STRATEGIES IN THE REPRODUCTION OF GEOMETRIC FIGURES:

A DEVELOPMENTAL ANALYSIS.

John Stephen Pigram

Thesis submitted for the degree of Doctor of Philosophy.

University of Keele, 1983.

TEXT BOUND CLOSE TO THE SPINE IN THE ORIGINAL THESIS

ACKNOWLEDGEMENTS

My thanks to the following members of the Department of Psychology at the University of Keele for their help with statistics and experimental design; Alan Branthwaite, Jim Hartley, Mark Trueman and Jim Reid. I must also thank my supervisor, John Sloboda, for being able to select the good ideas that I have had from the less good ones, and for helping to transform these into concrete experiments. I am also grateful for his comments on earlier drafts of this thesis.

I am indebted for their assistance to the headteachers, staff and most of all pupils of the following schools; Seabridge Infant and Junior School, Hassell Street Junior School, Keele Church of England Primary School and Edenhurst School.

My thanks also to Gavin Bremner at the University of Lancaster for the helpful discussions we had during the Summer of 1982. These led to Study V in the thesis, a modified version of which has been accepted for publication in the British Journal of Developmental Psychology (in press).

ABSTRACT

The thesis examines one important area of the skills that underlie the development of non-representational graphic ability, namely the strategies used by children and adults when reproducing geometric figure stimuli in a variety of test conditions. A review of the experimental literature in this area revealed a number of methodological weaknesses in previous studies, which included the failure to control for the precise nature of the figure stimuli presented to subjects and the need to employ more rigorous methods of assessing accuracy of reproduction. The five studies in the thesis take these criticisms into account by careful attention to the nature of the stimuli and to the methods used to classify copying strategies.

The findings of the studies can be summarized as follows; with age comes an increasing consistency in the tendency to employ uniform stroke directions when copying simple figures, and to isolate and draw as complete units 'good' parts of more complex figures. Differences in the accuracy of copying, as in well as the sorts of strategies used, are found as a function of age, stimulus complexity, and the presence or absence of a delay between the perception and reproduction of each stimulus.

CONTENTS

LITERATURE APPRAISAL

Overview

This thesis has one main aim. It attempts to trace the use of strategies in the copying of geometric figures by children and adults. The five studies reported in the thesis also examine the relationship between strategy and accuracy of reproduction across a number of experimental conditions. Although a great deal of systematic research has been carried out in the past fifty years on the development of representational skills in children, a relatively small amount of this research has concentrated on the process rather than the product of graphic skills. To questions need to be asked at this point. Firstly, why study drawing and copying behaviour? Furthermore, why concentrate on the copying of geometric figures rather than realistic objects?

The study of drawings has long attracted the attention of psychologists who have sought to explore further the ways in which the child comes to represent the world around him. Increasing ability in representational drawing has been taken as an indicator of intellectual advancement and developing self-concept, with specific drawing tasks being given to the child to measure these abilities (for example Goodenough, 1926; Piaget and Inhelder, 1956). Simple figure reproductions have also been employed for the assessment of neurological damage in the child and adult (Bender, 1938). There has also been interest in the development of the most commonly used forms in the spontaneous drawings and scribbles of children from an early age (Kellogg; 1969, 1979).

The thesis does not, however, attempt to associate the study of copying strategy with any wider theory of cognitive development. Rather, its starting point is to examine the regularities in graphic behaviour across a range of differing, but well-controlled stimuli. Only after assessing these regularities can one hope to develop a coherent picture of the development of copying skill. The approach used to study copying in the thesis sees such regularities as 'rules' or strategies, the former term having been first used in the study of copying behaviour by Goodnow and Levine (1973).

The study of copying rules in the thesis is at a number of levels and partly as a function of the complexity of the stimulus. This ranges from noting the direction of drawing of lines in different orientations, either singly or as part of a larger figure, to the global principles or rules that govern the copying of a figure as a whole. The assessment of copying accuracy in the thesis has its basis in two research areas; that which has examined for educational purposes the effectiveness of different instructional procedures on early handwriting practice, and studies that have used measurements of copying error to assess developmental reproductive skill.

Two final areas of interest in the thesis deserve to be mentioned at this point. The first of these concerns the emphasis placed on the regularity of the principles used to derive figure stimuli. This is seen as important for the single reason that the kind of strategies that are implicated in controlling copying behaviour are themselves a function of stimulus construction and complexity. The second area of interest concerns the processes with which figures are encoded in a delayed reproduction task, and asks whether such processes are primarily visual or verbal ones. Because of the complexity of the task used to examine this issue, adult rather than child subjects are used.

The following is a brief summary of the aims and methods of the five studies reported in the thesis;

Study I is a preliminary and individualistic study. It examines over the period of one year the consistency with which drawing rules are applied across a range of stimuli by two six year old children. The study also looks at the change in accuracy of reproduction for the two subjects in a year in which handwriting instruction is commenced.

Study II uses a consistent framework to derive figure stimuli. It tests the hypothesis that the facilitated perceptual manipulation of good Gestalt parts within these figures is also present in a reproduction task. This study uses adult subjects.

Study III interrelates the issues of strategy and accuracy in reproduction from a developmental standpoint. The study uses the figure generation framework of Study II to derive figures of differing complexity. These figures are copied in an immediate or delayed condition to assess the role of memory in copying strategies. A more detailed analysis within this study examines the way parts are drawn in both successful and unsuccessful copies, and derives a working model to account for the drawing of these parts.

Study IV asks whether the processes by which adults encode stimuli in a delayed reproduction task are visual or verbal ones. Interference tasks are used for this purpose, with a further analysis examining the extent to which simple directional rules are followed both within the figure as a whole and its component parts.

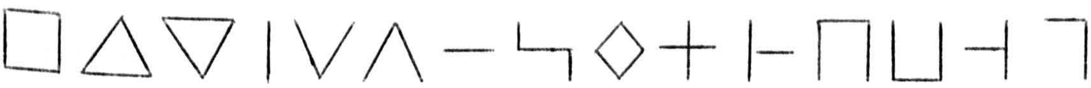
Study V examines angular distortion and the use of consistent directions for single lines drawn from baselines, but within the context of copying a complete, enclosed figure. The study is a developmental one, comparing adults' level of response with that of three child groups.

The Strategy-based Approach and the work of Jacqueline Goodnow

The single study most relevant to the thesis embodies the need to describe and examine the regularities in drawing behaviour during a simple reproduction task, and is that of Goodnow and Levine (1973). This study takes as its rationale the description of drawing strategies in terms of a 'grammar of action'; this term being used to outline the principles with which the individual strokes comprising reproductions of simple geometric figures are constructed. As such, Goodnow and Levine's study was conceptually a simple one, acknowledging research which had previously noted the sequences and paths used when reproducing individual geometric figures (Gesell and Ames, 1946; Ilg and Ames, 1964), but extended this analysis to describe in terms of 'rules' the principles that regularly occur across different figures. The questions that are asked in the 1973 study are essentially those that are expanded upon and analysed more fully in the thesis; namely the testing for the presence and development of copying rules, the interaction of rules of different kinds as a function of differing stimulus construction, and the type and level of errors committed by children of differing ages and with figures of differing complexity.

Goodnow and Levine's (1973) study showed that for the set of fifteen stimulus figures attempted by each subject, the use of six common drawing rules varied primarily as a function of subject age. These six rules were separated into two categories; rules which described the starting point on a figure copy ('Start Rules'), and rules which noted the method of progression through a figure after a starting point had been chosen ('Progression Rules'). Figure 1 below gives the fifteen stimuli used in the study, these having been derived from Graham, Berman and Ernhart (1960), itself a study which examined stimulus complexity and accuracy of reproduction.

Figure 1; The Fifteen Stimuli used by Goodnow and Levine (1973).



The six drawing rules that were used to explain the copying strategies for successful reproductions of the majority of the fifteen figures given above were as follows;

'Start Rules'- Left Start (start at a leftmost point on the figure)
Top Start (start at a topmost point on the figure)
Vertical Start (start with a vertical stroke)

'Progression Rules'- Draw all Horizontal Lines from Left to Right ('L-R')
Draw all Vertical Lines from Top to Bottom ('T-B')
Thread (i.e. draw with a continuous stroke)

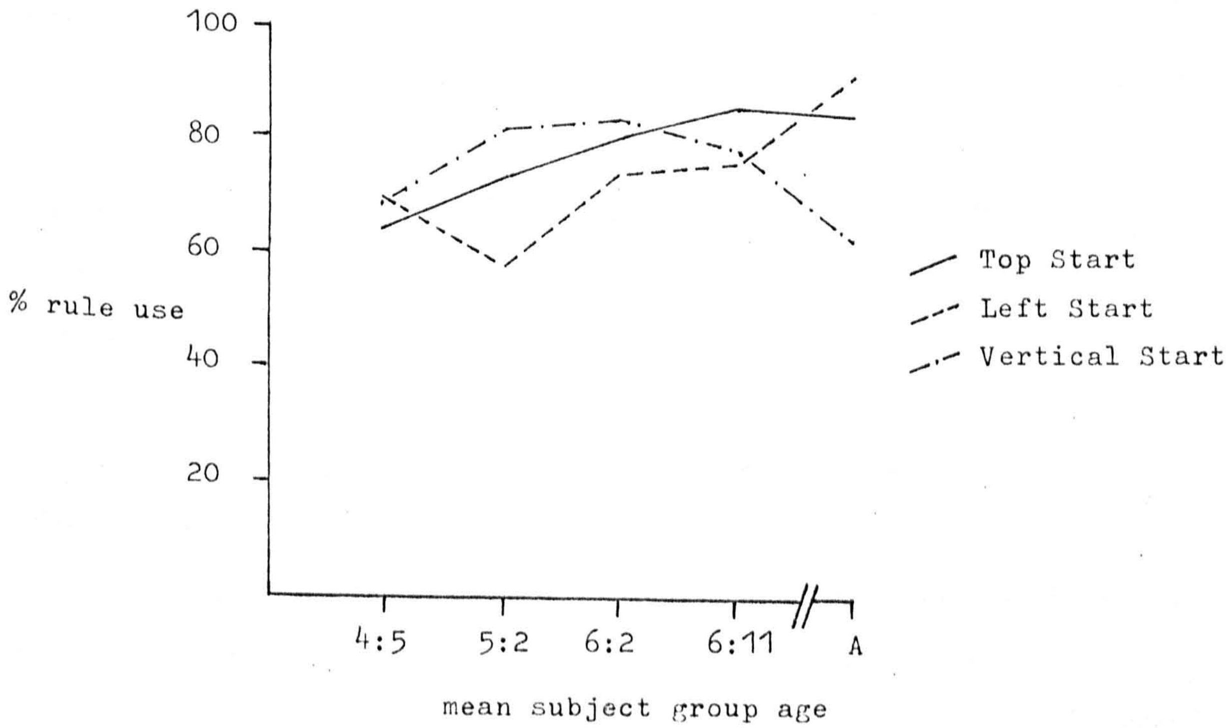
Two considerations about the use of these rules need to be raised at this point. Firstly, although a further rule was invoked to account for the starting behaviour of those figures with apexes (◇ , △ , ∧), that of 'start at the top and come down the left oblique', remaining figures with oblique lines (▽ , ∨) had these lines effectively re-classified as verticals for rule-use analysis. Secondly, it can be seen that all six rules cannot be applied to every stimulus figure, thus raising the concept of 'rule conflict'. For example, when drawing a square, the T-B and L-R rules can both be used without conflict, but both of these are incompatible with the Thread rule. Rule conflict is examined in Goodnow and Levine's (1973) paper primarily with regard to that present between the Left and Top Start rules, with the finding that for figures where no conflict between these two rules is inherently present, both rules are used widely and in conjunction with each other. However, where such conflict is present the use of either rule is dependent on subject age and the structural nature of the individual stimulus.

Examined for figures where the use of each rule was possible (regardless of possible rule conflict), it was found that for the right-handed subjects that were used exclusively in this study use of the Left and Top Start rules increased from mean subject age 4:5 years to adulthood, but that the use of the Vertical Start rule peaked at approximately six years to decline by adulthood. Progression rule use increased with age for the T-B and L-R rules, but the percentage use of the Thread rule was also found to decline after the age of seven. Figure 2 reproduces and condenses the graphs from Goodnow and Levine (1973) that show these age trends in rule use.

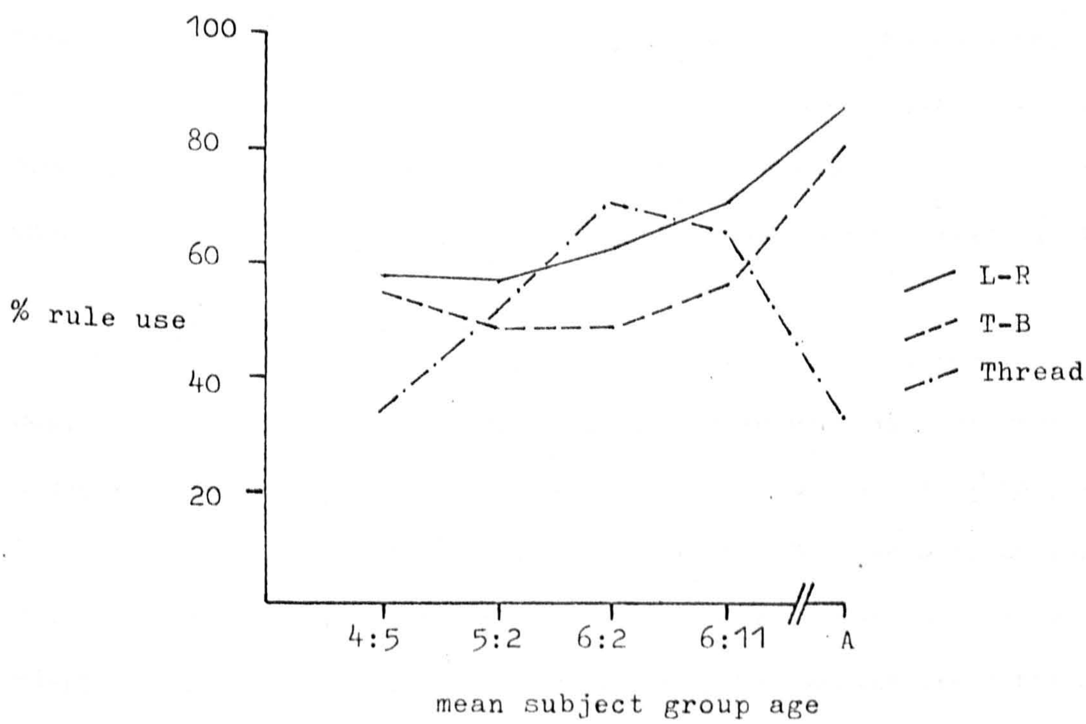
Figure 2; The Developmental Use of Start and Progression Rules

(from Goodnow and Levine (1973))

Start Rules



Progression Rules



In the second half of the 1973 study Goodnow and Levine went on to interpret the relatively commonly-found reversal of the lower-case letters 'b', 'd', 'p' and 'q' in terms of the preference when printing these letters for combining the Vertical Start and L-R rules, by using geometric figures that corresponded in structure to these forms. The combined use of these two rules for the four letters explains neatly why 'd' and 'q' figures tend to be reversed more often than their 'b' and 'p' counterparts (Lewis and Lewis, 1965), as the position of the enclosed loop that separates each pair of figures is to the left of the vertical for 'd' and 'q', and hence is more likely to be omitted if starting with a vertical and printing from left to right.

Apart from further research into rule use, Goodnow and Levine's (1973) study held potential for future studies examining difficulties experienced by young children when first learning to write, either in terms of the rule-based errors that were committed or the method of instruction for letter formation given to the child. Given that Goodnow and Levine's approach would appear to have been a valid one, why examine in greater detail the development of copying strategies instead of directly applying the principles inherent in the rule-based approach to aid early letter printing? Furthermore, if a further examination of the development of strategies in graphic tasks is thought to be necessary, why concentrate on copying, rather than spontaneous freehand drawing tasks?

The answers to the above two questions are interrelated. Many issues concerning the nature of the strategies used in copying tasks remain unanswered by both Goodnow and Levine's (1973) and ensuing studies. The thesis examines at least some of these issues. For example, to what extent are there different levels or types of strategy used in copying simple or more complex figures? Examined in the thesis are different levels and kinds of strategy, ranging from an analysis of individual line directions to the importance of the drawing of complete Gestalt units within larger and more complex figures.

To carry out such studies care must be exercised in the design of figures employed as stimuli. The advantage of copying over spontaneous drawing tasks in non-representational studies of strategy lies in the greater level of control in the stimuli that are drawn in the former type of task. The concern over the structural nature of the stimulus is present throughout the thesis, and regarded as being underemphasised in previous research. To this extent a consistent framework from which stimuli are derived on regular principles is employed in three out of the five studies reported. As has already been noted, structural considerations are also relevant when designing instructional principles for early letter formation and printing. One commonly used method is the teaching of a directional path specific to each individual letter, with the expectation that over time, and with practice, such paths become automatized (Jarman, 1979). Little research has been carried out, however, into the extent that the commonly taught paths concur with the directional strategies spontaneously used by children when copying very simple figures and lines, such as those included in upper and lower-case letters. Is letter formation instruction based on either the use of directional rules or copying, as opposed to tracing techniques, the most efficient way to proceed?

In attempting to provide answers to these and other questions, the five studies in the thesis draw on a range of previous research that is, in some cases, only distantly related to research into copying strategies. The inclusion of such a broad spectrum of research is necessary, however, to place each study in context and to relate it to previous findings in appropriate areas. This literature can be separated out for present purposes into seven overlapping areas, the first of which examines studies concerned primarily with strategy in copying and drawing tasks.

Extensions of the Strategy Approach.

The study of strategy in copying is concerned with two related issues, namely the direction of drawing of individual lines and their ordering within a complete figure. A number of studies have examined the strategies used in tasks that resemble those of copying and drawing in terms of the necessarily sequential ordering of component elements. This short section reviews a small number of such studies, and examines the extent to which the constructional principles given in the papers of Beagles-Roos and Greenfield (1979) and Taylor and Bacharach (1981) are hierarchically organized.

Goodnow (1977) includes the rule-based approach to the study of the copying of geometric figures as part of a more general approach to the examination of representational and non-representational drawing skills. The common thread that draws together the different elements in this short book is the importance placed upon the principles used in combining the component parts of a drawing or copy into a coherent whole. The influence of this structural approach has been an important one, with van Sommers (1983) confirming Goodnow's assertion that the choice of parts in the representational drawing of young children is a 'conservative' one. For the young child, van Sommers claimed, new information about a subject is added primarily in the form of embellishments to the child's existing drawing schemas, with changes to each schema occurring less easily. The conservatism of the young child's approach is a schematic, rather than motor-oriented one.

One approach to the study of drawing skills in adults which made use of strategies is that of Beittel (1972). This underestimated work examined strategies in terms of the wider principles or modes of drawing that control the more detailed construction of elements within an individual picture. For example, Beittel postulated the existence of 'spontaneous' and 'divergent' drawing strategies, with 'strategy signs' that are present in the drawing pointing to which of these two approaches had been used. To summarize Beittel's conclusions, the ultimate objective of divergent strategies is primarily one of 'discovery', and of spontaneous strategies, 'problem-solving'. Although Beittel included in the Introduction to his book the hierarchical organization of strategies given by Miller, Galanter and Pribram (1960), this aspect is not developed further in his own model. The aim of Beittel's theorizing was to improve artistic and drawing technique, but with simpler methods toward this goal being provided by Edwards (1979). Whether either of these techniques are effective in teaching or improving graphic skills in the older child or adult is open to debate.

More theoretically advanced approaches to the development and use of strategies which are not directly tested by the use of drawing tasks have been provided by Taylor and Bacharach (1981) and Beagles-Roos and Greenfield (1979). The former paper related the selection by three to five year olds of one of three systematically distorted human-like figures to the spontaneous drawings of the same subject by each child. Taylor and Bacharach found that 'metaknowledge' about 'drawing systems' develops with age, and 'changes the nature of the original concepton of the subject'. If one can conceive of a hierarchical system of rules that control the drawing of geometric figures, as Pigram (1979) has hypothesised, then such 'metaknowledge' about drawing would be at or near the top of such a hierarchy.

Beagles-Roos and Greenfield developed further the concept of a hierarchy for reproduction tasks, but used the ordered construction of parts in a simple reproduction of a tree with component parts that had already been provided by the experimenter to test their hypothesis. It was found that the older of the subjects aged between four to five and a half years tended to employ 'interrupted' strategies for the completion of the pictures, which in practice meant that further sections of a copy were started before previous ones had been finished. Although the younger children were able to demonstrate this more complex strategy when asked, they did not use it in their spontaneous reproductions. Although this study showed that older children used more complex methods for assembling picture elements, it does not necessarily follow that the principles behind such constructions are hierarchical ones. For hierarchical control to be invoked there must exist the possibility of influence from the larger, higher units of organization to the lower, atomistic ones. The authors suggested that because interrupted constructed sequences are employed and that these influence smaller 'sub-assemblies', the principles used by older children are necessarily hierarchical because of this downward control. This conclusion is a realistic one.

One theoretical approach considered but not used in the thesis, and one which could be said to be at the lower end of a theoretical hierarchy of rules, is that of Production Systems to explain in minute detail the sequencing of each stroke within an individual copy of a geometric figure. This methodological approach sees cognitive skills as hierarchically organized and with consistent subroutines for the smaller behavioural elements (Young, 1978). Theoretically, the six drawing rules of Goodnow and Levine (1973) could be considered as examples of such subroutines, with Production Systems being derived for individual children to control the way these or other rules are used in the copying of individual figures (Young, personal communication). This approach is not pursued in the thesis due to the technical difficulties in actually constructing an effective Production System, partly a function of the low levels of consistency with which children of differing ages employ some drawing rules, and to the restricted number of very simple figures to which any one Production System would be relevant. Nevertheless, an individually-based study of rule use is given in the thesis, but with an emphasis on the regularity or otherwise of rule use across stimuli.

Further Studies of Copying and Drawing Strategies.

The central theme that unites the following studies is the analysis of directional principles that guide a child or adult through the reproduction of a simple figure. Although Goodnow and Levine's (1973) examination of drawing strategies in terms of rules was a novel one, several previous studies had charted the changing preferences for directions and starting points in the copying of simple figures. The most complete of such surveys were those of Gesell and Ames (1946) and Ilg and Ames (1964). These two studies quite simply noted the most commonly used drawing paths of children aged between four and a half and ten years when attempting to draw such figures as a square, circle, cross, triangle and diamond (Ilg and Ames), and also single horizontal and vertical lines from the age of two and a half years (Gesell and Ames). Both studies traced the developmental changes in strategy preference in a normative, but atheoretical manner, concluding that with age comes an increasing preference for more fixed directional principles, such preferences later to reappear in a simpler, modified form as Goodnow and Levine's Progression Rules.

The developmental trends examined by Gesell and Ames (1946) and Ilg and Ames (1964) and put into a theoretical framework by Goodnow and Levine (1973) were primarily those of right-handed, Western children. Studies following that of Goodnow and Levine have tested for differences in copying strategies as a function of handedness and culture. Goodnow, Friedman, Bernbaum and Lehman (1973) examined the influence of directionality in the teaching of the native script. Comparing subjects using English (left to right) or Hebrew (right to left) scripts, copies of a series of stimuli similar to those in Figure 1 were made. For both type of script users, Goodnow et al found 'broadly similar' developmental trends for the use of the six Start and Progression rules given in the Goodnow and Levine (1973) study, but with some minor differences. For example, the use of the Thread rule declined at an earlier age for the Israeli children in the study, and for the ├, ┼, and ┤ stimuli the Israeli children started more often with the horizontal line than did the American children. Goodnow et al explained such differences as 'the result of experience with paths taught for forming letters', and emphasised the similarity between early writing and copying behaviours. Nevertheless, the levels of usage of the L-R rule in the Israeli children remained too high for a complete explanation in terms of the acquisition of the right-left directionality solely via the teaching of the Hebrew script to an acceptable one, as Pigram (1979) pointed out.

