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**AN INFORMATION PROCESSING APPROACH TO THE DEVELOPMENT
OF THE PIAGETIAN CONCEPT OF SERIATION**

by

EDWARD G. ELACKSTOCK

**A dissertation submitted to the Graduate Faculty in Psychology
in partial fulfillment of the requirements for the degree of
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This manuscript has been read and accepted for the Graduate Faculty in Psychology in satisfaction of the dissertation requirement for the degree of Doctor of Philosophy.

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AN INFORMATION PROCESSING APPROACH TO THE DEVELOPMENT
OF THE PIAGETIAN CONCEPT OF SERIATION

by

Edward G. Blackstock

ABSTRACT

The power of information processing models to resolve the problems of accounting for horizontal decalage and explaining the processes of transition as related to Piaget's theory is discussed. A model of the development of the concept of seriation based on the information processing paradigm is presented. An experiment involving 90 children (30 kindergarteners, 20 1st graders, 20 2nd graders and 20 3rd graders), is reported in which the subjects performed 18 length seriation tasks each. There were 9 recognition tasks and 9 reconstruction tasks within which the number of strips and the shape of the strips were varied. The results confirmed the previous finding (Blackstock and King, 1973) that recognition performance is easier than and developmentally precedes reconstruction performance. The results also show that number of strips and shape are powerful variables affecting seriation performance. An error analysis suggests that locking strategies change with age and physical variables, and a model of development based on the neo-Piagetian information processing theory of Pascual-Leone is outlined.

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INTRODUCTION

Theorists concerned with explaining cognitive development within a Piagetian framework have been plagued by two problems: 1. the difficulty of accounting for the observed phenomenon of horizontal decalages; and 2. adequately describing or explaining the process of transition from one stage to another. 'Horizontal decalage' is the term Piaget ascribes to the commonly observed phenomenon that a child can solve one but not a second of two problems where both problems require precisely the same thought processes for correct solution. A common example in the literature is that children are able to conserve length while they are not able to conserve weight. Recent studies of the seriation of length and weight have shown the same kind of result. The central purpose of this thesis is to demonstrate that regular variations in seriation performance in any particular stage of development, horizontal decalages, are caused by regular variations in either physical dimensions of the stimuli or task demands (context). This thesis will apply an information processing model to account for these variations. Moreover, it will be shown how this kind of analysis can link variation in performance associated with horizontal decalages with the variation in processes associated with vertical decalages.

This introduction will first describe the general characteristics of information processing models. This will be accomplished by describing those models which have inspired my own approach.

The second part of the introduction will review and discuss theory and research specifically related to the concept of seriation. This will include a discussion of the relative merits and problems with the traditional Piagetian formulations, as well as a complete and exhaustive review

of all other research concerned with the development of the concept of seriation.

The third and final part of the introduction will set forth a detailed outline of the present study.

Information Processing Models (Past)

The central characteristics of information processing models is the reduction of any performance, or sequence of performances, into finer components or episodes, coupled with an explanation of how these components are integrated to produce the observed performance. This theoretical and methodological approach derives mainly from each of three distinct, but not independent research traditions:

1. The tradition of task analysis and empirical validation
2. The analysis of "strategies" in problem solving
3. The computer simulation of cognitive processes

The first tradition, task analysis, is mostly identified with the work of Gagne (1962; Gagne and Paradice, 1961). The essence of his technique consists of the analysis of a given skill - such as simple arithmetic ability - into a set of simpler subskills. Each of these can in turn be analysed further, so the eventual outcome of the analysis is a hierarchical structure for the skill. Of central concern to this approach are techniques for the experimental validation of such hierarchies, some of which attain considerable statistical sophistication (Resnick and Wang, 1969; Resnick, 1970).

Two important ideas they articulate are 1) the notion of a component of a skill as an activity that actually occurs during its performance, and 2) the contrasting notion of a prerequisite, a subskill on which training enhances performance of the main skill but which does not appear during

its execution. An example of the latter, is practising scales on the piano as a prerequisite for performing a concerto. Also important is the idea that explicit sequencing information is a separate component of the hierarchy, in recognizing that not only do the components occur during the performance of a skill, but also they occur in a particular order and under particular conditions. Thus their analysis begins to take on some of the dynamic properties of a process model in addition to the static, structural properties of a hierarchy of skills.

The second tradition can trace its roots to the early days of experimental psychology, but a more recent identifiable source is Bruner's well known study of concept identification strategies in adults (Bruner, Goodnow & Austin, 1956). The flavor of this approach is conveyed in Olson's (1970) investigation of the growth of children's ability to construct a diagonal line. His starting point is the observation that children can recognize a diagonal long before they can construct one. His book is centered around the question: what prevents a child from constructing a diagonal if he can correctly recognize one? His pursuit of this question yields a detailed experimental analysis of the nature of the diagonalization skill, which he analyzes as a hierarchically integrated series of subskills or processes.

A characteristic of this line of research is its emphasis on rule-governed behavior. A fine example of this can be seen in the work of King (1966) on the development of conjunctive and disjunctive rules. The topic of "strategies" seems now to have given way to the "grammar of action" (Bruner, 1971; cited in Goodnow & Levine, 1973). For example, Greenfield, Nelson and Saltzman (1972) studied the performance of a simple task (the arrangement of five nesting cups) by very young children, aged

one to three years. They identified three strategies, found a statistically significant consistency in the use of a particular strategy by a given child, and showed evidence for a developmental progression through each of the strategies in turn. Furthermore, they found certain relations between a child's ability on this task and his performance on another: a child could correctly insert an extra cup into an already ordered stack if and only if he was able to use the most advanced of three strategies. Goodnow and Levine (1973), in a paper on "Sequence and syntax in children's copying", make a strong case for the use of rules to describe behavior and provide a clear statement of the benefits to be gained therefrom. They argue for the ability of rule-based formulation to cut across the distinction between sensori-motor and cognitive activities, and to unify the description of behavior across tasks and across modalities. They point out that such formulations meet "a requirement...seldom met by cognitive concepts, namely a fairly precise relationship to behavior" (p. 94). And like Olson (1970), they show how typical mistakes, instead of being dismissed as noise due to "performance errors", can be understood as a necessary consequence of the rules governing the child's behavior.

The analogies habitually drawn by these investigators between the rules describing behavior and those of grammatical syntax may occasionally seem far-fetched, yet their basic point - which they draw from Lashley (1951) - is well taken: behavior exhibits structure, and we must study that structure if we are to understand the behavior. What is notable about these investigators, however, and from the viewpoint of the present study constitutes the primary weakness of their research, is their failure to enquire into the processes responsible for the observable behavior and their contentment with its description. It is almost as if they failed to take their own analogy sufficiently seriously: they seem to ignore the

fact that the rules of syntax belong to a generative grammar. They confine themselves, as it were, to an analysis of the surface structure instead of examining the underlying deep structure and the transformation from one level to the other (c.f. Chomsky, 1965).

The third major tradition is that of the computer simulation of cognitive processes. Comparisons have been drawn between computer programs and aspects of human behavior since the late 1950's (Newell, Shaw & Simon, 1958), but in recent years the nature of this relationship has been changing. Klahr (1973) points out that information processing explanations can be viewed at three levels, ranging from the metaphoric to the concrete: it would seem that computer models have over the years been migrating downwards through these levels. At first, computer simulation studies merely used the general ideas of programming as a source of metaphors (Miller, Galanter & Pribram, 1960) or contented themselves with exploring the theoretical possibilities (e.g. Hunt, Main & Stone, 1966). Since then, however, an extensive theory of human problem solving behavior has emerged which yields information processing models closely tied to the details of the behavior actually observed (Newell & Simon, 1972). Research in this area typically proceeds by the close analysis of an extensive protocol of problem solving behavior, followed by the construction of a model to reproduce the protocol as faithfully as is practicable. For a full exposition and defense of this methodology the reader is referred to Newell and Simon (1972).

Cognitive development is probably the most potent use to which the newer information processing techniques can be applied (Franham-Diggory, 1972). In part, this is because information processing psychologists have begun to recognize the significance of Piaget's developmental analysis of "genetic epistemology" (Piaget & Inhelder, 1969; Elkind & Flavell, 1969).

But Piaget's formulations tend to remain at a rarified level of abstraction and, as has often been noted, it is quite difficult to bring them into close contact with actual behavior. This is especially frustrating from an information processing point of view, since Piaget seems so nearly to be talking in process terms (Cellerier, 1972). He deals with "cognitive representation", his "schemata" can be identified at least tentatively as fragments of a program, and many of his observations seem to demand a processing explanation. Providing such an explanation consists of more than a mere working out of the details of Piaget's theories. It involves the challenging task of designing information processing models of cognitive development, based on Piaget's notions, which serve both to explicate those notions in concrete terms and to square them with the observed facts of human development.

Information Processing Models (Present)

There currently seem to be two major models of information processing applied to cognitive development in general and Piagetian theory in particular. These two models are the ones emerging from the students of Newell and Simon at Carnegie-Mellon and from the Neo-Piagetian theory of Pascual-Leone.

The central technique of the model emerging from Carnegie-Mellon (c.f. Newell & Simon, 1972; Klahr & Wallace, 1973; Baylor & Gascon, 1972; Young, 1973) is the use of "production systems" to capture the regularities in a subject's behavior. A production system (PS) is a set of rules expressing what the subject does under what conditions. Each rule is a condition-action statement of the form $C \rightarrow A$, and means simply that in the circumstances specified by C the subject performs action(s) A. As a simple example, Newell and Simon give the following production system to

describe the behavior of a thermostat intended to keep the temperature of a room between 70 and 72 :

T1: Temperature 70 & furnace=off → Turn-on furnace

T2: Temperature 72 & furnace=on → Turn-off furnace

The action on the right side of T1 applies whenever the condition on its left is satisfied, and similarly for T2.

One of the advantages of production systems lies in the explicitness of their control structure. A production system presents the set of possible actions that the child can take, together with the basis on which he decides between them: whereas a flowchart or algorithm states only the outcome of that decision.

The first work to make use of production systems was concerned with the analysis of verbal protocols gathered from adults tackling symbolic problems in cryptarithmic, formal logic, and chess (Newell and Simon, 1972). Subsequent research by others has managed to break free of these restrictions, and deal with the non-verbal protocols of performance on concrete tasks. Clearly, this is something that had to be done if the production system techniques were ever to be applicable to the behavior of children. Thus, Klahr and Wallace (1972) have constructed production system models for the Piagetian problem of class inclusion (Klahr & Wallace, 1972) and for quantification (Klahr, 1973), based largely on the analysis of error patterns and response latencies. They have also outlined a more ambitious but speculative model of the development of conservation of quantity (Klahr & Wallace, 1973). At the same time, in Montreal, Baylor and Gascon (1972) have written production systems for children's behavior on problems of weight seriation, which they have also compared with the seriation of length (Baylor, Gascon, Lemoyne-Plourde & Pothier-Desaulniers, 1972). This study of the comparison between length and

weight seriation demonstrates the particular power of information processing techniques to account for horizontal-decalages. Weight and length seriation normally exhibit a horizontal decalage of about two years. When the information processing demands of the tasks are made more similar, this difference all but disappears. Specifically, the experimenters examined the seriation of seven sticks of different lengths hidden inside cigar tubes, the child being forbidden to have more than two sticks uncovered at any one time. In this way the length seriation task was made analogous to the weight seriation, and sure enough the children's performance on the hidden sticks task was worse than when the sticks were freely visible, and only slightly better than on weight seriation.

The most recent work to emerge from the Carnegie-Mellon group is one closely related to the present study on the development of length seriation. The technique demands the extensive analysis of a very limited sample of seriation behavior. For example, Young (1973) video-taped a few subjects on one type of seriation task employing standard stimuli (wooden blocks). His detailed analogies of those tapes yielded quite interesting production systems but because of his methodology he was unable to achieve his goal of generalizing those production systems to other behavior. It is not enough to be able to link a production system, or any information processing model, to one or two performances of one or two subjects in one situation. Models must be applicable to a wide range of seriation performance in a wide range of subjects. The goal of any information processing system should be to model the control of short term memory and the interface with the perceptual system as well as the coding of visual information. It is an assumption of the present study that any attempt to construct such a system without first establishing the fact that physical and memory variables affect performance in regular ways across a large variety of subjects

is premature. The specific problem with Young's seriation studies is that not enough is yet known about the seriation behavior and, more importantly, changes in seriation behavior to begin to write production systems which could account for perceptual or representational processes as well as the processes of development.

The other current way of using the information processing paradigm to solve the Piagetian problems is that which is now being explored by Pascual-Leone. Pascual-Leone's theory contains three basic notions: that Piagetian type schemes are the proper units of investigation, the notion that there is a "field of activation" for those schemes which is regulated by the principle of "schematic^{over}determination of performance", and the construct of "scheme boosters" applying on the schemes to increase their activation or assimilatory strength. Most interesting in his postulation of the importance of maintaining the general notion of schemes is his discussion of the paradox involved in dividing schemes into two types: figurative and operational. The notion is that the content of a figurative scheme, that is the mental image of objects or events, can only be the result of operations or operational schemes. (Of course, many operational schemes never result in figurative components.) This paradox is similar to the problem found in computer programming in distinguishing sharply between programs and data (e.g. Newell, 1972). As a first step in shifting to an information processing paradigm Pascual-Leone shifts the definition of a scheme from a structural definition to a semantic-pragmatic one. The only difference between this definition and Piaget's is that it takes into account the production, by the subject, of what other systems would call stimuli, while Piaget's definition would account only for the effecting components of behavior. In other words we begin to develop a process model in which the figurative schemes, or the schemes

associated with perceptual or intuitive seriation, play a vital part whenever the higher order concrete operational schemes of seriation are brought into usage. This aptitude of these satisfied lower level schemes to be the releasers of other schemes gives to the scheme unit the capability for becoming the building block for the complex hierarchical structures which are found in pattern recognition (Neisser, 1967; Lindsay and Norman, 1972), in conceptual development (Inhelder and Piaget, 1959), or in problem solving (Newell and Simon, 1972). It accounts for the possibility of simultaneously having in the subject's repertoire schemes corresponding to different levels of generality of the same input, (e.g., a seriation scheme vs. a stick scheme, pair scheme, height scheme, straight line scheme, etc.).

The importance of this subtle change in the definition of scheme becomes more apparent when we consider the second central aspect of Pascual-Leone's theory, the notion of a field of activation. The notion of a field of activation corresponds to the pre-attentive short-term sensorial storage or sensorial information storage discussed in modern human information processing theories (e.g., Haber, 1969; Lindsay and Norman, 1972). The analogy used by Pascual-Leone to describe his conception of a field of activation is a good one and I repeat it here. Imagine that the subject's repertoire of schemes is represented by a panel of light bulbs. When the input arrives and activates a set of schemes, it is as if a pattern of lights would appear on the panel. This pattern of lights or set of activated schemes is the Field of Activation. Implicit in this notion of a field of activation is the important idea of the difference between activation of schemes and application of schemes. Not all schemes in the field of activation will actually produce the subject performance: only

these schemes which are compatible and dominant in terms of their assimilatory strength or activation weight will determine the response. Other incompatible weaker schemes will be inhibited. The factors which influence the activation weight of schemes are the scheme boosters and they modify the assimilatory strength of the schemes according to a manner specified by the Schematic Overdetermination of Performance principle. The essence of the schematic over-determination principle is that the mental or behavioral performance of a subject is codetermined at any moment by the dominant set (in the mathematical sense of the word set) of schemes activated in the repertoire and that each one of these schemes tends to share in the shaping of the actual performance proportionally to its current assimilatory strength or total activation weight.

The scheme boosters, the third main factor in Pascual-Leone's theory, are the most interesting aspect as far as the present study is concerned. These scheme boosters determine which set of schemes in the field of activation are weighted to determine performance. Pascual-Leone postulates five scheme boosters, two of which are important to us here. The three we will not deal with are the Affective operator (A) and the learning operators (C and L). The two scheme boosters which are central to the present study are the (F) and (M) operators.

In general the (F) operator deals with the relationship between the physical properties of the objects involved in any performance in two major senses: the factors which contribute to the actual construction of the objects of perception and the factors which determine how those perceived objects become transformed into problem solving performance. The first component corresponds in part to what in the literature is frequently called "salience," "obviousness of cues," "sensitivity to stimuli," "stimulus magnitude," etc. It is easy to see how this aspect relates to the

discussion above of the importance of the magnitude of the differences between objects involved in a seriation. The second component corresponds to what the Gestalt School called "autochthonous field forces" and what Hochberg (1957; 1964) has called "Minimum Principle." The notion of "minimum principle" is quite complex but for the purposes of the present study it suffices to say that its central role is to minimize the structural or informational complexity related to any specific performance. In the case of seriation performance the (F) factor would be that which determined the extent to which the physical characteristics of the objects involved either facilitated or inhibited the activation of the set of schemes which would eventuate in seriation performance. The relevance of the (F) operator becomes especially clear when it is combined with the most interesting of Pascual-Leone's five scheme boosters, the (M) operator.

In the context of Piaget's theory the construct M can be considered to be an explication of Piaget's notions of centration and centration mechanism. M is a mental attention mechanism (or a central and very active short-term memory construct) which grows in power with age. It can also be construed as a central computing space M or mental processor (Pascual-Leone, 1968; Pascual-Leone & Smith, 1969). The M power, that is, the number of different schemes which M can weight in a single centration or M operation, increases regularly with the different Piagetian substages. Now, if all factors were held constant, including the F factor (which is the same as saying that you are using the same material or objects) a subject at any age (or substage of development) would be able to order x amount of objects which would increase regularly with age as the power of M increases. If, however, you kept the age of the subject constant, and varied the F factor, or the physical dimensions of the objects, then you would vary the number of those objects the subject could seriate. This

formulation assumes, of course, that any feature in a seriated array is equal to a single scheme, but that the unified scheme of seriation can only be the result of the activation of the lower level, or more primitive, schemes that are the building blocks of the higher order scheme.

While it is clear that Pascual-Leone has come a long way in applying an information processing approach to the problem of horizontal decalage and transition, he remains within the tradition so far as he has focused his attention on conservation problems. Bellin (1971) has noted that "It is a curious fact that from the entire range of interesting and important Piagetian experiments and observations, the most studied has been the conservation phenomenon." The need to study a concept for which development could be shown to be either continuous, discontinuous, or both has been felt for some time. If we study a concept such as seriation, in which the sensory information and the physical reality are not contradictory but complementary, and in which the sensory information could be varied regularly along a continuum from having highly salient perceptual qualities to having minimally perceptually salient qualities, then it becomes possible to conduct an experiment in which the results are able to show either a continuous development from the use of sensory information, to the use of conceptual, or highly symbolic or abstract information, or an abrupt change from one mode to the other. An experiment with seriation should also be capable of demonstrating the interaction between perception and conception and age in solving problems.

Information Processing Models (Future)

Using Pascual-Leone's (1969, 1972, 1974) model as the major guiding principle, along with what I feel to be the best aspects of the Carnegie-Mellon models, I have constructed an information processing model of the

concept of seriation. It should be kept in mind that the following model is tentative and is designed here more to represent the kind of model I hope to develop after a great deal more research than to be a definitive model of developmental processes.

Let us first call a seriated configuration as perceived by, or constructed by adults, Se. Now this configuration Se is composed of features or aspects se₁ ... se_n, each of these features being seriated to the extent that se₂ depends upon se₁. The generic symbol, se, must at each instance of the application of this model be specified in relationship with the specific features of the task. While the features se_x are general constructs their specific meaning in the present model is as follows:

se₁ = the parallel nature of the line formed by lining up the strips in a vertical orientation.

se₂ = the horizontal line formed by lining up the strips at the bottom.

se₃ = the diagonal line formed by lining up the strips at the tops.

se₄ = the perceived relationship $A < B$.

se₅ = the perceived relationship $< N <$.

It may or may not be the case that features which depend upon each other for use by the seriation scheme are developmentally acquired in the same order in which they are used in performance. These aspects se₁ ... se_n may also be ordered according to their saliency or constructability. Prior to the development of any se construct a child must perceive a collection of strips or lines as merely a collection of lines with no special topological position or order in space. He probably will, before the appearance of any se₁ bring to the perception of strips a rudimentary and infralogical quantity operator Q. Of course, the se may be present at any time, and

may even be activated at any time, but just does not get applied because its activation is not boosted by the F metaconstruct, or the nature of the stimuli to which it might be applied. In the case of any seriation the aspect se₁ is the abstraction of, or construction of, the dimension along which the seriation will proceed. In the present study the se₁ would be the perception of the strips as a unitary group of vertical lines. If se₁ were not applied to a recognition task a group of sticks or strips which were seriated would look the same as a group of strips in any order or for that matter any other orientation in space. If se₁ were not applied to a reconstruction task a child presented with a seriated row of blocks as a model might make a train, a tower or any other configuration and believe he had performed successfully. Blackstock (1970) found that this was the case when he presented 3-year-old children with reconstruction seriation tasks. This also explains the finding of King and Blackstock (1971) that the presence or absence of a model has no effect on reconstructive seriation performance.

The construction of the feature se₁ is not sufficient, however, to succeed on the simplest recognition task in the present study. Once se₁ has been constructed se₂, the straight horizontal line at the bottom of the seriated strips, may be constructed. It is logically necessary that se₂ developmentally follows se₁ because the horizontal line cannot be constructed unless the vertical lines are. It is important to see here that se₂ is not simply the construction of the horizontal but the construction of the horizontal by the lining up of vertical lines. It is the construction of a relationship between objects in space. All features are constructed by rather than discovered by the subject. The third construct, or feature, relevant for the seriation of length or height would be se₃, the diagonal line across the tops of the ordered strips. That the construction

of the diagonal developmentally follows that of the horizontal is not logically necessary, but that it is empirically true, and the reasons therefore, have been dealt with extensively by Olson (1968 and 1970).

The fourth construct would undergo a development of its own with the progression from a simple arbitrary pair relationship, $A + B$, to a non-arbitrary pair relationship, $A < B$, $B < C$, to triples or the coordination of 2 pairs, $A < B < C$, $A < B + B < C$. The final and ultimate seriation construct, seg is the perception or conception that any element N can be at the same time smaller than and larger than: $< N <$.

The general, content free, recognition strategy or plan that a child would bring to any recognition task could be analyzed as consisting of 5 parts: 1. look at the model, 2. construct a perception of a configuration using the salient features of the model and store that configuration in short term memory (STM), 3. look at the stimulus to be compared, 4. test for equivalence to the encoded configuration, 5. make a positive or negative decision. This sequence is similar to what Pascual-Leone (1973) has outlined as an identity-equivalence sequence. Among those factors, the one which is the focus of this study consists of the encoding process, which involves the construction of the configuration Se. I will also focus on the decoding processes for the recognition task which will be labelled Rg while those for reconstruction will be labelled Rn. The overall recognition process will be labelled Erg while the overall reconstruction process will be labelled Ern.

A symbolic representation of the steps involved in executing the recognition strategy would be:

1. $Erg, Se_1 (se_1 \dots se_n) \rightarrow \underline{Se}_1$
2. $Erg, Se_2 (se_1rg_1 \dots se_nrg_n) \rightarrow \underline{Se}_2$
3. $Erg, Rg (\underline{Se}_1 (se_1 \dots se_n) - \underline{Se}_2 (se_1 \dots se_n)) \rightarrow 0 \text{ or } \bar{0}$

4. Erg, Rg (Se₁ = Se₂) → stop

4'. Erg, Rg (Se₁ = Se₂) → return to step 2.

Erg = the executive scheme which guides all the operations at each point in the recognition performance sequence.

Se₁ = the act of encoding, constructing the elements, or features, se₁ ... se_n and integrating them into the configuration Se₁ and storing it in short term memory. The underlining of any component represents that it is the product of the not underlined process.

Se₁ = the product of the process Se₁.

Se₂ = the act of constructing the perception of the test stimulus.

Se₂ = the product of the process Se₂.

Rg = the decoding process peculiar to recognition of comparing a standard stimulus to a test stimulus.

- = the act of comparison.

