	0.62*	0.62*	0.67*	0.67*	0.67*	0.67*	900	0.67*	0.63*	0.45	1.00*	900	0.63*	0.61*
r_{13}	0.62*	0.77*	0.77*	0.52	0.52	0.67*	0.67*	900	0.13	0.83*	0.39	1.00*	900	0.27	0.21
r_{23}	0.62*	0.81*	0.81*	0.77*	0.77*	-0.10	-0.10	900	-0.24	0.45	0.26	1.00*	900	0.24	0.21
r_{45}	0.70*	0.13	0.13	900*	900*	0.39	0.39	-0.10	0.39	900	0.46	0.39	-0.10	900	0.46
r_{46}	0.63*	0.39	0.39	900*	900*	0.39	0.39	-0.10	0.39	0.42	0.57	-0.15	-0.10	0.13	0.57
r_{56}	0.70*	0.77*	0.77*	1.00*	1.00*	1.00*	1.00*	1.00*	0.39	900	0.39	0.67*	1.00*	900	0.39

NS = 11, r = 0.61.

Table E13. Intra-hand correlations ('consistency') of movement sequences used by five-year-old boys copying a square

	#	t	b	l	r	h	v	↑↑	↓↓	↑↓	↓↑	→→	←←	⇄	⇆
r_{12}	0.72*	1.00*	1.00*	0.54	0.54	1.00*	1.00*	1.00*	0.57*	-0.12	0.54	1.00*	1.00*	0.13	0.35
r_{13}	0.10	900*	900*	0.54	0.54	900*	900*	900	-0.13	0.18	0.54	1.00*	900	0.32	0.54
r_{23}	0.39	900*	900*	0.41	0.41	900*	900*	900	0.57*	0.68*	0.68*	1.00*	900	0.69*	0.85*
r_{45}	0.65*	0.68*	0.68*	-0.08	-0.08	1.00*	1.00*	900	0.72*	900	0.54	1.00*	900	0.64*	0.68*
r_{46}	0.65*	0.68*	0.68*	-0.08	-0.08	1.00*	1.00*	900	0.72*	900	0.54	1.00*	900	0.64*	0.68*
r_{56}	1.00*	1.00*	1.00*	1.00*	1.00*	1.00*	1.00*	900	1.00*	1.00*	1.00*	1.00*	900	1.00*	1.00*

Table E14. Intra-hand correlations ('consistency') of movement sequences used by five-year-old girls copying a square

	#	t	b	l	r	h	v	↑↑	↓↓	↑↓	↓↑	⇉	⇇	⇄	⇆
r_{12}	0.70*	1.00*	1.00*	0.68*	0.68*	1.00*	1.00*	1.00*	0.68*	0.68*	0.64*	0.41	900	0.57*	0.68*
r_{13}	0.62*	1.00*	1.00*	0.68*	0.68*	1.00*	1.00*	1.00*	0.68*	0.68*	0.64*	0.27	900	0.27	0.68*
r_{23}	0.84*	1.00*	1.00*	1.00*	1.00*	1.00*	1.00*	1.00*	1.00*	1.00*	1.00*	0.78*	900	0.78*	1.00*
r_{45}	0.74*	1.00*	1.00*	1.00*	1.00*	1.00*	1.00*	1.00*	0.68*	900	0.69*	0.57*	900	0.57*	0.69*
r_{46}	0.68*	0.68*	0.68*	1.00*	1.00*	0.68*	0.68*	1.00*	0.50	900	0.54	0.27	900	0.57*	0.54
r_{56}	0.90*	0.68*	0.68*	1.00*	1.00*	0.68*	0.68*	1.00*	0.84*	900	0.85*	0.78*	900	1.00*	0.85*

NS = 13, r = 0.56.

Table E15. Inter-hand correlations ('generality') of movement sequences used by four-year-old boys copying a square

	#	t	b	l	r	h	v	↑↑	↓↓	↑↓	↓↑	→ →	← ←	→ ←	← →
r_{14}	0.00	-0.09	-0.09	-0.09	-0.09	0.38	0.38	900	0.22	0.41	900	900	900	0.53	0.27
r_{15}	0.22	0.17	0.17	-0.09	-0.09	0.22	0.22	-0.11	0.22	0.25	900	900	-0.11	-0.09	-0.22
r_{16}	0.22	-0.09	-0.09	0.00	0.00	0.22	0.22	-0.11	0.05	0.27	900	900	-0.17	0.33	-0.41
r_{24}	0.37	0.22	0.22	0.05	0.05	1.00*	1.00*	900	0.10	-0.25	-0.36	900	900	-0.53	-0.58
r_{25}	0.49	0.41	0.41	0.05	0.05	0.76*	0.76*	-0.11	0.10	0.10	0.05	900	-0.17	-0.36	-0.09
r_{26}	0.81*	0.22	0.22	0.22	0.22	0.22	0.22	-0.11	0.80*	-0.17	0.22	900	0.35	-0.33	0.25
r_{34}	-0.41	0.53	0.53	0.22	0.22	0.67*	0.67*	900	-0.25	0.22	-0.36	900	900	0.36	-0.17
r_{35}	-0.09	0.67*	0.67*	0.22	0.22	0.51	0.51	0.67*	-0.25	0.36	0.05	900	900	0.53	-0.09
r_{36}	0.36	0.53	0.53	0.50	0.50	0.51	0.51	0.67*	0.22	-0.22	0.22	900	900	0.22	-0.17

NS = 10, r = 0.64.