The role of handedness, inherent direction of script and the use of directional rules was further examined by Dreman (1974). For the Israeli adults in this study that used Hebrew (with its right to left directionality), right-handers drew the single horizontal lines in the figures in the Bender Gestalt Test (1938) from left to right at a 92% rate, but with left-handers continuing to use the L-R rule at a relatively high 79%. Dreman concluded that few of the simple directional trends used by adults in graphic tasks were due to cultural influence, confirmed by Reed and Smith's (1961) finding that 86% of Western left-handers drew horizontal lines in a right to left direction. At what age, therefore, can such directional patterns be said to set?

Connolly and Elliot (1972) noted the directions used by three to five year olds when freely painting single horizontal, vertical and oblique lines. From the pattern of data generated from this study, it can be seen that even at this young age, and tested using such a gross motor task, verticals were more often drawn from top to bottom and horizontals from left to right, although there was also a high proportion of 'to and fro' directions for both these and oblique lines, presumably due in part to the young age of the subjects and the nature of the painting task itself. What is to be concluded from the studies which have examined handedness and directionality? The simplest explanation concerning the developing use of directional rules is that they are present before formal writing instruction is given, although the level of use is capable of modification by environmental factors if the handedness of the subject is not in concordance with the inherent directionality of the way the script is taught. The use of directional rules on a range of stimuli before and after initial writing instruction is examined in Study I.

Relatively few studies have modified Goodnow and Levine's (1973) 'grammatical' rule use analogy with regard specifically to the copying of geometric figures, despite its apparent success in summarizing directional drawing trends. Ninio and Lieblich (1976) did continue with this approach, investigating further with child subjects between the ages of four and twelve years the nature of the possible conflicts and combinations of rules using three very simple stimuli (| , —, ⊥). Ninio and Lieblich's analysis for the first of these figures was in terms of the complexity of the choice of drawing strategy. It was found that younger subjects avoided more complex strategies for the copying of the figure, choosing those with fewer degrees of freedom. However, further extrapolation from Ninio and Lieblich's study is limited due to the very small range of stimuli on which their conclusions were based.

Using an expanded series of eight simple geometric figures, Nihei (1980) derived three organizational principles to account for the combination of component lines within figures. Subjects aged from five years to adulthood were found to employ one or more of the following principles to differing extents;

Fixed anchoring-	the same point (or line) served as the starting point for all strokes.
Fluid anchoring-	lines drawn exclusively from the end of the previous stroke (equivalent to the Thread rule).
Ballistic starting-	strokes started from a point disconnected from previously drawn lines.

The five year old children used both Fixed and Fluid anchoring, but not the more complex Ballistic starting, and by the age of six Fluid anchoring was used almost exclusively. Adults, however, used a combination of all three principles for different figures, but nevertheless ensured that the simpler L-R and T-B rules were rarely infringed. Thus for both Ninio and Lieblich (1976) and Nihei (1980) the development of copying strategies in geometric figures is marked by an increasing willingness with age to employ more complex organizational principles, but which do not override the simpler directional rules for individual component lines. The findings from these two studies helps to explain the declining use of the Thread rule in Goodnow and Levine (1973).

To what extent, however, can even the simple principles controlling the drawing of line direction justifiably be called 'rules'? If a certain rule is used to only a limited extent by a certain age group or with certain limited types of stimuli, is it a 'rule' at all? This point was raised by Pigram (1979), in a study which examined further the levels of rule use for subjects older than Goodnow and Levine's (1973) oldest child group of mean age 6:11 years, finding that for a similar range of figures as the original study, rule use after this age change continued to change regularly up to the mean age of 9:5 years. Pigram concluded that the term 'rules' might well be better replaced by that of 'plans' (with reference to Miller, Galanter and Pribram, 1960) to reduce the pejorative aspects of the former term. This suggestion is rejected in the thesis due to the possible confusion that might arise in comparing results with previous studies.

A more serious criticism of previous studies of copying strategies is the limitation placed on the interpretation of their results due to either the lack of control or comparability over the figures used as stimuli , or to the very limited and simple nature of the stimuli that are used when some level of control is exercised (for example Ninio and Lieblich,1976; Nihei, 1980). The copying strategies delineated by such studies could be said to be largely a function of the figures used as stimuli.

Younger children, however, are not always capable of successfully copying more complex figures. Di Leo (1970) gave the following approximate ages at which different geometric figures are successfully copied; circle (three years), cross (four years), square (four and a half years), triangle (five years) and diamond (seven years). Nevertheless, even unsuccessful attempts to reproduce more complex figures may highlight different kinds of copying strategies not considered by previous research. For example, if stimuli more complex than those given in Figure 1 cannot be accurately reproduced by children of a certain age, but a part within the incorrect whole is reliably reproduced, what can be concluded about the role of that part in the reproduction as a whole? Questions such as this re-emphasize the importance of the structural nature of the stimulus in studies not only of copying ability (Beery, 19868a, Graham et al, 1960) but also that of strategy. Little research has been conducted that investigates specifically how the structural nature of the stimulus affects copying strategies.

One further criticism of studies of copying strategies is the lack of attention paid to the processes that underlie the ability to reproduce figures successfully. To this extent the above-mentioned studies of copying strategies are descriptive rather than analytic, outlining the commonly used drawing principles but not the developing abilities that may relate to these.

Skills Related to Copying Ability.

The study of these skills has taken place against a number of theoretical backgrounds, for example the use of copying ability or related skills as unique indicators of levels or stages of mental development, or to examine the levels of copying ability displayed by children currently able to display other perceptual or motor skills. There are two major studies in this area which attempt to correlate a measure of copying ability with indices of perceptual and motor skills, as well as those of chronological and mental age. These are the studies of Townsend (1951) and Birch and Lefford (1967).

Townsend's (1951) aim was different to that of Birch and Lefford (1967), and was ultimately concerned with the practical question of the nature of the relationship between perceptual and motor skills and early writing, and to what extent these skills were related to a general measure of intelligence. Townsend's now rather dated review of the research literature led him to test whether the ability to copy geometric forms develops independently of its component skills, with the abilites included in this study being those of form perception and fine motor skill.

Before the results of Townsend's (1951) study are reported, one question to be raised at this point is how 'copying ability' itself comes to be measured. This is of central concern to the thesis, and considered to have been relatively neglected by past research to the extent that each past study has employed different methods of measuring accuracy and error. The studies which have attempted to examine and define more precisely the nature of copying skill have given some thought to the different sorts of errors that can be committed when reproducing a figure and the ways in which such errors interrelate. In general, lesser consideration to this problem has been given by the more educationally-based studies of copying and early writing, where the judgement of a copy as 'correct' has tended to be a rather arbitrary one. Although the majority of these studies report acceptable interjudge accuracy measurement correlations, the difficulty in inter-study comparison remains. Similar problems arise when, for example, different methods of measuring motor ability or form perception are used. Study I in the thesis pays special attention to this problem, using a variety of methods to measure reproductive error.

The problem of error measurement was central to Townsend's (1951) study. In this study, each copy of the seventeen geometric figure stimuli (the nine Bender Gestalt designs and eight others) were judged on four accuracy dimensions, giving a maximum accuracy score of four per copy. These four dimensions were as follows, with acceptable/unacceptable judgements made on each;

'inclusion of all components'
'representation of essential form'
'preciseness'
'correct orientation'

No consideration was given to the possibility of the weighting of these four dimensions, although inter-judge scoring correlations of .9 were reported. Moderate to low intercorrelations were obtained between the four accuracy dimensions (ranging from .26 between correct orientation and preciseness, and .78 between inclusion of all components and representation of essential form). As a whole the total copying score correlated at .60 with a measure of form perception, .52 with motor ability, .58 with mental age and .34 with chronological age. The higher correlation of form reproduction scores to mental age than chronological age was also to be supported by Beery (1968b). Noting that overall levels of copying accuracy did not increase after the age of eight years, Townsend (1951) concluded that;

> 'measures of either mental age or form perception which rely on copying responses may be unreliable in that copying in and of itself is an unpredictable variable in the subject'

Birch and Lefford's (1967) monograph can be said to have analysed the components and correlates of developing copying skill at a higher level. This study emphasised the essential link between sensory and motor processes, and examined the nature of this 'intersensory integration' using tasks of visual analysis, synthesis and recognition, dot-connecting and tracing, as well as a visual-motor task. The visual synthesis task involved putting together a series of component elements to form a simple geometric figure, and the visual-motor task asked children to draw triangles and diamonds with three levels of perceptual support. Similar to Townsend (1951), the scoring of the reproductions in the visual-motor task was on a scale of five equally weighted dimensions, but more realistically with these dimensions varying according to the nature of the stimulus to be copied (ie a triangle or a diamond). Given below are the five scoring criteria for both stimuli;

triangles	diamonds
relative size of parts	relative size of parts
spatial orientation (vertical)	relative size of angles
spatial orientation (horizontal)	spatial orientation
angle formation	angle formation
straightness of lines	straightness of lines

Quantitative criteria were used to judge whether the reproduction was acceptable or unacceptable on each of these dimensions. Like Townsend (1951), Birch and Lefford (1967) found a rapid increase in an overall measure of copying ability between the ages of five and six years, and also that the measures of angle formation and line straightness were the most reliable across figures and with increasing age. To summarize Birch and Lefford's lengthy conclusions, with age came an ability to integrate information from the different sensory systems and to organize actions competently. However, beween the ages of five and eight years only low positive correlations (approximately .2) were obtained between measures of analysis/synthesis and drawing tasks when no perceptual support was provided. Levels of correlation between these tasks increased after the age of six when perceptual support was given, with drawing that used background grids more accurate than that where dots had been provided to help the subject. No explanation was given for these contrasting results, apart from the claim that the 'ancillary visual information' improved the control of directed action.

Intersensory integration was hypothesised to consist of a combination of perceptually-based analysis and synthesis and motor skills, with each of these three components being themselves interrelated to differing degrees. Greenberg (1972), noting the low correlation between analysis and synthesis in Birch and Lefford's study, found an increased interrelationship between these two factors when a modified, more perceptually-based synthesis task was employed. Further support for the notion of developing perceptual and motor integration came from Connolly (1968), with his conclusion that 'visual-kinaesthetic equivalence improves with age', with this being 'probably as a result of neural maturation and learning'.

The pattern of results from the above studies can be said to show that the ability to reproduce geometric figures by drawing is correlated to a modest extent with more purely perceptual and motor skills, and that this ability is more closely related to mental than chronological age. Several studies have shown, however, that the ability to reproduce geometric figures lags behind the ability to perceive differences between figures. This developmental lag was noted and explained by Maccoby and Bee (1965) in terms of the greater 'number of attributes' in the figure that have to be noted before it can be successfully reproduced as opposed to merely successfully discriminated. Strayer and Ames (1972) found that for children aged between 4:10 and 5:5 years only discrimination training that emphasised the orientation of component elements in the figure stimuli, and not discrimination training per se, led to increased copying performance.

Maccoby (1968) took a different approach to the testing of the developmental lag between perception and performance, claiming that one reason for the lack of success by young children in copying some figures is that they draw 'holistically- to reproduce the figure with a single movement of the hand'. Interestingly, Graham et al (1960) did not find any support for a similar Gestalt-based claim of Werner (1948) that the reproductions of younger children would be more 'primitive' than those of older children, namely that the copies would be more simple, closed and symmetrical. Nevertheless, Maccoby, reporting an experiment carried out by Goodson, noted that gross directional discrimination training and practice at drawing a figure's component lines did improve overall reproductive accuracy, although a tracking task did not. Abercrombie's (1970) analysis of the developmental lag emphasises the fact that a simpler, 'global' copy of a geometric figure reduces the information load in the task to more manageable levels for the child, and also noted the persistence of the global response in brain injured children and adults.

Further analysis of the exact nature of the spatial abilities tested by copying tasks have also been carried out. Mitchelmore (1978) traced the developmental stages passed through by children aged between seven and fifteen years when making three-dimensional copies of solid figures, modifying the four stages given by Lowenfeld and Brittain (1966) for spontaneous representational tasks, which ranged in this latter study from 'preschematic' to 'realistic' representations.

More critically, Ninio (1979) questioned whether geometrically-based tasks are appropriate for the testing of spatial representation at all. Ninio claimed that Piaget and Inhelder's (1956) assertion that drawings are symbolic representations of conceptualized spatial relations is not a fair one, as any one drawing is contaminated by the problems encountered in actually producing the drawing, including those of motor control. The thesis avoids the question of the nature of the relationship between representational systems or schemata and graphic output by concentrating for the most part on non-representational, two-dimensional copies, with any conclusions made about the nature of copying strategies in such tasks not being directly associated with, or developed into, a wider theory of cognitive development.

In summary, comparison between studies of copying ability is hindered by the different methods used to judge accuracy of reproduction, and also by the different means of assessing skills assumed to be related to that of copying. Perhaps the fullest, yet also conceptually one of the simplest studies solely concerned with the development of copying ability is that of Graham et al (1960), which has already been mentioned above. A wide, but nonetheless arbitrary series of eighteen figure stimuli were employed, and eight scoring dimensions used to judge each copy in an 'acceptable/unacceptable' form. These eight dimensions included a measure of form reproduction, the open or closedness, and correctness of line straightness or curvature in the figure, as well as judging the correct relationship, size, number and intersection of parts, and finally a measure of adequate overall orientation. Graham et al found that even with the very young two and a half to five year old subjects used in the study, accuracy of reproduction on each dimension increased with age and as a function of the simplicity of the stimulus, the latter being defined quite simply by the number of lines present in the stimulus figure. The finding of both an age and stimulus complexity factor in accuracy of copying was replicated by Beery (1968a) using older subjects aged between six and fourteen years and with stimuli that contained between four and twenty four sides. The role of figure complexity and its measurement is one central to the thesis and examined in detail in due course.

What is the ultimate practical relevance of the above studies? The relationship between copying strategies and early writing instruction has already been mentioned, but the above studies have also drawn attention to the need for adequate discrimination between stimuli for the successful acquisition of both writing and reading skills. The classic study by Gibson, Gibson, Pick and Osser (1962) analysed the improvement in visual discrimination skills between the age of four and eight years. Regardless of its theoretical implications, this study re-emphasized the importance of control over the exact structural nature of figure stimuli, in this case of 'letter-like forms'. The presence in transformed versions of the stimuli as such structural features as closedness, curvature and lack of symmetry all served to increase errors in a matching-to-sample discrimination task. The study by Gibson et al raised two issues that are of direct relevance to the thesis; structural considerations in designing figure stimuli, and secondly the use of copying and discrimination training in early handwriting instruction. It is research relevant to the latter area that is examined first.

Handwriting and Copying.

Although much of the educationally-based research on the development of handwriting skills is not relevant to the thesis and is not considered here, some aspects of this research are appropriate to the study of directional and sequential strategies in the reproduction of simple figures. As Gibson et al (1962) have shown, the link between single letters and simple geometric forms is by no means tenuous, with geometric forms having been used to test the effectiveness of different methods of perceptually or motor-based training, the ultimate aim of such programmes being the improvement of early printing and writing skills. Besides considering a small number of review papers, this section also examines handwriting research for three specific reasons; to judge the efficacy of copying practice on early printing, to examine the use of the teaching of directional production sequences on letter formation (and in particular those in terms of rules), and finally to draw attention to the difficulties experienced by young children in printing certain alphanumeric characters, and the methods used to assess these difficulties.

Two broad reviews of handwriting research covering the period spanning the past twenty years are those of Askov, Otto and Askov (1970) and Peck, Askov and Fairchild (1980). The latter, wider review covers such areas as the nature of the upper and lower-case letters most legibly written, the effectiveness of different instructional techniques, the effects of speed, stress and body position on writing performance, and so on. Although there was a developing interest in the 1960s in the nature of the learning process in handwriting, little important research was carried out, claimed Furner (1969). As part of a rare collection of studies devoted specifically to handwriting skills, Herrick and Okada

(1963) surveyed the methods and principles most commonly used in handwriting instruction. Copying, in one of four forms, was found to be the most widely used method. These four consisted of the copying of correct letter forms from stationary blackboard or book models, copying from formational demonstrations by the teacher, from displayed alphabets or 'forming letters in the air.' As well as copying, the four most other common methods in use were, in order, exercises and drills, tracing, 'rhythm' and manual guidance. Although 95% of the teachers contacted in this survey said that they taught handwriting, in only 7% of cases was provision made for remedial programmes for those children with inadequate writing skills.

A greater number of papers review research on instructional techniques for the teaching of handwriting as part of an experimental piece of research. Summarized simply, such papers examine the differential usefulness of programmes which employ copying, tracing or perceptual discrimination techniques. Furner's (1969) now rather dated review of the research into the perceptual and motor elements in handwriting stressed the need for instruction which would 'promote perceptual development'. Sovic (1979) claimed that a 'dynamic', movement-based approach was most effective in the development of writing skills. This conclusion was in line with that of Wright and Wright (1980), who found more accurate lower-case letter formation from a moving, than static formational model for subjects aged approximately six years.

Several other studies have examined the use of instruction based on the copying of forms or letters against that of discrimination or tracing. The majority of such studies find copying, either by itself or in conjunction with other techniques, to be the most effective technique. For example, Hirsch and Niedermeyer (1973) found copying to be more effective than a 'faded tracing' technique, the latter being a condition which gradually reduced the level of perceptual prompt given. No improvement in this study was found to be due to discrimination training. Askov and Greff (1975), using a slightly different faded tracing technique, also found the copying condition to be more effective in a study which gave unfamiliar shorthand characters as stimuli to the children in the study. Hayes (1982) compared a control condition against four further conditions, all of which employed copying practice to some extent. Hayes found an interaction between subject age and practice condition, with six year olds who only received copying practice reproducing the letter-like forms no more accurately than similarly aged controls. For nine year olds, an increasing number of prompts, including that of the verbalization of appropriate stroke sequences, led to greater reproductive accuracy.

There has not been unanimous support regarding the efficacy of copying practice over other forms of training. Williams (1975) found that for subjects aged between four and five and a half years, discrimination training led to more accurate posttest scores on a copying task than did a copying or control condition, or a condition with both copying and discrimination practice. Although copying practice improved copying performance above control levels, there was no transfer effect to novel stimuli in copying performance for this group.

Rand (1973) found that training which emphasised rules for geometric figure construction led to superior performance on a drawing, but not a discrimination task. These were not, however, the six rules of Goodnow and Levine (1973), but involved the drawing and joining of dots at the corners of the stimuli. Further research which has examined the instruction of sequential production sequences in aiding the copying of letters and geometric figures includes that of Jarman (1979). This is a teacher's handbook for early printing instruction, grouping together letters for teaching purposes as a function of the similarity of stroke directions and starting points that can be applied to each. Jarman considered structured letter printing practice essential, having claimed in 1973 that;

> 'letting children write as they wish as long as the results are legible is disastrous from a developmental point of view.'

This essentially contradicts the conclusion of Moxley (1975), who although outlined useful techniques which work toward more accurate letter reproduction, was in favour of letting the child experiment with sequential strategies. More relevant to the thesis are the findings of Kirk (1978, 1981) and Simner (1981). Both authors employed the six start and progression rules of Goodnow and Levine (1973) as an instructional procedure to aid the formation of upper and lower case letters. Kirk (the latter study being an abridged version of her 1978 thesis) used a pre/posttest paradigm to analyse both the qualitative (use of the six rules) and quantitative (accuracy) aspects of letter formation as a function of rule-based instruction. Subjects were aged between 4:8 and 5:9 years and three instructional methods were used to teach the rules (demonstration, verbal, both). Both quantitative and qualitative aspects of letter formation were found to increase as a whole over all three instruction conditions above a control condition with no rule instruction. The posttest use of both start and progression rules also was found to be higher for 'simpler' letters. For such letters, increased rule use was hypothesised as being due to 'the efficient execution of an articulated plan' and although for more complex letters rule-based instruction 'permitted children to attend to coordinating the movement required to execute the plan', it did not specify the precise nature of the plan itself.

Simner (1981) examined further the difference between upper and lower case letters and numbers as to their theoretical suitability for rule-based instruction. In this study, it was found that of the 170 right-handed subjects aged between 5:4 and 7:11 years, a single stroke pattern for each character was employed to a great extent in 50/61 of the characters tested. These patterns were not, however, those that would have been predicted from a direct application of Goodnow and Levine's (1973) six rules, with the Thread rule being singled out as more appropriate to geometric figure copying than letter production. The relationship between predicted and obtained stroke patterns for letters is further examined in Study I.

Two studies which attempt to trace the sources of directional behaviour displayed in graphic tasks are those of Bernbaum, Goodnow and Lehman (1974) and Thomassen and Teulings (1979). Noting the general consistency with which the Top Start and Thread rules were used across copying, tracing and pointing tasks for three simple geometric figures, Bernbaum et al concluded that such directional behaviour is not task specific, with transfer possible between activities. The fact that different levels of use occurred for the Left Start rule, the only other rule examined in this study, led the authors to question whether the ultimate sources of directional behaviour vary as a function of the direction itself. Thomassen and Teulings, in the conclusion of their study which had noted the development of simple directionality in writing and drawing tasks, hypothesised that a higher order motor system develops for 'the precise and perhaps symbolic functions', which replaces with age a more primitive motor system specialising in rapid motor tasks.

The final area of research to be examined in this section concerns the methods used to measure accuracy in tasks examining the development of writing skill. Conclusions about the relative difficulty in producing certain upper and lower case letters ultimately rest upon the methods used to assess reproductive accuracy. This issue is of importance not only for the comparison of studies of writing and printing accuracy, but also in an educational context, where the assessment of writing skills may rely on qualitative judgements by the teacher which tend to be unreliable, as Feldt (1962) showed. To be able to select the most sensitive, reliable indicators of developing writing or copying accuracy from among the many chosen for this purpose to date would be a fillip for research in this area.

Newland (1932) made an early attempt at error classification, and Lewis and Lewis (1965) gave eleven error types which related differentially to the production of both a complete character and its component parts, although the same authors (1964), drawing conclusions about the relative difficulty experienced by six year olds in reproducing lower case letters with descenders fail to state the methods by which reproductive accuracy was measured. As an example of the lack of comparison possible between studies in this area, Coleman (1970), using subjects of approximately the same age as those of Lewis and Lewis (1964), failed to mention any of the four letters given by the latter study as being among the most difficult to reproduce in their own study, and Stennett, Smythe, Hardy and Wilson (1972) in turn agree with Coleman about only one letter ('u') being in the most difficult four letters. Thus these three studies mention eleven out of a maximum possible of twelve different characters as being the most difficult for the five to six year old to print. Williams (1975) used a scoring system to assess the reproduction of letter-like forms which gave equal weighting to both the method of production and appearance of each figure, with a total combined maximum score of six per stimulus. This system gave only moderate interjudge scoring correlations, ranging from .66 to .89, with William's scoring method also being used by Kirk (1978, 1981) who reported interjudge reliability measures of between .78 to .96.

Further criticism of the relative unreliability and lack of comparability between methods of judging accuracy of letter reproduction is tempered by the very real difficulties in determining the error categories for inclusion in an assessment method. Lehman (1973) developed a method to judge the physical distortion from a single letter model in purely quantitative terms by using a transparent overlay of the original stimulus which was marked with one millimetre grid lines against which an enlarged version of the copy was judged. Although this method was successful in Lehman's study it is regarded as being impractical for the number of individual copies generated and analysed in the thesis. Each study reported therefore explains in detail the assessment methods used and the reason for their selection, these having been formulated in the light of the criticisms given of the methods above.

Stimulus Construction and Complexity.

A central concern of the thesis is how the structure of a stimulus affects accuracy of reproduction and the use of drawing rules. The current section reviews the research literature which has examined in detail the influence of stimulus structure on copying, although it does not directly concern itself with the processes by such stimuli are encoded in drawing or discrimination tasks, or with the role of stimulus orientation. Both of these areas are covered in due course.