In ordinary words the execution of the recognition strategy by an adult would go like this:

1.) The subject approaches the task with the knowledge that recognition type of performance is going to be demanded of him. The subject looks at the model and tries to organize the information coming from the model into things which he can remember. First he decides that there are a collection of black strips and that they are lined up in an up and down or vertical way. Next he makes a horizontal line across the bottom of the strips. Next he makes a diagonal line going up to the right across the tops of the strips. Next he decides that each individual strip is at the same time taller than the one to its left and shorter than the one to its right. The subject then decides that that is really about all he will be able to remember about the model and looks away to continue the recognition task.

2.) The subject looks at the test configuration and begins to organize the information coming from it. First he tries to see the same number of strips he saw in the model and make them so that they are all lined up vertically. After doing this he makes a decision whether or not the processes of making the lines vertical in the model and making the lines vertical in the test configuration were identical. If they were he goes on to try to construct, or see, the horizontal line at the bottom of the strips. If he decides that the processes were not the same he will reject

the test configuration and look for another. He will follow this same procedure until he reaches the limits of how much information, or how many features or things about the configurations he can think about or hold in short term memory at one time.

3.) If the subject gets to the point in the recognition task where while looking at the test configuration he is able to see the vertical lines, the horizontal line, the diagonal line, and the fact that each strip is at the same time taller than the one to its left and shorter than the one to its right, then he will decide if the total of all the processes performed in constructing the test configuration are identical to those performed in constructing the model. If the processes are more or less in any way not identical he will decide to reject the test configuration. If they are identical he will clap his hands.

A symbolic representation of the steps involved in executing the reconstruction strategy would be:

1. $Er_n, Se_1 (se_1 \dots se_n) \rightarrow \underline{Se}_1$
2. $Er_n, Rn (se_1 + rn_1 \dots se_n + rn_n) \rightarrow \underline{Se}_2$
3. $Er_n, Rg (\underline{Se}_1 (se_1 \dots se_n) - \underline{Se}_2 (se_1 \dots se_n)) \gg 0 \text{ or } \bar{0}$
4. $Er_n, Rn, Rg (\underline{Se}_1 - \underline{Se}_2) \rightarrow \text{stop}$
- 4'. $Er_n, Rn, Rg (\underline{Se}_1 - \underline{Se}_2) \rightarrow \text{return to 1 or 2}$

Er_n = the executive scheme which guides all the operations at each point in the reconstruction performance sequence.

Se_1 = construction and storing, or encoding, of \underline{Se}_1 .

Rn = the reconstruction operator which guides the actions involved in \underline{Se}_2 ; the actual physical construction of the configuration \underline{Se}_2 .

rn = the specific reconstruction operator which guides the action involved in the actual construction of each particular feature.

In other words the execution, by an adult, of the reconstruction strategy would go thusly:

1.) The subject approaches the task with the knowledge that reconstruction type performance is going to be demanded of him. The subject looks at the model and encodes it in precisely the same way it is encoded for the recognition task (see above).

2.) Now the subject transports a number of strips (usually the correct number) to the blank card. The subject then runs through or repeats his internal construction of the perception of the strips in a vertical orientation. He then transforms this process into overt actions which end with the same result. This process could work like a redundant feedback loop, construction of percept, construction of external configuration, construction of percept, etc., until the subject decides that the construction of the feature while looking at the model is an identical process to constructing the same feature when looking and the product of the overt constructing actions. The subject would then go on to construct the next feature.

3.) Having performed step 2 the subject will then perform step 3 in exactly the same way step 3 was performed in the recognition task.

The strategies outlined above are the strategies adults would use in solving the different seriation tasks. How this model can be applied to the actual seriation performance of children of different ages will be detailed in the discussion section.

Up to the present there have been very few studies which have dealt in any way with the development of the concept of seriation. Piaget and Szeminska (1941) first introduced the problem of seriation as it relates to the coordination of schemes underlying the operations of ordination and cardination. The tasks employed at that time were designed to demonstrate and describe operational seriation. Children were required to discover the correspondence between dolls of different sizes and sticks of different sizes as well as other operational tasks such as the insertion of new elements into an already constructed seriation. The basic conclusion drawn was that the evolution of ordination goes hand in hand with that of cardination. In a later volume devoted to the exposition of the concepts of classification and seriation and their relationship, Inhelder and Piaget (1964) set forth two main problems to be solved, the first dealing with whether or not operational seriation is abstracted from a perceptual configuration and the second with the relationship between

perceptual and operational seriation.

The first problem has been dealt with by Blackstock and King (1973). We demonstrated that recognition memory for seriation preceded reconstruction memory developmentally, and that the number of objects to be seriated and the perceptual or figural characteristics of the non-seriated configurations used in that experiment had a marked effect on children's ability to perform on seriation tasks. Our general conclusion was that the developmentally early perceptual image evolves into an operational image via an integration with other schemata of a more motoric origin.

The importance of the second problem, the relationship between perceptual and operational seriation, has been outlined above. It is surprising that Piaget devotes so little attention to its resolution. His method of dealing with this question was to demonstrate that graphic anticipations (drawings made by children who have seen the disarranged elements and are asked to imagine what they will look like when they are properly lined up) of seriations with good figural form precedes the ability to perform operational seriation (defined here as the ability to line up sticks according to height when the differences between each stick are so small that the operation of measuring is necessary). Piaget demonstrated that children of four years could neither seriate nor anticipate seriations by drawing, that children of six years could anticipate seriation by drawing but could not actually construct the seriations they had drawn, and that children of eight or nine could anticipate both globally and analytically and perform operational seriations. His argument is that there is a stage during which a child is able to imagine a seriation and draw it before it is able to reconstruct one from its disarranged elements. The notions here are confusing! If a child is able to imagine a seriation

before he can construct one then how can it be that:

. . . a subject has a perception of a serial configuration . . . because he recognizes the structure as one which he himself can construct or reconstitute. (Inhelder and Piaget, 1964, p. 249)?

Our interpretation above (Blackstock & King, 1973) is relevant here. While a perceptual seriation may be derived from general sensorimotor schemes and actions, the ability to construct a seriation must be preceded by the ability to perceive one.

The evidence from the graphic anticipation experiments serves the purpose of demonstrating the difference between perceptual and operational seriation but offers little explanation of their relationship. However, in one of the variations of the anticipation experiments a variable was introduced which has great potential. In this study, which was designed to show the connections between tactile seriation and graphic anticipation, Piaget also varied the number of objects to be seriated and found that the subjects were able to perform the tasks with 5 objects long before they could do so with ten objects. We see that in discussions of perceptual seriation the number of objects is significant while in discussions of operational seriation Piaget feels there should be no developmental difference between the ability to seriate 3 or 4 objects and ten objects. This position could only be taken in a competence framework where the nature of structure is formulated independently of any content.

Subsequent studies on the concept of seriation have been rare. Elkind (1964) conducted a replication study which confirmed Piaget's general findings on the characteristics of operational seriation. Elkind also demonstrated that three dimensional blocks were slightly easier to seriate than two dimensional slats which were easier to seriate than thin sticks which he called one dimensional. Elkind seemed here to grasp the

notion that it might be interesting and valuable to systematically vary the figural aspects of, or the amount of information available in, the objects to be seriated, but he declined to discuss the possible implications of those results for Piaget's theory. He also found differences in performance between configurations involving 4, 7 and 9 objects. Another study concerned directly with the development of seriation was one conducted by Siegel (1972). Her main findings were that young children looked more at end sticks of a seriation than did older children, i.e., younger children employed a different looking strategy, and that there was a distinct developmental difference between the ability to seriate three and four items.

In addition to these few studies dealing directly with the development of the ability to seriate, Piaget (1968) has reported a series of experiments demonstrating long-term memory improvement for seriated configurations. The most interesting result of these experiments, as it relates to the present study, is that as the children increase in age their remembered configurations contain more elements, and those elements are arranged into better figural forms. Piaget has divided the developmental changes in configurations remembered into five stages, but Carey (1971) points out that those divisions were not necessarily dictated by the data, but may have been dictated by the theory. All of the studies carried out on the concept of seriation have revealed little about how that concept develops. Indeed, all studies carried out within a structural framework have only been able to show how the concept differs from age to age and from situation to situation. How do the transitions from state to state happen? How does one account for horizontal decalages? Beilin (1971) states that "What basically has to be answered is whether magnitude differences are related to qualitative changes identified with stage structures."

Pascual-Leone (1970) suggests that "any attempt to save the general stages construct must account separately for the general structural invariants and for the response variability." Both Beilin and Pascual-Leone are, of course, referring to the problems of horizontal decalages, which Beilin (1965) has noted have caused a great deal of the resistance on the part of American psychologists to accepting Piaget's theory. The problem has been further confounded by the postulation by many Piagetian investigators and Piaget himself, of many substages, i.e., stages within stages. Attempting to reverse this trend, which is barren of explanatory power, Pascual-Leone has postulated the existence of his central computing space M which increases in a lawful manner during normal development. This notion is completely compatible with Piaget's notion of a general intellectual factor or general structures. As noted above, there are two aspects of Pascual-Leone's formulations which apply directly to the present study. The first is that the central computing space can be represented numerically by the number of schemes or "items of information" that the child can handle simultaneously; plus factors which remain constant during a testing situation. The second aspect is the one dealing with figural form or F factor. To repeat, the general notion is that if the items of information have lower salience or less perceptual good form, then the number of items any specific child can handle simultaneously will decrease. Pascual-Leone (1970, p. 305) states:

It has frequently been shown that the probability of a cue S (i.e., a releasing response for a scheme) (occurring) depends on its 'salience,' which in turn depends both on learning and on the 'innate' perceptual organizational laws . . . it is reasonable to assume that: the lower the 'innate' salience and/or SR compatability of a scheme, the higher the level of the M operation required to bring about its activation. This 'innate' modulator or construct-variable corresponds probably to the figural factor (and the "field effects") of Piaget and Inhelder.

It is possible to glimpse in the notions of Pascual-Leone the beginnings of a method of dealing with a problem which Piaget (1971, p. 11) has claimed is akin to the problem of friction in physics - a problem which needs to be solved but for which no solution seems possible. This is the problem of accounting for horizontal decalages, or resistances, with any general theoretical formulation. Flavell and Wohlwill (1969) note that "horizontal decalages . . . represent purely ad hoc constructs. It is possible to look at them, however, as referring to aspects of the automation side of the model, concerned with the mechanisms for coding and processing information, rather than with the reasoning processes as such."

There are two studies which have approached the problem of transition from an information processing point of view. The first was that of Nassefat (1963) who studied the transition from concrete to formal operations in the age period from nine to thirteen years. He made novel use of Green's index of consistency to support his concept of the transition period as one during which performance across formally equivalent tasks becomes progressively more consistent. The second study is that by Uzgiris (1962) as reported by Wohlwill and Flavell (1969). She focused on the acquisition of conservation of substance, weight, and volume. She varied the materials used as well as the manner in which they were employed. Flavell and Wohlwill found that her data supported their model of transition.

The Present Study

On the most general level the present study will attempt to show that the physical dimensions of the elements of a seriated array determine, in important ways, performance involving those objects, at all levels of development of the concept of seriation in essentially the same way. This

would be support for the notion that the strategies for processing portions of the potential information from the physical dimensions undergo qualitative changes as the result of quantitative development or expansion of a central computing space. In addition the present study will investigate the relationship between recognition and reconstruction memory for seriation, attempting to show how strategies for these different kinds of encoding and decoding demands differ. It has already been conclusively demonstrated that recognition performance is easier than and precedes developmentally reconstruction performance (Blackstock and King, 1973). The central point of contrasting the two modes of decoding here is to find out if the kind of errors made in each mode are similar or different. It is important to note that the author does not believe that recognition performance equals preoperational seriation and reconstruction performance equals operational seriation. Surely a recognition task could be constructed which demanded operational schemes to solve (for instance the task of recognizing that 2 different sets of seriated auditory tones are different from a larger set of non-seriated auditory tones, and different in the same way) if the memory and information processing demands were great. At the same time, preoperational children clearly reconstruct seriations when the dimensions are easily constructed and the information processing demands are not great.

Assuming that any specific performance necessarily implies the existence of specific psychological structures is a serious error made by investigators such as Bower (1968) in his work on the concept of the permanent object in infants and Bryant and Trabasso (1971) in their work on transitivity judgements in young children. De Boysson-Bardies and O'Regan (1973) demonstrated how young children could succeed on a test of transitivity without using the strategies which Piaget said transitivity perfor-

mance was a demonstration of. It is one thing to postulate a psychological structure and cite a specific behavior as being the product of that structure. It is an entirely different thing to observe a specific behavior and state unequivocally that it demonstrates the existence of that structure.

De Boysson-Bardies and O'Regan (1973) put it nicely:

...it is difficult for any single experiment to bring unequivocal evidence for the existence or absence of a given cognitive capacity. Just as failure can always be attributed to difficulties such as with material or memory overload, success can always be brought about by the use of some kind of material-oriented heuristic which happens to work in the given situation.

However, given an awareness of the fallacy of assuming one can uncover competence by merely lowering task and memory demands, it would be a further error to assume that developmental changes in span of attention and short term memory capacity did not play a role in the development of operational strategies. It would also be a mistake to assume that experience with objects of different physical dimensions and the applying of different kinds of processing strategies (such as perceptual or intuitive strategies) to those objects did not play a crucial role in the development of operational strategies. This study will attempt to show how changes in physical dimensions and processing strategies are related to changes in age.

As seen in the discussions above, the physical dimensions of objects involved in seriation performance can influence that performance in two main ways. The first has to do with the size of the differences between the objects and the second with the degree to which the objects, once seriated, make a good figural form. This study focuses on the latter dimension because I am most interested in how variations in physical dimensions affect the way that information is transformed into performance. Therefore I have varied the shape of the tops of two dimensional slats to maximally facilitate good form, to maximally inhibit good form and a condition between

the two. (The variations of the shape of the tops can be seen in figure 1.) The slats which facilitate good form should facilitate performance at all levels of development, even for adults. Of course, variations in physical dimensions will have a greater effect at younger ages because the activation of less developed schemes is more dependent on scheme boosters. Therefore younger children will succeed tasks involving scheme facilitating stimuli and fail on tasks involving stimuli which inhibit the activation of the seriation schemes. As age increases and schemes get stronger in the sense that the scheme contains more information and is therefore applicable to more situations and can assimilate more different stimuli the power of inhibiting characteristics diminishes. This variable, figural form, will interact with the number of strips involved in any seriation. The present tasks employ either 4, 7 or 10 strips. As is the case with the different shapes there will be a clear developmental progression from the ability to seriate 4 strip collections to the ability to seriate 10 strips, and the number of strips will affect performance at all levels of development. It will be most interesting to see how the number of strips in any seriation interacts with the shape of their tops to determine seriation performance. Certainly, as either number of strips or shape of tops increases in difficulty the other dimensions should suffer. All of these nine conditions (3 shapes X 3 numbers of objects) will be tested for both recognition and reconstruction memory. The two factors, number of strips and shape, should interact to affect performance on both recognition and reconstruction tasks in interesting ways. If good form increases the recognizability of a seriated row then perhaps a row of seven strips of a top shape which facilitates good form will be more recognizable than a row of four (there will be less good form). It could be the case that in some instances increasing the number of objects facilitates recognition and makes reconstruction more

difficult. However, the present author thinks this will not be the case because it is probably that the process of constructing a mental image to use in a recognition task, while being easier in this sense of requiring fewer processing steps, is essentially the same as the processes which lead to the operational construction of a seriation and are therefore affected by physical dimensions in the same way. Altogether each subject will be asked to perform 18 seriation tasks. This study will employ four age groups spanning the transitional period from preoperational to concrete operational thought: 6, 7, 8 and 9 year olds.

Performance on the 9 recognition tasks will be measured by success or failure as well as the looking time. The looking time measure will (as detailed in the methods section) determine the average amount of time each subject spends scanning a configuration before making a recognition or non-recognition decision. This will be an independent measure of good form. These times will be analyzed by a 4 factor, 3 (shape) X 3 (number of strips) X 4 (age; 6, 7, 8 and 9) X 6 (order), analyses of variance. Performance on the reconstruction tasks will be measured by success or failure. On each task a subject will get a 1 for success and an 0 for failure and these numbers will be analyzed by a 5 factor: 3 (shape) X 3 (number of slats) X 2 (task; recognition/reconstruction) X 6 (order of task presentation) X 4 (age); repeated measures analyses of variance.

The method of determining the strategies that are used to process information in all the tasks will be an error analysis. The stimuli for the recognition task are so constructed that any regular or recurring errors will indicate regular or recurring looking strategies. If the younger children make different kinds of errors on the recognition tasks than the older children it will probably be because they will use different kinds of looking strategies. When a child is able to apply a new looking stra-

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tegy to a recognition task he may not yet be able to apply it to the reconstruction task. All the configurations that are made on the reconstruction task will be carefully recorded so that any regularities in non-seriated constructions can be observed. It is hypothesized that the errors made on the reconstruction tasks will have something in common with the errors made on the recognition tasks and that the kind of errors made (kind of strategies used) will vary with variations in physical dimensions and/or age.

If the ability to perform different seriation tasks involving materials varying in their physical dimensions is causally linked to the development of qualitatively different strategies for abstracting information from stimulus configuration or if, in other words, variations in pre-operational performance are not merely unexplained or unexplainable phenomena within a stage of development but are rather evidence of regular changes in preoperational schemes which necessarily lead to changes in information processing strategies, then:

1. Variations in the shape of the tops of strips will cause variations in performance on both recognition and reconstruction seriation tasks, the effects of these variations will decrease with age but be always present and will affect performance in the same way, or same direction, at all levels of performance. If these variations in performance are similar across tasks and ages then it will have been demonstrated that physical dimensions affect performance regardless of task or the level of development of seriation schemes. This is a fact often obscured by demonstrations of conservation that demand the disregarding or ignoring of perceived physical dimensions and one which establishes the link between pre-operational and operational seriation.
2. Variations in the number of strips to be seriated will cause variations

in performance on both recognition and reconstruction but always be present and will affect performance in the same way, or same direction, at all levels of performance. If these variations in performance according to number of strips occur when task and other physical variables are held constant, the continuous and quantitative aspect of development of the seriation schemes will have been demonstrated. It will also support the previous findings of Blackstock and King (1973).

3. The variation of shape and number will interact so that variations in shape will cause variations in performance with any number and vice versa. While all of the above hypothesized results would support Pascual-Leone's notion of M space this result would be the most convincing. If a child at any stage of development has a limited operating capacity then increasing the difficulty of one dimension will decrease his ability to operate on other dimensions. If a child has to devote more M space to abstracting the relevant features from difficult shapes he will have less M space available to deal with the number of objects involved.
4. Recognition performance will always be better than reconstruction performance, all other variables held constant.

This finding would support our earlier findings (Blackstock & King, 1973) as well as those of Olson (1970). While this difference between recognition and reconstruction performance by itself is not as surprising or significant as it once was, it becomes quite significant when it is combined with the other variables in the present study. If increasing the task demands causes regular changes in the level of performance regarding other kinds of variables both the notion of a limited computing space and the hierarchical organization of stimulus variables will have been supported.

5. The kinds of errors made will change as a function of age and variations of the main factors above. Only by observing errors can we determine

qualitative changes in information processing strategies. If there is no qualitative change in errors then we will have failed to demonstrate a link between perceptual and operational seriation.

Methods

Subjects Ninety children attending an elementary school in West Orange, New Jersey, participated as subjects. The subjects were homogeneous to the extent that they were all white and from the lower-middle to middle socioeconomic class. The children were enrolled in four different classes: 30 children, 15 males and 15 females, were enrolled in kindergarten and had a mean age of 5 years 11 months, with a standard deviation of 4.3 months; 20 children, 11 males and 9 females, were enrolled in first grade and had a mean age of 7 years and 2 months, with a standard deviation of 6.1 months; 20 children, 10 males and 10 females, were enrolled in second grade and had a mean age of 8 years and 2 months, with a standard deviation of 8.6 months. The children used in the study were selected at random from the class rosters.

Stimuli For the recognition tasks black paper strips were glued to blank white index cards measuring 15 cm. wide and 10 cm. high. These black paper strips were 1 cm. wide and were cut so that their tops either sloped upwards from left to right at an angle of about 45 degrees (shape I), formed a straight line parallel to the bottom of the card (shape II), or sloped downwards from left to right at an angle of about 45 degrees (shape III). The tops of the strips cut in shape I formed a straight diagonal line across the tops when they were placed in a seriated order according to height. Strips of shape II formed a stair-like appearance while shape III strips formed a very jagged line across their tops when seriated from left to right according to height. All of these strips varied in height

from 4.75 cm. to 9.75 cm. in .50 cm. steps. The height of all strips was measured at the midline from top to bottom. The strips were glued to the index cards in groups of 4, 7 or 10. For the cards containing only 4 strips the 4 lowest heights, 4.75, 5.25, 5.75, and 6.25 cm. were used. For cards containing only 7 strips the 7 lowest were used, and the cards with 10 strips used, of course, all 10 heights. There were constructed 9 decks of index cards, each deck composed of 10 cards. The first deck was composed with 4 strips, all of shape I, per card. On one card in this first deck, hereafter called deck 4I, the strips were arranged in a correct seriation. The strips on all cards were centered with .25 cm. between each strip. The bottom of the strips always formed a straight line at the bottom of the card. On each of the other cards in deck 4I the strips were arranged in non-seriated order so that 1 and only 1 pair of strips changed places. As there are three possible inversions in seriations involving 4 items, 3 cards were composed of non-seriations in which the second pair of strips changed place, and 3 cards were composed of non-seriations in which the third pair of strips changed positions. The seriated card was labelled as card #0 on its back. All cards containing a first pair inversion were labelled 1, all with 2nd pair inversions 2, and all the 3rd pair inversions 3. Therefore, in deck 4I there was 1 seriation (0), three 1s, three 2s, and three 3s. Decks 4II and 4III were arranged in the same manner. Drawings of the stimuli used in recognition tasks 4I, 4II and 4III appear in figure 1. There were 3 decks of cards for the tasks involving 7 strips. In each of these 3 decks one card contained a correct seriation (again card #0), 6 cards contained 1 each of the different seriations it is possible to make by inverting one pair and one pair only, and 3 cards contained a non-seriation picked at random from the 6. No non-seriation was represented more than twice in

the 7 strip decks. The numbering of the cards in the 7 strip decks followed the same convention as did the 4 strip decks, the card containing an inversion of the first pair of strips on the left being labelled 1, all the way through to the card containing an inversion of the last pair of strips to the right being labelled card 6. There were also 3 decks of cards containing 10 strips on each card. As with the previously described 6 decks, in each of these 3 decks representing the 3 shapes (I, II and III) one card contained a correct seriation. The non-seriations were constructed and labelled as they were for the previously described decks, there being 9 different non-seriations. The non-seriation with a first pair on the left inversion was labelled 1, and the non-seriation with a last pair on the right inversion was labelled 9.

For the reconstruction tasks strips were used that were in all respects identical to the strips used for the recognition tasks except that they were constructed from rigid black cardboard and were not glued onto any white cards. These strips were, of course, presented in the same 9 variations as were the strips in the recognition tasks: 4I, 4II, 4III, 7I, 7II, 7III, 10I, 10II and 10III. There was one essential difference. For each task the subject was presented with 4 times as many strips as he/she needed to complete the task. For instance, for a reconstruction task requiring the subject to make a 4 strip seriation he/she would be given 4 strips of each size - 16 strips in all. For reconstruction involving 7 strips the subjects would again be given 4 strips of each size - 28 in all, and for the tasks involving 10 strips he/she would be given 4 strips of each size - 40 strips. Care was taken with the sloping strips, so that they did not get turned over during the subjects' performance of the task.

As outlined in the methods section, each card in each of the 9 decks used in the recognition task was, except for the one seriation (or card #0) a non-seriation with one pair of strips inverted. For 4 strip configurations the card with the first pair on the left inverted was card #1, while the card with the last pair on the right inverted was card #3. Card #2, of course, had the center pair inverted. Whenever a subject selected a non-seriation as the seriation, or made an error in recognition, the card selected as, or confused with, the seriation was recorded. Figure 13 shows the distribution of errors on recognition tasks according to age and the location of the inverted pair of strips in a non-seriated configuration. It is clear that children in the kindergarten age group mistake each of the 3 different non-seriations containing 4 strips an equal number of times; 9, 10 and 9. However, all the older children consistently mistake cards on which the non-seriation is made by inverting an end pair (card 1 and 3) more than non-seriations made by inverting the center pair (card 2).