Table E16. Inter-hand correlations ('generality') of movement sequences used by four-year-old girls copying a square

	#	t	b	l	r	h	v	↑↑	↓↓	↑↓	↓↑	→ →	← ←	→ ←	← →
r_{14}	0.80*	0.62*	0.62*	900*	900*	0.39	0.39	900	0.39	0.83*	0.61*	-0.15	900	0.69*	0.61*
r_{15}	0.39	0.39	0.39	-0.10	-0.10	1.00*	1.00*	900	0.39	900	0.04	0.67*	900	900	0.04
r_{16}	0.80*	0.77*	0.77*	-0.10	-0.10	1.00*	1.00*	900	1.00*	0.35	0.57	1.00*	900	0.43	0.57
r_{24}	0.80*	0.61*	0.61*	900*	900*	0.67*	0.67*	900	0.67*	0.45	0.45	-0.15	900	0.31	0.61*
r_{25}	0.39	0.62*	0.62*	-0.15	-0.15	0.67*	0.67*	900	-0.15	900	0.15	0.67*	900	900	0.46
r_{26}	0.80*	0.81*	0.81*	-0.15	-0.15	0.67*	0.67*	900	0.67*	0.35	0.31	1.00*	900	0.43	0.57
r_{34}	0.68*	0.39	0.39	900*	900*	-0.15	-0.15	900	0.13	0.61*	0.39	-0.15	900	0.31	0.21
r_{35}	0.44	0.77*	0.77*	0.52	0.52	0.67*	0.67*	900	0.62*	900	0.37	0.67*	900	900	0.46
r_{36}	0.49	1.00*	1.00*	0.52	0.52	0.67*	0.67*	900	0.13	0.42	0.04	1.00*	900	-0.05	0.18

NS = 11, r = 0.61.

Table E17. Inter-hand correlations ('generality') of movement sequences used by five-year-old boys copying a square

	#	t	b	l	r	h	c	↑↑	↓↓	↑↓	↓↑	→ →	← ←	→ ←	← →
r_{14}	0.26	1.00*	1.00*	0.37	0.37	1.00*	1.00*	900	0.23	900	0.38	-0.08	900	0.43	0.68*
r_{15}	0.39	0.68*	0.68*	-0.23	-0.23	1.00*	1.00*	900	0.43	-0.12	0.54	-0.08	900	0.03	0.68*
r_{16}	0.39	0.68*	0.68*	-0.23	-0.23	1.00*	1.00*	900*	0.43	-0.12	0.54	-0.08	900	0.03	0.68*
r_{24}	0.01	1.00*	1.00*	0.68*	0.68*	1.00*	1.00*	900	0.23	900	0.22	-0.08	900	0.03	0.35
r_{25}	0.26	0.68*	0.68*	-0.12	-0.12	1.00*	1.00*	900	0.43	-0.08	0.68*	-0.08	900	0.03	0.68*
r_{26}	0.26	0.68*	0.68*	-0.12	-0.12	1.00*	1.00*	900	0.43	-.08	0.68*	-0.08	900	0.03	0.68*
r_{34}	0.49	900*	900*	-0.12	-0.12	900*	900*	900	0.59*	900	0.54	-0.08	900	0.50	0.54
r_{35}	0.80*	900*	900*	-0.12	-0.12	900*	900*	900	0.82*	-0.12	0.68*	-0.08	900	0.50	0.85*
r_{36}	0.80*	900*	900*	-0.12	-0.12	900*	900*	900	0.82*	-0.12	0.68*	-0.08	900	0.50	0.85*

NS = 13, r = 0.56.

Table E18. Inter-hand correlations ('generality') of movement sequences used by five-year-old girls copying a square

	#	t	b	l	r	h	v	↑↑	↓↓	↑↓	↓↑	→ over →	← over ←	→ over ←	← over →
r_{14}	0.42	1.00*	1.00*	-0.12	-0.12	1.00*	1.00*	1.00*	0.37	900	0.39	0.27	900	0.13	0.22
r_{15}	0.52	1.00*	1.00*	-0.12	-0.12	1.00*	1.00*	1.00*	0.37	900	0.39	0.27	900	-0.30	0.54
r_{16}	0.40	0.68*	0.68*	-0.12	-0.12	0.68*	0.68*	1.00*	0.43	900	0.50	-0.18	900	-0.30	0.35
r_{24}	0.45	1.00*	1.00*	-0.08	-0.08	1.00*	1.00*	1.00*	0.10	900	0.39	0.27	900	0.13	0.54
r_{25}	0.54	1.00*	1.00*	-0.08	-0.08	1.00*	1.00*	1.00*	0.54	900	0.72*	0.27	900	0.13	0.85*
r_{26}	0.18	0.68*	0.68*	-0.08	-0.08	0.68*	0.68*	1.00*	0.64*	900	0.84	-0.18	900	0.13	0.68*
r_{34}	0.54	1.00*	1.00*	-0.08	-0.08	1.00*	1.00*	1.00*	0.10	900	0.39	0.57*	900	0.27	0.54
r_{35}	0.63*	1.00*	1.00*	-0.08	-0.08	1.00*	1.00*	1.00*	0.54	900	0.72*	0.57*	900	0.27	0.85*
r_{36}	0.42	0.68*	0.68*	-0.08	-0.08	0.68*	0.68*	1.00*	0.64*	900	0.84*	0.27	900	0.27	0.68*

NS = 13, r = 0.56.

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