Although the majority of the studies that follow have been concerned with the influence of the structure of the stimulus in perceptual tasks and using adult subjects (itself a factor thought by Garner in 1970 to have been underemphasised), the studies of Beery (1968a) and Graham et al (1960) have examined directly the influence of stimulus complexity on the copying accuracy of geometric figures by children. Graham et al stated that for the eighteen forms used in this study, the simplest way of rating figural complexity was as a direct function of the number of parts present in the figure as a whole, and concluded that for the two and a half to five year olds in the study;

> 'the stimulus is probably as significant a variable in determining the reproduction as is age.'

Graham et al (1960) defined a 'part' in this study as a 'discontinuity or direction change' in the figure, but stated that the level of sharpness of line turn could be an influential factor. The number of line turns in a filled figure had been found to increase complexity for adult subjects in perceptual tasks by Attneave and Arnoult (1956) and Attneave (1957), and was implicated in Attneave's 'information theory' model. A figure with fewer or less sharp turns increased the redundancy of information in the figure and led it to be rated as more simple. Beery (1968a) found that for subjects aged between the ages of six and fourteen, the number of sides in a figure (below eight) was a good predictor of how well the figure would be drawn.

A theoretical analysis of the measurement of figural complexity is a complicated issue, detailed discussion of which is seen as out of place in the thesis. More important for present purposes is to accept one method of assessing stimulus complexity (the number of component parts or lines being that chosen), and to examine the different ways in which stimuli rated differentially on this dimension are reproduced. The issue therefore becomes a relative one, and facilitates the answering of such questions as to the nature of use of copying rules for figures of varying complexity, and whether there is a more efficient method of analysing copying strategies for more complex figures, perhaps in terms of the ordering of larger segments or parts within figures.

The importance attatched to the properties of the complete stimulus or display has been emphasised by the Gestalt theorists since the 1930s. The Gestalt approach, as summarized by Hochberg (1974), sees the complete stimulus as having properties beyond those of the sum of its component elements, with 'laws of organization' governing the interrelationship of elements that influence the 'goodness' of the figure as a whole. Such laws include good continuation between and proximity of component parts, with symmetricality and enclosure of the figure as a whole aiding perceptual processes. Unfortunately, early Gestalt theorizing remained unsupported in the main by data gathered in rigorously controlled experiments, relying on demonstrations of Gestalt effects on perceptual processes, and was further weakened by claims such as the 'isomorphism' (or identical topological organization) between perceptual and cortical organization. Nevertheless, the Gestalt tradition is an important one, with research has been carried out within the last twenty years to examine more closely the influence of such factors as symmetry and enclosure on perceptual displays.

Both Boswell (1976) and Deregowski (1971) have drawn attention to the role of figural symmetry using child subjects. Boswell found that for a task which involved reproducing a display by drawing dots in a square grid, stimulus symmetry in both horizontal and vertical axes led to more efficient reproduction. Vertical symmetry aided copies to a greater extent than horizontal symmetry, but with no six dot asymmetrical display ever being copied by correctly by any child across the age range (from 5:9 to 9:9 years). Deregowski, using a similar grid reproduction technique for subjects aged between seven and ten years found, unlike Boswell, that no age effect existed in overall reproductive accuracy, but that patterns with vertical symmetry were easier than patterns which had been vertically repeated. No difference between these two conditions was found to exist for horizontally structured displays.

Fehrer (1935), in an early study on the role of stimulus symmetry in the perceptual processes of adult subjects, found that symmetrical figures were easier to learn than asymmetrical ones. Palmer and Hemenway (1978) further noted that for adult subjects the reaction times for the detection of closed patterns with vertical symmetry was faster than that for patterns with horizontal symmetry, in turn quicker than for patterns with left or right diagonal symmetry. After noting the results of a task which varied the number and axes of symmetry in a similar display, Palmer and Hemenway concluded that a two-stage process operated for the perception of bilateral symmetry, with rapid, simultaneous analysis of symmetry that is biassed toward the horizontal and vertical orientations being followed by the more detailed evaluation of the stimulus about the selected axis of symmetry, with the time taked to complete this latter process a function of the structural complexity of the whole figure. Rock and Leaman (1963) also demonstrated the increased perceptual salience of symmetry about the vertical axis, showing that the phenomenal rather than retinal axis of symmetry was more more important in determining perceived orientation. Rock and Leaman claimed that the facilitated perception of vertical over horizontal symmetry is not adequately accounted for by the isomorphic aspects of Gestalt theory. The authors argued that an increased sensitivity to vertically symmetrical displays develops with age, this process being less strong for horizontal symmetry, and asserted that;

> 'there is nothing intrinsically 'left' or 'right' in external objects the way there is top or bottom.'

The above studies show quite specifically the advantages of the presence of vertical over horizontal symmetry in the perceptual display as a whole, aiding the goodness of the figure or pattern in question. Further studies that have examined stimulus goodness in perceptual tasks include Hochberg and McAlister (1953), Garner and Clement (1963), Pomerantz (1977) and Handel and Garner (1966). Casperson (1950) found, however, that stimuli derived according to the Gestalt conception of 'simplicity' were discriminated no more accurately than less simple figures. Hochberg and McAlister defined the goodness of a pattern in terms of an inverse function of the amount of information needed to define it, providing in this paper support for an information theory approach to the rating of figural goodness. Garner and Clement (1963) criticised the usefulness of such an approach in defining figure goodness, claiming that redundancy is a property of sets of patterns, not of individual patterns themselves. This study took a different approach to the problem of goodness definition, claiming that any single pattern can logically be assumed to be part of a larger set of equivalent patterns. The larger this set, the less good the pattern was found to be. Symmetry was found to be central in defining pattern goodness. Handel and Garner (1966) again found evidence of smaller inferred equivalent sets for good patterns, stating that such structures tend to be 'unique'. As regards the effects of the goodness of the pattern as a whole on specific components of an information processing task, Pomerantz (1977) concluded that goodness benefitted the memory, but not the encoding elements in a discrimination task.

The role of good parts within figures, rather than the level of goodness of the stimulus figure as a whole, is of greater concern to the thesis. Garner (1978) emphasised that 'component' and 'wholistic' properties coexist within the same stimulus, and proceded to outline functional and theoretical differences between these two types of property within perceptually-based tasks of different kinds. figure. Vitz and Todd (1971) developed a model for the perception of single figures which was based on a hierarchy of component elements. The perceptual process was stated in this study to be a sequential one (as it was in that of Pomerantz, Sager and Stoever (1977)), with the analysis of parts followed by the integration of parts into a complete figure. In the supporting studies included in Vitz and Todd's paper, the judged complexity of simple geometric figures that contained symmetry correlated very highly (.98) with the complexity calculated using the principles contained in their model, as did more complex, asymmetrical figures, but at a slightly lower .96 level.

The single most relevant study for the thesis on the relationship between component parts and the complete stimulus is that of Palmer (1977), the theoretical basis for this study being given in Palmer (1980). The former paper developed and tested a hierarchical model for the coding in a number of perceptual tasks of a series of stimuli constructed on regular principles using a figure generation framework. Palmer's model was based on the presence of good parts in a figure aiding the perception of the figure as a whole, with good parts being more easily recognised and manipulated than less good parts. Palmer's 'hierarchical network theory' gave such features as the proximity, continuity and connectedness of component elements, as well as similarity in line length an orientation increasing the goodness value of parts. Palmer found support for his model from four kinds of task; the separation ('parsing') of figures into two mutually exclusive parts, the subjective and calculated goodness ratings of parts within figures, the speeded search for parts within figures ('part verification'), and a part construction task ('synthesis'). Further research by Palmer and his co-workers has assessed the role of levels and different axes of symmetry in aiding the perception of figures (Palmer and Hemenway, 1978), and the effects of both internal (Palmer and Bucher, 1982) and external (Palmer, 1980) information on the perceived pointing of equilateral triangles.

One fundamental aspect of Palmer's work was the use of a consistent framework from which to generate and quantitatively rate stimuli on each of the goodness dimensions. The framework used, though simple, presented other advantages. Parts could be derived with precise control over their structural features, and the goodness value of any one part within a variety of figural contexts could be calculated. Study II in the thesis takes the structural dimensions stated by Palmer (1977) to be those most influential in determining the goodness value of parts, and uses these to derive stimuli from which to test for the facilitated manipulation of figures with good parts in drawing rather than perceptual tasks. The framework, in its original or a modified form, is also used in Studies III and IV in the thesis.

The Encoding of Geometric Figures

The previous two sections have emphasised the importance of structural features present within the stimulus as a controlling factor in reproduction or perceptual tasks. The current section examines research on the processes controlling the encoding recognition or reproduction of figures, with specific attention being paid to verbal aspects of these processes.

The majority of research in this area has used immediate or delayed recognition tasks. Few studies have examined the encoding methods employed by children in reproduction tasks. The most common procedure has involved interference tasks, performed in the time between the initial perception and the recognition/reproduction of the stimulus. This methodology rests on the assumption that an irrelevant task carried out in the same modality as that in which the encoding is thought to take place (for example visual, verbal, structural) will disrupt performance in the main task more than irrelevant tasks in other modalities.

Reed (1973) reviewed the role of verbal descriptions in pattern perception. The studies included in this chapter used a variety of experimental methods, including correlations between verbal descriptions and recall performance, and the differential disruptions caused by visual and verbal interference tasks. Reed concluded that;

> 'visual codes are used primarily in recognition, and verbal codes are used primarily in recall'.

Were this conclusion to be transferred directly to the reproduction of geometric figures, one would expect greater interference to be caused by verbal, rather than visual interference tasks.

The influence of verbal processes in pattern recognition has been further supported by the findings of Cohen (1966) with adults, where 'distorting' verbal labels given concurrently with simple figures led to a deterioration in both the reproduction and recognition of such figures. This study did not, however, hypothesise as to at what stage in the task as a whole interference took place. Glanzer and Clark (1964) developed the 'verbal-loop hypothesis', which stated that the recall of figures employs appropriate verbal descriptions of such figures, and found a correlation of .865 between the judged complexity of a figure and the number of words needed to describe it. In a series of studies, Cohen and Granstrom found support for the verbal-loop hypothesis (1968a), and noted the influence of verbal processes at the encoding stage of a reproductive memory task (1968b), later to claim, though, that a visual store is used to some extent in such a task (1970). In this latter study, however, the authors felt that an explanation in terms of the encoding of figures being primarily visual, and the decoding or reproduction mainly verbal was 'intuitively' wrong, claiming that 'good verbalizers have better encoding (input) which facilitates their recall performance.' This explanation does not really solve the problem of the nature of visual or verbal processes in encoding or reproduction, but merely changes the emphasis to that of what 'good' verbalization consists of, and to what extent it may improve recall or reproduction performance. Less research has been carried out in this specific area, although there has been general debate about the validity of using a subject's own descriptions or verbalizations about internal processes as experimental data, as described in due course.

Hayes (1982) attempted to isolate the effects of verbalization and visual and verbal practice on a letter-like form reproduction task using children aged between six and nine years, and found that increasing the number of perceptual prompts led to improved performance, with those subjects in both age groups who verbalized the formational stroke sequence for the figure's reproduction copying most accurately. When adults were asked to engage in a sequential problem solving exercise, Gagné and Smith (1962) concluded that verbalization 'facilitates ... the discovery of general principles' for the solution of the problem. Is it likely therefore that appropriate verbalization would aid the memory-based reproduction of geometric figures?

The question of whether verbal data taken from the subject should be employed as a valid experimental technique has been considered by Nisbett and Wilson (1977) and Ericsson and Simon (1980). Although the thesis does not employ verbal data as a direct explanation of cognitive processes, the debate between these two sets of authors is nonetheless a relevant one, as some consideration is given to adults' verbal description of figure stimuli in Study IV. Nisbett and Wilson considered that for explanatory purposes, introspective reports by subjects are unreliable, and may reflect motivational rather than causal aspects of performance. Ericsson and Simon were more enthusiastic however, claiming that if certain safeguards about the gathering of such data were followed, the use of verbal reports may be a suitable technique for investigating cognitive processes.

As for the reproduction and recognition of geometric figures, several studies have claimed that an explanation solely in terms of visual or verbal coding is inadequate. Rock, Halper and Clayton (1972) hypothesised that the analysis of the stimulus in a visual recognition task was in terms of a 'geometrical description' which did not involve verbal processes. Palmer (1977), in the study described at length in the previous section, described the processes of representation of stimuli as 'hierarchical networks of nonverbal propositions', and although Reed (1974) and Reed and Johnsen (1975) employed the term 'structural descriptions' to explain the storage of patterns in memory, the former of these two studies concluded that 'the description is stored as a complex interaction of visual and verbal memory codes'.

There thus seems to be conflicting evidence about the extent of influence of verbal processes in what would intuitively seem to be the primarily visual task of reroducing figure stimuli by drawing, although it should be noted that much of the evidence is drawn from recognition or discrimination, rather than reproduction tasks. If verbal processes are implicated, two further questions need to be asked; are verbal processes central to a reproduction task, and if so, by what means can reproductive figure memory be improved by the use of appropriate verbalization? Although these questions may seem distant to the other areas of copying strategies covered in the thesis, Study IV attempts to examine whether the methods used by adults in a reproductive figure task with a memory component can be separated out into distinct verbal and visual categories, and the way in which such a task affects the drawing strategies employed.

Stimulus Orientation and Accuracy of Reproduction.

This final section of the literature appraisal stands apart from the apparently similar area of 'Stimulus Construction and Complexity' due to the considerable amount of research carried out specifically into the effects of different orientations of the accuracy of reproduction of complete figures, single lines, and single lines drawn from baselines. Past research in this area can be separated out into three broadly dichotomous fields; studies that have employed discrimination, as opposed to drawing, copying or line positioning tasks, those that look at the orientation of complete figures rather than single lines, and those that have adult rather than child subjects. The research areas of greatest interest to the thesis are those concentrating on the specific biasses and effects found to exist when children draw single vertical, horizontal and oblique lines from a model, whether or not a baseline has been presented to aid the subject.

The single most important finding that could be said to unite a large proportion of the studies in this area, regardless of their methodological approaches, is the relative difficulty experienced in discriminating or drawing lines or figures in an oblique orientation. Appelle (1972) reviews the supporting evidence from a variety of behavioural and neurological studies in adults, children and an assortment of animals. Appelle's conclusion was that this 'oblique effect' has a central origin in man, established at or above the level of the visual pathways. No explanation is offered, however, of the differences in strength of the oblique effect due to the attentional of memory components of the task itself.

A number of studies have been carried out which examine the importance of the immediate visual framework surrounding the stimulus, and offer explanations of the way this framework is used differentially as a function of subject age. Naeli and Harris (1976) found that the advantage shown by young children in the more accurate copying of square over diamond-shaped figures disappeared when the square was placed within a non-matching, diamond-shaped framework. The authors concluded that framework cues are used if and when present by young children (for example in the positioning or copying of figures within the more common rectangular backgrounds), but when these cues are removed a tendency to drift toward the horizontal and vertical orientations remained, as was shown by the positioning errors of the diamond within a square background.

Bryant (1969), in a series of four single line discrimination studies argued that the perceptual disadvantage demonstrated by oblique orientations could be explained by the adoption of the young child of a 'match-mismatch' coding principle which took into account the relationship of a line to its immediate background. The high level of accuracy for all line orientations in simultaneous discrimination tasks could be explained by the straightforward paralleling of the target to the standard line, but for successive discriminations only mismatch, and no matching cues existed for an oblique line in relation to the background, leading to a deterioration in discrimination performance. By the approximate age of seven successive oblique line discrimination becomes more accurate, accounted for by Bryant in terms of the developing use of absolute coding for oblique lines after a mismatch signal.

An earlier study that had noted the problems experienced when young children attempt to discriminate between pairs of oblique lines was that of Rudel and Teuber (1963), this study using as its theoretical base the animal studies that were to be later reviewed by Appelle (1972). The confusion found in the former study of the direction of pointing of a single oblique line when presented as one of a pair is a topic to which further research has been directed. Jeffrey (1966) replicated Rudel and Teuber's findings of oblique line discrimination difficulties, but found that training which emphasised the direction of pointing of each oblique line aided discrimination. Olson (1970) examined a number of factors influencing the acquisition of diagonality, including the development of motor, perceptual and linguistic skills. Olson combined these elements to derive effective instructional procedures to aid accurate oblique discrimination.

The question of the role of mirror-image orientation of stimuli in discrimination tasks is not directly examined in the thesis, but worthy of brief consideration here as an adjunct to the studies of angular reproduction and discrimination. Huttenlocher (1967) concluded that discrimination between two visual elements presented simultaneously in a mirror-image form was difficult for the children aged approximately five years in this study, and that problems in discriminating accurately not only occured for left-right mirror-image discriminations, as Rudel and Teuber (1963) had shown, but also for up-down discriminations. Sekuler and Rosenblith (1964) found that the type of discrimination errors committed depended on whether stimuli were presented in a horizontally or vertically aligned fashion, with the former arrangement increasing vertical mirror-image errors. Bryant (1974), reviewing and comparing his own results to those of Huttenlocher, offered an explanation of oblique line discrimination difficulties not dependent on whether the display is in a mirror-image form, but whether each pair of lines give the match-mismatch cues relied upon by young children in simple perceptual discriminations.

More recent research has examined further the different aspects of children's discrimination difficulties with pairs of oblique lines, with Fisher and Heincke (1982), for example, noting the importance of both the degree of slope and the left-right direction of the oblique. In a series of delayed discrimination tasks, Williamson and McKenzie (1979) again found poor performance with oblique line discrimination, but regardless of the left/right orientation, degree of slope or mirror-image presentation of the pairs of oblique lines. No supportive evidence was found in this study for Bryant's match-mismatch hypothesis. Fisher (1979) noted the importance of immediate framework cues when these are present, but claimed that the four year olds in her sample were capable of successful mirror-image oblique discrimination in a 'context-free' condition. Scher and Unruh (1983) have found that older children (aged 10+ years) and adults continue to rely on the immediate perceptual framework in a delayed single-line discrimination task.

More relevant to the thesis have been studies which have examined the use of immediate visual frameworks and baselines on accuracy of single line reproduction rather than discrimination. Brittain (1976) found that for children aged between three and five years the less accurate reproductions of triangles in comparison with circles was diminished when both figures were copied within pieces of paper of an identical shape to the stimulus itself. Similarly, in the first of Naeli and Harris' (1976) studies, the more difficult diamond was copied more accurately than a square by five year olds when both were reproduced within diamond-shaped frameworks. Simpler stimuli have been used in studies which have examined more closely the methods by which framework cues come to be employed in drawing tasks, with further clear-cut findings of oblique line difficulties. By merely asking children aged between 3:4 and 4:3 years to drawn from memory single vertical, horizontal and oblique lines, Berman

(1976) found mean angle errors to be greater for the oblique than for the horizontal or vertical (36.5°, 16.7° and 20.3° respectively).

Ibbotson and Bryant (1976) discovered that the tendency to perpendicularize oblique lines when drawn from baselines (Piaget and Inhelder, 1956) was stable across both abstract and meaningful material and using either a line positioning of copying task. This 'perpendicular error' was reduced when the baseline from which the oblique was copied was vertical rather than horizontal or oblique (the 'vertical effect'). Freeman (1980) reviewed extensively the studies of differential copying accuracy as a function of target line and baseline orientation, and quoting Bayrakter (1979), concluded that the perpendicular bias was not susceptible to the introduction of cues which paralleled the immediate framework. Freeman's view can be summarized as follows;

> 'Can there be any further doubt that the major focus of interest is the baseline, that verticality is privileged, and that the perpendicular bias really does disturb relational coding?'

Bremner and Taylor (1982) replicated and extended Ibbotson and Bryant's (1976) design by incorporating target lines to be drawn from dog-leg as well as straight lines in different orientations. It was found in this study that children tended to bisect angles from dog-leg baselines, even when the original stimulus arrangement presented the target line as perpendicular to the baseline. This distortion was only present, however, when the baseline as a whole was in an oblique orientation. Bremner and Taylor offered two explanations of this finding; either the reproductions of the figures were distorted 'locally' by angle bisection, or more generally by a tendency to make the complete figure more symmetrical. Bremner (1982), in a further similar study, has concluded that perpendicular and bisection effects interact as a function of where on the baseline (at the end or in the middle) the target oblique is positioned.

The overall conclusions to be drawn in this area are complex ones, with the accurate reproduction of single lines a function both of target and baseline orientation, and the extent to which these parallel the immediate visual framework. Differences in the construction and positioning of target lines in even simple displays have been shown to influence copying or line placement accuracy. The thesis, in Study V, examines directly a hypothesis derived from Bremner and Taylor's study, but employs a consistent stimulus design (a right-angled triangle) to this effect. As well as being included in the research of Palmer (1980) and Palmer and Bucher (1982), simple triangular stimuli had previously been used in a similar experimental framework by Attneave (1968). An early piece of research by Hanfmann (1933) on copying accuracy in children also used triangles as stimuli, with interesting error categorization that included making note of third-angle difficulties. In short, right-angled triangles provide the opportunity for the subject to draw each of the three single simple line orientations within a familiar geometric figure, and also permitting each line orientation to be presented as a baseline from which errors in angle reproduction can be judged.

Summary

The main areas of interest in the thesis are those separated into the different groups of studies above. The overriding concern is to trace the developing use of strategies for the copying of simple geometric stimuli, but behind this aim lie considerations of the influence of structural differences within and between stimuli (including the role of figural complexity and the presence or absence of 'good parts'). Furthermore, a full analysis of copying strategies cannot be completed without an analysis of errors of production. For the younger child such errors will occur for simple stimuli, but for the older child or adult errors may not solely be a function of the difficulty of the stimulus, but also the methods by which attempts to reproduce the figure, or to memorize it in the case of a delayed recall task.

For the child approaching or recently having arrived at school age, the relationship between copying practice obtained with geometric figures and early letter printing experience is by no means tenuous, as has been shown above by the studies using letter-like figures to examine the child's discriminative or perceptual-motor abilities. The final aspect of research carried out in the thesis attempts to combine the areas of strategy and error, and examines further the well supported findings of angular and orientation biasses made by children in a variety of discrimination or reproduction tasks, including an analysis of whether the direction of drawing single lines to or from baselines in different orientations affects accuracy of response.

To conclude, the main questions that are asked in the thesis are as follows;

To what extent do Goodnow and Levine's (1973) copying rules apply to more complex figures?

How is figural complexity to be measured?

How is copying accuracy to be measured, and what factors influence accuracy of reproduction?

Do copying strategies interact with the learning of handwriting?

How are figures encoded in a delayed reproduction task?

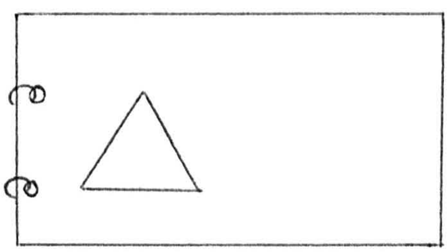
EXPERIMENTAL DESIGN

Irrespective of differences in methodology between the six studies reported in the thesis, each study employs a uniform approach to the presentation of copying stimuli and to the measurement of strategy and accuracy. These uniformities in experimental design are outlined in this short section.

Stimuli

Each of the stimulus figures was xeroxed singly onto a piece of horizontally presented white A5 paper (14.7 by 21 cm). With the exception of Study V, lines comprising each stimulus were coloured black. The figure (of approximate size 5 by 5cm) was positioned centrally on the left-hand side of each piece of A5, with the right-hand side left blank for the reproduction. The complete set of stimulus pages was ring-bound on the left to form a booklet for each subject. Between each booklet page was placed a piece of similarly sized plain coloured paper to prevent the subject viewing through to following figures. An example of a booklet page is given in Figure 3.

Figure 3; The Layout of a Stimulus Page.