Considerations of the 7 strip configurations becomes more complex and more interesting. The numbering system used with the 4 strip configurations is again used here. Card #1 contains a non-seriated configurations made by inverting the first pair of strips on the left, card #6 is made by inverting the last pair on the right, and so on and so forth. There are 6 non-seriations in all. Of these 6 non-seriations cards 1 and 6 have in common the same amount of seriation, i.e. they both have 6 strips in the the proper order and 1 strip out of place. If numbers from 1 to 7 were made to represent the different heights with 1 being the shortest and 7 being the tallest, then card #1 would be represented 2-1-3-4-5-6-7 and card #6 would be represented 1-2-3-4-5-7-6. The underlined portion of the representations are, of course, the strips which are consecutively in the proper order. Now cards 2 and 5 of this group would be represented

1-3-2-4-5-6-7 and 1-2-3-4-6-5-7, respectively. Notice that they both have 5 strips in proper consecutive order, or the same amount of seriation. Cards 3 and 4 would be represented 1-2-4-3-5-6-7 and 1-2-3-5-4-6-7, respectively. It is clear from figure 13 that cards 1 and 6, the cards containing the most seriation because their end pairs are inverted, are mistaken for seriation more often than are cards 2 and 5 or 3 and 4. This result holds across all age groups. The same result is seen in the 10 strip configurations. These results seem to suggest that it is not the specific location of any inversion as much as it is the global appearance that causes an error to be made. The results suggest a global image strategy rather than a serial left to right or right to left visual scanning strategy. Looking at the totals at the bottom of figure 13 it is clear that more cards containing inversions at the ends are confused with seriations. Looking down the rows it is clear that configurations which have an end pair inverted are more often confused with seriations by older children but have no more potent effect than do configurations with interior inversions for younger children.

Reconstruction errors of the type where a child did not line up some strips in some order were not used in the following analysis. Those types of errors will be discussed in a later part of the results section. An interesting finding regarding reconstruction seriation errors was that nearly no subject who attempted to make a seriation used an incorrect number of strips. To demonstrate this all the reconstruction errors containing the correct number of strips were counted and compared with the number of reconstruction errors containing an incorrect number of strips. Those differences are presented according to age groups in Table 9. It is clear that simple numeration developmentally precedes seriation. This interaction has been previously dealt with by Elkind (1964) and Freeman (1971).

The subjects were given 4 of each size strip for several important reasons. The foremost is that the possibility of a subject solving the reconstruction task using pre-operational seriation schemes alone must be minimized. Secondly, it is important to minimize the applicability of schemes other than the operational seriation schemes to the solution of the problem. For instance, in traditional seriation tasks just the right number of objects are placed before the subject. The criteria for operational seriation is often stated as the ability of the subject to select the smallest of the remaining sticks, without trial and error, as the seriation task progresses. But selecting the smallest of a collection of items could be a non-operational strategy (searching for an object that is at the same time larger than the one that he previously selected and smaller than ones to come after) or purely pre-operational or perceptual strategy (searching for the smallest of a collection). There is another concept which is always confounded with the concept of seriation on traditional seriation tasks; the concept of numerosity. Freeman (1971) has previously worked on the connection between the two concepts. It is important in reconstruction seriation tasks to know how the subject knows she/he has completed the task. If just the right number of objects are present the subject will use them all up. If the subject is given more objects than he can possibly use we will be able to determine whether he stops performing because he has constructed the proper number of strips or because he ran out of reconstructing space or whatever. By using 4 times the number of strips necessary we also insure that each selection from the objects on a table will always involve objects smaller than and bigger than the most appropriate selection.

Procedure Each subject met individually with the experimenter for about 45 minutes during which the 18 tasks were administered. I fetched each

subject from their classroom, asking if they would like to come play some games. E and the subject walked a short distance down the corridor to a low table separated from the corridor by a solid screen. The subject and E sat adjacent to one another facing the wall. The lighting was indirect from fluorescent lights overhead.

There were 9 test trials for the recognition task and 9 test trials for the reconstruction task. The 9 recognition test trials were always administered first. Recognition and reconstruction tasks were not counterbalanced for 3 reasons: 1. As mentioned in the introduction it has been conclusively established that recognition performance is easier than and developmentally precedes reconstruction performance, all other things being equal. Therefore, a demonstration of this effect was not central to the present study; 2. In a previous study (Blackstock and King, 1973) order of presentation of recognition and reconstruction tasks was shown to have no effect upon performance; and 3. Counterbalancing would not have been practical given the limitations of time and number of subjects available for the present study. Within each task there were 6 different orders in which the 9 test trials were administered. These 6 orders were determined by the number of strips used, the 6 orders being: 4-7-10, 4-10-7, 7-4-10, 7-10-4, 10-4-7, and 10-7-4. Within each of these 6 orders of presentation the order of presentation of the 3 different shapes was randomly determined. For any given child the same order was used for both tasks.

In the recognition test trials the experimenter selected the appropriate deck from the group of 9, extracted the card containing a correct seriation (card #0), and carefully placed this card on the table in front of the child saying: "Look carefully at this card. See how these black strips on it are all lined up just the right way. (E would then run his finger along the top of the strips from left to right). I am going to take this

card and hide it in this deck here (picking up the appropriate deck in his right hand), and then we'll see how quickly you can find it." E would then ask the subject to turn aside and "hide (his/her) yeres" while E hid the card in the deck. Making sure that his action was hidden from the subject E would place the seriated card in either the 8th or 9th position in the deck of 10 cards. Each subject had learned on a pre-test procedure described below, and was instructed before each test trial, to turn, with one hand, as fast as he could, each card over until he came to the right card, the hidden card for which he was searching. Upon discovering the correct card he was to clap his hands together to indicate that he had found it. The hand-clap signal was not decided upon accidentally. During the numerous pilot studies done for this study many methods were tried by which a child could signal success, including a verbal sign or a push of a button. However, as often as not the child would either look at E or clap his hands in joy before answering or pushing. As it was important to time the speed of finding as accurately as possible it seemed natural to make serendipitous use of the natural, joyous, hand-clap.

Having given the instructions and hidden the correct card, E placed the appropriate deck directly in front of the subject and covered the deck with his left hand. E then said to the subject: "Open your eyes and look here on the table. Remember the rules. Turn over the cards one at a time with one hand and find the card I just showed you as fast as you can. When you find the right card remember to clap your hands. Ready, GO!" With the command to begin E simultaneously removed his hand from on top of the deck of cards and started his stop watch. When S clapped his hands E stopped his watch and said: "Good. Now let's play with some different cards." E recorded the time, the card selected and the position of the card in the deck. This procedure was followed for each of the 9 recognition test trials.

For the reconstruction test trials E placed a blank white index card the same size as those to which the black strips were pasted for the recognition tasks directly in front of S on the table. Immediately adjacent to this blank card was placed a card containing the correct seriation (card #0) appropriate to the particular test trial. E would next spread on the table, just above S's blank card, 4 times the number of strips S would need to make a perfect copy of the correct seriation. There were 4 each of strips of the different sizes represented on the model card. E would then say: "Look carefully at this card (pointing to the card with the correct seriation). See how these black strips on it are all lined up just the right way (E would then run his finger along the tops of the strips from left to right). Now you take some of these strips up here (pointing to the strips spread on the table), and make your card (pointing to the blank one) look just like this one (pointing to the card containing the correct seriation)." S was given up to three minutes during which time E said nothing and avoided giving S any feedback whatsoever. S had learned during the pre-test procedures described below, and was instructed before each test trial, to clap his hands when he had completed making his card. The hand-clap signal was crucial here because children trying to solve a reconstruction type problem taking many steps usually search for feedback from E during the task. As E wanted to discourage this strategy E carefully avoided even looking as though he were looking at what the child was doing until he heard the hand-clap signal. It was easy for E to do this and still carefully observe what the child was doing simply by leaning back in his chair and looking over S's shoulder. When S looked up E looked away. The child was, in effect, working alone. At either the hand-clap signal or at the end of 3 minutes E asked S if the card he made was "just like this one (pointing to the model card)." E did this whether or not S had succeeded

in making a correct seriation. If S said "yes " and was correct he was given a score of 1 for that trial. If S gave any other combination of performance and reply E said: "Can you make your card look more like this one? Go ahead and try." If S still failed to make a correct seriation, or then changed a correct seriation to a non-seriation, he was given a score of 0 for that test trial. Quick drawings were made of the subject's configuration if the strips were not vertically lined up similar to the model. If the strips were lined up E recorded the configuration by noting the number of each strip and its location in the configuration. In a correct seriation the smallest strip would be labelled 1 and the largest strip either 4, 7 or 10 according to the number of strips in the seriation. E also wrote comments on the type of strategy the child seemed to be using in making his construction.

When a child had completed both tasks he was given some M&M candies, told he had done a very good job, and that he was very smart, and was taken back to his classroom.

Before the actual test trials were begun each child went through a pre-test procedure to insure that he understood the rules of the game and had established the appropriate mental set. For recognition the child first had to find a card with a picture of an animal on it among a deck containing 9 other animal pictures. The procedure was identical to that described above for the recognition test trials. For reconstruction a cut-out picture of an animal was cut into 4 equal strips. He was given a blank card, a card with a picture of the animal was placed next to the blank one, and he was asked to make his card look just like the model. Only children who performed correctly on these pre-test procedures were used as subjects. All of the children seen passed the recognition pre-test. Six kindergarten children and one first grade child failed the reconstruction pre-test and

were not used as subjects.

Design The overall design of the experiment was a 5 factor analysis of variance with repeated measures. The between subject factors were Age (4 levels: 5-11, 7-2, 8-2, and 9-2), Order (6 levels: 4-7-10, 4-10-7, 7-4-10, 7-10-4, 10-4-7, 10-7-4). The within subject factors were Task (2 levels: recognition and reconstruction), Number of Strips (3 levels: 4, 7, and 10), and Shape of the Tops (3 levels: I, II and III).

Results and Discussion

This section will be divided into 4 major sections. The first will be an analysis of the success scores on all of the test trials. This section will demonstrate the main effects and their interactions. The second section will report the analysis of the average looking time for each of the 9 decks of stimulus cards used in the recognition tasks. This independent measure of performance is most significant in showing that while there may appear to be no difference in performance according to the variables manipulated, a finer measure will reveal those differences. It will also show that changes in average looking times anticipates changes in overt performance. The third section will report on the analysis of the kinds of errors made in both the recognition and reconstruction tasks. The error analysis is, of course, most important in that it will link qualitative changes to quantitative ones demonstrated by the above analyses. The 4th section will propose a specific model of the development of the concept of seriation suggested by the present data as well as the broad theoretical model of Pascual-Leone.

Part I: Success/Failure The central dependent variable, or performance measure, in the present study, was success or failure on the 9 recognition

and 9 reconstruction tasks. If, on any of the 9 recognition tasks the child clapped his hands upon seeing the correct seriation (card #0) he was given the score of 1. If he clapped his hands upon seeing any other card he was given a score of 0. On the reconstruction tasks the subject was given a score of 1 if and only if he lined up the correct number of strips, each of a different size, in the correct order. He was given a score of 0 for any other performance. Therefore each subject had 9 scores for recognition and 9 scores for reconstruction - 18 scores in all.

On these scores was performed a 5 factor, repeated measures, analysis of variance. The specific design used was that incorporated by the Balanova program of Herzberg (1973) which is modelled after the analysis found in Weiner (1962). The between subjects variables were age (4 levels) and order (6 levels), while the within subjects variables were task (2 levels: recognition and reconstruction), number of strips (3 levels: 4, 7 and 10), and the shape of the tops of the strips (3 levels: see figure 1). The analysis of variance revealed a significant effect for age ($F = 18.38$; $df = 3,66$; $p < .001$), for task ($F = 391.09$; $df = 1,66$; $p < .001$), for number of strips ($F = 70.58$; $df = 2,132$; $p < .001$), for the interaction between number of strips and age ($F = 3.04$; $df = 6,132$; $p < .005$), for the interaction between task and number of strips ($F = 18.25$; $df = 2,132$; $p < .001$), for the interaction between task and shape of tops ($F = 8.82$; $df = 2,132$; $p < .001$), for the interaction between task, number of strips and age ($F = 4.26$; $df = 4,264$; $p < .025$). The effects of all other variables and their interaction were not significant. Table 1 gives a summary of the analysis of variance.

Table 2 gives a summary of these results by showing the percentage of subjects passing the recognition and reconstruction tasks according to shape of tops of strips, number of strips, and age. One can see in this

table an interesting pattern begin to develop. In the recognition scores for the kindergarten children we see that task 4I is passed by a high percentage of subjects (80%) while task 10III is passed by a low percentage of subjects (23%). The tasks between 4I and 10III diminish in percentage of subjects passing in a complex and uneven way, but the general pattern is a diagonal decrease from the upper left cell (4I) to the lower right cell (10III). Now look at the reconstruction scores for the same children. There is virtually no pattern - a few subjects can handle 4 strip seriations. If reconstruction tasks, per se, are too difficult for children at this level of development then the number of strips or the shape of those strips will make no difference in their reconstruction seriation performance. Contrast this first pair of blocks of scores with the recognition and reconstruction scores for the 2nd grade group. Here we see that for the recognition task the differences between the upper left cell (4I) and the lower right cell (10III) has greatly diminished, there in fact being 5 cells with identical percentages in them. Children of this level of development have mastered seriation recognition skills to the extent that the stimulus variables have little effect on success or failure. (Those stimulus variables do still effect performance as evidenced by looking times.) On the reconstruction task, however, a pattern very similar to the pattern obtained by kindergarten children on the recognition task appears. The point is that the stimulus variables (number of strips, and shape of tops), have a constant effect on mental processes. If you increase the difficulty of the task or the complexity of the decoding processes necessary you increase the age at which the pattern of the effects becomes observable. If you take a finer measure of performance (looking time) you reduce the age at which the effect becomes observable.

Looking at any cell in the blocks of 9 entries in Table 2 one can

quickly observe the age effect by seeing how the percentage in that cell⁵¹ changes with increasing age. For instance, the sequence for 4I recognition tasks is 80, 95, 100 and 100 for kindegarten, 1st, 2nd and 3rd grades respectively. For 10III recognition tasks the sequence is 23, 25, 25 and 60. By comparing cells horizontally one can see the constant and marked difference between recognition and reconstruction performance.

To further demonstrate the main effects the mean scores for recognition and reconstruction tasks were obtained by summing across subject, order, number of strips and shape variables and dividing. These means are presented according to age groups and task in Table 3. This table shows clearly that recognition is easier than, and precedes developmentally, reconstruction ability. This table also shows that increasing age affects both tasks in much the same way. Figure 2 shows graphically that the greatest increases in ability is between 1st and 2nd grade for both tasks.

These results are consistent with informal observations of seriation behavior and are supported by a great deal of previous research. That recognition performance is easier than and developmentally precedes reconstruction performance has been previously postulated (Piaget, 1968; Olson and Pagliano, 1968), and empirically verified (Blackstock and King, 1973). In the present study 9 pairs (recognition - reconstruction) of tasks were presented to each of 90 subjects. Of these 810 pairs on only 8 did a subject pass the reconstruction task and fail the recognition task. It is reasonable to assume that reversals such as this occur in 1% of the cases because of the extraneous situational variables such as distractions during a specific performance or the unpredictable playing of young children. A case will be made below that recognition performance must always be easier than and developmentally prior to reconstruction performance on any stimuli which are identical to both tasks because the processes involved

in recognition performance are always an integral part of the processes used for reconstruction.

That the number of objects in a seriation would affect performance has been suggested previously (Piaget, 1964; Elkind, 1969; Siegal, 1972) and has been empirically verified for seriations containing either 4 or 5 objects (Blackstock and King, 1973). It is not surprising then that a strong effect was found for number of strips in the present study. The implications of this finding for a model of the development of seriation are great. No longer can one hold the position that a child either has the concept of seriation or does not, or chooses to apply it or not apply it independently of the task demands and the nature of the stimuli involved in a specific situation. Whether or not an operational scheme of seriation is applied must certainly be determined by number of objects involved, the shape of the tops, the task demands, the overall testing context, and of course, the internal environment of the subject at the time of testing.

That the shape of the tops of the strips should influence performance was barely suggested by Piaget (1964) when he discussed the importance of the size of the difference between the elements of a seriation. Mean scores representing the interaction between age and number of strips is graphically represented in figure 4. These mean scores were obtained by summing across subject, and shape variables. These scores show a greater increase in ability on 4 strip tasks than on 7 and 10 strip tasks between 1st and 2nd grade. To make a finer analysis of this three way interaction effect between task, age, and number of strips, the effects for recognition and reconstruction were separated. The mean scores for the recognition and reconstruction tasks are graphically presented in figure 5. It is clear that in the recognition tasks the interaction effect caused by greater gain between the 1st and 2nd grade age groups on 4 strip tasks is virtually non-existent.

In fact there is less of a gain on the 4 strip tasks than there is on both the 7 and 10 strip tasks. When we look at the mean scores for the reconstruction tasks alone in figure 5 we see that the interaction effect is all here. The gain on 4 strip tasks for children between 1st and 2nd grade (44 points) is greater than the gain between K and 3rd grade on the 7 and 10 strip tasks (41 points). Although this interaction is complex and difficult to interpret its existence does not compromise the main effects.

To examine the interaction between age and the shape of the tops of the strips mean scores were obtained by summing across subject, order, task, and number of strips variables and dividing. These mean scores are graphically presented in figure 6. Here we see the marked gain between 1st and 2nd grade for both shape I and shape II but not for shape III tasks. To again make a finer analysis of the interaction effect between age and shape I obtained means for recognition and reconstruction separately. These means are graphically presented in figure 7. It is clear, especially for the reconstruction tasks that the large gain in scores which, for most stimuli, occur between 1st grade and 2nd grade occurs later in development when shape III stimuli are concerned. Both ceiling and floor effects probably contribute greatly to the interaction effect here.

The interaction effect between task and number of strips was examined by obtaining mean scores by summing across subject, age, order, and shape variables and dividing. These mean scores are graphically presented in figure 8. It is apparent that the difference between recognition and reconstruction scores is greater for tasks involving 7 and 10 strips than it is for those involving 4 strips. This result could be interpreted to mean that increasing the number of items in a seriation affects the ability to reconstruct more than it affects recognition. In other words, the diagonal line rising across the tops of 10 seriated strips might be a

powerful stimulus, in terms of its goodness of form. If a child is using a strategy of looking for a straight line across the tops the addition of a few more strips is certainly likely to have less of an inhibiting effect than it would on a reconstruction task where the addition of more elements means that more operations over a longer period of time must be carried out.

Another interesting interaction is that between task and shape. To examine this interaction mean scores were obtained by summing across subject, age, order, and number of strips variables and dividing. Those means are graphically presented in figure 9. On the recognition task there is less difference between shape I and shape II (.08 points) than between shape II and shape III (.26 points). This is because the difference between shape which facilitates the perception of a straight line and the stairlike configuration of shape II is much less striking than the difference between stairs and the jagged line of shape III. It is surprising that the reconstruction scores do not follow this same pattern.

In summary, we see that performance on both the recognition and reconstruction tasks improve markedly with age. It is also apparent that the greatest improvement in performance on both tasks takes place between the age represented by the 1st grade age group (\bar{x} age = 7-2) and the 2nd grade age group (\bar{x} age = 8-2). The only exception is for tasks involving shape III where the greatest improvement takes place between the 2 oldest age groups. Although recognition performance is far above reconstruction performance at all age levels, both types of performance undergo drastic improvement at about the same age. It is also clear that increasing the number of strips to be seriated had a greater effect on reconstruction performance than it did on recognition performance, a result found earlier by Blackstock and King (1973). It was also shown that the number of strips involved in any reconstruction seriation task had a greater effect for the

older subjects than for the younger subjects, probably because the younger children made very few reconstructions with more than 4 strips. The shape of the tops of the strips was also shown to have a strong effect upon both recognition and reconstruction seriation performance. For the younger subjects shape did not make a difference on reconstruction performance because that performance was virtually nil. For the oldest subjects shape had a marked effect on reconstruction performance, shape III being most interesting. For the youngest subjects who were most influenced by perceptual qualities shape had the strongest effect on recognition performance. For subjects in the 2 oldest age groups shapes I and II differed little in their effect on recognition performance while shape III still made recognition more difficult. Finally, there was less difference between recognition and reconstruction performance on 4 strip tasks than there was between them on 7 and 10 strip tasks, and the shape of the tops of the strips had a more irregular effect on recognition performance than it did on reconstruction performance.

Part II: Looking Time The amount of time a subject looks at any stimulus is a performance measure independent of success or failure on any task. A subject must look before solving any problem related to any specific stimuli and that subject must have a plan or strategy for looking before the act of looking takes place. The amount of time a subject looks at any stimulus configuration will at any time be co-determined by the pre-looking plan and the nature of the stimuli being looked at.

In this study a fairly gross measure of looking time was used. As outlined in the methods section, any test trial began when the experimenter uncovered the top card of a deck and said "Go", and ended when the child clapped his hands as a signal that he had completed the task. The time was

measured in seconds, from the word "go" to the hand clap of the subject.

To arrive at an average looking time for any card in any deck that overall time was divided by the number of cards looked at. This procedure resulted in a looking time score for each of the 9 recognition task conditions. Each subject therefore had 9 separate looking time scores.

A 4 factor, repeated measures, analysis of variance was performed on these looking time scores. The specific design used was that incorporated in the Balanova program of Herzberg (1973). The between subjects variables were age (4 levels) and order (6 levels) while the within subject variables were number of strips (3 levels: 4, 7, and 10) and the shape of the tops of the strips (3 levels: see figure 1). The analysis of variance revealed a significant effect for age ($F = 10.31$; $df = 3,66$; $p < .001$), for number of strips ($F = 75.65$; $df = 2,132$; $p < .001$), for the shape of the tops of the strips ($F = 3.67$; $df = 6,132$; $p < .001$), and for the interaction between the number of strips and the shape of their tops ($F = 2.78$; $df = 4,264$; $p < .05$). The effects for all other variables and their interactions were not significant.

A summary of this analysis of variance of looking time appears in Table 5. It is most interesting that the results of this independent measure of performance are identical to those obtained on the success/failure analysis. Means of the average looking time scores were obtained by summing over subject and order variables and dividing. These means appear in Table 6 arranged according to age, shape and number of strips. If any one cell in the blocks of nine cells representing 3 shapes X 3 numbers of objects is compared across the 4 age groups it will be seen that the mean looking time decreases steadily. For instance for task condition 4I the sequence in order of age groups from youngest to oldest is 1.66, 1.30, 1.08, and .996. This pattern holds for every task condition except for 10III which has the

sequence of 2.62, 2.66, 2.47, and 1.76. In other words, with one minor exception increasing age consistently reduced the looking time for any particular stimulus configuration. The mean looking times are presented in Table 6.

To show the interaction between age and the number of strips used in a configuration, mean looking times were computed by summing across subject, order and shape variables and dividing. These mean looking times are presented in Table 7 according to age and number of strips. Looking across any row you will see that the mean looking time for any of the 3 different number of strips consistently decreases with increasing age. Looking down any column you will see that looking time consistently increases as a function of increasing the number of strips. The interaction between these 2 variables is graphically presented in Figure 10. While the looking time in 4 and 7 strip tasks decreases regularly as age increases there is no difference in looking time on the 10 strip tasks for children in the 1st and 2nd grade age groups.

A similar result occurs when we consider the interaction between age and the shape of the tops of the strips. To obtain the mean scores involved in this interaction scores were summed across subject, order and number of strips variables and divided. These mean scores are presented in Table 8 according to age and shape. Looking down each column you will see that as shape changes from I to III the looking time increases. There is no exception. However, looking across each row you will see that increasing age means decreasing looking time in every case except for shape III between the 1st and 2nd grade age groups. The exception to the pattern occurs in the same place as it did with the number of strips: the most difficult of the 3 conditions between the 1st and 2nd grade age groups. The interaction between age and shape is graphically presented in figure 11. Compare figures 10

and 11 to see the similarities in the nature of the interaction.

In summary, it is clear that age, the number of strips involved in any configuration and the shape of the tops of those strips affect performance measured in terms of average looking time, on a seriation recognition task. While average looking time for any particular task decreases sharply and consistently with age, it still varies according to shape and number in pretty much the same way and to the same extent regardless of level of development. While looking time decreases regularly across the 4 ages for tasks involving 4 and 7 strips of shapes I or II, there seems to be a consistent irregularity on tasks involving either 10 strips or strips of shape III (the most difficult tasks) between the 1st and 2nd grade age groups.

Part III: Error Analysis Although success or failure on the recognition and reconstruction tasks was the main dependent variable of this study, the analysis of the kinds of errors made by the subjects may be most significant for finding out something specific about the kinds of mental processes and information processing strategies involved in seriation performance.

There are several kinds of errors that can be made in recognition and reconstruction seriation performance. Of course, the kind of errors that it is possible to make on a recognition task is more controlled by the design of the experiment than is the kind of reconstruction errors possible. The only configuration that can be mistakenly recognized as seriation are those configurations presented by the experimenter. Non-seriations, or alternative configurations have been constructed as carefully as possible to reveal underlying perceptual strategies. However, even their design limits the kinds of strategies than can be uncovered. These stimuli were designed to be most sensitive to differences in serial scanning strategies and are less sensitive to parallel or global strategies and changes in those

strategies. On reconstruction seriation tasks there are 2 broad categories of possible errors. Some errors that are made have minimal implications for the underlying concept of seriation. For instance, failure to line up the bottom of the strips horizontally or failure to use the proper number of strips. The second broad category of reconstruction errors are those errors which have a direct bearing on the concept of seriation. I have identified 3 kinds of errors which seem to be most interesting. The first is the inversion (i) kind of error in which the subject places a smaller strip to the right of a previously placed strip, rather than a larger one. In other words, the model indicates that the seriation goes $A \ll B \ll C$ etc., and the subject places $A \ll C \gg B$. The relationship $C \gg B$ is therefore an inversion of the proper order $B \ll C$. A second type of error is a skipping (s) error in which a subject places a strip next to one already placed which has a bigger difference than the difference between the preceding pair. In other words, where the model indicates that the proper seriation is $A \ll B \ll C$ etc., the subject produces $A \ll B \ll D$ etc.. The relationship $B \ll D$ is therefore an error of skipping an element. The third type of error is the repeating (r) error in which the subject places a strip to the right of one already placed which is the same size as that strip. In other words, where the model indicates $A \ll B \ll C$ etc., as the proper seriation, the subject produces $A \ll B = B = B$. The relationship $B = B = B$ is an error of repeating elements of the same size. Drawings of examples of these three different kinds of reconstruction errors appear in figure 12. I have given an example of the 3 types of errors in each of the three different shapes to show how different the effect of the same error can be on different shapes. Another kind of consideration which will be important for our purposes here is the location in the configuration where the error takes place. This will be more significant for recognition tasks than for reconstruction tasks.

The rest of the reconstruction errors dealt with here are those falling into one of the three categories already described: inversion, repetition, and skipping. Of all the errors made the number of pairs of strips was calculated. For example, if a subject made a configuration containing 7 strips he constructed 6 pairs of strips. Some of these pairs would be correct pairs: if a child made the pair 2-3 that would be correct. If a child made a pair 2-4, 3-3, 4-2, that would be incorrect. All the reconstruction errors made were carefully tabulated and are presented in the appendix. Also calculated was the percentage of errors each type of error (inversion, repetition, or skipping) is responsible for in each task condition.

Part IV: The proposed model A model of the step by step development of the concept of seriation, as well as step by step descriptions of seriation performance at each level of development, which was suggested by all the accumulated data on seriation will be outlined below. The strongest theoretical influence on the model constructed below is the neopiagetian theory of Pascual-Leone (1969, 1972, 1974).

The terms of the model and a theoretical description For a child of any age, what features of the seriated configuration (Se) will be encoded, or stored, in STM will be determined cojointly by the processes available to that child and the availability of the features in the seriated configuration (Se). The youngest children in the present study, kindergarten children, are at the developmental level at which they can construct the parallel line feature (se₁) and the horizontal line feature (se₂) but are just beginning to be able to construct and store the diagonal line feature (se₃). Children at this stage of development are able to construct the diagonal line feature (se₃) if the seriated configuration (Se) construction contains few items

and the shape of the tops of the strips activates the appropriate F meta-construct which can then boost application of the diagonal line feature (se_3). If the diagonal line feature (se_3) is boosted and becomes an integral part of the child's seriated configuration (Se_1) (the parallel line feature (se_1) + the horizontal line feature (se_2) + the diagonal line feature (se_3)), then only stimulus cards satisfying all three conditions will be recognized as seriations. The probability that the diagonal line feature (se_3) will be boosted decreases as the number of items in a configuration increases and as the shape of the tops shifts from shape I to shapes II and III. As the probability of the diagonal line feature (se_3) being boosted decreases the probability of a test stimulus satisfying only the parallel line feature (se_1) and the horizontal line feature (se_2) being recognized as seriation increases and as all stimulus cards satisfy those conditions the cards confused with seriation are randomly confused. We see in the results that most kindergarten children can construct the diagonal line feature (se_3) when there are 4 strips of shape I in seriated configuration (Se) but that very few can construct the diagonal line feature (se_3) when there are 10 strips of shape III in seriated configuration (Se). We also see that kindergarten children look at 4 strip configurations of shape I for a much shorter time than they look at 10 III configurations. This difference is much greater than the difference an extra eye movement (200 msec.) or two would take. The child is probably spending more time trying to construct and store, or encode, the diagonal line feature (se_3). The error analysis does show that errors made on the recognition tasks by kindergarten children are pretty much random.

First grade children do better on recognition tasks than do kindergarten children, but not too much. The most dramatic change from the performance of kindergarten children is that configurations with inversions towards the

center (see figure 16), especially for $4I$ configurations. This is probably true because the child's mental space has expanded sufficiently to allow the first application of the seriated pairs feature (\underline{se}_4). If the seriated pairs feature (\underline{se}_4) is simply the construction by the child of the relationship $A \ll B$, and A represents the line of the far left and B represents the line on the far right of any configuration then all non-seriations in the present study satisfy that feature. However, if the child's ability to construct the seriated pairs feature (\underline{se}_4) develops to the extent that it represents the relationship $A \ll B \ll C$ then only the 4 strip configurations with inversions at the end positions satisfy the conditions of that feature. A factor about the development of the ability to construct the features $\underline{se}_1 \dots \underline{se}_n$ needs some further elaboration here. As the child's M space increase so is the number of features he is able to hold simultaneously in STM increasing. However, the simultaneous holding of several features applies only to recognition performance. A child may "play" with any feature individually in the process of developing the ability to construct that feature. The feature only becomes relevant to seriation performance when it is applied in conjunction with other seriation features. There is a point in development, after a child has developed the parallel line feature (\underline{se}_1) and the horizontal line feature (\underline{se}_2), and can apply them together, that the child develops the diagonal line feature (\underline{se}_3) and begins to develop the seriated pairs feature (\underline{se}_4). If the child's mental space has developed only to the point at which he can apply or construct 3 seriated configurations (\underline{se}) features then on any problem he may first apply the diagonal line feature (\underline{se}_3) and then the seriated pairs feature (\underline{se}_4), but never both together. It is at this point of development that the first grade children in the present study are. On a 4 strip task 1st grade children are able to apply the parallel line feature (\underline{se}_1), the horizontal line feature (\underline{se}_2) and

perhaps the seriated pairs feature (se_1). On the more difficult recognition tasks 1st grade children seem to revert to the use of the diagonal line feature (se_3).

The relationship between recognition and reconstruction performance,

revisited: Before turning to a discussion of how the younger children perform on reconstruction tasks it would be relevant here to discuss the relationship between recognition and reconstruction as far as that relationship is relevant to the model being suggested. First, Olson's (1970) conceptualization of the recognition act is consistent with the present model:

... The act of recognition, judging a new event to be equivalent to some earlier event or model, does not involve re-recognizing or re-generating the entire original event - as an image theory may imply - but, rather, the choosing from some set of alternatives an event which may, for some purpose, be considered equivalent. This choice would presumably be based on some cues or features that had been selected or attended in the original event and not a copy of the total original event.

The central question then becomes whether or not the act of selecting relevant features to encode is the same for recognition and reconstruction. Maccoby and Bee (1965) note that "more features are required for reconstruction than for recognition." In his study of the development of the concept of diagonality Olson (1970) concludes that "the difference between 'perceiving' or recognizing the diagonal and performing or copying it is that different perceptual information is involved in the two cases... Performatory activity...requires perceptual information for the guidance of each component of the act...". The present model is consistent with Olson's formulation and provides something of a formalization thereof. I feel that the features, per se, are the same for recognition and reconstruction but that in reconstruction tasks to each feature is added a reconstruction

operator which is necessary to decode the features into the performatory act. If certain features such as verticality are easier to construct, in the sense of constructing a perception, than are features such as diagonality because the human nervous system is biased towards those orientations, then it is probably true that the reconstruction operator rn_1 , associated with the parallel line feature (se_1) begins to become elaborated or developed shortly after the ability to perceptually construct the feature $dees$. To go further, it is probably the interaction between the construction of the parallel line feature (se_1) and the horizontal line feature (se_2) and the reconstruction operators rn_1 and rn_2 that give rise to the construction of the diagonal line feature (se_3).

In summary, while recognition performance is always easier than and developmentally precedes reconstruction performance where a single feature is involved, the interaction of the two modes across 2 or more features is precisely what gives rise to the development of new features.

Reconstruction performance in younger children: Let us turn now to reconstruction performance in the first two age groups. Just as the child brings a basic recognition strategy (steps 1 through 4 above) to any recognition task so does the child bring a similar reconstruction strategy to any reconstruction task. The difference is that within the reconstruction strategies exist elements, all the elements contained in the recognition strategies, plus the specific reconstruction operator (Rn). For any seriated configuration (Se) the child must construct his own seriated configuration (Se) and encode it in STM, perform reconstruction operations Rn ($rn_1 \dots rn_n$) and (Se) ($se_1 \dots se_n$) in order to construct the seriated configuration (Se_2). When a seriated configuration (Se_2) has been constructed the processes are the same as the end processes for recognition. As we

have seen above, kindergarten children are only just able to hold the parallel line feature (se₁) + the horizontal line feature (se₂) + the diagonal line feature (se₃) in STM. If they held these features in memory they will be unable to attempt any reconstruction whatever because there is no more mental space available in which to activate and apply the reconstruction operator. If the subject goes ahead and does apply the reconstruction operator he will lose the seriated configuration (Se), or features of that seriated configuration (Se), he had previously constructed and stored and will make a reconstruction without a diagonal (a non-seriated configuration (Se)), without the bottoms lined up and/or without any maintenance of verticality. In the present study it was common for a kindergarten child to study the model of seriation carefully and then look at the pile of strips and the blank card. The child would then begin to touch the strips, look quickly back to the model, and never really commence reconstruction. The child seemed to be holding on to the stored configuration. A second common observation was that kindergarten children would look at the model, look at the loose strips and the blank card, look back at the model, hesitate, and then plunge into the making of a reconstruction which had nothing in common with the model. This child had opted to attempt reconstruction but by making that decision, the decision really being the application of a reconstruction operator, had lost the encoded seriated configuration (Se). When kindergarten children did attempt to reconstruct and did line the strips up vertically (a rather rare occurrence) they made the error of ignoring the horizontal line across the bottom of the strips and ignored the diagonal line across the tops. Looking again at figure 17 we see that i type errors, errors which most violently break up the diagonal line across the tops, are made almost exclusively by subjects in the kindergarten age group and disappear completely in 2nd and 3rd graders. This result is

consistently obtained even though the model of seriation is present throughout the reconstruction task! What we cannot find out from the results of the present study is the nature of the reconstruction operators of kindergarten children who seem to make random reconstructions having no seriated configuration (se) factors. Perhaps they are using as a parallel line feature (Se₁) a configuration constructed from elements in long term memory (LTM) as a model, or perhaps no configuration at all, performing truly serial behavior. Only when a child attempts a reconstruction and is partially or completely successful can we find out something about the strategies he is using.

At this point the reconstruction operator R_n must be described in greater detail. R_n is composed of components $\underline{rn}_1 \dots \underline{rn}_n$. The component \underline{rn}_1 is analogous to the feature constructor which constructs the parallel line feature (se₁), and is applied in conjunction with it.. For example, if only the feature constructor which constructs the parallel line feature (se₁) and the reconstruction operator \underline{rn}_1 were activated in a performance sequence the resultant seriated configuration Se₂ would be a number of slats lined up vertically with the bottom horizontal and top diagonal line disregarded. Whether or not the child picks up and transposes the strips one by one or picks them up in a bunch to transport is not significant. Previous studies which have focused on the action have been misleading. The important thing cannot be how the child gets the strips on to the card, but what he does with them once they are there. Following from the first example, if a child uses reconstruction components $\underline{rn}_1 + \underline{rn}_2$ he will make a seriated configuration (Se₂) with vertical strips with the bottoms lined up horizontally and the diagonal across the tops disregarded, and so on for \underline{rn}_3 and \underline{rn}_4 .

We have seen above that 1st grade children are just able to begin con-

structing the feature, the seriated pairs feature (se_u) and applying it to recognition tasks. At this point in development something begins to happen which illustrates the essence of the model of development I am presenting. There must come a time in the development of any child at which, for any given concept which is performed on any kind of objects, he has enough mental space, or a large enough field of activation, in which to construct a configuration with all the relevant dimensions (in the seriation case, $Se (se_1 \dots se_u)$) and have some space left over to do something else. This is the point at which quantitative and qualitative development interact. Only when a child has undergone enough quantitative development, i.e., expansion of mental space, which allows for the construction of a complete configuration plus some extra space, can he begin to operate, in a qualitatively different and novel way, on that configuration. When children in the 1st grade age group can easily construct a configuration, seriated configuration (Se), then they can begin to apply a reconstruction operator. Operational reconstruction performance starts only when all the constructive components $rn_1 \dots rn_u$ can be activated to some extent. The first real step of operational seriation reconstruction would be the construction of a pair of strips. Again, this pair may be transported to the blank card one at a time, together or as a bunch. The method of transportation is irrelevant. What is relevant to operational seriation is the first time a pair of strips is isolated from the global seriated configuration (Se). It is unfortunate that so much attention had been previously given to the notion that the proper operational definition of seriation was the selection of the smallest item, and so on until all the items were properly used up. This method of transportation may be the most convenient for subjects who possess a fully operational concept of seriation but has nothing to do with the beginnings of the development of that concept. When it is said that the child selects

the shortest one first it must already be assumed that the child has the concept of seriation and realizes that the configuration is composed of many strips of different heights which will need to be lined up. This is a major problem with existing information processing accounts of seriation performance. Indeed, in one account, the first step in performance is the activation of a seriation routine (Young, 1973).

So the first distinction a child makes in understanding length or height is that there are 2 different lengths or heights. This is Piaget's rule of couples (Cellerier, 1972). This is reflected in the results Piaget (1968) obtained in drawing of seriation where subjects, reproducing a seriation of 10 sticks, drew sticks of only 2 heights, small and large, or several pairs of sticks of 2 heights. In the present study 1st grade children constructed configurations of pairs of strips. They produced configurations containing the proper number of strips because they had already developed the concept of simple numeration (see Elkind, 1969) but organized the elements of the configuration only according to the relationship between any 2 elements. The first step of making a pair is, of course, the simple arbitrary relation $A + B$, where a common dimension between the 2 elements is not constructed. The first step in seriation must be the construction of the pair $A \triangleleft B$, where all strips fit into either one category or the other. For 1st grades the construction of the concept $A \triangleleft B$ is reflected in the encoded seriated configuration (Se) as the seriated pairs feature (se_{ij}), where the seriated pairs feature (se_{ij}) is perception that the vertical line at the left of the seriated configuration (Se) = A and the vertical line on the far right of the seriated configuration (Se) = B. These children begin reconstruction by first isolating a pair, testing that pair against seriated configuration (Se₁) and then making a second pair which is independent of the first. The child will continue to construct independent pairs

until he has made a configuration with the proper number of strips. If any pair is not $A < B$, such as $A > B$ or $A = B$, the child may change it or leave it the way it is. One might ask why the child would not immediately change an incorrect pair. If a child is approaching the problem without an operational notion of a whole composed of many different parts, but only a global notion of trying to reconstruct a global seriation composed of the parallel line feature (se_1) ... the seriated pairs feature (se_4) where the seriated pairs feature (se_4) is only $A < B$ then the failure of a first or second pair to meet the $A < B$ criteria does not necessarily mean that the completed construction will not. Out of 215 non-seriated reconstructions made there are only 3 in which the relationship $A > B$ exists between their first and last elements. It is interesting, however, that 1st grade children made the i type of error significantly less than s and r type errors. If a child has just acquired the feature $A < B$ then a sequence 1-2-4-5 would violate that feature at no location and in no way. That the 1st grade children do make as many s type errors as they do r errors suggests that the first feature may be $A = B$ rather than $A < B$. That is, the notion that a pair involved in seriation A can either equal B or be smaller than B. A small developmental progression would be the separation of the feature $A = B$ into 2 distinct features: $A < B$ and $A = B$.

De Boysson-Bardies and O'Regan (1973) point out that the simple feature $A < B$, where there are no heights other than A and B for the child, may even be operating in simple transitivity problems involving 3 or 4 items and it is probably true for small seriations also. If there are 4 items A, B, C and D with the relationship $A < B < C < D$, then B could be paired with A by simple conditioning and C with D in the same manner. In other words, if each of the elements ABDD were a different color, as they are in most transitivity studies and the seriation studies of Voyat (1972), then the child

can learn that the color of B goes with the color of A, and C with D, the arbitrary relationship $A + B$, and performance on tasks studying transitivity or 4 item seriations are simply tapping the $A + B$ feature. Because the strips in the present study were all identical except for height that problem does not apply to us directly. The problem it does touch on is how to know what kind of performance represents a change in psychological structure from a 2 item relation $A < B$ to a 3 item relation, or triple, $A < B < C$. The children in the first grade age group have developed to the point at which they are able to construct the parallel line feature (se_1) + the horizontal line feature (se_2) + the diagonal line feature (se_3) quite easily and are just developing the seriated pairs feature (se_4) into $A < B$ and then $A < B < C$ relationships. These features are available to the recognition operator. However, 1st grad children are not yet able to, (do not have enough space left over), to apply these structures with a reconstruction operator. If the reconstruction operator is applied then only the most rudimentary form of the seriated pairs feature (se_4) ($A + B$) can be applied. This is clear from the fact that 1st graders are only somewhat successful on tasks involving 4I stimuli (45%), barely successful with 4II, 4III and 7I stimuli (30, 20 and 15% respectively), and completely unsuccessful on all other reconstruction tasks (see Table 2).

Recognition and reconstruction performance in older children: Something quite dramatic occurs between 1st grade performance and 2nd grade performance. On recognition tasks performance improves to near perfection except on tasks involving shape III. On the reconstruction tasks the percentage of subjects passing every task more than doubles. As the child began to be able to construct the seriated pairs feature (se_4) into $A < B < C$ and to be able to combine the seriated pairs feature (se_4) with the diagonal line

feature (\underline{se}_3), and use them simultaneously, recognition performance improved dramatically. What it means for reconstruction performance is that the feature, the seriated pairs feature (\underline{se}_4) can, for the first time, be used by the reconstruction operator. This means that after the first pair ($A < B$) of the seriated configuration (\underline{Se}) has been reconstructed a third item C or a second pair ($B < C$) can be reconstructed and that the 2 pairs can be coordinated into a unitary feature $A < B < C$. This step virtually guarantees success on tasks involving 4 strips. Performance on tasks involving shape I are facilitated because the child can also check the parallel line feature (\underline{se}_1) against the horizontal line feature (\underline{se}_2) making full use of the diagonal line feature (\underline{se}_3). However, 2nd graders can coordinate the diagonal line feature (\underline{se}_3) with the seriated pair feature (\underline{se}_4) only on tasks involving stimuli which facilitate the activation of \underline{F} metaconstruct which boosts the application of the relevant features. Therefore, when on shape II tasks involving more than 4 strips the child guides reconstruction by the seriated pairs feature (\underline{se}_4) alone, without the simultaneous use of the diagonal line feature (\underline{se}_3), \underline{s} type errors can be easily made. The problem is even more complicated on shape III tasks because the right side of the top of a strip forms an $A < B$ relationship with the left side of the top of a second strip whether it is, in fact, larger than or equal to the first strip. This makes the application of the seriated pairs feature (\underline{se}_4) and the diagonal line feature (\underline{se}_3) to any configuration of shape III of more than 4 strips difficult.

Children in the 3rd grade age group do not do much better on either recognition or reconstruction than 2nd grade children. There is a slight advance on the more difficult reconstruction tasks. The construction of the feature, the seriated pairs feature (\underline{se}_4) is as far as 3rd graders go. As the child grows and his mental space increases so do the kinds of tasks and

the kinds of stimuli to which the seriated pairs feature (so₁) can be applied increase.

A central idea that must be here reiterated is that while any particular strategy for abstracting information from physical objects is developing, performance based on that strategy steadily increases as a function of practice and of increasing mental space. When a strategy improves to a point at which it is operating at an optimum level, and there has developed more mental space than is required for that optimal operation, then new strategies will be tried out. These new strategies will be unsuccessful at first and their application will be limited to situations in which external factors will facilitate their operation. They will develop with practice and with expansion of mental space. That a model of this kind is operating is suggested by the error analysis. The errors of the youngest children attempting any specific task are random, suggesting that no regular strategy is being applied to the task. Slightly older children who still fail seem to do so in a regular way making the same types of errors consistently and then slightly older children achieve success.

In conclusion, the present study has conclusively shown that the physical properties of the stimuli used in any seriation task influence performance on some level at all stages of development and often determine the kind of operations which a subject can bring to bear upon the task. An exploratory model of how the concept of seriation develops which is consistent with all of the accumulated data on seriation has been presented. Much conceptual work and much theoretical work needs to be done. Many experiments need to be carried out. It is hoped that this study has made a contribution to the beginnings of a new way of conceptualizing development.

TABLES 1 - 9

Table 1

Summary of Analysis of variance of all scores on all tasks for all subjects, N = 90.

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Source of Variation	S.S.	d.f.	M.S.	F	p level
<u>Between Subjects</u>					
A (sex)	29.30	2	9.77	18.37	p < .001
B (order)	4.53	7	.91	1.70	n.s.
AB	4.06	15	.30	.56	n.s.
Subjects within (A,B)	35.08	66	.53		
<u>Within Subjects</u>					
C (task: recog. vs. recon.)	97.24	1	97.24	391.09	p < .001
CXA	1.54	3	.51	2.06	n.s.
CXB	1.04	5	.21	.84	n.s.
CXAXB	5.07	15	.34	1.36	n.s.
C X subjs. within (A,B)	16.41	66	.25		
D (no. of obj.: 4,7,10)	17.00	2	8.95	81.76	p < .001
DXA	2.03	6	.34	3.08	p < .001
DXB	1.15	10	.12	1.06	n.s.
DXAXB	1.63	30	.05	.50	n.s.
D X subjs. within (A,B)	14.45	132	.11		
E (shape: / - \)	19.22	2	9.61	70.58	p < .001
EYA	2.27	6	.38	2.78	p < .001
EYB	1.52	10	.15	1.12	n.s.
EYAXB	2.42	30	.08	.59	n.s.
E X subjs. within (A,B)	17.97	132	.14		
OXD	4.34	2	2.17	18.25	p < .001
OXDYA	3.47	6	.58	4.87	p < .001
OXDYB	1.43	10	.14	1.21	n.s.
OXDYAXB	3.53	30	.12	.99	n.s.
OXD X subjs. within (A,B)	15.68	132	.12		
CXD	2.09	2	1.04	8.82	p < .001
CXDYA	3.02	6	.50	4.26	p < .001
CXDYB	.83	10	.08	.70	n.s.
CXDYAXB	2.92	30	.13	1.11	n.s.
CXD X subjs. within (A,B)	15.62	132	.12		
DXE	.43	4	.11	1.42	n.s.
DXEYA	.72	12	.07	.86	n.s.
DXEYB	1.65	20	.08	1.08	n.s.
DXEYAXB	6.49	60	.11	1.42	n.s.
DXE X subjs. within (A,B)	20.10	264	.08		
CXDYE	1.01	4	.25	3.16	p < .025
CXDYEYA	.83	12	.07	.91	n.s.
CXDYEB	3.20	20	.16	.20	n.s.
CXDYEAxB	5.99	60	.10	1.25	n.s.
CXDYE X subjs. within (A,B)	21.11	264	.08		

Table 3

Mean scores on all tasks according to age and task condition,
for all subjects, N = 90

<u>task</u>	<u>age groups</u>			
	K (N=30)	1st (N=20)	2nd (N=20)	3rd (N=20)
recognition	.62	.66	.85	.86
reconstruction	.04	.11	.37	.45
combined	.33	.39	.61	.66

Table 4

Mean scores according to task, shape and no. of objects,
for all subjects, N = 90.