Exceptions to this method of presentation occurred in two studies. In Study I, the subjects were asked to copy letter stimuli directly below the model, the letters having been drawn on a line that extended across the upper half of the piece of A5. Four upper or lower case letters were given on each page, with assessment of copying accuracy including a measure of drawing relative to this line. In Study IV the adults viewed the centrally positioned figure on one page, turned to the following page for the duration of the interpolated task, and then onto a fresh page to reproduce the original figure. Other studies which included a delayed copying condition were carried out by the viewing of the stimulus being followed by the experimenter covering this figure with a piece of card until the copy had been completed.

Subjects

The children who served as subjects in each of the studies were taken from one of four Primary Schools close to the University of Keele. Experimental designs that compared subject groups of differing mean ages had these groups taken as far as possible from separate classes. This method reduced the possibility of subject groups having overlapping ages, and ensured that children taken from each class would have had approximately the same amount of school experience. In all cases adult subjects were volunteer undergraduates from the University of Keele.

Only right-handed subjects were employed in the thesis, the study of handedness and copying strategy being outside the range of study. Individual differences in the direction of drawing component lines in simple figures may be related to handedness, as a number of studies reviewed in the Literature Appraisal have shown. Similarly, the scope of the thesis excludes any examination of sex differences in drawing strategy and accuracy. Although differences in patterns of development between the sexes have been extensively studied elsewhere, they have not been emphasised in previous studies of copying and drawing strategies. This factor is taken into account in the thesis to the extent that studies that use groups of subjects have approximately equal numbers of males and females in each group. Thus the issue of sex of subject is controlled for rather than analysed.

Data Collection

This was achieved by one of two methods in each of the six studies; either the order and direction of each component line that comprised a reproduction was noted immediately by the experimenter on a scoresheet, or each copy was video recorded for later analysis. For reproductions of more complex stimuli video analysis was advantageous, as each copy could be viewed repeatedly. This also allowed detailed timing information to be extracted. Video cameras were placed directly above and in front of the subject, and after initial piloting of this procedure it was concluded that the presence of the camera did not interfere with the subject's performance.

The simpler direct method of transcribing stroke direction and order was more rapid, but required vigilance on the part of the experimenter and a clear viewing position to ensure that every stroke was noted. The scoresheets on which individual copying strategies were noted also carried details of the subject's name, age, sex, subject number, experimental condition and so on. Experimental testing with children took place within each School, and in a quiet well-lit room away from normal classroom activity. Tables and chairs of a height that the child would be familiar with were used. Adult subjects were tested in small laboratory rooms in the Department of Psychology. Testing of all subjects in each study was carried out on an individual basis.

Data Analysis

This varied as a function of the hypotheses tested in each study, but similarities in analytic approach are present throughout the thesis. Initial analysis concentrated on quantifying the component elements of each copy in numerical terms prior to statistical analysis. Thus copies were examined with regard to whether a certain drawing rule had been employed or an error committed. This early analysis of formation and appearance occurred at different levels in the studies, with strategy analysis ranging from the noting of individual line direction to whether complete parts had been included in each copy. The level of accuracy measurement also differed, varying from the noting of errors of individual angle construction to global errors in the figure as a whole. Each study that includes an analysis of copying accuracy explains in greater detail the methods used.

Where a within-subjects design was not possible, matched groups of subjects of similar sizes were employed, and data was collected in a form that permitted the most powerful statistical tests possible (for example ANOVAs, t-tests) to be carried out. Later more detailed experimental analyses in the thesis often employ sub-samples of the original set of data which infringe the assumptions that allow parametric analyses to be made.

The statistical tests were applied as recommended by Winer (1970), Siegel (1956), Ferguson (1976), Miller (1975) and Robson (1973).

Statistical Abbreviations

In both the tables of results in individual studies and in the Appendix abbreviations are used to denote statistical tests and levels of significance associated with these tests. These abbreviations are given below. Each table or figure in the text or Appendix has two elements in its title that locate it within the thesis as a whole. The Roman numerals I to V refer to the study number, and the characters a to z to the order of the table or figure in each study.

Levels of Significance

**** - $P < .001$

*** - $P < .01$

** - $P < .025$

* - $P < .05$

n.s. - not significant

df - degrees of freedom

Statistical Tests

Q - Cochran's Q

F - F ratio (from ANOVA)

t - t test

Xr^2 - Friedman's test

χ^2 - Chi Square

r - Spearman's rho

T - Wilcoxon test

STUDY I

Introduction

This study is a preliminary one, covering some of the groundwork examined in more detail in later studies. A series of basic questions are asked about the nature of drawing rule use across a number of differing figure stimuli, and whether rules can adequately describe the methods by which two six year old children print the upper and lower case alphabet over the period of one year.

This study takes as its starting point the finding of Goodnow and Levine (1973) that the use of four out of six drawing rules increases with with subject age in the copying of a selection of simple geometric figures. The Literature Appraisal examines this study in some detail. As Figure 2 has shown, with the exception of the Vertical Start and Thread rules strategies for production become more consistently used between the ages of four and seven years. According to the authors, increasing rule use reflected a growing regularity in approach to the copying task that is manifested in other areas of the child's development, for example language.

Nevertheless, a number of questions from the 1973 study remain unanswered. Although a description of copying behaviour in terms of rules has been shown to be sensitive to differences in subject age, how is the changing use of rules reflected on an individual basis? For example, is the Top Start rule suddenly applied to a greater number of stimuli with increasing age, or does its use change more slowly over a period of time? Furthermore, if levels of rule use do change dramatically, are these changes associated with alterations in other patterns of graphic behaviour? Perhaps more importantly for an individualistic study of drawing rules, the present study examines whether any one rule is consistently applied to a single stimulus over a period of time. If overall levels of rule use were found to be high across different stimuli, but that there was only a moderate level of consistency within copies of individual figures, then the use of drawing rules could be claimed to be a useful general method of approaching the copying task, and not one that is confined to individual stimuli. Conversely, should a high level of within-stimulus consistency exist concurrent with lower levels of overall use of any one rule or rules, then conclusions about the appropriacy of a rule-based approach would need to be more guarded and to take into account both the rule and the stimulus in question.

The issue of consistency of rule use is also examined in this study in relation to stimulus complexity. Both the overall levels and consistency of rule use are tested in this study for more complex stimuli than those employed by Goodnow and Levine (1973). The complex figures in this study (see Figure Id following) on average include a greater number of component lines and segments than the simpler, original stimuli that are also included.

Individual copying consistency is examined in a number of ways in this study for both figure and letter stimuli. Not only are overall levels of rule use examined between the different test sessions, but a measure of the consistency of the application of rules to similar geometric figures is taken both within and between each session. Both simple and complex figures are presented twice, but with different stimulus types being copied before each repeat presentation. Consistency of rule use for letters is only examined between sessions as only one copy of each letter stimulus was made at each test session. The between-session measure of consistency tests whether each of the six drawing rules was employed for identical stimuli in consecutive test sessions. The statistical analysis here examines whether there is a change in the percentage levels of whether rules were or were not used between Sessions 1 to 2, 2 to 3 and 3 to 4. The within-session measure notes whether for first and repeat copies of stimuli figure a similar set of rules was employed, and is confined to the figure stimuli which were presented twice at each test session. The latter method also includes a brief analysis of whether an identical copying strategy (not just the use of similar rules) was used for within-session figure copies.

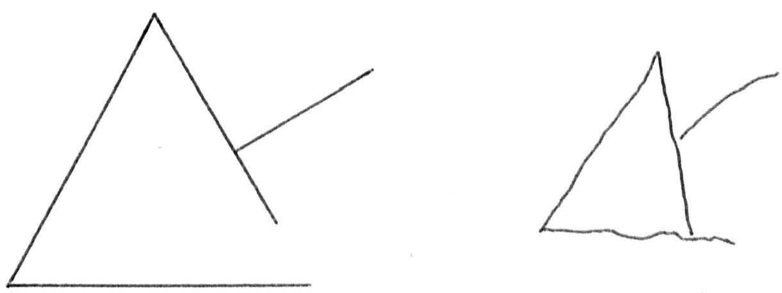
Two principles are in operation behind the selection of the two subjects used in the study. As Figure 2 (Page 9) shows, although there is a general increase in the use of the majority of the drawing rules with age, the single period in which the changing use of rules is most dramatic (in particular for Progression rules) occurs after the approximate age of six years. From this point use of the Thread rule drops dramatically, but both the L-R and T-B rules increase levels of use in step. Change in Start rule use is more gradual across the age range tested.

Formal writing instruction is often commenced in the Primary or First school at about this age. Up to the age of six practice with writing skills is often limited to the recognition and generally spontaneous copies of individual letters and simple words in a number of media that may include, for example, letters traced in sand or made from felt shapes. Children therefore become familiarized from an early age with both the physical nature of alphabetic characters and ways of forming them. During the year in which the experimental testing takes place in Study I the two subjects received their first formal writing instruction. This took the form of regular weekly instruction on the formation of letters, and practice both with the letters themselves and the strokes that are central to groups of letters. No details are given of the precise formational paths employed by the teacher, as it would have been a near-impossible task to ensure that no other formational paths were used by her or practised spontaneously by the two children over the period of one year. Although this study differs in its methodology from that of Kirk (1978, 1981), which examined the levels of usage of drawing rules for letters before and after a short instructional programme, this study's basic hypothesis is a similar one. This states that the formal writing instruction received by the children will influence the use of rules for copies of both letter and figure stimuli.

The final issue examined in Study I concerns the accuracy with which the complete range of figure and letter stimuli are reproduced. With the changes in rule use that are expected to occur between the age of six and seven years there is also hypothesised to be a reduction in the number of errors committed when copying each stimulus. To assess this the study employs an error checklist against which each copy is tested. This checklist draws upon and expands that of Lewis and Lewis (1965), a study that ordered the reproductions of alphabetic characters according to the mean number of errors made in each reproducton.

The expansion of the checklist was necessary to cover the full range of errors that could be committed on either figure or letter stimuli. Tables Ia and Ib in the Appendix give Lewis and Lewis' (1965) checklist and the modified version used in this study. The comments given with the present version are designed as aids in quantifying where a flaw in a copy was serious enough to be designated an error. This feature is not present in the original checklist. The expanded list was designed after a small sample of letter and figure copies from children in a nearby Infant school, and attempts to cover as fully as possible every conceivable category of copying error. The development of the checklist was further aided by attempting to reconstruct copies of stimuli solely by the errors that were known to have been committed. No weighting is given to the different elements in the checklist, and a single copy could score in more than one error category. Each error category in the checklist can be classified in two ways; either it is a formational or positioning error, and can be regarded as one that alters the global shape of the original stimulus or of just a segment or part within the whole. Table Ic gives further details of this categorization. An example of the operation of the error checklist is given for the copy of the figure below;

original | copy



This reproduction would have an error score of 4, having been faulted on errors 5b (over extension at line join), 6b (whole figure too small), 12 (lines not uniformly straight) and 15 (misshapenness).

The assessment of reproductive accuracy is therefore made by the use of a thorough checklist against which each copy made over the four test sessions is assessed. Only a minimal number of stimuli are inappropriate for inclusion and testing in each error category. This method of assessment further permits the ranking of stimuli within each group (simple and complex figures, upper and lower case letters) according to the overall difficulty in reproducing each stimulus over the four test sessions by both subjects.

To summarize, the following hypotheses are tested in Study I;

Overall levels of rule use will change over the year under examination for both letter and figure stimuli.

Consistency of rule use both within and between each test session will increase over this period.

Accuracy of reproduction for figure and letter stimuli will also increase.

Method

Subjects

The two subjects taking part in the study were both female and from the same class of a nearby Primary school. At the time of the first test session Emma was aged 6:0 years, and Shona 5:9 years. These two were chosen from a small sample of similarly aged children because both spontaneously used their right hand when drawing and were able to reproduce a diamond reasonably successfully, a feat of moderate difficulty for children of this age. It was felt that this ability would enable some of the more demanding stimuli to be attempted in the earlier test sessions. Until the first session neither child had received formal writing instruction at the school.

Stimuli

Fourteen simple and eleven complex figures were presented at each test session, as were all 26 upper and lower case alphabetic characters. The selection of simple figures was based on that of Goodnow and Levine (1973), omitting the single horizontal and vertical lines but including a circle. The stimuli were presented according to the principles given in the chapter on Experimental Design. Figure Id below shows both the simple and the complex figure stimuli. The letters were presented in the form given by Jarman (1979).

Figure Id; The Simple and Complex Figure Stimuli.

Simple Figures

Complex Figures

Procedure

The two subjects took part in four test sessions over the period of one year. These took place on the same day for each child and at approximately three month intervals. The dates of these sessions were as follows;

Session 1; 17th June 1981

Session 2; 23rd September 1981

Session 3; 14th January 1982

Session 4; 25th March 1982

Stimuli within each of the four groups (simple and complex figures, upper and lower case letters) were randomly ordered within each group, but each group was presented in turn. First and repeat presentations of figure stimuli were separated by other groups of stimuli. The order of presentation of the stimulus groups was varied randomly over the four sessions. Each test session lasted for approximately 30 minutes, and was video recorded for later analysis.

Measurement of Rule Use

Although the reproductions of all the upper and lower case letters and the fourteen simple and eleven complex figures are included in the analysis of copying accuracy, a rather smaller sample is included in the examination of rule use. This is due to the impossibility of applying some of the drawing rules to certain stimuli. Tables Id and Ie in the Appendix show which of the rules were tested for each stimulus group.

To summarize these tables, all three Start rules were applied to 10/11 simple figures (this excludes the circle) and Progression rules to 7/11 simple figures, this latter group being those stimuli to which all three Progression rules were appropriate. A smaller and varying number of Progression rules were applied to complex figures, but a greater number of Start rules were tested here. Sample size for both upper and lower case letters varies considerably, but statistical analysis and presentation of levels of rule use takes this into account.

A number of other considerations need to be raised at this point concerning the ways in which levels of rule use were assessed for both figure and letter stimuli. Unlike the analysis of reproductive accuracy in this study, oblique lines were taken as being vertical for the examination of rule use. This both simplifies measurement of rule use for figures that include oblique lines, and follows the principles of Goodnow and Levine's original (1973) study. However, to allow greater comparability with the analysis of accuracy of reproduction in the study, measurement of the use of rules is taken from all attempted reproductions of the stimuli. Thus the study does not place arbitrary limits on what is regarded as a 'correct' copy for purposes of rule analysis. This differs from the 1973 analysis, which did not include 'incorrect' copies for rule analysis.

As Tables Id and Ie also note, analysis of the use of individual Progression rules is excluded where there is no option but to employ that rule in a copy. For example, the Vertical Start and L-R rules are not examined for the  figure, where following Goodnow and Levine (1973), obliques lines are regarded for purposes of simplicity as verticals in the analysis of rule use in the present study. A rather different problem arises for stimuli with curved lines, an issue not encountered by the 1973 study which only included figures with straight lines. The principle that was adopted in the present study was to include stimuli with curved lines as far as possible in the analysis of rule use, but with certain limitations. A curved part of a stimulus could be included in the analysis of an individual rule if in the copy of the curve an overall horizontal or vertical direction could be ascertained. For example, although the letter D was included for analysis of the T-B rule, the letter C was not. The curve in the former letter is attached to a vertical line which modifies the overall shape of the curve. The letter C is more rounded (as presented in the versions given to the subjects), and does not contain a further straight line against which the overall direction of the curve can be judged.

Results

Overall Levels of Rule Use

Simple Figures

Table If below gives the percentage rate of use of all six drawing rules for both subjects across each of the four test sessions. As each figure was copied twice it was possible to obtain a score for the use of each rule on a particular figure (from 0 to 2). A Friedman's test was performed on this data to examine for changing rule use across the four sessions. Each percentage reported represents the mean value from the first and repeat copies. The value of the Friedman statistic (Xr^2) is given alongside the percentage levels of rule use.

Table If; Percentage Levels of Rule Use for Simple Figures.

Session

Emma

	1	2	3	4	Xr^2(3 df)	sig
Top Start	95	100	95	90	.27	n.s.
Left Start	75	70	75	80	.27	n.s.
Vertical Start	75	75	70	70	.15	n.s.
T-B	71	71	71	71	0	n.s.
L-R	71	71	71	71	0	n.s.
Thread	50	57	57	57	.26	n.s.

Shona

	1	2	3	4	Xr^2(3 df)	sig
Top Start	90	90	85	85	.27	n.s.
Left Start	60	65	75	80	1.08	n.s.
Vertical Start	95	85	80	75	.78	n.s.
T-B	43	64	71	50	1.45	n.s.
L-R	57	79	86	79	1.41	n.s.
Thread	71	57	50	71	1.16	n.s.

Table If shows that no significant changes in levels of rule use occur for the simple figures across the four test sessions, despite some marked differences in percentage use by Shona. The Top Start rule is used rather more by both subjects than the Left Start rule, a finding in line with that of Goodnow and Levine (1973) for comparable stimuli. Although the level at which Emma employs the Vertical Start rule remains approximately constant throughout the year, Shona's use of this particular rule falls by 20% from a near maximal level. Similarly, Emma's use of all three Progression rules fluctuates to a lesser extent than does Shona's. Neither subject shows a dramatic drop in the use of the Thread rule predicted by Figure 2 between the first and last session. The overall conclusion to be drawn from Table Ih is that rule use for simple figures does not change significantly over the test year, although there is a trend for differences in patterns of rule use to exist between the subjects.

Complex Figures

Table Ig gives the levels of use of the six rules for the complex figures. Despite some large differences in percentage rule use for these figure stimuli across the four sessions no significant differences are found. Where marked percentage changes do exist for complex figures they appear to be fluctuations rather than increasing or decreasing trends in rule use. For example, Shona employs the Left Start rule at widely differing levels between Sessions 1 and 2, and the increase of 22% in the use of the T-B rule between Sessions 1 and 3 is followed at Session 4 by a fall to the original level of 23%.

Table Ig; Percentage Levels of Rule Use for Complex Figures.

Session

Emma

	1	2	3	4	Xr^2(3 df)	sig
Top Start	64	73	73	73	.41	n.s.
Left Start	41	50	36	41	1.04	n.s.
Vertical Start	70	55	65	65	1.14	n.s.
T-B	18	18	14	14	.14	n.s.
L-R	50	50	39	56	.73	n.s.
Thread	0	0	0	0	0	n.s.

Shona

Top Start	59	73	82	73	1.01	n.s.
Left Start	59	14	41	36	5.05	n.s.
Vertical Start	75	60	70	60	.66	n.s.
T-B	23	32	45	23	2.07	n.s.
L-R	44	28	50	44	.44	n.s.
Thread	0	10	20	20	.54	n.s.

Why should a greater level of fluctuation in rule use be present for complex over simple figures? One possible answer to this question is linked to the levels of use of comparable rules between simple and complex figures. Visual inspection shows that overall levels of use for each of the six drawing rules is higher for simple than for complex figures. This is particularly marked for Progression rules where Emma, for example, did not employ the Thread rule on a single occasion when copying a complex figure, despite using it on over 50% of simple figure copies. It can be concluded that the six drawing rules, and particularly those governing the direction of lines through a figure, are less appropriate for the complex stimuli in Study I than for the stimuli for which the rules were originally tested. It is not that each child is unwilling to use these rules (as demonstrated by the high levels of use for the simple figures), but rather finds that the consistent directions implied by the use of such rules are not appropriate for these more complex stimuli. This explanation, however, does not take into account any possible interaction between accuracy of reproduction and the choice of copying strategy. This issue is examined in later studies in the thesis.

Upper Case Letters

Table Ih overleaf shows levels of use of the six drawing rules for the upper case letters in Study I. Unlike figure stimuli, letters were only copied once at each session, with the consequence that a statistical test employing nominal data (Cochran's *Q* test) was performed here.

Table Ih shows only a single significant changing level of rule use across the four testing sessions and for the six drawing rules, this being Emma's varying use of the Left Start rule. However, further interesting patterns of rule use emerge for both subjects from this table. Like both simple and complex figures, levels of use of the Top Start rule are higher than those for the Left Start, and for both Emma and Shona use of the Vertical Start and L-R rules is both high and consistent for upper case letters across the test year. Whether this represents a consistency in the use of rules for individual letters is examined in a following section. The Thread rule is employed at an overall level similar to that for simple figures, although the patterns of rule use given by both subjects imply that the use of the Thread rule is not a stable one, tending to increase over a period when the use of this rule is expected to decrease for simple figure stimuli.

Table Ih; Percentage Levels of Rule Use for Upper Case Letters.

Session

Emma

	1	2	3	4	Q(3 df)	sig
Top Start	85	92	100	92	4.80	n.s.
Left Start	54	46	65	62	9.32	*
Vertical Start	81	81	81	81	0	n.s.
T-B	70	57	70	52	6.65	n.s.
L-R	100	100	100	100	0	n.s.
Thread	64	86	71	79	6.00	n.s.

Shona

	1	2	3	4	Q(3 df)	sig
Top Start	85	77	85	96	4.93	n.s.
Left Start	65	58	69	58	7.36	n.s.
Vertical Start	81	81	81	75	3.00	n.s.
T-B	70	70	57	57	4.50	n.s.
L-R	100	100	100	100	0	n.s.
Thread	57	57	86	79	7.29	n.s.

Lower Case Letters

Table Ii notes the use of the six drawing rules for the lower case letters. Two significant trends emerge from this Table; Emma's use of the T-B rule fluctuates in an initially downwards direction, and Shona increasingly employs the Thread rule from a 59% level at Session 1 to a maximum level at the final test session. Levels of use of the Top Start rule are again higher than those for the Left Start, but unlike the upper case letters the latter rule is used at a similar and relatively unvarying level by both subjects.

One common feature between levels of rule use for upper and lower case letters is the 100% rate at which the L-R rule is applied to the twelve letters for which it is appropriate. This pattern stands the L-R apart from the two remaining Progression rules, whose use is at lower and varying levels. It would seem that even by the age of six the two subjects have a fixed left to right strategy for the printing of horizontal lines in letters. This is not matched by similarly high levels of use of the T-B rule. It would appear that the overriding preference shown by Emma and Shona is to start at the top of letters (in particular upper case letters), but to further ensure that horizontal lines are copied in a consistent direction.

Table Ii; Percentage Levels of Rule Use for Lower Case Letters.

Session

Emma

	1	2	3	4	Q(3 df)	sig
Top Start	65	77	81	81	6.14	n.s.
Left Start	58	54	58	54	2.00	n.s.
Vertical Start	71	71	71	71	0	n.s.
T-B	50	41	27	50	8.04	*
L-R	100	100	100	100	0	n.s.
Thread	94	100	100	100	3.00	n.s.

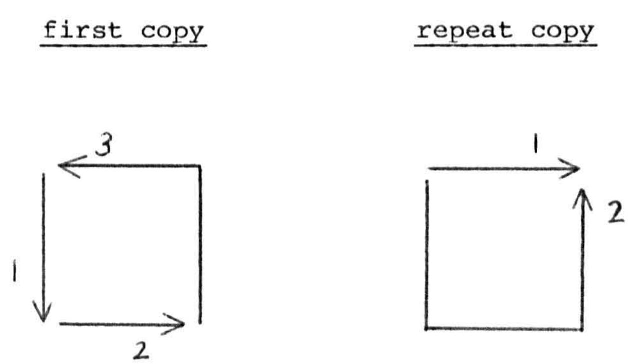
Shona

	1	2	3	4	Q(3 df)	sig
Top Start	73	73	88	88	6.00	n.s.
Left Start	54	58	58	54	.67	n.s.
Vertical Start	65	82	71	71	3.80	n.s.
T-B	64	64	55	55	2.40	n.s.
L-R	100	100	100	100	0	n.s.
Thread	59	88	94	100	14.50	***

Two conclusions can be drawn at this point about rule use in the copying of single letters. The first is that the six rules are not all appropriate for the copying of the letter stimuli, as judged by the differing and occasionally low overall levels of rule use. Secondly, at the approximate age of six the use of the majority of these rules is not at fixed levels, but rule use does not change to a significant degree or in a consistent direction. Visual inspection shows that the differing levels of rule use between the upper and lower case letters implies that these two groups of stimuli are quantitatively, if not qualitatively different, and should be taken separately for purposes of formational instruction, as Wright and Wright (1965) recommended. The hypothesis that the writing instruction received by Emma and Shona would alter levels of rule use in letters and figures is not supported.