RECOGNITION

no. objs.	shape		
	I	II	III
4	.93	.87	.67
7	.90	.78	.61
10	.85	.76	.38

RECONSTRUCTION

no. objs.	shape		
	I	II	III
4	.57	.46	.35
7	.27	.18	.08
10	.20	.06	.01

BOTH TASKS COMBINED

no. objs.	shape		
	I	II	III
4	.75	.66	.51
7	.59	.48	.34
10	.52	.41	.20

Table 5

Summary of analysis of variance of looking times on the recognition task for all subjects (N = 90).

Source of Variation	S.S.	d.f.	M.S.	F	p level
<u>Between Subjects</u>					
A (age: 4 levels)	74.75	3	24.92	10.31	p < .001
B (order: 6 levels)	4.00	5	.80	.33	n.s.
AXB	21.21	15	1.41	.59	n.s.
Subjects within (A,B)	159.49	66	2.42		
<u>Within Subjects</u>					
C (no. objs.: 3 levels)	32.09	2	16.04	75.65	p < .001
CXA	3.12	6	.52	2.45	p < .05
CXB	1.15	10	.12	.54	n.s.
CXAXB	3.87	30	.13	.61	n.s.
C X subjs. within (A,B)	28.00	132	.21		
D (shape: 3 levels)	50.51	2	25.26	52.82	p < .001
DXA	10.52	6	1.75	3.67	p < .001
DXB	5.90	10	.59	1.23	n.s.
DXAXB	10.26	30	.34	.72	n.s.
D X subjs. within (A,B)	63.12	132	.48		
CXD	2.31	4	.58	2.78	p < .05
CXDXA	3.54	12	.29	1.42	n.s.
CXDXB	5.63	20	.28	1.36	n.s.
CXDAXB	9.79	60	.16	.79	n.s.
CXD X subjs. within (A,B)	54.81	264	.21		

Table 6

Average looking time, in seconds, for each card according to the 3 different shapes and the 3 different numbers of stimuli used and compared across the 4 age groups

<u>Kindergarten, Subjs., N=30</u>					<u>1st grade subjs., N=20</u>						
	SHAPE			TOTAL		SHAPE			TOTAL		
	I	II	III			I	II	III			
	<u>4</u>	1.66	1.92	2.47	2.02	<u>4</u>	1.39	1.76	1.84	1.67	
no. objs.	<u>7</u>	1.71	2.15	2.10	1.99	no. objs.	<u>7</u>	1.61	1.83	2.09	1.84
	<u>10</u>	1.94	2.37	2.62	2.31	<u>10</u>	1.88	2.02	2.66	2.19	
Total		1.77	2.15	2.40	2.11	Total		1.63	1.87	2.20	1.90

<u>2nd grade subjs., N=20</u>					<u>3rd grade subjs., N=20</u>						
	SHAPE			TOTAL		SHAPE			TOTAL		
	I	II	III			I	II	III			
	<u>4</u>	1.08	1.33	1.40	1.27	<u>4</u>	.996	1.18	1.27	1.15	
no. objs.	<u>7</u>	1.44	1.57	1.94	1.65	no. objs.	<u>7</u>	1.22	1.35	1.42	1.33
	<u>10</u>	1.57	1.90	2.47	1.98	<u>10</u>	1.33	1.56	1.76	1.55	
Total		1.36	1.60	1.94	1.63	Total		1.18	1.36	1.48	1.34

Table 7

Mean times according to age and no. of objects for all subjects, N=90.

no. objs.	<u>age group</u>			
	K(N=30)	1st(N=20)	2nd(N=20)	3rd(N=20)
4	2.12	1.67	1.40	1.20
7	2.20	1.89	1.70	1.42
10	2.52	2.15	2.14	1.59

Table 8

Mean times according to age and shape
of strips for all subjects,
N=90.

<u>shape</u>	<u>age group</u>			
	K(N=30)	1st(N=20)	2nd(N=20)	3rd(N=20)
I	1.85	1.69	1.37	1.23
II	2.21	1.96	1.64	1.37
III	2.79	2.05	2.23	1.60

Table 9

Frequency of errors made using the correct number of strips compared to the frequency of errors made using the incorrect number of strips on the reconstruction tasks, according to age. Older children made more errors because they attempted more reconstruction - they also made many more correct reconstructions than did the younger subjects.

	<u>age group</u>			
	K	1st	2nd	3rd
errors with correct no.	36	50	55	55
errors with incorrect no.	0	3	13	7

FIGURES 1 - 16

FIGURE 1

DRAWINGS OF ARRANGEMENTS OF STRIPS USED
IN FOUR STRIP TASK CONDITIONS

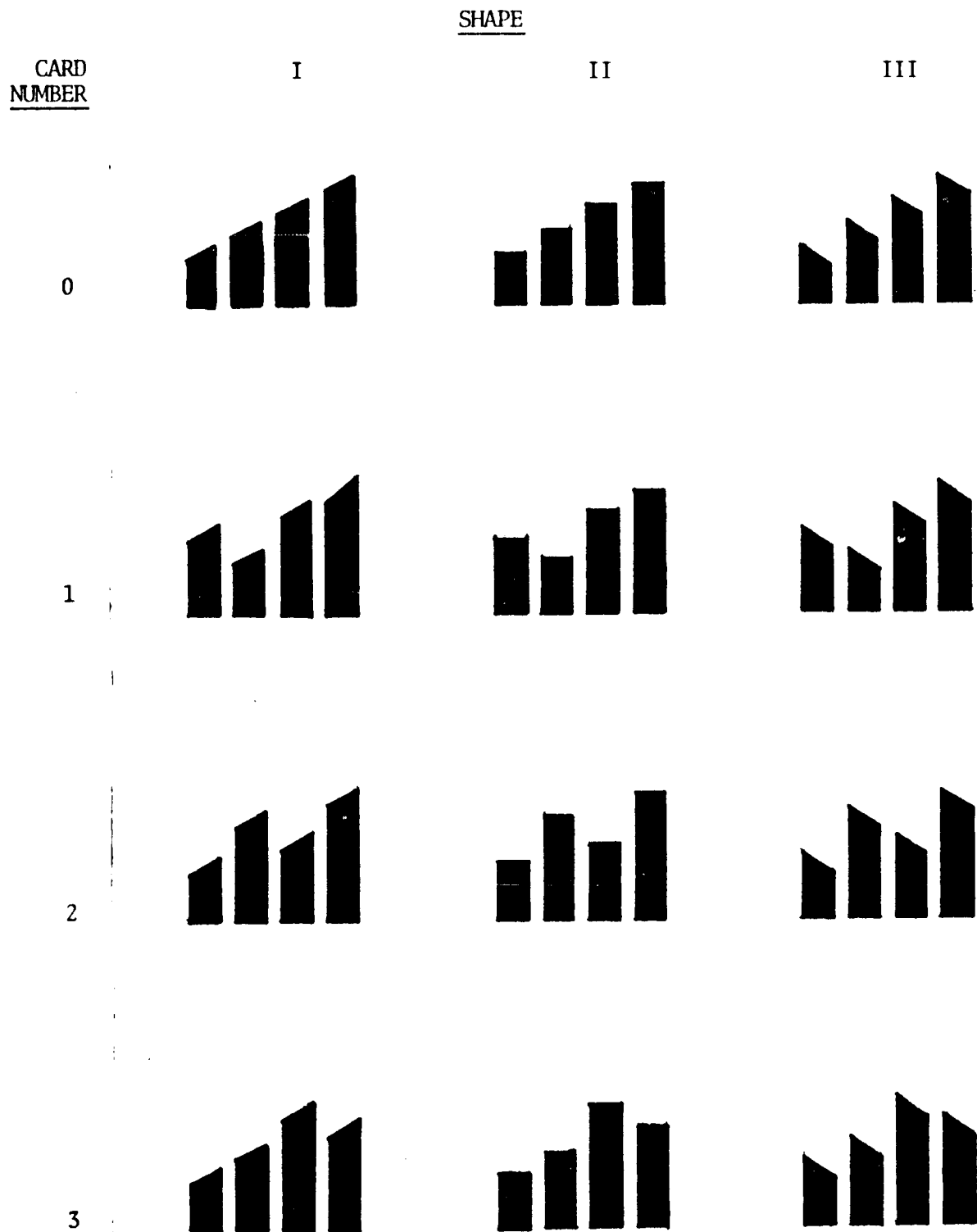
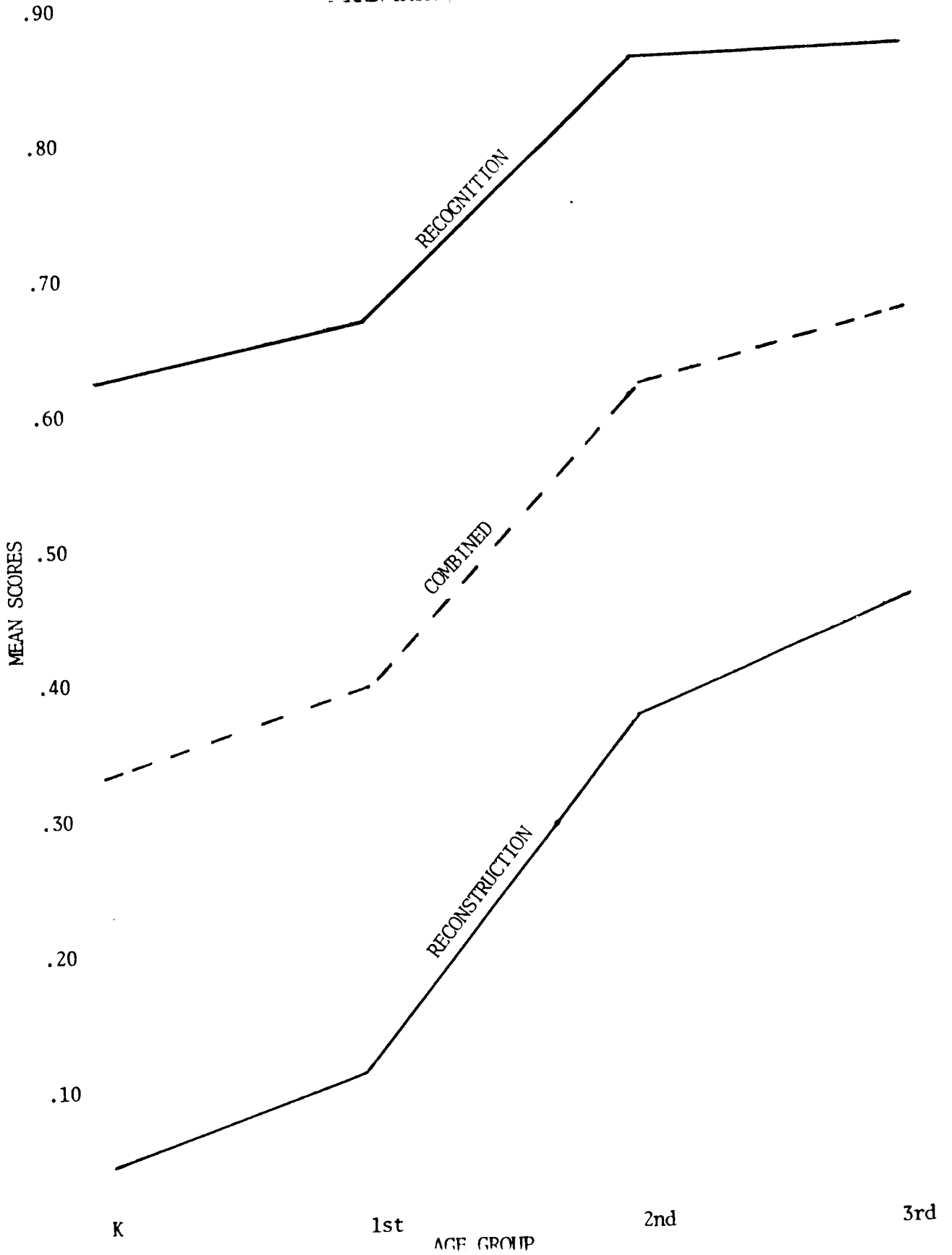


FIGURE 2
MEAN SCORES ON ALL TASKS
ACCORDING TO AGE GROUP
AND TASK



MEAN SCORES ACCORDING TO TASK
TYPE AND TASK CONDITION

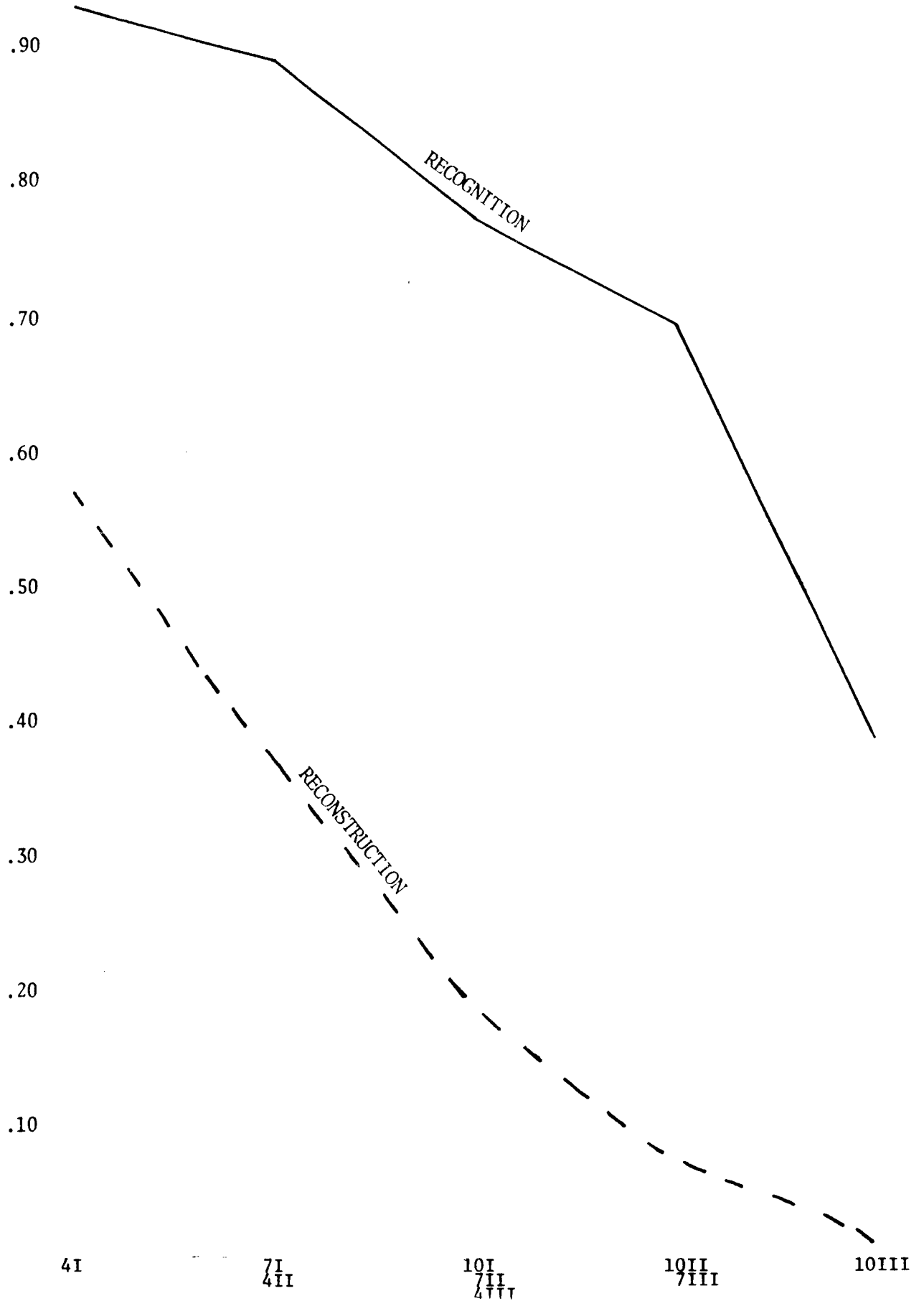
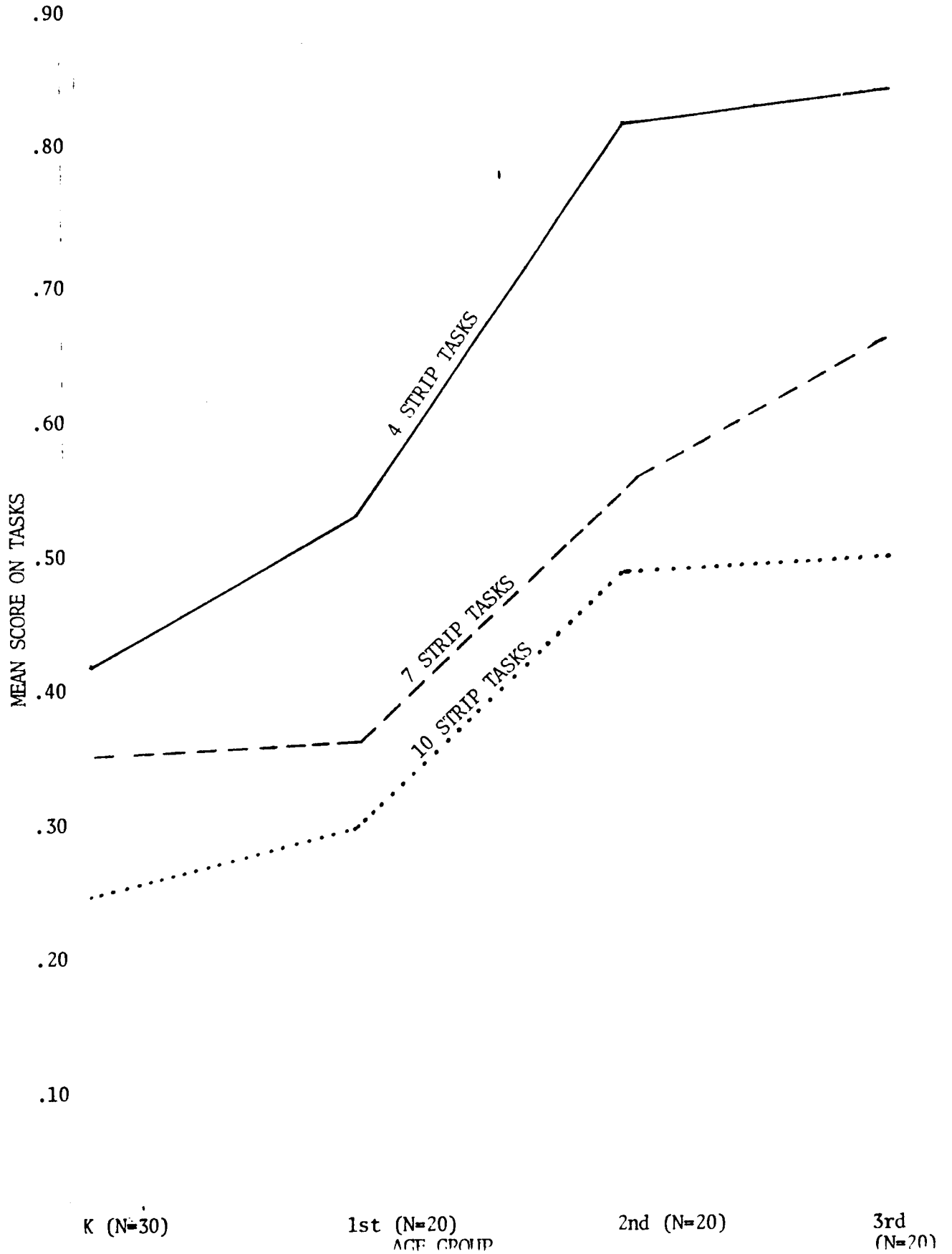


FIGURE 4

INTERACTION BETWEEN NUMBER OF STRIPS AND AGE GROUP



MEAN SCORES ON RECOGNITION AND RECONSTRUCTION TASKS ACCORDING TO AGE AND NUMBER OF STRIPS

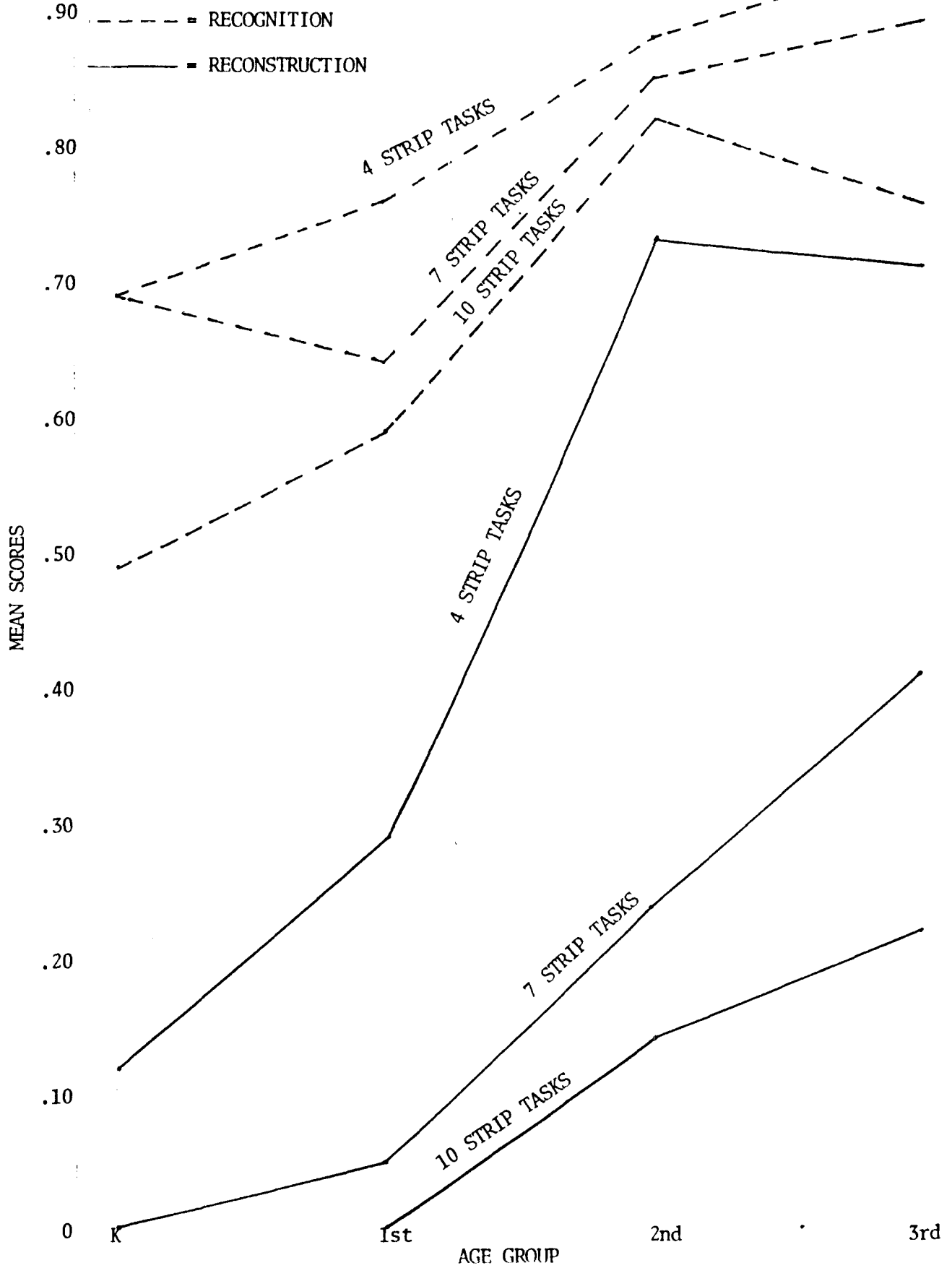


FIGURE 6
INTERACTION BETWEEN SHAPE
AND AGE GROUP

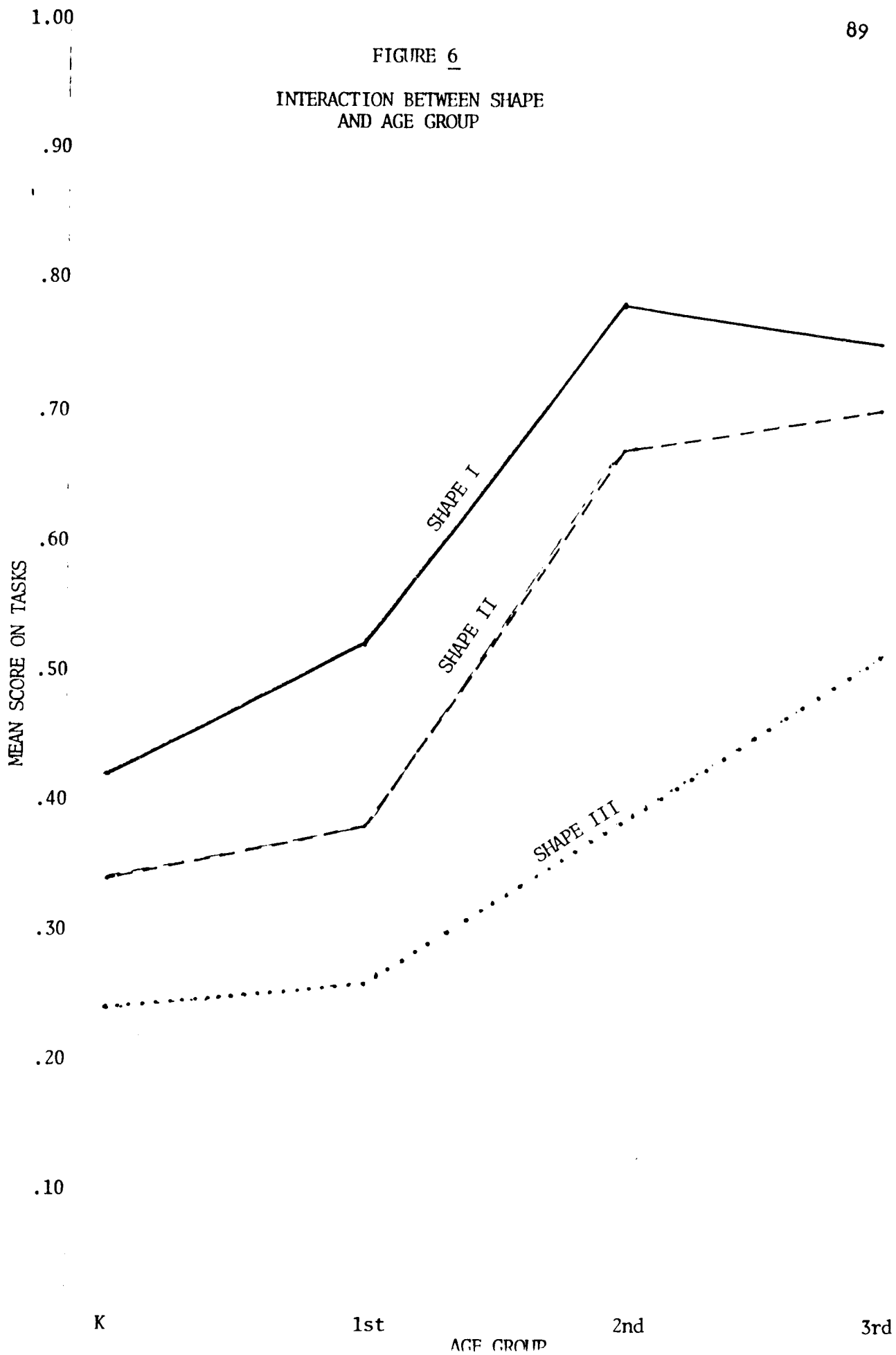


FIGURE 7

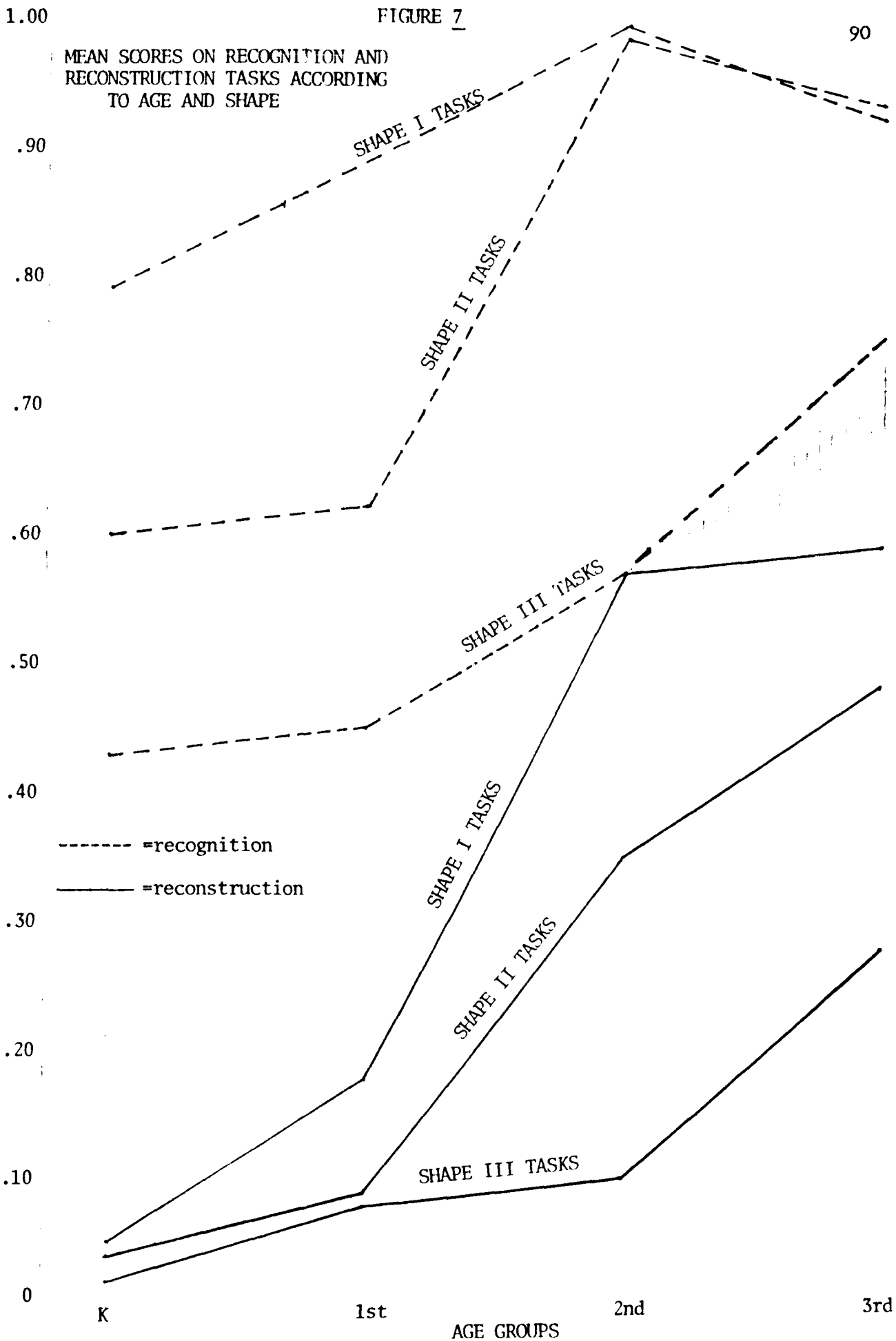
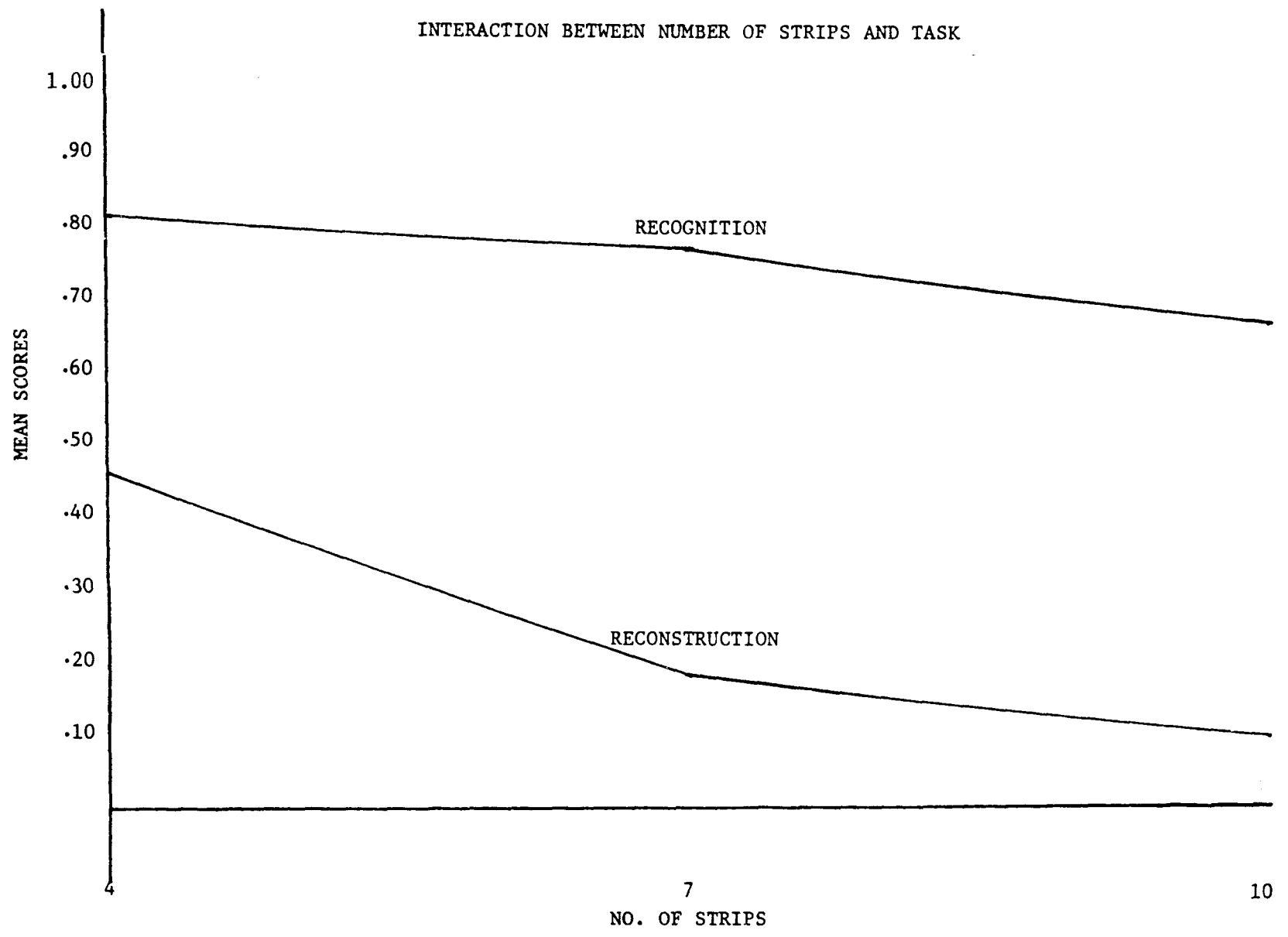


FIGURE 8

INTERACTION BETWEEN NUMBER OF STRIPS AND TASK



INTERACTION BETWEEN SHAPE OF TOPS AND TASK

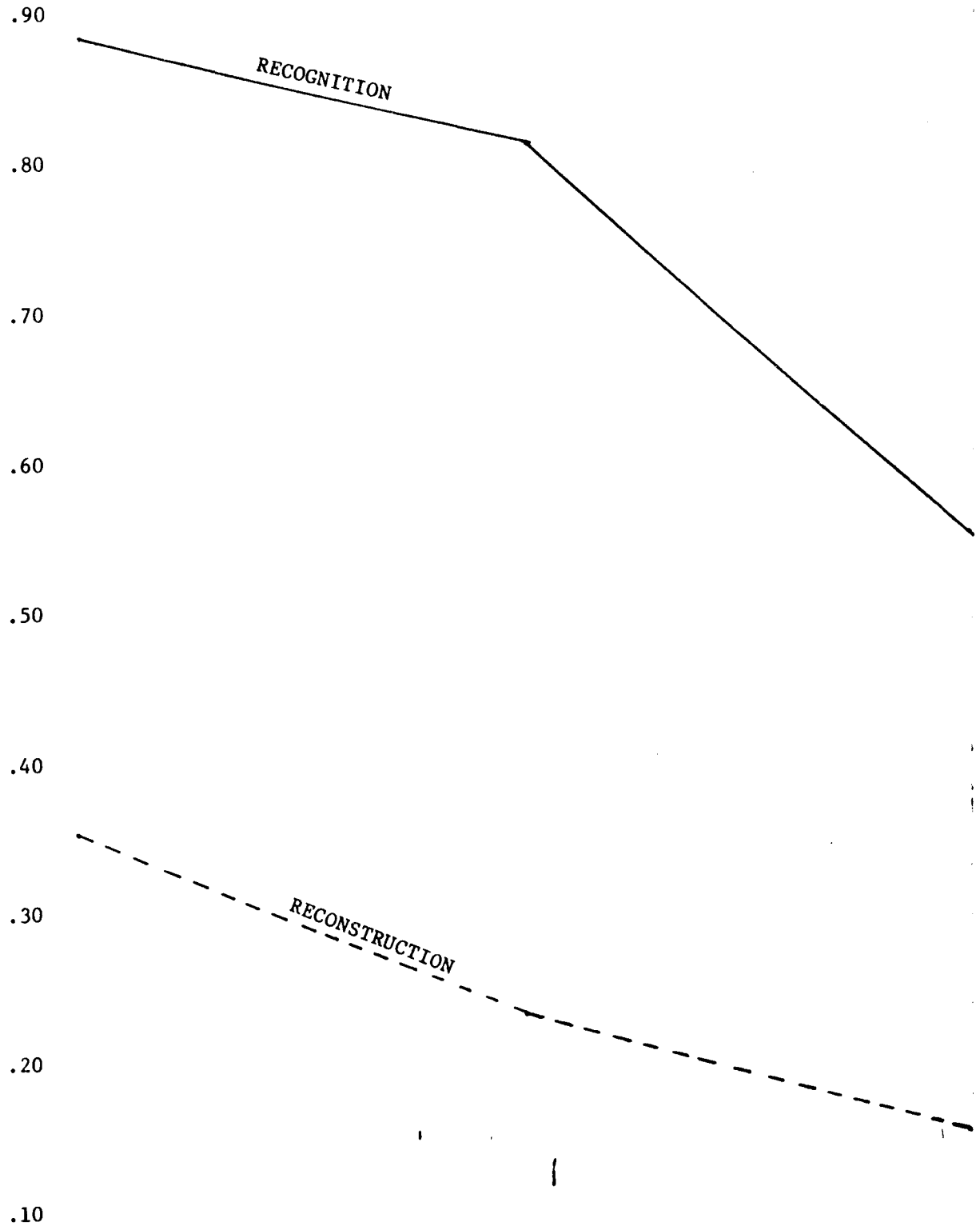


FIGURE 10

INTERACTION BETWEEN NO. OF STRIPS
AND AGE GROUP ON LOOKING TIME

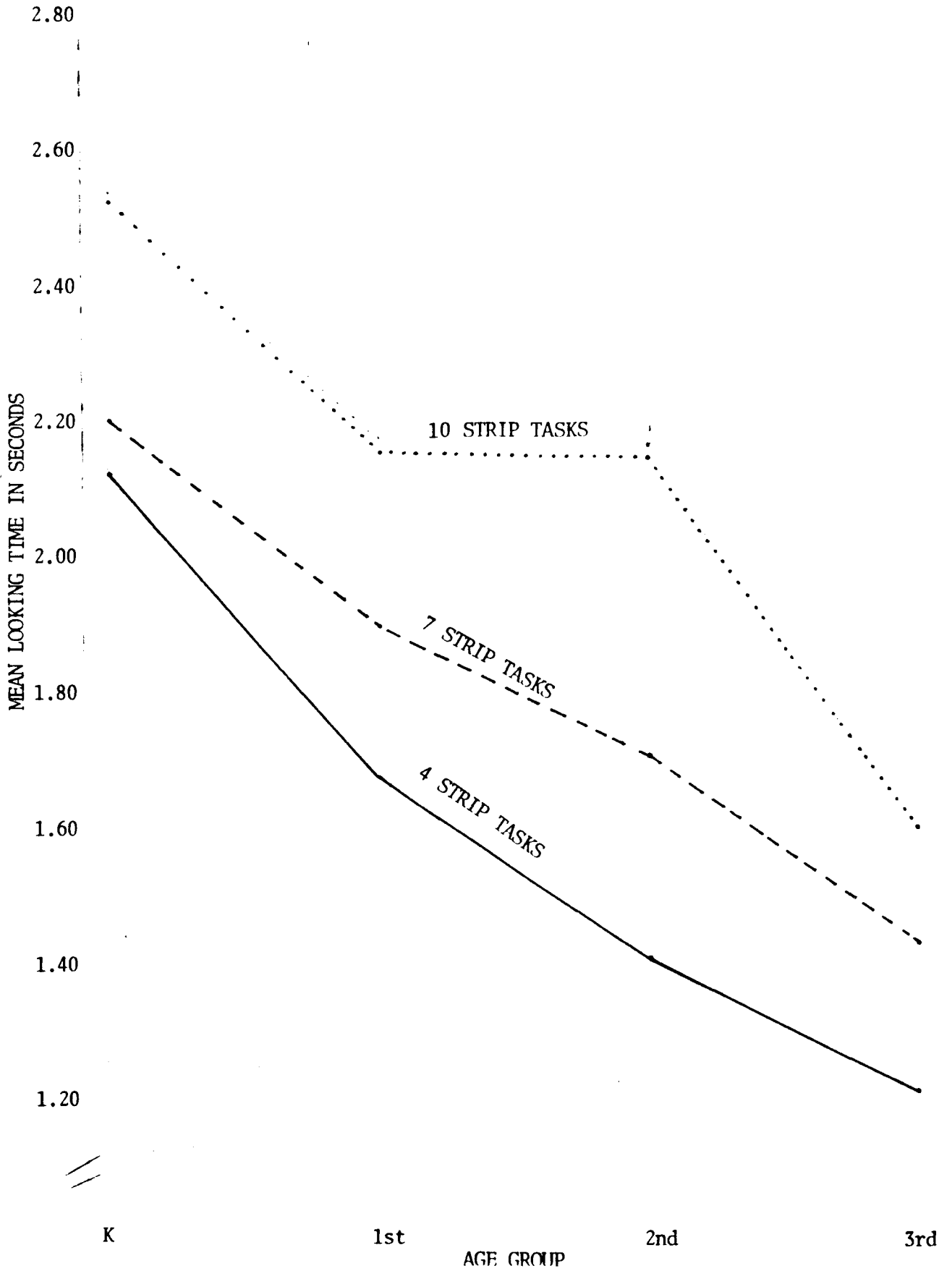


FIGURE 11

INTERACTION BETWEEN SHAPE AND
AGE GROUP ON LOOKING TIME

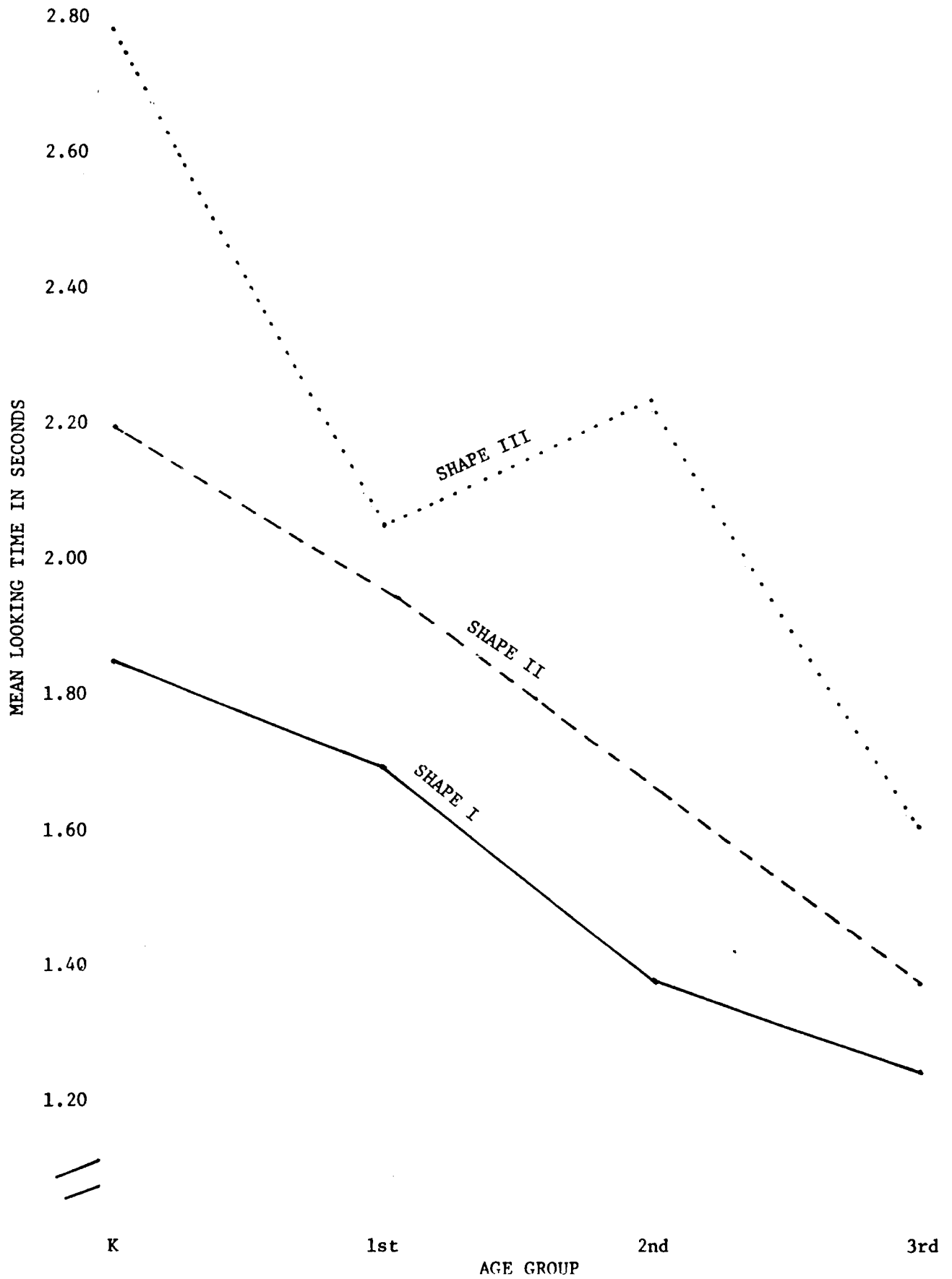


Figure 12

Drawings of the kinds of errors made on reconstruction seriation tasks which have the most direct bearing on the underlying processes involved

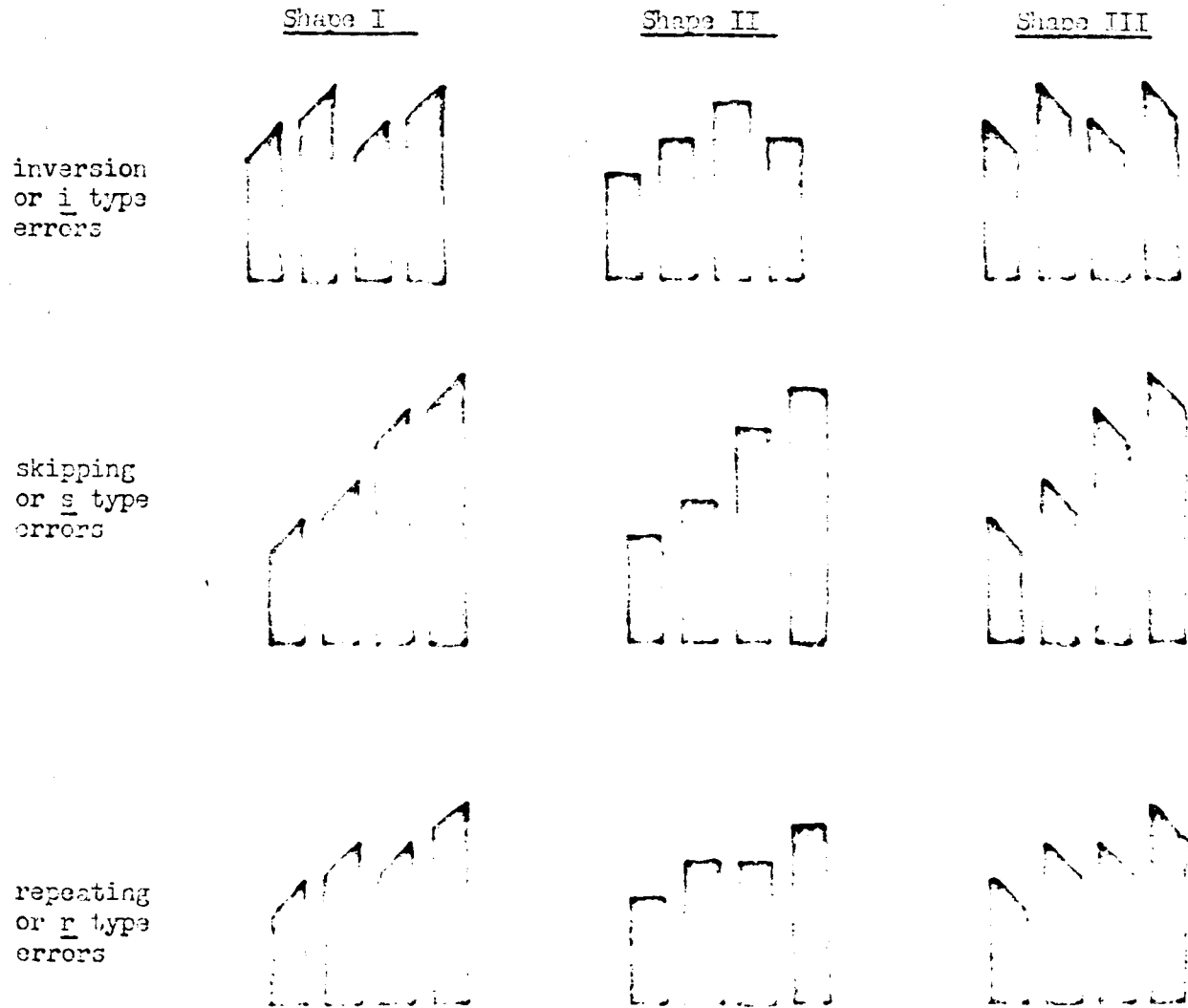


Figure 13

Frequency of errors on recognition tasks according to age and the location of the inverted pair of strips in a non-seriated configuration. Each drawing represents all shapes for that number of strips.