Consistency of Rule Use

This section examines the consistency with which copying strategies are employed across any two presentations of a stimulus in the same or different test sessions. The tables below give the percentage levels of consistency as measured in two different ways; the extent to which each of the two copies in the session was made using the same Start and Progression rules (for between and within-session consistency), and whether each first and repeat reproduction was drawn using an identical strategy; namely whether the order, direction and number of strokes were similar. This method was only employed for within-session analyses. The hypothetical reproductions below demonstrate how this method was employed.



Both copies above employ the Top and Left Start rules, and are judged to be consistent in this respect. Although the first copy commences with a vertical stroke, the repeat copy does not, and thus the two copies are inconsistent for the use of the Vertical Start rule. For the Progression rules, both copies fail to draw all the verticals from top to bottom, and are thus consistent here in that the T-B rule is not used. The first copy fails to employ the L-R rule for every line, but the repeat copy does, and hence the pair are inconsistent for the L-R rule. Neither copy uses the Thread rule, and as both reproductions are not copied using a similar pattern of line orderings and rules the two are judged not to have been produced with identical strategies.

Within-Session Consistency

The following tables combine data from the three Start and Progression rules for each subject and for both simple and complex figures. A Friedman's test examines changes in the level of consistency for the Start and Progression rules within each of the four test sessions, and a Cochran's Q test employed for the testing of changes in consistency in identical strategy. Sample size for both within and between-session consistencies is given in Table Ij in the Appendix, with ten simple and eleven complex stimuli included in the analysis of identical strategy.

Table Ik; Percentage Consistency of Start and Progression Rule Use Within Sessions.

Simple Figures

Start Rules	Session 1	2	3	4	Xr^2(3 df)	sig
Emma	90	97	87	100	.48	n.s.
Shona	97	73	93	93	1.32	n.s.
Progression Rules						
Emma	96	100	96	100	.66	n.s.
Shona	78	67	96	85	2.55	n.s.

Complex Figures

Start Rules	Session 1	2	3	4	Xr^2(3 df)	sig
Emma	78	88	84	88	1.04	n.s.
Shona	84	81	97	84	1.55	n.s.
Progression Rules						
Emma	80	96	92	96	1.03	n.s.
Shona	88	80	96	84	1.61	n.s.

Table Ik shows no significant changes over time in the consistency with which either Start or Progression rules are applied across the four test sessions. The overall pattern is that of a high level of consistency of strategy within each session for both simple and complex figures. A previous section of the Results has shown that some of the six drawing rules (and especially Progression rules) are used to only a moderate degree in complex figures, but Table Ik above demonstrates that there is consistency within each session to the figures for which they are, or are not used.

Table Il overleaf notes the extent to which identical strategies were employed for the first and repeat copies of simple and complex figures by both subjects within each of the four test sessions.

Table 11; Percentage Use of Identical Strategies for Simple and Complex Figures Within Sessions.

Simple Figures

	Session 1	2	3	4	Q(3 df)	sig
Emma	80	90	80	100	3.00	n.s.
Shona	80	50	70	70	3.00	n.s.

Complex Figures

	1	2	3	4	Q(3 df)	sig
Emma	18	36	55	45	4.20	n.s.
Shona	27	9	55	27	6.65	n.s.

Table I1 fails to note any significant changes in the percentage levels with which identical first and repeat copying strategies are used by either of the two subjects within each of the four testing sessions. One pattern that does emerge is that identical strategies are rarely used for complex figures, and when these are employed they are liable to fluctuation between the four sessions. One explanation of this finding is that as no simple progression paths exist through the complex figure stimuli, any one strategy is less likely to be repeated within a single test session. This is less the case for simple figures, where the choice of possible drawing strategies is fewer for each figure.

Overall conclusions about the consistency with which the six drawing rules are applied within each test session are straightforward. For both simple and complex figures, and for both Start and Progression rules the same individual rule is invariably used at a level above 80% for first and repeat copies, although identical strategies are not often employed for complex figures. The simplest explanation for this pattern of high within-session consistency is that the children are simply remembering the paths used in the first copy at the repeat presentation. To claim that the use of drawing rules is operating at a more profound level, between-session consistency would also need to be at a high level. This is examined in the following section for both figure and letter stimuli.

Between-Session Consistency

Examination of consistency of rule use between the four test sessions is given in Tables Im and In below, which note the percentage change in consistency of rule use between Sessions 1 to 2, 2 to 3 and 3 to 4 for both letter and figure stimuli. Data is given for both subjects and summarized for the Start and Progression rules, with statistical analyses testing for change between these three groups of two sessions. Sample size for figure stimuli is given in Table Ij in the Appendix, and for letters in Table Ie. Change in percentage consistency of rule use for individual letter stimuli is calculated on a 1/0 basis between each session, depending on whether a rule was (score 1) or was not (score 0) consistently used. For figure stimuli this calculation is based on the extent to which rule use changed in both the first and repeat copies at each session. For example, if the Top Start rule was used once in the two copies of an individual figure at Session 1 (score 1), and twice at Session 2 (score 2), then the difference between these two values is noted and employed in the statistical analysis. If the Top Start rule had not been used at all in Session 1 then this final value would be given as 2. Comments on between-session consistency follow Tables Im and In.

Table Im; Percentage Consistency of Start and Progression Rule Use for Figure Stimuli Between Sessions.

Simple Figures

	Session					
Start Rules	1	2	3	4	Xr^2(2 df)	sig
Emma	93	95	93		.05	n.s.
Shona	87	90	95		.95	n.s.
Progression Rules						
Emma	98	100	100		.07	n.s.
Shona	79	74	83		.74	n.s.

Complex Figures

Start Rules						
Emma	80	86	89		1.56	n.s.
Shona	63	75	80		2.55	n.s.
Progression Rules						
Emma	84	82	94		.74	n.s.
Shona	84	84	84		.06	n.s.

Table In; Percentage Consistency of Start and Progression Rule Use for Letter Stimuli Between Sessions.

Upper Case Letters

	Session					
Start Rules	1	2	3	4	Q(2 df)	sig
Emma	88	90	96		3.50	n.s.
Shona	88	84	87		1.56	n.s.
Progression Rules						
Emma	87	84	89		.75	n.s.
Shona	91	80	84		3.46	n.s.

Lower Case Letters

	1	2	3	4	Q(2 df)	sig
Start Rules						
Emma	91	94	96		3.50	n.s.
Shona	76	82	93		9.30	*
Progression Rules						
Emma	84	93	88		3.43	n.s.
Shona	84	84	88		.73	n.s.

Tables Im and In report only a single example of significantly changing between-session consistency, this being Shona's increasing consistency of use of Start rules for lower case letters. However, increasing consistency is reported in twelve out of the fourteen analyses in these tables where differing percentage consistencies are reported between the first and last comparisons. This proportion is highly significant ($P < .01$) using a Binomial test with equal hypothetical probabilities for increasing or decreasing percentages. From Tables Im and In it can be concluded that not only is between-session consistency high, there is also a trend for it to increase.

Taken together with the data from the measures of overall levels of rule use and within-session consistency, a pattern of the extent to which rules are applied to the different stimuli and their changing use over time now emerges. Examined for stimuli where the use of an individual rule is possible, overall levels of rule use do not change between the ages of six and seven years for the two subjects in question, but do vary as a function of the appropriacy of the rule to the stimulus in question. For example, Start rules are more often employed than Progression rules when copying complex figures, as this group of stimuli present no easily-planned paths through each figure. The differing but unchanging overall levels of rule use for letters imply that by the age of six these two children have relatively fixed spontaneous methods of printing both upper and lower case letters that are not susceptible to change from instructional or developmental factors. The evidence from within and between-session analyses attest further to the unchanging nature of these strategies. The drawing rules are either employed or ignored for repeated copies in the short and long term for letter and figure stimuli, with evidence of increasing between-session consistency over time.

Accuracy of Reproduction

All letter and figure stimuli are included in the analysis of reproductive accuracy. Values for the simple and complex figures included in the statistical analysis in this section are the mean values from the first and repeat copies obtained from the error checklist. Table Io below gives the mean error scores for both subjects across the four test sessions, with the F values in the table being from the one-way ANOVAs performed on each set of data.

Table Io; Mean Error Scores for Figure and Letter Stimuli.

	Session 1	2	3	4	F	df	sig
Simple Figures							
Emma	2.68	2.36	2.36	1.71	1.89	3-52	n.s.
Shona	3.11	2.57	2.65	1.96	1.90	3-52	n.s.
Complex Figures							
Emma	4.73	3.36	4.00	3.36	2.07	3-40	n.s.
Shona	4.23	3.68	3.41	3.45	.84	3-40	n.s.
Upper Case Letters							
Emma	3.73	2.54	3.23	2.50	2.83	3-100	*
Shona	3.38	3.42	3.50	4.15	1.70	3-100	n.s.
Lower Case Letters							
Emma	2.88	2.08	2.73	2.23	2.16	3-100	n.s.
Shona	2.88	2.81	3.31	3.19	.79	3-100	n.s.

Only one of the eight patterns of changing error levels attains significance in Table Io, that being the fluctuating accuracy of Emma's copying of upper case letters. There is thus no support for the hypothesis of decreasing levels of error between the ages of six and seven in the present study. Comparison of error levels between stimulus types in the above table is limited by the inapplicability of some of the error checklist categories to certain stimuli, but comparisons can be made both between the two subjects and within stimulus groups. For this latter comparison care must be taken due to the fact that the 'first oblique drawn too vertically' is not appropriate to all stimuli.

The mean number of errors committed by Emma decreases for all four stimulus types between the first and fourth sessions regardless of fluctuations between these two points in time. For Shona, however, this pattern of an overall trend for decreasing errors is only present in figure stimuli. This implies that despite the increased amount of practice obtained in printing letters in the test year, there was no concurrent increase in the quality of reproduction.

Table Ip in the Appendix ranks the stimuli within each group according to the mean number of errors committed by both subjects across the four test sessions. From this table an approximate measure of the relative difficulty of stimuli within each group can be obtained. The short section below discusses these rank orders for each stimulus group.

<u>Simple Figures</u>

Several interesting features emerge from this section of Table Ip. Firstly, there is a disparity between the difficulty reported in copying the two identical but mirror-image stimuli of Λ and V, with the latter figure found to be the easier. This could be accounted for by the resemblance of the V figure to the letters v and V, and the transfer of practice effects to the similar geometric figure. Both the upper and lower case versions of this letter are reported as being the easiest of each stimulus group to copy. If this was the sole explanation, however, then the circle would have been found to be prone to fewer errors due to practice with the letters o and O, and also because circular forms are spontaneously produced many times in scribbles from an early age (Kellogg; 1969, 1979). One further possible explanation of the relative ease of the V over the Λ figure is that the drawing of the former can combine the highly employed Top Start and Left Start rules, the use of these two being mutually exclusive in the latter figure. If ease of reproduction is related to the number of simple drawing rules that can be applied to a figure then this explanation is a plausible one.

The three most difficult of the simple stimuli (△ , ▽ , ◇) are the sole figures of this stimulus group that contain areas enclosed by oblique lines. The diamond is reported as being by far the most difficult figure to copy, a finding in line with the previous studies of Di Leo (1971) and Graham et al (1960). The reported rank ordering of the fourteen simple figures in this study correlate at a level of .35 ($P < .05$) with order of difficulty for those figures employed by Graham et al, although the method of error measurement differed in this latter paper. There are, however, some notable differences between the two patterns of rank orderings. For example, although the V figure was reported as being the easiest for Emma and Shona to draw, it was ranked as the eighth most difficult out of the fourteen comparable figures included by Graham et al. This particular anomaly could be due to the lesser amount of practice obtained with this letter-like figure by Graham et al's subjects who were aged up to five years.

Complex Figures

Comparison with previous studies is not possible for these more complex figures, as no study has assessed the accuracy of the copying of geometric figures assumed to be difficult for the subjects tested. Inspection of Table Ip in the Appendix shows mean levels of error to be higher here than for simple figures, with the three most difficult stimuli being those with two or more enclosed parts. Interestingly, the  figure appears to be unexpectedly error prone in relation to the five stimuli that precede it in the ranked list, and which all possess oblique lines. If the combination of curved and horizontal or vertical lines within the same stimulus is consistently difficult to reproduce then this will be reflected in the rank ordering of upper and lower case letters that include this structural feature.

Upper Case Letters

Seven upper and lower case letters are similar with regard to shape and line positioning. These are C, O, S, V, W, X, and Z. For only one of these, Z, does Table Ip show the upper case copy to be more accurate than lower case reproductions. Taken together with the finding that the mean number of errors is higher for upper case letters, it would appear that Emma and Shona are more comfortable making reproductions of lower rather than upper case letters, whether this be due to practice effects or structural differences between the two letter groups.

The three most difficult letters in this stimulus group are those out of the total of seven that combine curved strokes with straight lines in other orientations. There is no significant correlation (r = .01) between the rank ordering of difficulty of upper case letters in Study I and that given by Lewis and Lewis (1965), the study on which the present error checklist was based.

Lower Case Letters

The rank ordering of these stimuli does correlate with that of Lewis and Lewis (1965), and at a significant .55 level ($p < .005$). Why there should be a correlation for lower but not upper case letters is somewhat puzzling, but one possible explanation centres on the relative lack of practice usually encountered by children of this age with upper case letters. This could also cause upper case copies to be produced with less consistent strategies over time than lower case copies, and thus the rank order of difficulty for upper case letters in Table Ip may not be a reliable one. The proportion of lower case letters that combines curves with straight strokes is greater than that for upper case letters, and is spread throughout the lower case rank ordering. This makes the assessment of the interaction of these two structural features somewhat more difficult to calculate.

To serve as a background to the above analysis of reproductive accuracy, Figure Iq overleaf gives copies of each child's printing of her own name over the four test sessions. A brief qualitative analysis shows that Emma's retracing of letters drops out by the final session, by which time she appears to be successfully maintaining a constant size between individual letters. Shona's writing of her own name becomes more fluid, with less breaks between strokes within letters and a fading out of retracing after the first session. Shona's changing shape of the letter R is indicative of her improved writing formation. At Sessions 1 and 2 this letter is formed from individual strokes, with the version at Session 2 comprising a circle and two straight lines. The strategy used at Session 3 is not clear, but by Session 4 it is likely that Shona started at the top of the letter and used the Thread rule.

Figure Iq; The Children's Copies of their own Names.

Session 1; Emma

Session 2; EmmaMcNeilFregagon

Session 3; Emma mac Neil Ferguson

Session 4; Emma mac Neil Ferguson

Session 1; Shana Ro SS

Session 2; Shona Ross

Session 3; Shon a Ross

Session 4; Shona Ross

Discussion

Study I has shown that the extent to which each of the six Start and Progression rules is used is a function of both the rule in question and the stimulus type. Neither levels of rule use nor accuracy of reproduction for letters or figures changes significantly over the year in which the testing was carried out. It would seem that in an unmodified form the six drawing rules, and in particular the Progression rules, are less appropriate for describing the copying strategies for more complex figures used by the two children in the study.

From this conclusion arise two further questions about the nature of copying strategies for all but the simplest of stimuli; in what ways do complex stimuli differ structurally from simple stimuli, and what is the nature of the copying strategies that these figures invoke? Table Ig shows that rules defining the direction of all the horizontal or vertical lines in a complex figure (L-R and T-B) are not used to a great extent, but it may nevertheless be the case that a high proportion of the individual verticals or horizontals in each stimulus are drawn using a top-to-bottom or left-to-right strategy. Studies IV and V examine the use of preferred directions for single lines.

Both within and between-session measures of consistency are high, often at a greater level than the overall levels of use of drawing rules to which they correspond. The implication of this finding for any rule-based method of letter formation instruction is that it must take account of the conclusion that even by the age of six the spontaneous use of drawing rules across a variety of stimuli is relatively fixed. Instructional procedures should therefore take into account the rules the children themselves use at this age, or to commence instruction at an earlier age. The latter method, however, would need to employ a very simple range of stimuli which each child would be capable of reproducing.

The distinction between simple and complex figure stimuli in Study I is rather an arbitrary one, with figures in the latter group having a higher number of component lines and more complex line orientations and junctions. Although Table Io has shown that the majority of complex figures generate a higher level of mean error than the simple figures, exact comparison between individual stimuli is made difficult by the lack of a common principle behind the generation of the simple and complex figures, and by the fact that the error checklist is not equally weighted to all stimulus groups or to stimuli within each group. This criticism of the error checklist is exacerbated by the fact that this method of assessing accuracy of reproduction is rather complex, requiring a degree of practice on the part of the experimenter. The emphasis placed on the need for thoroughness in the checklist would have been better balanced against a simpler method of error judgment for which a measure of inter-judge reliability could have been attained. Despite this drawback, it is unrealistic to claim that differences between the mean error levels reported for each stimulus are solely due to the vagaries of the method of assessment. Ensuing studies in the thesis pay more attention to the need for realistic comparisons between stimuli and for a simpler method for the assessment of reproductive accuracy.

It should be noted when assessing the lack of significance in the changes of rule use and copying accuracy over time that data was collected from only two subjects in this study. For example, it is disappointing to find neither Emma's nor Shona's changing use of identical copying strategies for complex figures in Table Il attains significance, nor does Shona' regularly decreasing use of the Vertical Start rule for simple figures or her fluctuating use of the Left Start for complex figures. Although the statistical analyses take this method of data collection and analysis into account, patterns of change reflect individual biasses that one would expect not to be present in a larger group study. This latter method of assessing changing graphic behaviour over time is employed in further studies in the thesis.

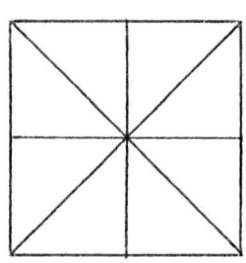
STUDY II

Introduction

Among the conclusions drawn from Study I is that drawing rules which control the direction of copying of all horizontal and vertical lines in a figure are used less when the figure itself is a more complex one. It has been suggested that complex figures may invoke copying strategies that go beyond the noting of individual line direction and take into account parts of the whole stimulus.

Study II follows closely the hypotheses derived from Palmer (1977), a paper that has already been reviewed in the Stimulus Construction and Complexity section of the Literature Appraisal. Palmer tested whether geometric figure stimuli that possessed parts with a high 'goodness' rating were manipulated more speedily in a series of perceptual tasks than figures without good parts. To this end he employed a figure construction framework (see Figure IIa below) from which the figures used in the study were derived.

Figure IIa; The Stimulus Construction Framework used by Palmer (1977).



To summarize the results of the 1977 study, it was found that the possession of a good part aided the speed with which the stimulus figure could be separated into its component parts ('parsing'), that good parts were more quickly constructed into a complete figure ('mental synthesis'), and that figures with good parts would have these parts more easily recognised ('part verification'). A high correlation between the subjective and (objective) goodness rating of parts was also found. The criteria for objective ratings are described in the following paragraph. Palmer saw the findings from this study as providing evidence for a hierarchical model for the representation of information in terms of 'structural units' at different levels of processing. The present study does not examine Palmer's claim of the existence of a hierarchical theory of representation, but does test whether the findings of facilitated perceptual manipulation in his study apply to the copying of a series of geometric figures derived according to similar principles.

Each of the figures derived in Palmer's (1977) study contained a total of six lines ('segments'). He derived a method for rating the 'goodness' of any <u>three</u> of these six lines as a component part. The stimulus features that were used in the goodness rating of parts were strongly influenced by Gestalt principles, and are given below. The calculation of part goodness was made by comparing each of the three lines within a named part with the remaining two lines in the part ('within-group elements') and each of the other three lines in the figure ('between-group elements') on five dimensions. For each nominated three-line part the average difference between within-group values and between-group values was computed and summed across the five scoring dimensions given below. Each of these dimensions was weighted according to its 'salience for perceptual organization' determined independently by a stepwise multiple regression technique (see Palmer, 1977, Page 472). For a part to have a high goodness rating, within-group elements would score highly at the expense of between-group elements. The five scoring dimensions are as follows;

Connectedness: Score 1 if the two lines share an endpoint, score 0 if they do not.

Proximity: This is the complement of the distance between the two mid-points of each line, with vertical and horizontal lines having a unit length of 1.

Continuity: If the two lines form a 'compound line' (i.e. they are connected and in the same orientation) score 1, if not score 0.

Orientation Similarity: Scored as below;

|| or = or // or \\ = 2

|— or / \ = 1

|/ or | \ or —/ or —\ = 0

Length Similarity: If the pair have the same length, score 1. If they are of different lengths score 0.

Figure IIb below gives examples of a number of stimuli derived from the figure construction framework and used in Palmer's 1977 study, together with the goodness rating of different three line parts within each figure. It can be seen that Palmer separated these parts arbitrarily out into groups of high, low and medium goodness.

Figure IIb; Examples of Palmer's (1977) Figure Stimuli and the Goodness Rating of Parts.

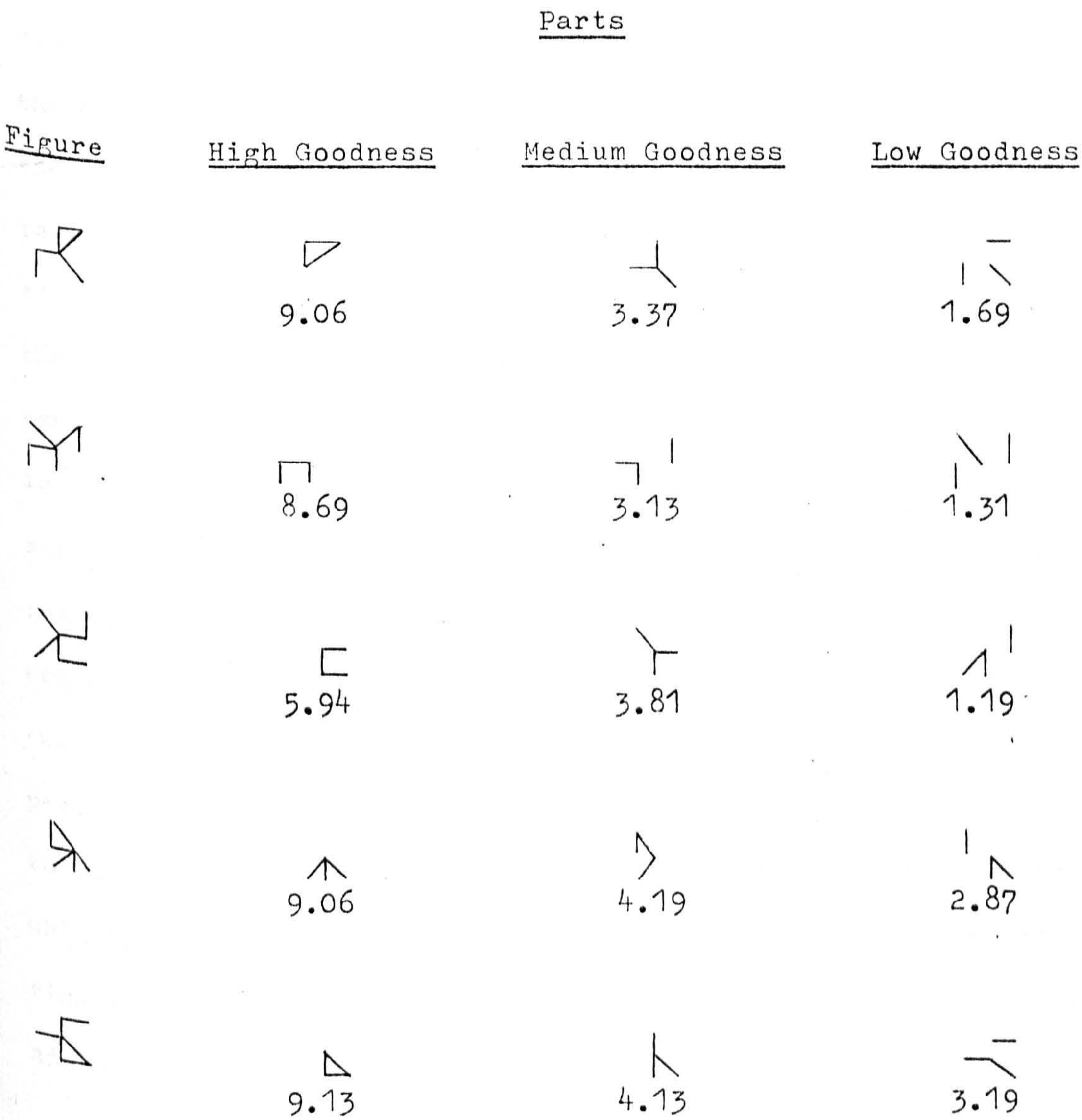


Figure IIb above demonstrates that of these examples, the higher rated parts are those whose component lines are closer together, are more likely to be touching, are more similar in length and so on. The goodness rating of a part also takes into account the context (i.e. the complete figure) in which the part appears. For example, the goodness rating of the two triangular parts in Figure IIb differs because of the structure of the remaining three lines in the figure. The perceptual reaction-time tasks used by Palmer on adult subjects are not replicated in this study, although the central hypothesis of the original study, that good parts aid the manipulation of geometric figures in perceptually-based tasks, is extended here to a copying task. Not only is it expected that good parts in figures will increase the speed with which the stimuli are drawn, but also that the good parts themselves will be perceived as emergent from the remainder of the figure and will be drawn in a complete, uninterrupted sequence within the figure as a whole. A simultaneous copying task is used in this study in which there is no timed delay between the initial perception and reproduction of the figure. This method allows the subject to continuously scan and compare his own reproduction with the model whilst the copying is in progress. Later studies compare reproductive figure memory in greater detail. Using a simultaneous copying task and adult subjects, it is expected that;

Copying will commence more rapidly for figures with good parts after the initial perception of the figure.