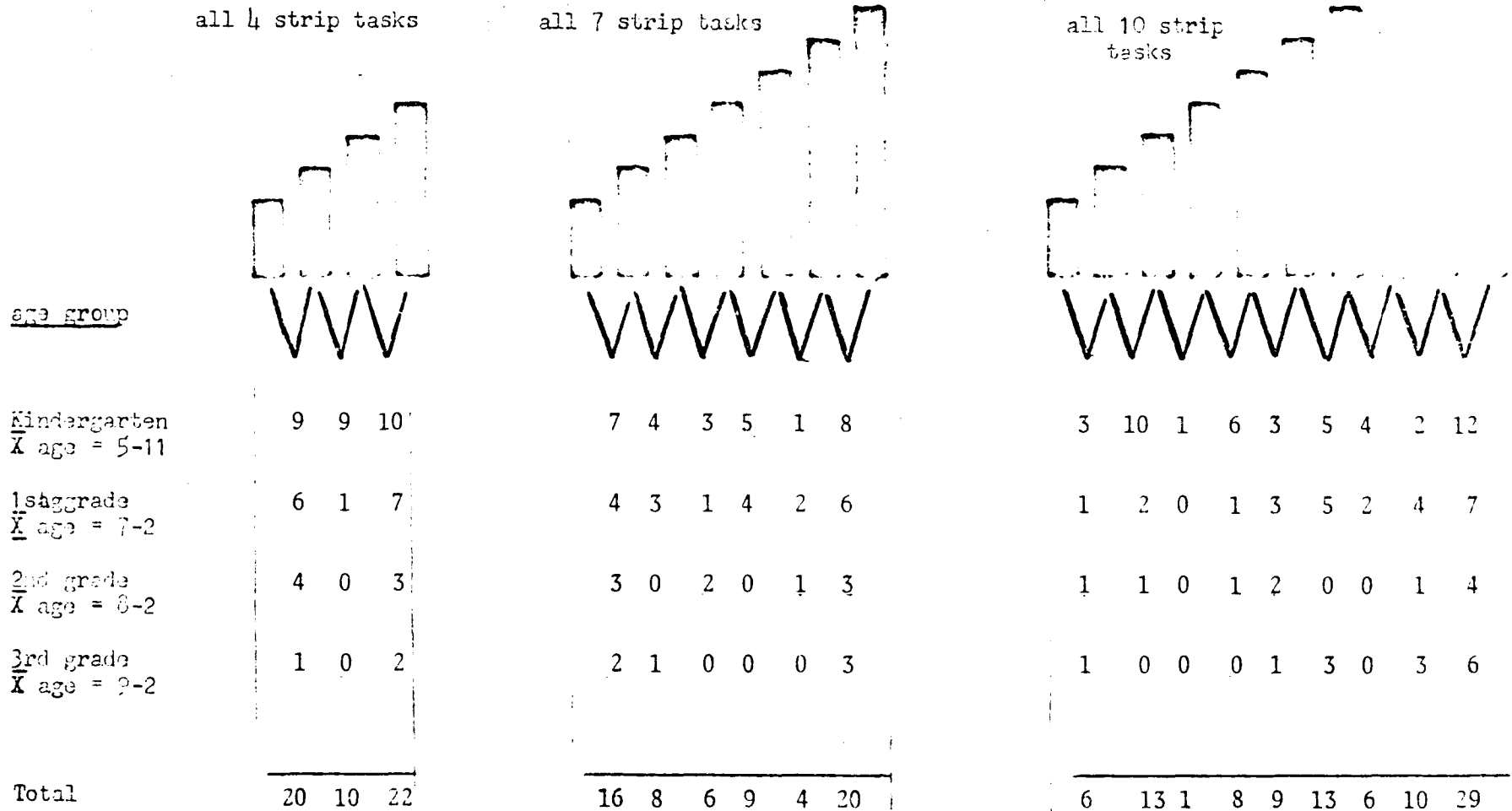


Figure 14

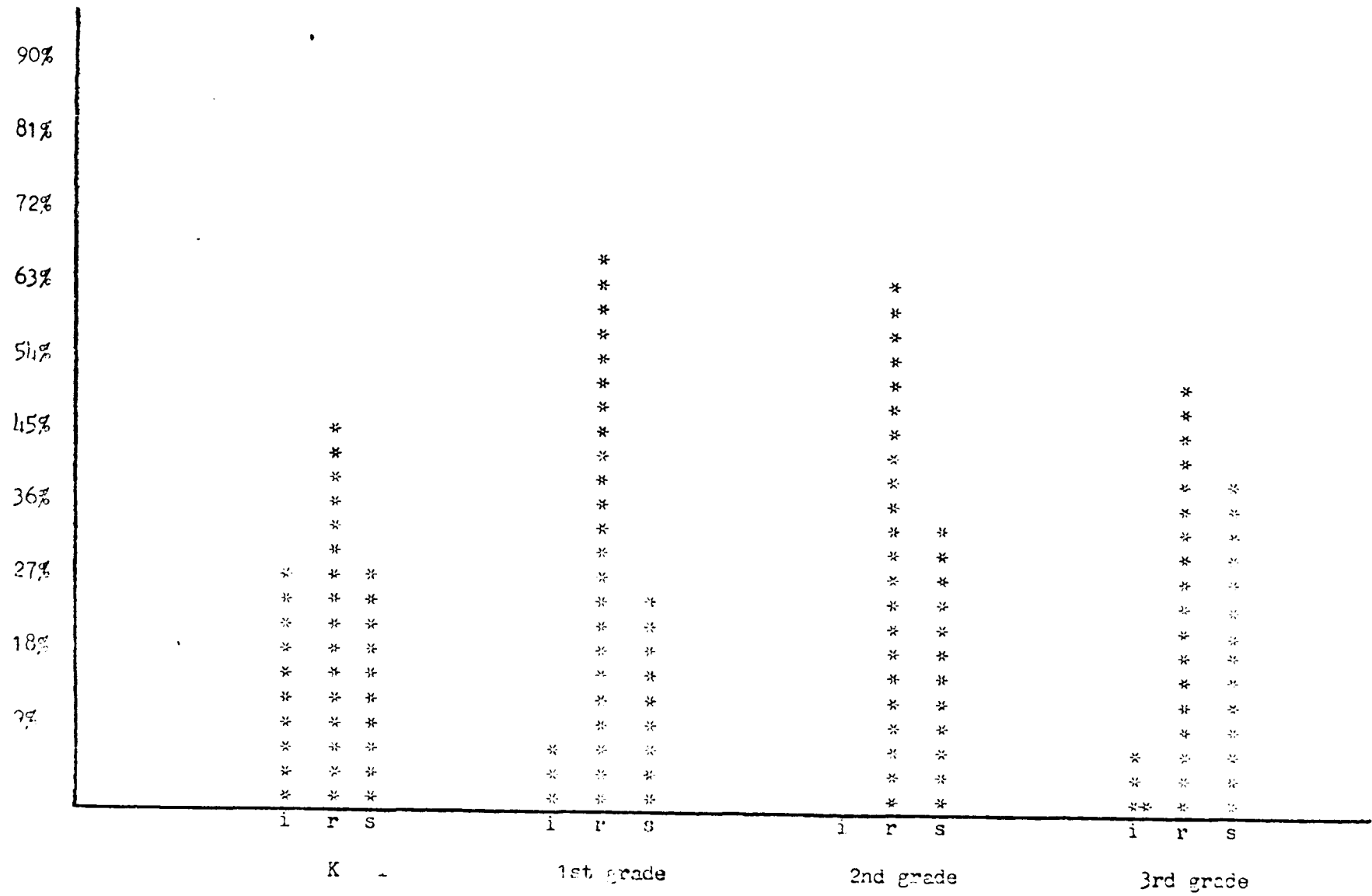
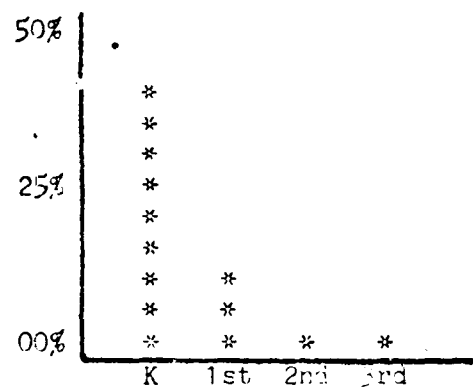
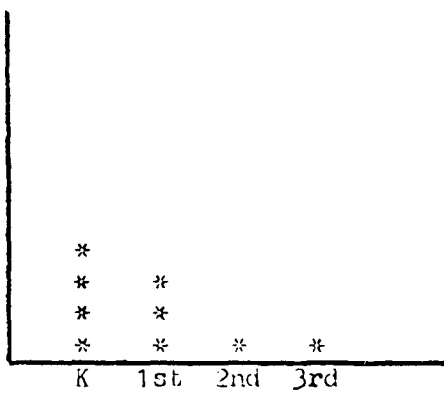


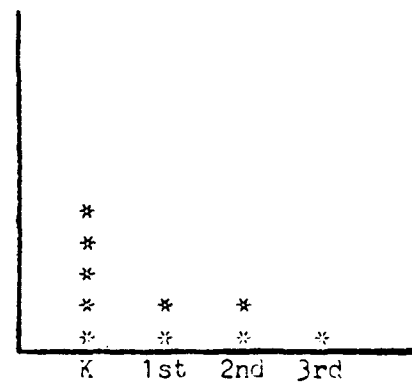
Figure 15



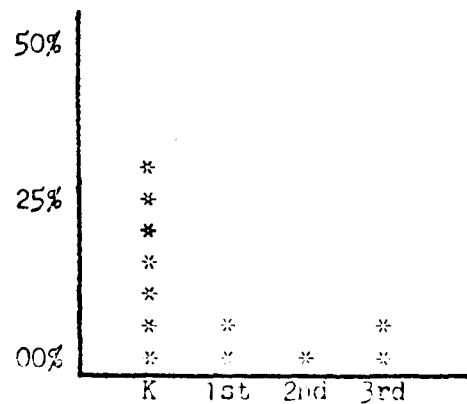
i errs on task 4I



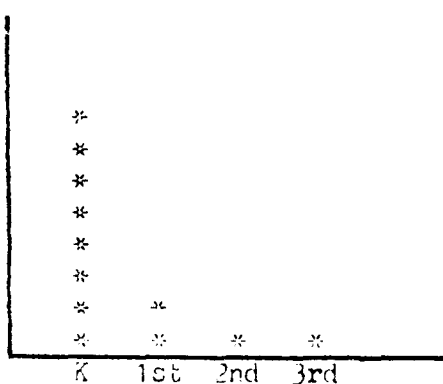
i errs on task 4II



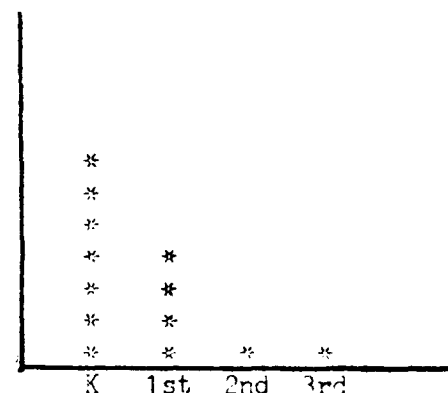
i errs on task 4III



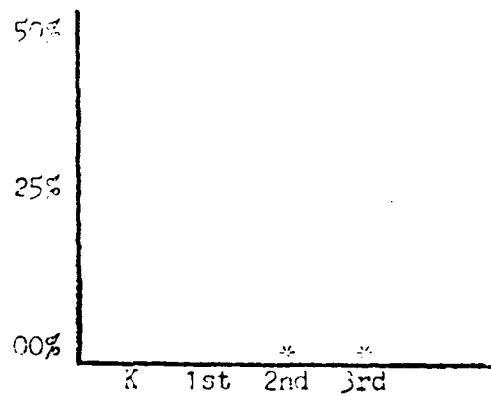
i errs on task 7I



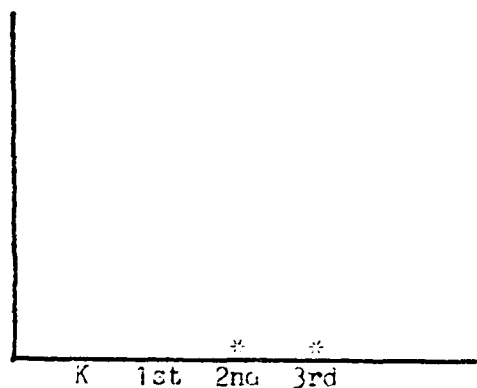
i errs on task 7II



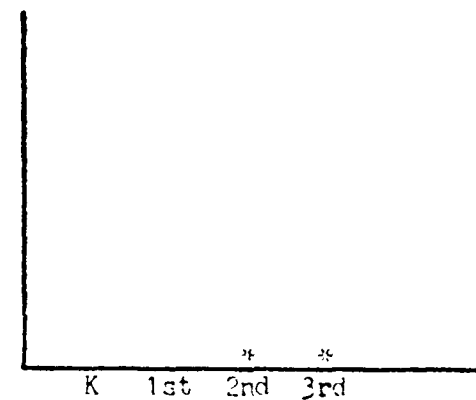
i errs on task 7III



i errs on task 10I



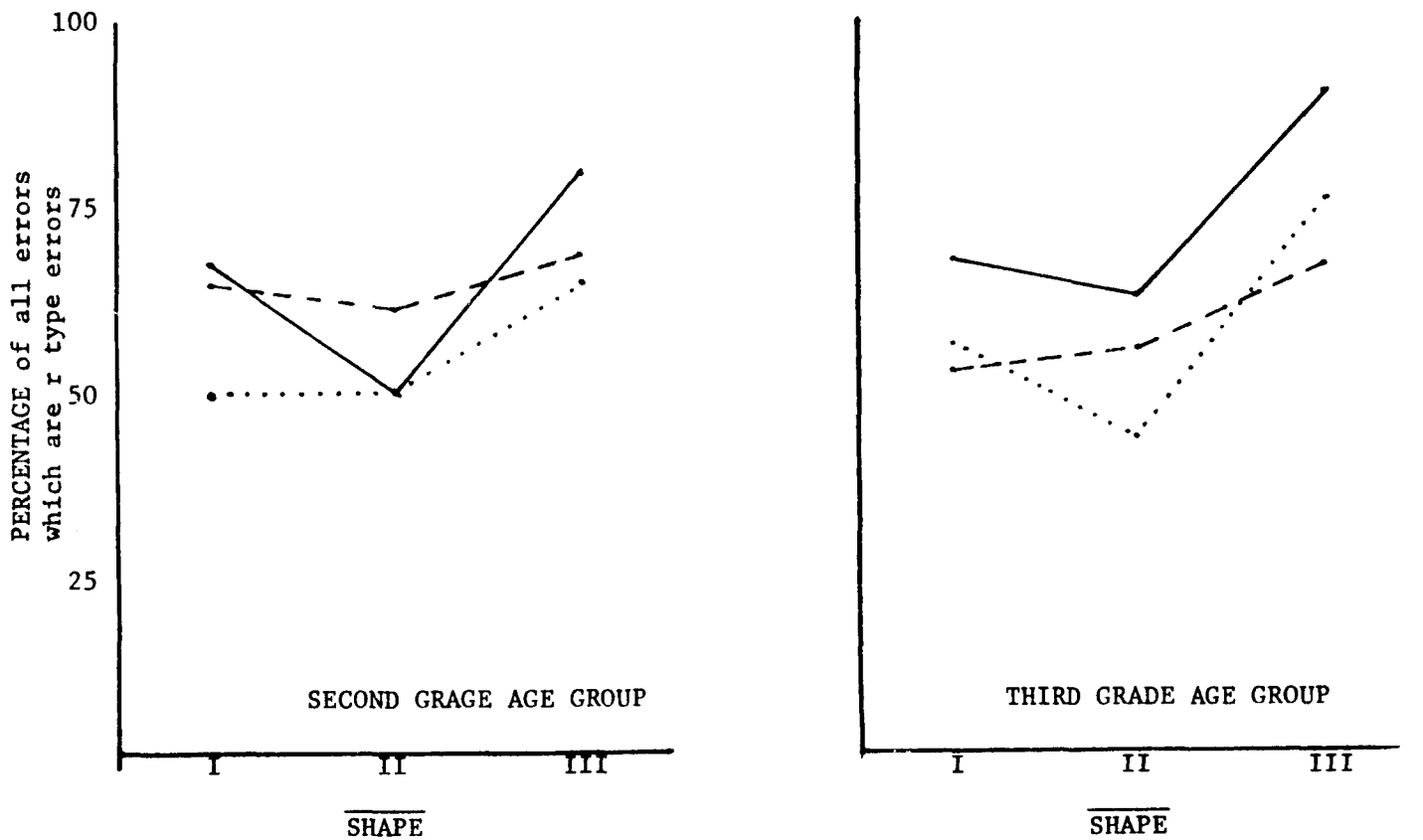
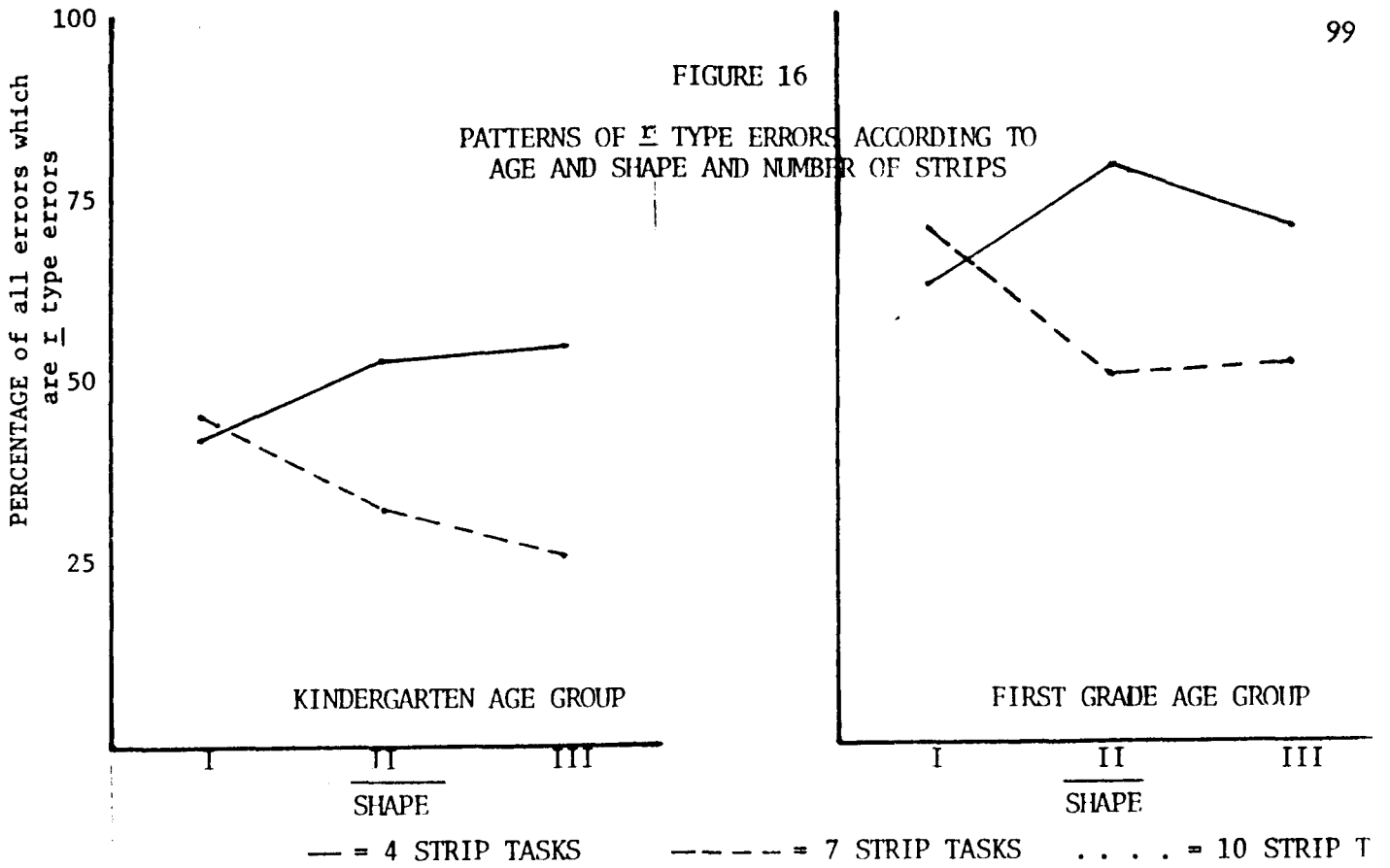
i errs on task 10II



i errs on task 10 III

FIGURE 16

PATTERNS OF \bar{r} TYPE ERRORS ACCORDING TO AGE AND SHAPE AND NUMBER OF STRIPS



APPENDIX A

Mean scores according to age group and no. of
objects for all subjects, N=90

no. objs.	<u>age group</u>			
	K(N=30)	1st(N=20)	2nd(N=20)	3rd(N=20)
4	.41	.52	.81	.83
7	.34	.35	.54	.65
10	.24	.29	.48	.49

Mean scores on recognition tasks according to
age and number of objects for all subjects
N=90

no. objs.	<u>age group</u>			
	K(N=30)	1st(N=20)	2nd(N=20)	3rd(N=20)
4	.69	.76	.88	.94
7	.69	.64	.85	.89
10	.49	.59	.82	.76

Mean scores on reconstruction tasks
according to age and no. of objects

no. objs.	K	<u>age groups</u>		
		1st	2nd	3rd
4	.12	.29	.73	.71
7	.00	.05	.24	.41
10	.00	.00	.14	.22

Mean scores according to age group and shape of tops of slats

<u>shape</u>	K	<u>AGE GROUP</u>		
		1st	2nd	3rd
I	.42	.52	.78	.75
II	.24	.38	.67	.70
III	.24	.26	.38	.51

Mean scores on recognition tasks
according to age and shape

<u>shape</u>	k	<u>age groups</u>		
		1st	2nd	3rd
I	.79	.87	.99	.92
II	.65	.67	.98	.93
III	.43	.45	.57	.75

Mean scores on reconstruction tasks
according to age and shape of tops

<u>shape</u>	K	<u>age groups</u>		
		1st	2nd	3rd
I	.05	.18	.57	.59
II	.02	.09	.35	.48
III	.04	.08	.10	.28

Mean scores according to task and no. of objects

	no. of objects		
<u>task</u>	4	7	10
recognition	.82	.77	.67
reconstruction	.46	.18	.09

Mean scores according to task and shape of tops

<u>task</u>	<u>shape</u>		
	I	II	III
recognition	.89	.81	.55
reconstruction	.35	.23	.15

Patterns of errors on recognition tasks according to age and location of the inversion in non-seriated configurations.