Figure containing good parts will be drawn more rapidly than those without good parts.

Good parts in figures will be drawn as 'units' (i.e. in an uninterrrupted sequence).

Good parts in figures, when drawn as units, will be drawn more rapidly than the remainder of the figure.

Figures containing good parts will be drawn more consistently across first and repeat reproductions of each figure than stimuli without good parts.

Method

Stimuli

The method of constructing stimuli in this study simplifies that given by Palmer (1977) in a number of ways. Firstly, only two dimensions are used for the goodness of rating of parts within figures; these being connectedness and proximity, the two dimensions having the highest weighting values in Palmer's original method of good part calculation. These two dimensions are given equal weighting in the present method of good part calculation. Although the present study follows Palmer's method of selecting only three-line parts from six-line figures, a precondition of part selection in this study is that each of the lines in a nominated part must touch at least one of the other two part lines. This measure excludes parts such as those included in the third column of Figure IIb.

All possible combinations of three lines that satisfied the connectedness criterion were rated for their goodness value as a part within the complete six-line figure. Rather than use Palmer's method of separating parts into high, medium or low goodness categories a single dichotomous measure is employed here. Stimuli are separated into those figures that have either one or two good 'outstanding' three-line parts and those without good parts. The stimuli in these two groups are labelled 'G figures' and 'NG figures' respectively. Figures with two good parts are constructed from independent groups of three lines within the complete figure; lines included in one good part are not included in the other. The 'minimum acceptable part scores' given below are arbitrary values used as cut-off points for good part selection. These were determined by inspection to give the correct number of appropriate stimuli. To be included as a part both of the criteria given below needed to be satisfied.

Connectedness Value G1: Calculated as in Palmer (1977); score 1 if each pair of lines touched, 0 if they did not. Minimum acceptable part score .2.

Proximity Value G2: With unit length of verticals and horizontals as 1 and of obliques 2, the proximity value of part was the complement of the distance between the mid-points of each line pair. Minimum acceptable part score .15.

Six-line figures were randomly generated from the framework in Figure IIa and assessed for part goodness until ten figures with good parts and ten without good parts were derived. These figure stimuli are given in Tables IIc and IId below, along with the G1 and G2 goodness ratings associated with each good part.

Table IIc; Stimulus Figures with Good Parts.

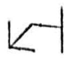
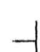
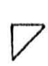
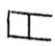
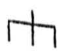
Figure	Part(s)	Goodness Rating G1	Goodness Rating G2
		.89	.43
		.89	.38
		.44	.32
		.78	.35
		.33	.22
		.78	.29
		.33	.19
		.33	.17
		.78	.34
		.67	.15
		.56	.24
		.33	.15

Table IId; Stimulus Figures without Good Parts.

Figure	Part(s)	Goodness Rating G1	Goodness Rating G2
	-	-	-
	-	-	-
	-	-	-
	-	-	-
	-	-	-
	-	-	-
	-	-	-
	-	-	-
	-	-	-
	-	-	-

Although a number of right-angled triangles are rated as good parts in the figures in Table IIc, no similarly sized or shaped elements emerge as good parts from the figures in Table IId, even though two figures contain such shapes. This is due to the influence of the differing contexts that are taken into account when assessing the part goodness value.

To enable a measure of consistency of strategy to be made, each of the twenty stimuli were copied twice by each subject. Stimulus order was randomized, but no repeat copies were made until each of the twenty stimuli had been reproduced for the first time. The figure stimuli were drawn and formed into a booklet according to the principles given in the Experimental Design chapter.

Subjects

Seven female and three male Undergraduates from the University of Keele served as subjects in the study. All subjects were volunteers, and had not previously been informed of the nature of the study.

Procedure

The testing took place individually and in a small well-lit laboratory. Each subject was informed that he or she would be asked to reproduce the figure on the left-hand side of each booklet page to the right of the original, and was asked to;

'complete each drawing as quickly as you can, but try to ensure that your drawings resemble the originals closely'.

After completing each copy the subject was told to turn the booklet page past the blank intervening page and onto the next figure.

Data Collection

The test sessions were video recorded by a camera placed above and in front of each subject. To allow the timing of individual strokes within drawings, a second camera was focussed on a digital timer and the output from the two cameras was mixed into a single picture before being recorded. This allowed the timing of any event to be established to the nearest .01 of a second. The following data was collected from the recordings and entered into the timed analysis of reproduction.

Time to Start of Drawing: This was taken as the time from which the blank page interposed between each stimulus page reached a vertical point as it was being turned, to the time at which the first pen mark appeared on the copy page.

Time to Draw a Line: This was recorded from the first noticeable pen mark to the point at which the pen was lifted after drawing the line. Thus any pause before the final pen lift was included in the time taken to draw the line in question.

Time to Draw a Part: Similar to the above category; i.e. the sum of the times taken to draw the three lines included in a good part.

The digital timer was accurate to one hundredth of a second, and although drawing times reported in the Results are to this level of accuracy, due to the fact that the timer output was being video recorded, times reported are only accurate to .02 of a second. Due to a recording error a total of nine repeat stimulus copies from Subjects 1 to 3 were accidentally erased. Where relevant, statistical analyses take this into account.

Results

Time to Start of Drawing

The hypothesis that copying will commence more rapidly for figures with good parts (G figures) than figures without good parts (NG figures) is tested in this section. Table IId below gives the mean number of seconds taken before each G and NG figure was commenced in both first and repeat copies, as well as the mean overall time across these two presentations. A repeated-measures t test was performed on each set of data given in Table IIe in the Appendix.

Table IId; Time Taken to Start of Drawing for G and NG Figures.

	Mean Time Taken(Seconds)			
	G Figures	NG Figures	t(9 df)	sig
First Copy	1.55	1.43	3.76	***(2-tail test)
Repeat Copy	1.48	1.52	.50	n.s.
Mean Value	1.52	1.47	1.03	n.s.

The results in the above table provide no support for the claim that the time taken to start drawing G figures will be less than that for NG figures. There is some evidence for the converse to be the case, with the length of time taken to start drawing the first copy of each figure being significantly less for NG figures. The implications of this finding are that good parts in figures (as defined in the present study) do not affect what might be termed the 'decision', or 'processing' time before a copy is commenced. This is not, however to imply that no further decisions are made during the course of a reproduction. Moreover, the single significant trend in the opposite direction indicates that another stimulus feature or series of features that have not been controlled for in the construction of the figures is being responded to.

Length of Time Spent Drawing

Table IIf below gives the mean time taken to draw each set of G and NG figures over the first and repeat presentations, as well as the mean of these values taken from each subject. The data from which this table is collated is in Table IIg in the Appendix.

Table IIf; Mean Drawing Time for G and NG Figures

	Mean Time Taken(Seconds)			
	G Figures	NG Figures	t(9 df)	sig
First Copy	5.19	4.53	6.14	****(2-tail test)
Repeat Copy	5.16	4.49	4.85	****(2-tail test)
Mean Value	5.18	4.51	5.94	****(2-tail test)

The table above provides no support for the hypothesis that figures with good parts will be drawn more speedily than those without good parts, and evidence is supplied from all three series of means taken for the opposite to be the case. T tests failed to reveal any significant differences in the mean amounts of time spent drawing and starting G and NG figures between the first and repeat copies. The conclusion drawn from Table IId can be extended to this table; that subjects are consistently responding to features in the stimuli other than the defined good parts.

This conclusion does not automatically imply that the same stimulus elements are being responded to both the 'processing' and drawing aspects of the task. Although this issue is dealt with in greater detail later, the first two columns of timings in Table IIh in the Appendix give the rank ordering of figures according to the mean length of time spent in starting to draw, and actually drawing each one. Table IIh also shows whether each figure ranked in the 'Time to Start Drawing' column is a G or NG figure. The correlation between these two sets of timings is .55 ($P < .02$, one-tailed test), indicating support for the view that there is something in common that is being responded to in both timed aspects of the task.

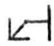
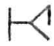
Also of interest is that the percentage range in mean times between the fastest and slowest stimuli in Table IIh is much greater for the time spent drawing each figure than for the time spent starting to draw. The 'processing' time for the slowest figure is 35% greater than that for the fastest figure, but for the time actually spent drawing this percentage increase rises to 108% above that of the fastest stimulus. It therefore appears that greater differences in timing as a function of stimulus construction appear in the drawing component of the task. The nature of those stimulus features that are invoking faster copying behaviour is examined later in this study.

Good Parts Drawn as Units

The previous sections of the results have shown that the presence of one or two outstanding good parts in a figure does not aid the speed with which the figure is either commenced or drawn. The present section examines whether these good parts are nevertheless drawn in an uninterrupted sequence in the figure as a whole, namely as a 'unit'. If this were found to be the case then it would be feasible to conclude that although good parts do not aid the speed of reproduction of the figure as a whole they are themselves recognised and isolated within the figure. The analysis below does not take into account the order the units within the figure copy as a whole or the ordering of individual lines in each unit. Table IIi below gives the ten figures with good parts, and the proportionate use of each good part within the total number of reproductions gathered for each figure. The sample size occasionally falls below the maximum of 20 due to the accidental tape erasure.

Table IIi; Percentage Levels of Drawing Good Parts as Units.

Figure	Good Part	Sample Size	% Drawn as Units
		18	100
		18	100
		20	100
		20	100
		20	50
		20	75
		20	95
		20	45
		20	65
		20	35
		19	95
		20	40

Table IIi shows a considerable variability in the percentage rates with which good parts in figures were drawn as units, ranging from 100% for both good parts of the  and  figures, to 35% for the  part in the  figure. The apparent reason for the low percentage use of this particular good part is that although it represents the three line part with the highest goodness rating in the figure as a whole, there is one outstanding and obvious four-line part in this figure, the square, that was infact drawn as a unit in 13/20 reproductions. The inadequacies of the method of good part selection and its failure to take account of parts other than those consisting of three lines is discussed in due course.

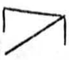
Interesting and important comparisons can also be drawn from Table IIi in the extent to which triangular parts are drawn as units. Those stimuli where a line in the triangle does not form a compound line within the remaining figure are more likely to be drawn as a unit than those where it does. The explanation to take account of this finding notes the interaction of drawing strategies with structural features present in the stimulus, where it would seem that the trend to isolate triangular parts by drawing may be overriden by the tendency to draw component lines with a single stroke.

Speed of Drawing Good Parts.

This section tests the hypothesis that when good parts are present in a figure and drawn as units they will be drawn faster than the three remaining lines in the figure. In this analysis only figures with one, and not two good parts are employed, with a one-tailed Wilcoxon test used to compare the percentage time spent drawing the unit with the remaining figure lines. For example, if a hypothetical unit took two out of a total of five seconds spent on the complete reproduction, then the reported percentage for this unit would be 40%.

Table IIj below gives the seven stimuli included in this analysis, together with the mean percentage length of time spent drawing the unit and the T value associated with the one-tailed Wilcoxon test. Table IIk in the Appendix gives the percentage levels for each figure on which Table IIj is based.

Table IIj; Mean Percentage Length of Time Spent Drawing Units.

Figure	Part	Sample Size	% of Time	T	sig
		10	38.3	0	***
		15	44.5	18	***
		19	47.6	49.5	*
		13	58.9	0	***o
		7	40.6	5	n.s.
		18	46.9	43	*
		8	42.6	3	**

o - against direction of hypothesis.

Table IIj supports the hypothesis that when drawn as units, the majority of good parts are copied more rapidly that the remaining three lines in a figure. The one exception to this finding is the  figure, for which the good part represents a junction of lines in three orientations which by definition cannot be drawn without at least one time-consuming pen lift. A comparison can be drawn here with the  figure, whose good part is identically shaped and positioned to that of the former figure, and which is also drawn on average more rapidly as a timed percentage than the good part in the  figure. One difference between these two stimuli that may account for the different percentage timings of the units in these figures is that the  in the  figure is included as part of two compound lines that are more likely to have been drawn more speedily than two single lines in different orientations. The effect of this strategy would be to reduce the time spent drawing the figure as a whole, a fact confirmed by comparing the relative positions of the  and  figures in Table IIh. This table shows that the former figure takes on average nearly three seconds longer to draw than the latter, and therefore the relative rapidity with which the  figure is drawn is less likely to show the  part to a timed advantage.

Consistency of Copying Strategy.

A different method of assessing consistency of reproduction to that used in Study I is employed here to test the hypothesis that figures with good parts are drawn in a more consistent manner than figures without good parts. The present method notes whether both the order and direction of individual lines in a reproduction are similar across first and repeat copies, giving a score of 1 on both of the dimensions given below is this is the case. The 'consistency value' is taken as the mean of the scores from the individual measures of order and direction similarity. For example, in the two reproductions below the first, third, fifth and sixth lines are drawn in the same order across the copies; but only the first, fifth and sixth lines are drawn in the same direction. The consistency value for this pair of reproductions is therefore 3.5.

first copy　　　　repeat copy

order value;　　　1+0+1+0+1+1 = 4

direction value;　1+0+0+0+1+1 = 3

consistency value;　　　　　= 3.5

It was found that the mean consistency values of figures with good parts was 4.56, and for figures without good parts 4.54. A one-tailed independent-samples t test found the difference between these means not to be a significant one ($t = .09$, 18 df, n.s.). Analysis of the Order and Direction components separately also failed to reveal consistency differences between G and NG figures.

There is thus no support for the hypothesis that figures with good parts are drawn more consistently across first and repeat copies than figures without good parts. The overall mean consistency values of both G and NG figures do however show that both sets of figures are drawn in a consistent manner, which is somewhat surprising given the relative complexity of the majority of the stimuli. The third column of values in Table IIh in the Appendix ranks the stimuli according to the mean consistency value reported for each. In comparing the three columns of this table, one might hypothesize that figures that tend to drawn or to be started more quickly are in some way simpler than stimuli that invoke slower copying behaviour. From this assumption it could be also be claimed that as the stimuli that are copied and started more quickly would have less time spent on considering the strategies for production both before and during copying, the strategies themselves would be more consistent. Infact, the mean consistency value of each figure does not correlate significantly with the time spent drawing of the figure ($r = -.29$, 8 df, n.s.), but does correlate at a .05 level with the time taken to start drawing each figure ($r = -.51$). The simplest conclusion for this finding is that the consistency of copying strategy is determined before the figures are commenced, and that subjects have at least some idea of how an individual figure will be drawn before the first stroke is made.

The results given so far have not shown support for the advantages found by Palmer (1977) for figures with good parts in perceptually-based tasks to be transferred to a simultaneous copying task. Nevertheless, evidence has been given to suggest that subjects are influenced by features in the stimuli not controlled for in the two categories of G and NG figures in this study. What are the features that are being responded to? Inspection of Table IIh in the Appendix shows that figures that possess two compound lines (figures ranked 1, 3, 4, 5, 10, 11 in the first column of Table IIh) and those that symmetrical about either the vertical or horizontal axis (figures 1, 3, 5, 10, 11) are amongst those started and drawn more quickly. These two categories are not mutually exclusive, but to discover whether these two groups of figures are started or drawn significantly faster than the remaining stimuli Table IIl below notes the mean drawing and starting times for these two stimulus groups and values and significances of the one-tailed independent-samples t tests performed on the data.

Table III; Mean Starting and Drawing Times for Figures With or Without Two Compound Lines or Symmetry.

	Mean Length of Time (Seconds) for Figures					
	With	n	Without	n	t(18 df)	sig
Two Compound Lines						
Starting Time	1.40	6	1.53	14	2.96	***
Drawing Time	3.71	6	5.27	14	5.48	***
Symmetry						
Starting Time	1.41	5	1.52	15	2.33	**
Drawing Time	3.69	5	5.18	15	4.27	***

Table III shows that both the presence of two compound lines and symmetry in a figure influences the speed with which reproductions are both started and completed. Significant results in this table are achieved despite the difference between the mean lengths of time in starting a copy being less than one fifth of a second between the comparison groups. The finding that the presence of two compound lines aids the speed of reproduction is not a surprising one given the likelihood of compound lines being perceived and drawn as a single and speedier stroke, but the fact that both symmetry and the presence of two compound lines quickens the time to the start of a copy is more interesting. Presumably these two features influence the perception and consequent drawing of the figure as a whole, regardless of the level of goodness rating of any one part of these or other figures. All five symmetrical figures and five out of the six figures with two compound lines are defined in this study as being without any one or two good parts, attesting again to the influence of other uncontrolled stimulus properties. The issue of global properties of the stimulus and their effects on reproductive speed are taken further in the Discussion.

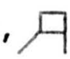
Discussion

The results from Study II can be summarized as follows; it has been found that those figure stimuli that possess one or two good three-line parts were neither drawn, nor started to be drawn more quickly than figures without one or two good three-line parts. Evidence has been provided that subjects are responding to stimulus features not accounted for in the construction of figures with good three-line parts. Although these figures are not as a group drawn more rapidly, the study has shown that the good three-line parts themselves to tend to be drawn in an uninterrupted sequence as a unit, and these units are drawn more rapidly than the remaining three lines in the figure. The pattern of findings that emerge from these individual analyses are that good parts tend to be perceived and drawn as such, but the speeded starting and drawing of figures is influenced by other stimulus features. The hypothesis is also advanced that the planning of a strategy for reproducing each stimulus takes place before the copy is commenced. The hypotheses derived from Palmer (1977) concerning the faster perceptual manipulation of figures with good parts have not been supported in a copying task.

Subsidiary analyses in the study have shown that stimuli with two compound lines or with global symmetry in the vertical or horizontal axis tend to be drawn and started more quickly than remaining figures. As these two categories are not mutually exclusive in the figures used in this study the majority of stimuli are included in both of these groups. A further more controlled study would need to be carried out to determine which of these two stimulus features was the more influential. Only one figure included in either of the two compound line or symmetry groups, the  figure, had been originally defined as having a good part using Palmer's modified method. This finding shows that features of the complete stimulus, as well as parts that are formed from configurations apart from those consisting of three lines are responded to in either or both of the 'processing' and drawing elements of the copying task. Although these two aspects of the same task may employ different skills and be differentially affected by stimulus features, these two elements do have a level of mutual influence. The time spent before starting a reproduction may involve planning that considers the strategies for the ordering, direction and combination of individual strokes or parts, and whilst engaged in the actual drawing task continuous or intermittent visual and motor feedback is present.

The extent to which stimuli may lend themselves differentially to these two aspects of the copying task is worthy of consideration. Most of the figures that were started quickly were also those that were drawn quickly, which may imply that subjects are planning a potential drawing path through the figure in the time before the reproduction commences. Therefore the stimuli with easier and faster paths need less time for these paths to be formulated and are hence commenced more rapidly. Exceptions to the pattern given above do however exist; although the  figure is the second fastest of the sample of twenty to be drawn it is only the eleventh fastest to be commenced. A further study with a greater level of control over the stimulus features that have retrospectively been found to be of importance would be needed to define which figural features aid the perceptual, rather than the motor aspects of the present task.

By definition, Palmer's (1977) figure construction framework cannot account for global stimulus features such as symmetry or enclosure in the figure as a whole. This is due to the fact that his method of part goodness rating assigns values to pairs of lines, and enclosure, for example, is not a property of a pair of lines. Although several stimuli with good triangular parts were derived in both the original and the present studies this was because each pair of part lines ('within-group elements') had high values on each of the goodness rating dimensions, and thus it was not the enclosure per se that was being selected for. The present study has shown that some global stimulus features that cannot be accounted for in Palmer's method of good part evaluation are of influence in a reproduction task.

Stimulus categorization in the present study also excluded any part that possessed anything other than three lines. Only one of the figures with a square part,  was included in the G figure category, but this had been included because of the high proximity and connectedness scores of a three-line intersection (⊣). This limitation was necessary in the present study to test directly the appropriacy of Palmer's findings to a copying task, where only three-line parts in six-line figures had been employed. The framework from which the stimuli were derived in the present and original studies is, however, seen as a valuable one and used in two further studies in the thesis. From this sixteen-line framework stimuli can be derived that can be controlled for the number and structure of component lines in a complete figure or in a designated part.

Two further aspects of the present study that are worthy of future attention concern an examination of copying accuracy as a function of controlled stimulus complexity and the interaction of the use of directional drawing rules and stimulus features. Accuracy of reproduction has not been examined in the present study; adult subjects tend to copy with very few mistakes in a simultaneous copying task, and no serious reproductive errors were noticed in the present study. Further examinations of reproductive accuracy in the thesis benefit from the consistent, controlled stimulus framework shown to be of value here. The interaction between drawing rules and stimulus features has been briefly examined in this study, and is analysed in future studies with respect to the extent to which simple directional rules are employed when drawing outstanding stimulus parts. The extent to which combinations of stimulus lines emerge as a part may be influenced by the levels of directional rule use within the lines in question. This issue is also examined in due course.

The timed microanalysis of drawing strokes has been shown to be a valid and useful technique in this study, with the speed at which complete reproductions and individual lines are drawn being capable of being measured to an adequate level of accuracy. The lack of support for the central hypotheses in the study helps to demonstrate the unique combination of perceptual and motor skills that are employed in reproducing geometric figure stimuli.

STUDY III

Section A

Introduction

Study II has shown that adult subjects organize their reproductions of geometric figures as a function of the presence within each figure as a whole of certain structural elements. Furthermore, speeded copying is facilitated by different kinds of figures and by the use of 'efficient' copying strategies. It was found that symmetrical figures and figures with two or more compound lines are both started and drawn more rapidly.

The present study employs child subjects to investigate the influence of figural complexity on reproductive skills at four ages and in two copying conditions. An additional part of the study (Section B) uses a smaller range of figures and a single age group to examine more closely the different strategies employed when figures are correctly or incorrectly copied, and to investigate whether any changes in strategy with age are present in the copying task.

To date, systematic examination of the development of accuracy in the copying of non-representational stimuli has concentrated on obtaining normative information about which stimuli can be successfully drawn at a certain age (e.g. Ilg and Ames, 1964; Di Leo, 1971). A small number of children's intelligence tests incorporate tasks involving the copying of geometric figure stimuli (as opposed to representational objects) within a more global measure of development. The tests include the Frostig Test of Visual Perception and the British Ability Scales. Both the Bender Gestalt test and the non-developmental Memory-for-Designs test (Graham and Kendall; 1946, 1960) examine qualitatively the reproduction errors made by subjects suffering from neurological damage. The McCarthy Scales of

Children's Abilities analyze both qualitatively and quantitatively the reproductions of a series of stimuli (○ , | , — , ┘, ✳, ⊕ , ⊠ , ▱, ◇◇) which are included in both the Perceptual-Performance and Motor scales and in the 'General Cognitive Index'. With the exception of Graham and Kendall's test, these examples of the formal analysis of the copying of non-representational stimuli involve copying the stimulus whilst it remains in view and without a memory component.

Why should copying become more accurate as the child gets older? To attempt to answer this question it is necessary to view the ability reproduce graphically in a wider context. Even if one perceives copying as a unique skill, it does contain a combination of perceptual and motor elements found in other related tasks. For example, similar perceptually-based tasks include simple figure discrimination, and the controlled movement of the pen of pencil in drawing or copying is in itself an example of fine motor control. As the section entitled 'Skills Related to Copying Ability' in the Literature Appraisal, and in particular the study by Birch and Lefford (1967) have both noted, there is an essential link or 'integration' between the perceptual and motor process in a copying task. Therefore, from a theoretical standpoint it must be assumed that as there has shown to be a maturational development of the skills comprising copying, the skill of copying itself will improve with age.

A number of questions are asked in Study III. Firstly, although the intelligence tests mentioned above find that children get better at copying in the crucial early school years, is this improvement also to be found in a delayed copying task where the figures have to be memorized before being reproduced? Secondly, if an age improvement both with and without a delay is found, how is it to be explained? Furthermore, why should copying be more accurate when there is no delay between the perception and reproduction, especially when, as in the present study, the delay between these two activities is kept to a minimum? It is the fact that children may have poor structural representation that predicts that they will perform worse with a delay.

Section B of the study returns to the issue of reproductive strategies in an attempt to explain how children actually tackle the copying task, and the extent to which differences in strategy between two different age groups can account for those in overall reproductive accuracy. Section B also tests for differences in strategy as a function of copying in the immediate or delayed condition, with the aim here to test whether differences in the order and number of component lines in correct copies differs between the immediate and delayed conditions.

The systematic investigation in the immediate and delayed copying conditions requires that we control both for subject age and stimulus complexity. Stimulus complexity is defined as the number of lines present in stimuli generated on a random basis from the framework used in Study II. The number of component lines in a stimulus was found by Graham et al (1960) to be the major determinant of figural complexity and hence copying success in a copying task using very young children between the ages of two and a half and five years. The stimuli in the present study contain between four and seven lines, with the sole other constraints on stimulus construction being that each component line must connect with at least one other line, and that no compound lines are permitted. This latter measure was necessary as Study II has shown that compound lines tend to copied and perceived as single ones.

The following hypotheses were tested in Section A of the study;

Older children will copy more accurately than younger ones.

Fewer correct reproductions will be made in the delayed condition than in the immediate condition.

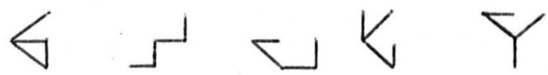
A greater number of simple stimuli than complex stimuli will be copied correctly.

Method

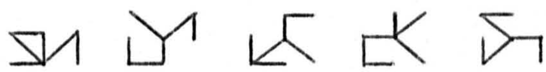
Stimuli

A total of four stimulus figures at each complexity were derived randomly from the figure construction framework employed by Palmer (1977). These stimuli are given in Figure IIIa below;

Figure IIIa; The Sixteen Figure Stimuli used in Study III.

Four-line figures: 

Five-line figures: 

Six-line figures: 

Seven-line figures: 

Copies of these stimuli were drawn and randomly ordered in a booklet according to the principles given in the Experimental Design chapter. One booklet was given to each child in the immediate and delayed copying conditions.

Subjects

A total of 48 subjects were used in Section A; six at each age level in both of the copying conditions. A between-groups design was employed to prevent any possible transfer effects between the two copying conditions. Subjects from both sexes were employed, all spontaneously using their right hands when drawing, and all coming from a nearby Primary School. Subjects within each of the age groups (henceforth referred to as the six, seven, eight and nine year olds) came from within the same Classes at the School. This age range was chosen as it spans a crucial period of cognitive development in the child, and furthermore is one in which the subjects could be expected to gain expertise in a variety of graphic skills. The mean ages and standard deviations of these groups is given below in Table IIIb.

Table IIIb; Mean Ages and Standard Deviations of the Subject Groups.

	Mean	Standard Deviation
Immediate Condition		
6 year old group	6:9 years	2.3 months
7 year old group	7:7 years	3.2 months
8 year old group	8:8 years	2.0 months
9 year old group	9:9 years	2.2 months
Delayed Condition		
6 year old group	6:4 years	1.2 months
7 year old group	7:8 years	3.3 months
8 year old group	8:7 years	2.4 months
9 year old group	9:7 years	2.3 months

Procedure

Subjects in both the immediate and delayed copying conditions were tested individually in a small room near each child's own classroom. In the immediate condition subjects copied each stimulus figure whilst it remained in view and with no restriction on the amount of time needed to make each copy. In the delayed condition subjects viewed each stimulus for five seconds before it was covered with a piece of card by the experimenter. Each reproduction was to be started as soon as possible after the stimulus had been covered, with again no restriction on the length of time spent drawing. In both conditions each reproduction was made on the same page but to the right of each stimulus. Only a single attempt was allowed at each stimulus copy, but two practice figures were given in each of the copying conditions.

Data Analysis

The order of individual strokes comprising each copy were noted concurrently with the reproduction by the experimenter on a scoresheet. The sixteen copies made by each child were scored as being 'correctly' or 'incorrectly' reproduced on a 1/0 basis. To be judged as being correctly reproduced each copy needed to possess the correct number of lines and to have maintained the correct topological relationship between each of the component lines. Inaccuracies in the orientation of the complete figure and of individual lines were permitted, as were moderate distortions in the size of the complete figure or of a line or part. The Discussion in Section A gives examples of correct and incorrect reproductions of one particular figure.

Results

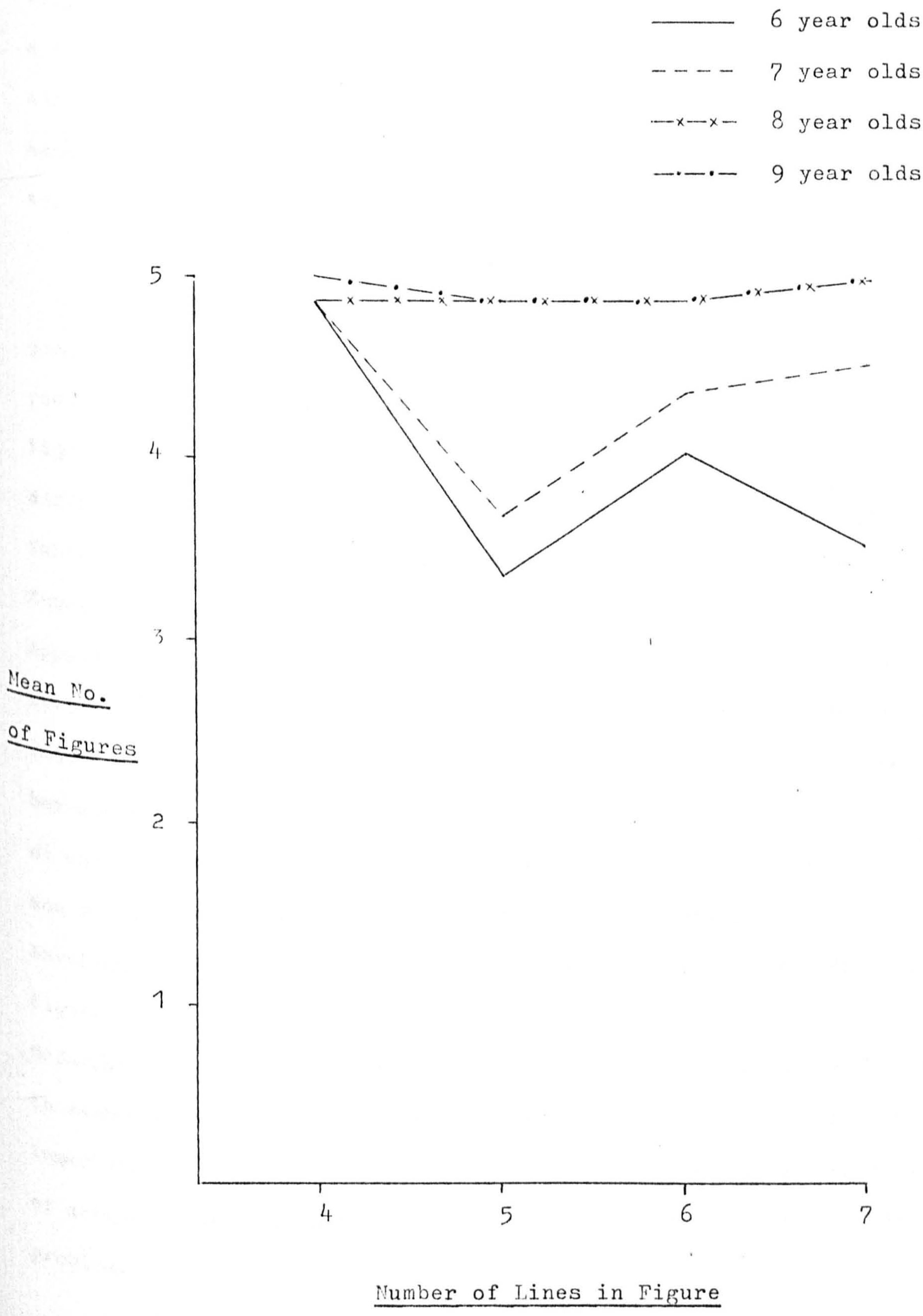
Immediate Copying Condition

The data from the immediate and delayed copying conditions is analysed separately in the following section of the Results. Comparison between the conditions follows these analyses. Table IIIc below gives the mean number of figures copied correctly by each age group and in each of the stimulus categories by subjects in the immediate copying condition, with Figure IIId on the following page representing this data graphically.

Table IIIc; Mean Number of Figures Copied Correctly in the Immediate Condition (n = 6 per cell)

Age Group (Years)	Number of Lines in Figure: 4	5	6	7	Mean
6	4.83	3.33	4.00	3.50	3.92
7	4.83	3.67	4.33	4.50	4.33
8	4.83	4.83	4.83	5.00	4.87
9	5.00	4.83	4.83	5.00	4.92
Mean	4.87	4.17	4.50	4.50	

Figure IIId; Graph of the Mean Number of Correctly Copied Figures in the Immediate Condition.



A two-way ANOVA performed on the data in the Immediate condition failed to reveal a significant age effect ($F = 2.94$, d.f. = 3,20, P = n.s.) that was presumably due to the ceiling effect visible in Figure IIId. A significant effect due to figure complexity was noted ($F = 4.84$, d.f. = 3,60, $P < .01$), as was a significant interaction between the age and figure variables ($F = 2.31$, d.f. = 9,60, $P < .05$). Table IIIe in the Appendix gives the complete ANOVA table. The age x figure interaction is analysed below.

Inspection of Figure IIId shows that the eight and nine year old groups copied each of the four stimulus groups very accurately. The two younger groups responded at similar levels, both finding the four-line figures easy to copy correctly, and surprisingly experiencing greater difficulty with the five-line figures than those with six lines. Although Table IIIc shows an increasing mean number of correctly drawn figures as a function of age, the large error term evident in Table IIIe in the Appendix reduces these differences to a non-significant level. Scheffe tests at a 10% acceptance level between individual pairs of means in the figure complexity condition failed to show any significant differences between the four mean values, but a large number (21) of significant pairs of mean comparisons were revealed for the post-hoc Scheffe analysis of the age x figure interaction. Of these 21 significant comparisons, ten involved the mean value obtained by the six year old group for five-line figures, and a further ten for this age group drawing seven-line figures. Reference to Table IIIc shows these mean values to be the lowest reported in each condition. However, ceiling effects may be present in the Immediate condition. Increasing the maximum number of lines in the range of stimuli (i.e. from seven to nine or ten lines) may have alleviated this problem.

Overall conclusions about copying performance in the immediate condition show that with the exception of the youngest two age groups (and in particular the six year olds), copying success was not affected by the number of component lines in the stimulus figure up to seven, although the ANOVA result did show differences in figure complexity to be influential in the analysis as a whole. As Figure IIId shows, the youngest two age groups both experienced greater difficulty with the five-line than with those containing six lines. Speculation about why this should be so is deferred until a later, more detailed analysis of the structural properties of individual figure stimuli has been carried out.

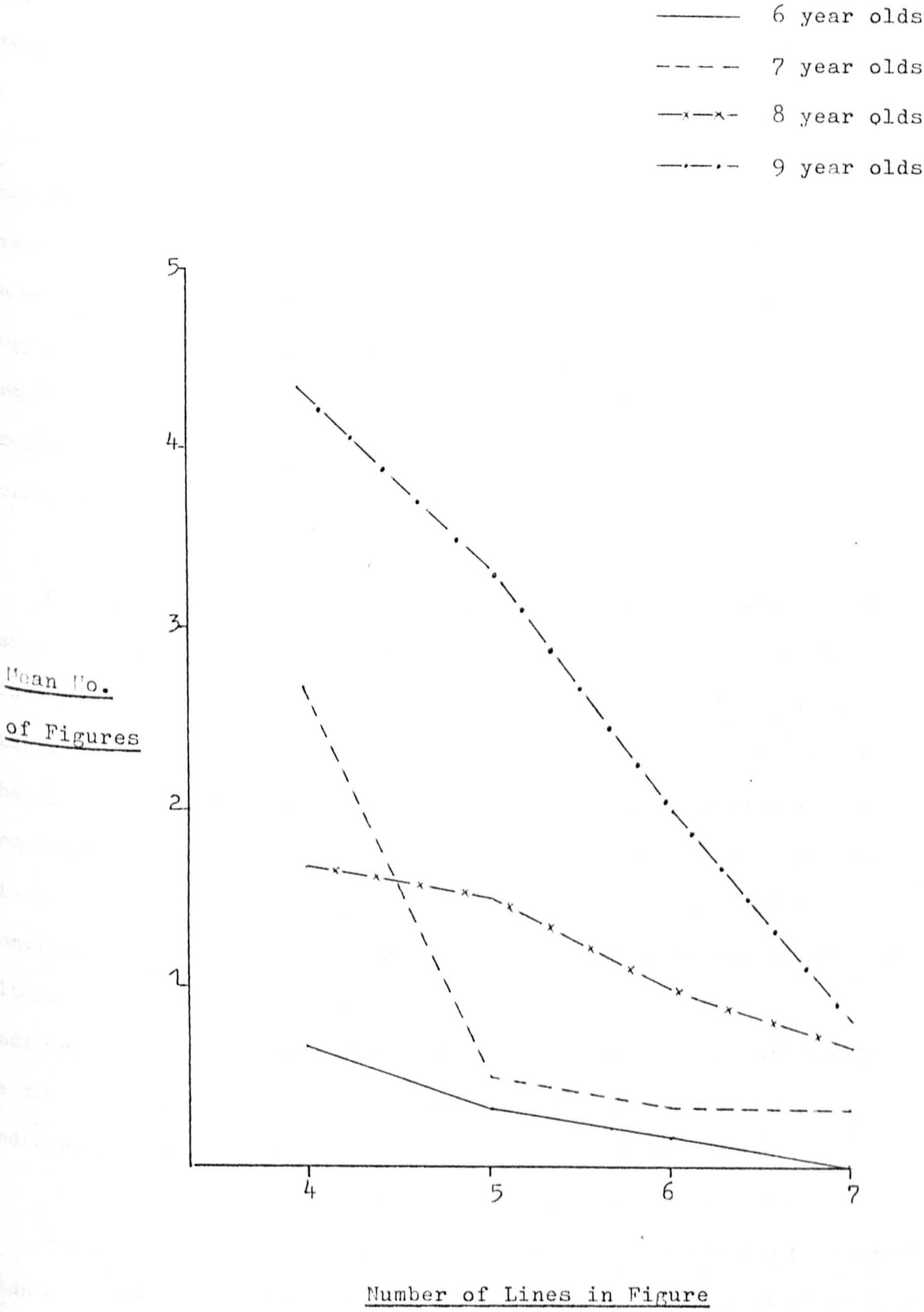
Delayed Copying Condition

Table IIIf below shows the mean number of each of the four stimulus groups copied correctly by each age group in the delayed condition. Figure IIIg that follows presents this data graphically.

Table IIIf; Mean Number of Figures Copied Correctly in the Delayed Condition (n = 6 per cell)

		Number of Lines in Figure				
		4	5	6	7	Mean
Age Group (Years)	6	.67	.33	.17	0	.29
	7	2.67	.50	.33	.33	.96
	8	1.67	1.50	1.00	.67	1.21
	9	4.33	3.33	2.00	.83	2.63
	Mean	2.34	1.42	.88	.46	

Figure IIIg; Graph of the Mean Number of Correctly Copied Figures in the Delayed Condition.



A two-way ANOVA performed on the delayed condition data gave the following results: age condition; F = 13.42, d.f. = 3,20, P < .001; figure complexity condition; F = 33.52, d.f. = 3,60, P < .001; age x figure interaction; F = 5.59, d.f. = 9,60, P < .001). Table IIIh in the Appendix gives the ANOVA table in full.

To summarize the results from the delayed copying condition; it has been found that both the age of the subject and the number of lines present in the stimulus figure influence copying success. Figure IIIg shows clearly that with the exception of the seven year old subjects copying four-line figures, younger subjects copy less well at each figure complexity level, and that each age group finds that figures with a greater number of component lines are more difficult to reproduce correctly.

Post-hoc analysis of the means reported within each of the conditions using Scheffe tests showed that for the age variable the sole single significant comparison was between the six and nine year old groups. Similarly, four-line figures were found to be easier to copy correctly than those with six or seven lines. Analysis of the age x figure complexity interaction not surprisingly revealed a large number (44) of significant single mean comparisons. Of this total, 30 concerned comparisons made by the nine year old group against other age groups. An alternative explanation notes that 28 of the 44 were the result of individual comparisons against mean values for figures with four lines. As Table IIIf shows, the mean values given for each of these two individual groups are amongst the most extreme reported.

Overall levels of performance in the delayed condition are both lower than those in the immediate condition, and change as a function of subject age. Although Figure IIIg shows that the ability to copy correctly increases within the age range tested, even the nine year old subjects fail on average to correctly draw more than a single one of the five seven-line stimuli. The seven year olds respond at a similar level to all but the simplest of the four groups of stimuli, where the performance of this group exceeds that of the next oldest eight year old groups. The youngest age group appear to find copying in the delayed condition a rather too difficult task, achieving very little success with even the simplest of figure groups.

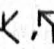
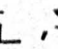
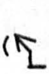
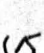
Immediate/Delayed Condition Comparison

To test whether at each age group and for each figure complexity level the number of correctly drawn stimuli was greater in the immediate than in the delayed copying condition, independent-sample one-tailed t tests were carried out comparing relative success in these two conditions.

Table IIIi in the Appendix gives the t values from these tests, together with the levels of significance associated with these values. It can be seen from this table that each of the sixteen comparisons revealed copying made in the immediate condition to be significantly more accurate than delayed copying, and at a probability level that never failed to exceed .025. Aside from noting that all 16 immediate/delayed condition differences are significant ones, further more detailed comparison about the size of these differences is limited by the ceiling effect in the immediate condition shown in Figure IIId. Discussion about overall levels of accuracy of performance are therefore best contained within each of the copying conditions.

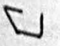
Discussion

The results from Section A of Study III can be summarized as follows; significant differences in the ability to reproduce geometric figures correctly were found to be a function of subject age in a delayed, but not an immediate copying condition, even though the delay before the onset of copying was kept to a minimum. The number of lines in the stimulus figure was found to influence levels of reproductive success in both conditions. Copying without memory in the immediate condition led to greater success at each of the 16 age/figure comparisons than delayed copying.

From the above results, little can be concluded directly about the methods and strategies with which stimuli were actually reproduced. One interesting and anomalous result that emerged from the immediate, but not the delayed copying condition was the relative difficulty experienced by the six and seven year old subjects when copying five-line figures (see Figure IIId). Inspection of the range of the five-line figures (, , , , ) and of the nature of the errors committed on them by the seven year olds in the immediate condition shows that five out of the total of eight incorrect reproductions were found to be for the  figure. Thus only one seven year old in the immediate condition copied the  figure correctly. Despite the lower overall level of success in copying this particular stimulus in the delayed condition, only five out of a total of 27 incorrect reproductions concerned this figure. All of the five incorrect copies in the immediate condition were drawn with errors in the top-left segment of the figure. Four out of the five children drew the figure with this segment too narrow (), and one with it too broad (). Although both of these examples are topologically correct, the orientation of the individual lines involved is not regarded as being sufficiently accurate. These two types of error raise separate issues concerning reproductive accuracy that are both worthy of further comment.

The first issue concerns what might be termed 'verbal encoding' before or during the reproduction of a figure. This process may help a subject to make sense of the apparently meaningless series of lines that comprise a figure, with the copying of the complete stimulus or part of it taking account of the way in which the figure had been labelled. As the section entitled 'The Encoding of Geometric Figures' in the Literature Appraisal has already noted, verbal processes have been implicated in figure reproduction tasks. The  figure was the one that also attracted the most spontaneous comment from subjects of all ages, with the figure or just its top-left section being named an 'arrow'. This verbalization may account for a number of copies of this figure having the top-left section narrowed in width to make it resemble an arrow (). One rather higher level of abstraction for this stimulus was given by a 7:5 year old boy who spontaneously described the figure as 'a little person kneeling down'. At what level or to what extent the subjects used verbal encoding in this study is unknown, but further examples of uninvited description point to the possibility of some form of verbal encoding being used. For example, one subject aged 6:8 years in the immediate copying condition gave the following descriptions whilst he was drawing;

 - 'rather like stairs, with a bit missing'

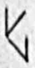
 - 'a motor boat missing a bit'

 - 'an unusual tree'

 - 'an arrow that's been bent'

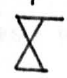
Worthy of note is the fact that the above four examples concern comments made about relatively simple figures, and it may be that for the age range tested in the present study more complex stimuli do not lend themselves to verbal descriptions. Furthermore, any systematic examination of verbal encoding, especially using child subjects, would be fraught with procedural difficulties. A child not offering a spontaneous verbal description, or incapable of supplying one post-hoc, may nevertheless be using some form of verbally-based process to aid reproduction. Conversely, the extent to which subjects who offer verbal descriptions actually employ them when copying would be a further unknown factor. Study IV specifically investigates the issue of verbal encoding in figure reproduction, and attempts to surmount the methodological difficulties mentioned by employing adult subjects (theoretically more capable of accurate verbal descriptions than children). The experimental format of Study IV makes use of interference tasks operating in different sensory modalities to ascertain the sensitivity of geometric figure reproduction to verbal interference.