<u>no. of objects</u>	<u>cards mistaken as seriations</u>	<u>age groups</u>			
		<u>K</u>	<u>1st</u>	<u>2nd</u>	<u>3rd</u>
4	1 & 3	9-10	6-7	4-3	1-2
4	2	9	1	0	0
7	1 & 6	15	10	6	5
7	2 & 5	5	5	1	1
7	3 & 4	8	5	2	0
10	1 & 9	15	8	5	6
10	2 & 8	12	6	2	3
10	3 & 7	5	2	0	0
10	4 & 6	11	6	1	3
10	5	3	3	2	1

Errors made by kindergarten children on all recognition tasks

Card Number	4I	7I	10I	4II	7II	10II	4III	7III	10III	Total
1.	1	1	0	6	4	3	2	2	0	19
2.	3	1	3	2	1	2	4	2	5	23
3.	<u>2</u>	0	0	<u>0</u>	0	0	<u>8</u>	3	1	14
4.		2	0		1	2		2	4	11
5.		0	1		1	1		0	1	4
6.		<u>1</u>	1		<u>2</u>	3		<u>5</u>	1	13
7.			2			0			2	4
8.			0			1			1	2
9.	—	—	<u>1</u>	—	—	<u>3</u>	—	—	<u>8</u>	<u>12</u>
Total	6	5	8	8	9	15	14	14	23	

Errors made by 1st grade children on all recognition tasks

Card Number	<u>Task Condition</u>									<u>Total</u>
	4I	7I	10I	4II	7II	10II	4III	7III	10III	
1.	0	1	0	2	2	0	4	1	1	11
2.	0	1	0	1	1	1	0	1	1	6
3.	1	0	0	1	0	0	5	1	0	8
4.		1	1		2	0		1	0	5
5.		0	1		0	1		2	1	5
6.		0	0		3	0		3	5	11
7.			0			0			2	2
8.			0			4			0	4
9.	—	—	<u>1</u>	—	—	<u>1</u>	—	—	<u>5</u>	7
Total	1	3	3	4	8	7	9	9	15	




Errors made by 2nd grade children on all recognition tasks

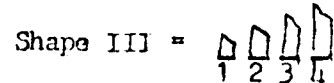
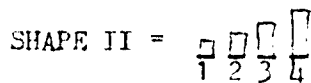
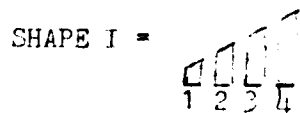
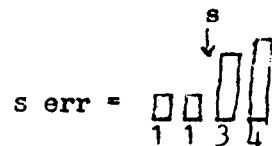
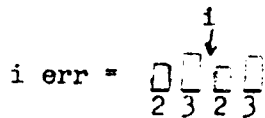
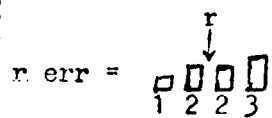
Card Number	<u>Task Condition</u>									<u>Total</u>
	4I	7I	10I	4II	7II	10II	4III	7III	10III	
1.	0	0	0	0	1	0	4	2	1	8
2.	0	0	0	0	0	0	0	0	1	1
3.	0	0	0	0	0	0	3	2	0	5
4.		0	0		0	0		0	1	1
5.		0	0		0	0		1	2	3
6.		0	0		0	0		3	0	3
7.			0			0			0	0
8.			0			0			1	1
9.	—	—	<u>0</u>	—	—	<u>0</u>	—	—	<u>4</u>	4
Total	0	0	0	0	1	0	7	8	10	

Errors made by 3rd grade children on all recognition tasks

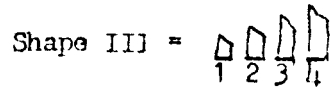
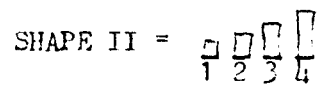
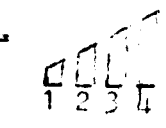
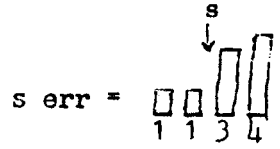
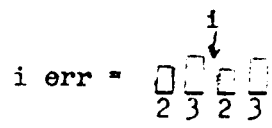
Card Number	<u>Task Condition</u>									Total
	h1	71	101	h11	711	1011	h111	7111	10111	
1.	0	0	0	0	0	0	1	2	1	4
2.	0	0	0	0	0	0	0	1	0	1
3.	0	0	0	1	0	0	1	0	0	2
4.		0	0		0	0		0	0	0
5.		0	0		0	0		0	1	1
6.		1	0		1	0		1	3	6
7.			0			0			0	0
8.			0			1			2	3
9.			h			1			1	6
Total	0	1	4	1	1	2	2	4	8	

RECONSTRUCTION ERRORS ON FOUR ITEM TASKS

SHAPE	Age Group		
	Kindergrtm \bar{X} age =5-11	1st grade \bar{X} age =7-2	2nd grade \bar{X} age =8-2
I 	2 2 3 2 TT pairs =15	2 4 4 4 TT pairs =27	1 3 3 4 TT pairs = 6
	3 2 4 4 TT errors =12	2 2 3 4 TT errors =19	2 3 4 4 TT errors = 3
	1 1 2 3 error rate=80%	1 2 2 4 err rate =70%	err rate = 50%
	3 2 3 2	1 1 1 4	
	2 3 2 4 r errs = 42%	1 2 2 4 r errs = 63%	r errs = 67%
	1 2 4 4 i errs = 11%	i errs = 00%	
	3 4 3 3 s errs = 26%	s errs = 33%	
	4 4 3 4		
	3 4 4 4		
II 	2 2 3 4 TT pairs =33	3 3 4 4 TT pairs =33	1 1 3 4 TT pairs = 12
	2 3 4 2 TT errs = 21	2 3 3 4 TT errs = 19	1 1 2 4 TT errs = 8
	1 1 3 4 err rate =64%	4 3 4 4 err rate =58%	1 1 2 4 err rate = 75%
	1 4 4 4	1 2 4 4	1 1 2 4
	2 4 2 4 r errs = 48%	2 2 3 4 r errs = 79%	r errs = 50%
	2 3 3 4 i errs = 14%	1 1 2 4 i errs = 11%	i errs = 00%
	1 3 3 4 s errs = 38%	3 4 4 3 s errs = 10%	s errs = 50%
	1 3 3 4	1 1 2 3	
	1 3 3 4	1 1 2 3	
	2 3 4 4	4 4 4 4	
2 4 4 3	3 4 4 4		
III 	1 2 4 4 TT pairs =33	2 3 4 4 TT pairs = 36	2 3 3 3 TT pairs = 24
	1 2 4 4 TT errs = 22	2 2 2 4 TT errs = 21	3 4 3 4 TT errs = 14
	2 2 3 4 err rate = 67%	2 3 4 4 err rate =58%	1 3 3 4 err rate =58%
	1 2 4 2	1 1 2 4	2 3 4 4
	3 4 4 4 r errs = 55%	2 4 4 4 r errs = 71%	3 3 3 4 r errs = 79%
	1 3 4 4 i errs = 18%	2 2 3 3 i errs = 05%	3 4 4 4 i errs = 07%
	1 3 4 4 s errs = 27%	1 1 2 4 s errs = 24%	1 3 3 4 s errs = 14%
	1 1 2 2	2 2 3 4	3 3 4 4
	1 3 3 3	1 3 3 4	
	2 3 4 1	2 2 3 4	
4 4 3 2	4 4 1 2		
	2 3 4 4		



Age Group		Age Group		Age Group		
1st grade \bar{X} age =5-11	1st grade \bar{X} age =7-2	2nd grade \bar{X} age =8-2	2nd grade \bar{X} age =8-2	3rd grade \bar{X} age =9	3rd grade \bar{X} age =9	
TT pairs =15 TT errors =12 error rate=80% r errs = 42% i errs = 42% s errs = 16%	2 4 4 4 2 2 3 4 1 2 2 4 1 1 1 4 1 2 2 4 1 2 4 4 3 4 3 3 4 4 3 4 3 4 4 4	TT pairs =27 TT errors =19 err rate =70% r errs = 63% i errs = 11% s errs = 26%	1 3 3 4 2 3 4 4 TT pairs = 6 TT errors = 3 err rate = 50% r errs = 67% i errs = 00% s errs = 33%	1 3 4 4 2 3 3 4 1 1 2 4 2 3 3 4 TT pairs = TT errs = err rate = r errs = i errs = s errs =	TT pairs = TT errs = err rate = r errs = i errs = s errs =	
TT pairs =33 TT errs = 21 err rate =64% r errs = 48% i errs = 14% s errs = 38%	3 3 4 4 2 3 3 4 4 3 4 4 1 2 4 4 2 2 3 4 1 1 2 4 3 4 4 3 1 1 2 3 1 1 2 3 4 4 4 4 3 4 4 4	TT pairs =33 TT errs = 19 err rate =58% r errs = 79% i errs = 11% s errs = 10%	1 1 3 4 1 1 2 4 1 1 2 4 1 1 2 4 TT pairs = 12 TT errs = 8 err rate = 75% r errs = 50% i errs = 00% s errs = 50%	2 4 4 4 1 2 4 4 2 3 4 4 1 3 3 4 TT pairs = TT errs = err rate = r errs = i errs = s errs =	TT pairs = TT errs = err rate = r errs = i errs = s errs =	
TT pairs =33 TT errs = 22 err rate = 67% r errs = 55% i errs = 18% s errs = 27%	2 3 4 4 2 2 2 4 2 3 4 4 1 1 2 4 2 4 4 4 2 2 3 3 1 1 2 4 2 2 3 4 1 3 3 4 2 2 3 4 4 4 1 2 2 3 4 4	TT pairs = 36 TT errs = 21 err rate =58% r errs = 71% i errs = 05% s errs = 24%	2 3 3 3 3 4 3 4 1 3 3 4 2 3 4 4 3 3 3 4 3 4 4 4 1 3 3 4 3 3 4 4	TT pairs = 24 TT errs = 14 err rate =58% r errs = 79% i errs = 07% s errs = 14%	1 2 4 4 2 3 3 4 3 4 4 4 3 3 4 4 1 1 2 3 2 3 4 4 2 3 3 4 s errs = 1	TT pairs = TT errs = err rate = r errs = i errs = s errs =



RECONSTRUCTION ERRORS ON SEVEN ITEM TASKS

SHAPE	Age Group		
	Kinderggrtn \bar{X} age = 5-11	1st grade \bar{X} age = 7-2	2nd grade \bar{X} age = 8-2
I	1 1 2 3 5 6 7 r = 45% 1 2 3 4 4 6 7 i = 28% 1 2 3 3 4 4 5 s = 27% 2 1 7 7 5 6 5 err rate = 46%	1 1 1 2 2 3 4 r = 70% 4 5 5 6 6 6 7 i = 05% 1 1 2 1 4 6 7 s = 25% 1 2 3 3 6 7 7 2 2 2 2 3 3 6 1 2 3 4 4 6 7 err rate = 56%	2 3 4 5 6 7 7 r = 65% 1 1 2 3 4 6 7 i = 00% 1 2 3 5 5 7 7 s = 35% 2 2 2 4 5 6 7 1 1 2 4 5 6 7 1 2 3 3 4 5 7 3 4 5 6 7 7 7 2 2 3 4 5 6 7 err rate = 35%
	2 2 1 3 4 5 6 r = 33% 1 3 4 5 5 6 5 i = 33% s = 33%	1 2 2 2 3 5 7 r = 50% 1 3 3 4 4 7 7 i = 05% 1 3 4 5 6 5 5 s = 45% 1 3 4 4 6 7 7 1 1 2 2 4 6 7	1 2 3 5 6 7 7 r = 61% 1 2 3 3 5 6 7 i = 00% 1 2 2 4 4 5 6 s = 39% 1 1 2 3 4 5 6 1 2 3 5 6 7 1 1 2 3 6 7 1 2 4 5 6 7 7 2 3 3 5 6 7 7 1 5 6 7 7 7 7 1 2 3 4 6 7 1 2 3 4 5 6 6 7 1 2 4 5 6 7 7
	1 2 4 5 6 7 7 r = 45% 2 3 1 4 3 5 4 i = 10% 2 3 4 6 5 7 2 s = 45%	4 4 5 6 6 6 7 r = 52% 2 2 2 2 4 6 7 i = 16% 1 2 4 5 4 7 6 s = 32% 1 4 3 3 6 7 6 2 2 2 3 3 3 4 1 1 3 4 5 6 7 1 2 3 4 6 7 7	1 1 1 2 3 5 7 7 r = 68% 1 1 3 4 4 6 7 i = 00% 1 1 2 3 3 3 4 4 s = 32% 3 3 3 4 4 5 7 1 1 3 4 5 6 7 1 1 2 2 4 5 7 1 3 3 3 4 5 6 2 3 4 5 5 6 7 1 2 3 5 6 7 7 1 2 2 2 4 5 5 7 3 3 4 6 6 6 7 6 6 6 7 7 7 7 2 2 3 4 5 7 7 4 4 4 5 5 6 7 1 2 2 2 3 3 3 3 1 1 2 3 3 3 4 4 2 2 3 4 4 5 7
III			

				Age Group											
Undergrtn \bar{X} age = 5-11				1st grade \bar{X} age = 7-2				2nd grade \bar{X} age = 8-2				3rd grade \bar{X} age = 9-2			
1 2 3 5 6 7	r = 45%			1 1 1 2 2 3 4	r = 70%	2 3 4 5 6 7 7	r = 65%	1 2 5 5 4 6 7	r = 50%						
2 3 4 4 6 7	i = 28%			4 5 5 6 6 6 7	i = 05%	1 1 2 3 4 6 7	i = 00%	1 3 5 5 6 7 7	i = 00%						
2 3 3 4 4 5	s = 27%			1 1 2 1 4 6 7	s = 25%	1 2 3 5 5 7 7	s = 35%	2 3 3 5 6 7 7	s = 40%						
1 7 7 5 6 5				1 2 3 3 6 7 7		2 2 2 4 5 6 7		1 3 5 5 6 6 7							
err rate = 46%				2 2 2 2 3 3 6		1 1 2 4 5 6 7		1 1 2 5 6 7 7							
				1 2 3 4 4 6 7		1 2 3 3 4 5 7		1 2 2 4 5 6 7							
				err rate = 56%		3 4 5 6 7 7 7		err rate = 53%							
						2 2 3 4 5 6 7									
						err rate = 35%									
2 1 3 4 5 6	r = 33%			1 2 2 2 3 5 7	r = 50%	1 2 3 5 6 7 7	r = 61%	2 3 3 4 5 6 7	r = 50%						
3 4 5 5 6 5	i = 32%			1 3 3 4 4 7 7	i = 05%	1 2 3 3 5 6 7	i = 00%	1 1 1 3 4 6 7	i = 00%						
s = 33%				1 3 4 5 6 5 5	s = 45%	1 2 2 4 4 5 6	s = 39%	2 3 5 6 6 7 7	s = 40%						
				1 3 4 4 6 7 7		1 1 2 3 4 5 6		1 4 5 5 7 7 7							
				1 1 2 2 4 6 7		1 2 3 5 6 7		1 2 3 5 5 6 7							
						1 1 2 3 6 7		1 1 2 4 6 7 7							
						1 2 4 5 6 7 7		1 3 5 6 7 7 7							
						2 3 3 5 6 7 7		1 2 3 5 6 7 7							
						1 5 6 7 7 7 7									
						1 2 3 4 6 7									
						1 2 3 4 5 6 6 7									
						1 2 4 5 6 7 7									
2 4 5 6 7 7	r = 45%			1 4 5 6 6 6 7	r = 52%	1 1 1 2 3 5 7 7	r = 68%	3 3 3 5 5 6 7	r = 60%						
3 1 4 3 5 4	i = 10%			2 2 2 2 4 6 7	i = 16%	1 1 3 4 4 6 7	i = 00%	1 1 3 4 6 6 7	i = 00%						
3 4 6 5 7 2	s = 45%			1 2 4 5 4 7 6	s = 32%	1 1 2 3 3 3 4 4	s = 32%	1 1 3 5 7 7 7	s = 30%						
				1 4 3 3 6 7 6		3 3 3 4 4 5 7		2 2 3 5 6 6 7							
				2 2 2 3 3 3 4		1 1 3 4 5 6 7		1 1 2 3 4 5 7							
				1 1 3 4 5 6 7		1 1 2 2 4 5 7		1 2 2 4 4 5 7							
				1 2 3 4 6 7 7		1 3 3 3 4 5 6		1 3 3 3 5 6 7							
						2 3 4 5 5 6 7		3 3 3 6 6 7 7							
						1 2 3 5 6 7 7		2 3 3 4 5 6 7							
						1 2 2 2 4 5 5 7		2 3 3 4 5 6 7							
						3 3 4 6 6 6 7		6 6 6 6 7 7 7							
						6 6 6 7 7 7 7		2 2 3 4 6 7 7							
						2 2 3 4 5 7 7		2 3 4 4 4 6 7							
						4 4 4 5 5 6 7		2 2 2 3 3 3 4 4 5							
						1 2 2 2 3 3 3 3									
						1 1 2 3 3 3 4 4									
						2 2 3 4 4 5 7									

RECONSTRUCTION ERRORS ON TEN ITEM TASKS

SHAPE	Age Group		
	Kindergrtn \bar{X} age = 5-11	1st grade \bar{X} age = 7-2	2nd grade \bar{X} age = 8-2/3
I	no child in this age group made reconstructions meeting the minimum requirement that they be ordered upright slats	1 1 4 3 3 4 7 9 10	1 1 1 2 3 5 6 8 9 10 2 1 1 2 3 5 6 7 8 10 1 1 1 2 3 4 5 6 7 8 9 1 r errs = 50% i errs = 00% s errs = 50%
		1 2 3 4 6 7 9 10	1 1 2 3 6 7 8 10 10 10 1 1 3 4 5 6 6 6 6 9 10 1 1 2 3 4 7 8 9 9 10 10 1 1 1 2 4 7 7 7 9 10 10 1 1 2 4 5 6 7 9 10 10 1 1 1 2 3 5 8 9 9 10 1 1 3 4 5 5 6 6 6 9 10 1 r errs = 50% i errs = 00% s errs = 50%
III		1 1 2 4 6 8 9 10	1 2 2 3 4 5 5 7 9 10 1 1 2 3 5 6 7 7 9 9 9 1 1 3 3 3 5 5 7 7 7 10 1 2 3 4 4 4 5 8 8 9 9 2 3 3 3 4 5 5 6 6 6 7 7 3 2 3 3 3 4 5 6 6 7 10 1 1 3 4 5 7 7 7 9 9 9 1 r errs = 65% i errs = 00% s errs = 35%

	Age Group		
Kindergtn \bar{X} age = 5-11	1st grade \bar{X} age = 7-2	2nd grade \bar{X} age = 8-2 3rd grade \bar{X} age = 9-	
no child in this age group made reconstructions meeting the minimum requirement that they be ordered upright slats	1 1 4 3 3 4 7 9 10	1 1 1 2 3 5 6 8 9 10 1 1 2 3 5 6 7 8 10 1 1 2 3 4 5 6 7 8 9 r errs = 50% i errs = 00% s errs = 50%	2 3 4 5 5 6 7 8 9 10 1 3 4 5 6 7 8 9 10 1 3 4 5 6 8 9 10 10 1 1 2 3 4 5 6 7 8 9 r errs = 57% i errs = 00% s errs = 43%
	1 2 3 4 6 7 9 10	1 1 2 3 6 7 8 10 10 10 1 3 4 5 6 6 6 6 9 10 1 2 3 4 7 8 9 9 10 10 1 1 2 4 7 7 7 9 10 10 1 2 4 5 6 7 9 10 10 1 1 2 3 5 8 9 9 10 1 3 4 5 5 6 6 6 9 10 r errs = 50% i errs = 00% s errs = 50%	1 2 3 5 6 7 8 9 9 1 2 4 5 8 9 10 1 2 3 5 6 7 7 9 10 10 1 1 2 3 4 6 7 8 10 10 1 2 3 4 5 7 8 9 10 10 1 2 3 4 4 5 6 7 8 9 1 2 3 5 6 7 7 9 10 10 r errs = 41% i errs = 00% s errs = 56%
	1 1 2 4 6 8 9 10	1 2 2 3 4 5 5 7 9 10 1 2 3 5 6 7 7 9 9 9 1 3 3 3 5 5 7 7 7 10 2 3 4 4 4 5 8 8 9 9 3 3 3 4 5 5 6 6 6 7 7 2 3 3 3 4 5 6 6 7 10 1 3 4 5 7 7 7 9 9 9 r errs = 65% i errs = 00% s errs = 35%	1 1 1 2 2 2 2 3 3 3 1 2 2 3 3 5 5 7 7 10 1 2 3 4 5 6 8 8 10 10 2 2 2 3 4 5 6 6 7 9 1 3 4 5 6 7 7 7 8 9 10 1 2 3 4 5 6 6 7 9 10 1 2 3 4 4 4 6 7 7 9 1 2 2 3 4 5 6 6 7 8 9 1 1 1 1 2 2 2 3 3 3 3 4 4 1 r errs = 75% i errs = 00% s errs = 25%

Frequency of subjects in the kindergarten age group either passing or failing both the recognition and reconstruction tasks.

		<u>recognition</u>		
		+	-	total
reconstruction	-	157	102	259
	+	10	1	11
total		167	103	270

$$X^2 = 156.00 \quad p < .001$$

Frequency of subjects in the kindergarten age group either passing or failing both the recognition and reconstruction tasks.

		<u>recognition</u>		
		+	-	total
reconstruction	-	157	102	259
	+	10	1	11
total		167	103	270

$$\chi^2 = 156.00 \quad p < .001$$

Frequency of subjects in the 1st grade age group either passing or failing both the recognition and reconstruction tasks.

		<u>recognition</u>		total
		+	-	
reconstruction	-	108	55	163
	+	14	3	17
total		122	58	180

$$\chi^2 = 99.32 \quad p < .001$$

Frequency of subjects in the 2nd grade age group
either passing or failing both the recognition and
reconstruction tasks.

		<u>recognition</u>		
		+	-	total
reconstruction	-	87	24	111
	+	67	2	69
total		154	26	180

$$\chi^2 = 81.18 \quad p < .001$$

Frequency of subjects in the 3rd grade age group either passing or failing both the recognition and reconstruction tasks.

	<u>recognition</u>		
	+	-	total
reconstruction -	84	19	103
reconstruction +	75	2	77
total	159	21	180

$$\chi^2 = 78.18 \quad p < .001$$

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