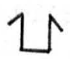
The second example given above of the distortion made in reproducing the  figure concerns the increase in angle size between the two lines that emerge at 45^{o} from the top-left oblique line (). One interpretation of this distortion is that this section of the complete figure is being simplified by transforming the two perpendicular lines into what resembles a single, compound line. The systematic distortion and simplification in the copies of simple figures by young children was examined by Graham et al (1960) when testing Werner's (1948) Gestalt hypothesis that predicted a 'primitivization' in the reproductions. Such primitivization included making the complete figure or parts of the figure more symmetrical than the original. Graham et al found little evidence for systematic distortion, although inspection of a number of examples of incorrect copies from the present study suggest that simplification in the form of over-symmetry of parts or wholes was present;

 as  (subject aged 8:7 years, immediate condition)

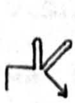
 as  (" " 6:5 " , " ")

 as  (" " 7:7 " , delayed ")

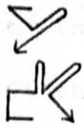
 as  (" " 6:4 " , " ")

 as  (" " 6:3 " , " ")

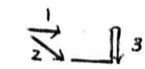
Whether these examples realistically represent a trend toward systematic over-symmetry is open to debate, as the distortions given above could be said to represent isolated examples of individual styles in drawing. Both Gardner (1980) and Somerville (1983) have found evidence for the existence of graphic styles in the representational drawings of young children, although the latter author argues that 'style' is an ill-defined concept in the drawings of the five to seven year old child. For copies of geometric figure stimuli the concept of style may be more gainfully associated with individual preferences for reproductive strategies which note the pattern of order, direction and combination of component lines. Examples from two subjects may serve to illustrate this point. The following child aged 7:8 years and in the immediate copying condition attempted to reproduce stimuli as far as possible by making use of a threading strategy, i.e.;

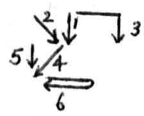
 as 

 as 

 as 

Conversely, another child aged 6:8 years and also in the immediate condition copied all twenty stimuli correctly, but often retraced and threaded the final line in each reproduction. For example,

 as 

 as 

These strategy preferences or styles appear to be individualistic methods of copying that may well not be susceptible to larger scale analyses that quantify the order and direction of line drawing in terms of rules, but rather could benefit from an individually-based analysis of the kind used in Study I. Section B of the present study delimits further the subject range and stimulus groups to examine in greater detail the exact nature of copying strategies for subjects in both the immediate and delayed conditions of Section A. This section examines the levels of success with which individual stimuli are copied and the extent to which single lines and parts within each stimulus are correctly drawn when the figure as a whole is not. Section B also looks further at the ways in which drawing strategies are influenced by copying in a delayed or immediate condition.

As a means of providing a background to the discussion of errors in reproduction, a complete series of twenty copies made by a single subject are given at the end of the Appendix for Study III in Figure IIIu. This subject, T.S., was aged 6:4 years and served in the delayed condition. The original stimuli in Figure IIIu are at half-size, but the orientation and size of the copies are as actually produced. This shows that the majority of the copies were reduced in size, itself a commonly found aspect in the reproductions of young children. As Figure IIIu is included for illustrative purposes only, no discussion of individual reproductions is made.

Section B

Introduction

Section A of Study III has demonstrated that not only are large scale figure complexity effects present in the reproduction of geometric figures in both immediate and delayed copying, but that within such effects may lie differences in reproductive strategy as a function of the structural nature of each stimulus. The present section of Study III tests further whether copying in an immediate or delayed condition affects the number of individual strokes needed to make a correct reproduction. The number of strokes needed to copy a figure is defined as the number of pen-lifts made after starting the figure, plus one. Thus a square can be drawn using a single stroke if a complete threading strategy is employed, or at the other extreme can be drawn with four strokes if the pen is lifted after copying each line of the stimulus. Breaks within lines were found to be rare occurrences, and were taken as a single stroke. The hypothesis here is that the continual appraisal and feedback possible when copying in the immediate condition will lead to a greater number of strokes being used in comparison with delayed reproduction. In the latter condition the complete stimulus needs to be memorized, if only for a short time, before a successful copy can be made as no direct comparison with the original stimulus is possible. Subjects are therefore more likely to encode in larger units, which will be reflected in a lower number of strokes used in successful copies.

A further analysis in Section B looks more closely at the strategies used in correctly reproducing the complete range of stimuli, and includes a brief analysis of the lines and parts that tend to be copied correctly when the stimulus as a whole has been incorrectly reproduced. In Section

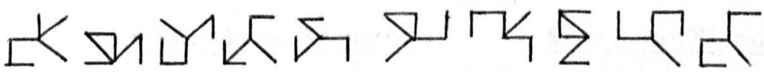
B new groups of subjects were tested in the immediate and delayed conditions, and with a smaller range of figure complexities. In order to strike a balance between subjects of an age that were able to copy moderately well in the delayed condition in Section A, but who did not respond at maximal levels in the immediate condition, Section B of this study employs exclusively eight year old subjects copying four and six-line figures in a between-subjects design.

Method

Stimuli

The method for constructing the four and six-line figures was identical to that used in Section A, with the original five figures in each stimulus group being added to by a further five at each level. The total stimulus range is as follows;

Four-line figures: 

Six-line figures: 

Subjects

A total of 23 right-handed subjects of both sexes, none of whom had served in Section A, were employed; 11 in the immediate condition and 12 in the delayed condition. The mean age and standard deviations of these groups is as follows;

	Mean	Standard Deviation
Immediate Condition	8:9 years	4.1 months
Delayed Condition	8:7 "	2.2 "

Procedure and Data Analysis

These were identical to the methods used in Section A.

Results

Level of Correct Copying

Table IIIj below gives the mean number of correctly copied four and six-line figures by subjects in both the immediate and delayed copying conditions out of a maximum of ten.

Table IIIj; Mean Number of Correctly Copied Figures

	Four-line Figures	Six-line Figures
Immediate Condition	9.91	9.45
Delayed Condition	5.08	2.50

As expected, subjects in the immediate condition experienced little difficulty in correctly reproducing either figure type. Comparison with the results in Section A is possible by halving the above scores, with the delayed condition showing that the 5.08 obtained for the four-line figures is rather higher than the comparable score for the eight year olds reported in Table IIIf in Section A (i.e. 2.54 in Section B versus 1.67 in Section A).

A two-way ANOVA performed on the data comprising the data in the above table revealed significant effects due to the copying condition ($F = 129.19$, d.f. = 1,21, $P < .001$) and to figure complexity ($F = 15.10$, d.f. = 1,21, $P < .001$). A significant copying condition x figure complexity interaction was also reported ($F = 7.42$, d.f. = 1,21, $P < .025$). Table IIIk in the Appendix gives the full ANOVA table.

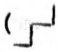
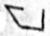
Number of Strokes used in Copying

The data from correct reproductions was analysed in terms of the number of strokes used in making each copy to test the hypothesis that fewer strokes would be needed in the delayed condition. Table IIIl below summarizes this data, giving the mean number of strokes used in copies of four and six-line figures, together with the sample sizes from which these means were derived.

Table IIIl; Mean Number of Strokes Used in Correct Reproductions.

	Immediate Condition		Delayed Condition	
	n	mean	n	mean
Four-line Figures	109	2.56	62	2.11
Six-line "	104	3.66	30	2.53

Wilcoxon tests comparing the mean number of strokes between the immediate and delayed conditions showed significant differences to exist for both four-line figures (T = 3, N = 10, P < .01) and for six-line figures (T = 0, N = 9, P < .01). Tables IIIm and IIIn in the Appendix give the sample sizes and means for each of the four and six-line figures in the two conditions. Interestingly, the mean number of strokes used in successfully copying four-line figures in the immediate condition is slightly greater than that used in copying six-line figures in the delayed condition. One hypothesis to explain the lesser number of strokes found to be needed in the delayed condition is that the enforced memory of the complete figure synthesizes component stimulus lines into parts, and it these parts that tend to be drawn with the use of a threading strategy that precludes unnecessary pen lifts.

Table IIIm in the Appendix, showing the mean number of strokes used in copying four-line figures, demonstrates that for two of the stimuli (, ) all examples of correct copying in the delayed condition employ only a single stroke, whereas for the latter of these two figures an average of 2.36 strokes was needed in the immediate condition. Other stimuli show less striking differences between the two conditions, although the trend for delayed copying to use fewer strokes is present for nine out of the ten four-line figures. Care is needed in interpreting similar data from individual six-line figures presented in Table IIIn due to the often small sample size in the delayed condition. Where comparison is possible, however, the mean number of strokes in the immediate condition exceeds that for the delayed condition in all nine figure stimuli. On average in excess of 1.1 extra strokes are used for copying six-line figures in the immediate condition, but the sizeable range in the mean number of strokes across both sets of figures attests to the influence of individual structural features in determining this aspect of figure reproduction.

One simple way of assessing the relative influence of different structural features within individual figure stimuli is to calculate the frequency with which each of the lines are included in otherwise incorrect reproductions. This measure is included as one of two analyses in the following section that examines the strategies employed in copying the individual figure stimuli.

Copying Strategies within Individual Figures

This section provides two descriptive analyses of the methods of production of the ten four and six-line figures. The first of these gives the percentage rate of inclusion of single lines within incorrect copies of each of the stimuli. By noting which component lines do or do not tend to be included in incorrect copies, it may be possible to derive hypotheses about the methods by which the eight year olds organize their reproductions. Because of the very high proportion of correct copies in the immediate condition only data from the delayed condition is analysed.

The second analysis takes the total set of correct reproductions as its data base, and examines the modal order of each stimulus line within the total number of correct copies obtained for each figure. This analysis compares strategies made in the immediate and delayed conditions. To summarize, the first section emphasizes levels of correct copying within individual stimuli, and the second the strategies for their successful reproduction. Figures IIIo and IIIp below show the percentage inclusion rates of individual lines within incorrect delayed copies of the four and six-line figures. Brief comments follow the majority of examples.

Figure IIIo; Percentage Inclusion Rates for Individual Lines in Incorrect Delayed Condition Copies: Four-line Figures.

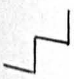
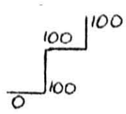
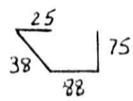
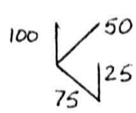
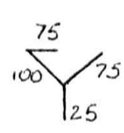
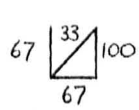
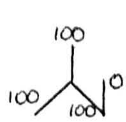
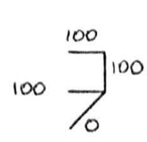
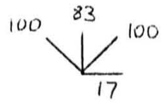
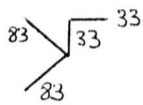
Figure	n	Line Percentages	Comments
	3		Note the small sample size. The isolated oblique is included in all three of the incorrect copies.
	1		-
	8		The lines within the right-angled two-line unit are those most often included. This is the only symmetrical part of the figure.
	8		The two most popular lines were drawn with consecutive strokes in 5/8 of the incorrect copies. The least drawn line is that which is most isolated.
	4		The vertical, not included in the near-enclosed part, is least often drawn. Small sample size.
	3		In 2/3 incorrect copies the oblique was drawn but reversed.
	5		A clear pattern. The symmetrical central part was always correctly drawn but never the (isolated) lower vertical.
	4		A similar trend to the above figure.

Figure IIIo Continued...

 6 

Two symmetrical three-line parts are present in this figure, with the lines comprising the part with the vertical axis of symmetry being more often drawn.

 6 

The two-line symmetrical part with the horizontal axis is preferred over that with an oblique axis.

Figure IIIp; Percentage Inclusion Rates for Individual Lines in Incorrect Delayed Condition Copies: Six-line Figures.

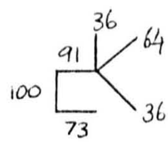
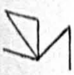
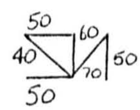
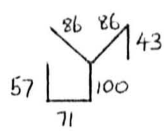
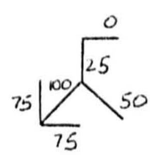
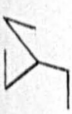
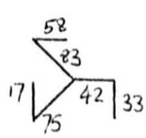
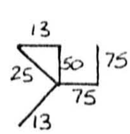
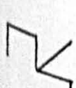
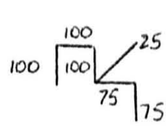
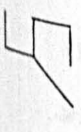
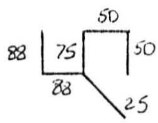
Figure	n	Line Percentages	Comments
	11		The lines comprising the ⊏ part are those most often recalled.
	10		No evidence for the lines forming the triangular part to be more often drawn.
	7		Unlike the ⊏< figure, the lines comprising the ⊔ part are not those correctly reproduced most often.
	8		The "arrow's" component lines are most often drawn with the isolated top line never recalled.
	12		A less clear pattern is present for this figure with no obvious line groupings. The two central obliques are most often copied.
	8		Lines forming the ⊔ section are preferred over those forming the triangle, with the most isolated line again being infrequently drawn.
	4		The sole oblique line is that least often drawn for this stimulus, although it is not the least attached line.

Figure IIIp Continued...

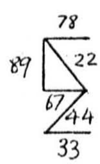


8



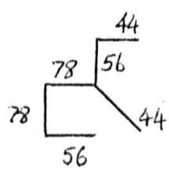
Again the sole oblique is infrequently included. The preference of the ⊔ element over the ⊓ cannot be explained by a preference for starting each reproduction with the leftmost vertical as only 3/8 incorrect copies commenced with this stroke.

9

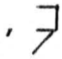
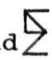


The most popular lines are those comprising the ⊏ part rather than the triangle.

9



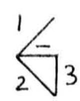
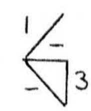
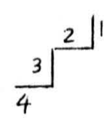
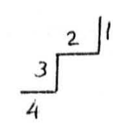
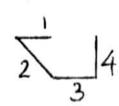
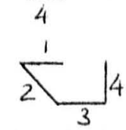
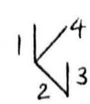
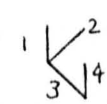
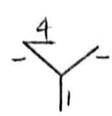
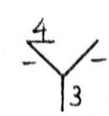
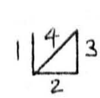
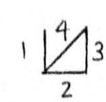
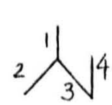
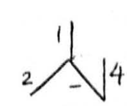
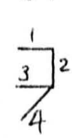
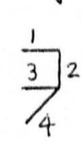
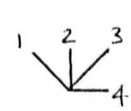
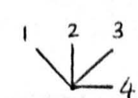
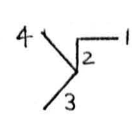
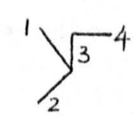
Differences between rates of line inclusion are not as great in this figure as in preceding stimuli. Inspection of this figure shows it to possess no outstanding emergent parts.

A number of tentative conclusions can be drawn from the detailed examination above of the preferred lines in incorrect delayed condition copies. Firstly, individual lines were often less likely to be included if they were isolated from the body of the figure, commonly by connecting with only a single line-join. Examples here are the , ,  and  figures, although a greater number of figures exist that do not concur with this finding (e.g. , , , ,  and ). Preferred parts consisting of two or more lines were not necessarily those that were enclosed, but rather tended to be symmetrical parts that were often in the centre of the figure, regardless of the orientation of the component lines within these parts.

The relative omission of less attached, isolated lines could be claimed to be related to the ordered strategies with which the stimuli are reproduced. If omitted lines in incorrect copies tended to be those drawn last in correct reproductions then a memory effect that biassed against the isolated figure elements would be implicated for the strategies used in figure reproduction. The following interpretative description of the modal stroke orders for correct copies of the four and six-line figures compares data gathered from the immediate and delayed conditions. Incorrect reproductions are excluded because the inclusion of this data would favour (by promoting in the drawing sequence) those lines most often given in incorrect copies.

Figures IIIq and IIIr below show the modal ordering of individual lines in correct copies of the four and six-line figure stimuli for sample sizes above one in each copying condition. Series of two or more lines joined by threading are given here as individual strokes with their respective orders. Analysis of the direction of drawing individual lines is not included, and the presence of a '-' symbol in the figures implies that no clear modal order exists for the line referred to. Comments on each stimulus follow the two tables.

Figure IIIq; Modal Line Orders for Correct Copies in Immediate and Delayed Conditions: Four-line Figures.

Figure	Immediate Condition n	Immediate Condition Line Order	Delayed Condition n	Delayed Condition Line Order
	10		5	
	11		9	
	11		4	
	11		3	
	11		6	
	11		9	
	11		6	
	11		8	
	11		6	
	11		5	

Both immediate and delayed condition strategies appear similar, with the figure modally being started at its topmost line. For the delayed condition both  and  strategies are feasible.

There is agreement for both conditions about the use of a Top Start rule in preference to a Left Start rule.

Once again similar strategies appear in the two copying conditions. Unlike the strategy for the preceding stimulus, whose overall direction was from top to bottom, this more horizontally constructed figure is drawn from left to right.

Strategy differences emerge as a function of copying condition here. Subjects in the delayed condition separate the figure into two vertically arranged parts, but the initial downwards direction is continued for immediate condition copies.

The sole similarity between the two modal strategies reported for this figure is that both leave the least-attached horizontal line until last.

Both the immediate and delayed modal strategies commence with all three of the Top, Left and Vertical Start rules.

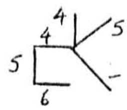
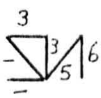
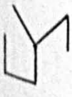
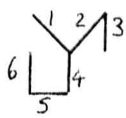
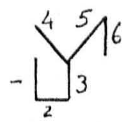
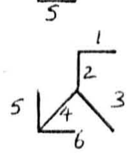
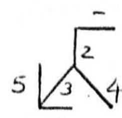
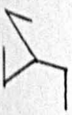
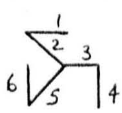
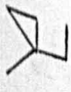
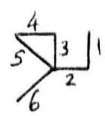
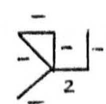
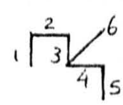
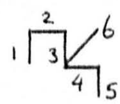
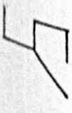
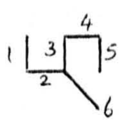
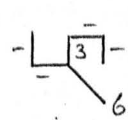
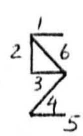
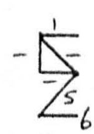
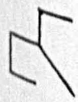
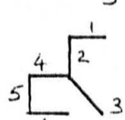
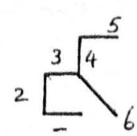
This stimulus is split vertically in both conditions by a strategy which starts at the top of the figure and comes down the left side.

It is the sole oblique that tends to be drawn last in correct copies of this figure rather than the least-attached top horizontal line.

An identical progression path is present in both immediate and delayed copies which proceeds from left to right.

Immediate and delayed condition copies differ here; in the former the modal strategy is to progress from top to bottom adding the oblique last. In the delayed condition, however, the figure appears to be split into two parts with the two joining obliques reproduced first.

Figure IIIr; Modal Line Orders for Correct Copies in Immediate and Delayed Conditions: Six-line Figures.

Figure	Immediate Condition n	Immediate Condition Line Order	Delayed Condition n	Delayed Condition Line Order
	9		1	–
	9		1	–
	11		4	
	11		4	
	11		0	–
	9		2	
	11		8	
	11		4	
	11		3	
	11		3	

No clear pattern emerges for the immediate condition copies apart from the most isolated lower horizontal being copied last.

A similar pattern is present for this stimulus. No agreement is present about a strategy for starting the figure, but the rightmost two-line section tends to be left until last.

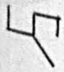
The two copying conditions provide complementary strategies here. Both immediate and delayed reproductions split the figure horizontally into two three-line parts, but the immediate condition subjects complete the top half of the figure before progressing downwards. The delayed condition copies tend, however, to do the opposite. It could also be claimed that the modal delayed condition strategy splits the stimulus into an initial four-line part and a final two-line part. Further analysis of the direction of copying the fourth line would help distinguish between these two alternatives.

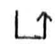
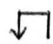
The modal immediate condition strategy splits the figure into two three-line parts, but delayed copies are only agreed about the ordering of the middle four lines in the sequence. Infact four different first lines were used in each of these correct delayed condition copies.

The path followed through immediate condition copies is one of drawing the first four-line section by progressing downwards and towards the right, then adding the final two lines.

The small sample size for the delayed condition prohibits a clear modal analysis, but reproductions made in the immediate condition lay open the possibility of a threading strategy being used for the complete figure.

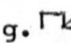
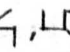
This more successfully copied figure appears to invite a threading strategy from left to right, with the sole oblique being the last line drawn.

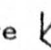
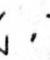
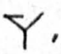
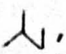
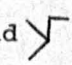
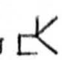
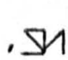
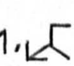
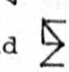


Like the previous stimulus, the single oblique line is left until last in both copying conditions. However, only immediate condition copies clearly select a modal path that permits threading in a left to right direction. The first three lines drawn in the delayed condition would appear to take the form of either  or  , namely constructing an initial three-line unit.

Differences exist between the strategies provided in the two conditions. For immediate copies a typical downwards progression path is completed by adding the upper oblique, but for the three delayed condition copies for which data exists the Top Start rule that is employed in the immediate condition is followed by the drawing of the triangle as the second, third and fourth lines, although the order of strokes within this part is not determined. It therefore seems that for correct copies of this stimulus subjects having to memorize the figure before reproduction do so partly in terms of the triangular section which is then recalled as a unit. Subjects copying in the immediate condition do not need formulate and memorize a strategy, but can progress in a favoured downwards direction with continual reference to the original stimulus before adding the final upper oblique.

 Although subjects in both conditions appear to separate their reproductions into two identical parts, opinion differs between the two groups of subjects as to which of these should be drawn first. Interestingly, the modal delayed strategy also permits threading of the first five lines to take place, but in a unfavoured upwards direction.

The descriptive analyses of the modal copying strategies presented above has shown that only for certain of the stimuli are differences between correct copies made in the immediate and delayed conditions clearly distinguishable, although it should be emphasized that few statistical analyses have been performed on the data. Nevertheless, differences that do exist between the copying conditions appear to be striking ones (e.g. for the  figure). Other stimuli seem to 'lend themselves' to certain consistent strategies for reproducing the complete figure or the greater part of it, regardless of whether the reproduction was made in the immediate or delayed condition. Typically these highly favoured strategies included a progression through the figure in a consistent direction that would allow threading to be used (e.g. , ). For these two figures in particular, the single lines that are left until last in the order of production are not those that are structurally the most isolated, but are rather in a position and orientation that would interrupt the preferred directional path.

There are a total of ten four and six-line figures for which one single component line can clearly be said to be less attached than remaining lines to the body of the figure in terms of having only a single line-join. The four-line stimuli in this category are , , ,  and , with the six-line figures including , , ,  and . Inspection, where possible, of the modal line order of each of these isolated lines from immediate and delayed condition copies revealed that for four-line figures 6/10 of the relevant modal strategies had drawn the isolated line last, with 3/6 being in the final sixth position for the more complex figures. Using a Binomial test both of these proportions are significantly greater than chance ($P < .01$ for both four and six-line figures), providing limited support for the hypothesis derived from incorrect copies that less attached lines would be those drawn last in correct copies as well as tending to be omitted from incorrect copies.

Do younger children organize their copies in this way? If, for example, six year old children did not tend to either omit or postpone the drawing of isolated lines in incorrect and correct copies respectively, then the strategies employed by these younger subjects could be said to be qualitatively different from those of older children. Any strategy differences that do exist between the age groups for a comparable range of stimuli may be able to explain in part the differences found in age-related copying ability. In order to discover whether this is the case, the most recent two analyses in Section B concerning isolated line inclusion and postponement are repeated with the six year old subjects from Section A, of which there were six in each of the immediate and delayed conditions.

A total of 11 stimuli from Section A contained one single isolated line, and Figures IIIs and IIIt that follow note the rate of inclusion of individual lines in incorrect delayed copies of these figures and modal orders in correct immediate and delayed condition copies.

Figure IIIs; Percentage Inclusion Rates for Incorrect Delayed Condition Copies- Six Year Olds in Section A.

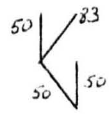
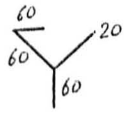
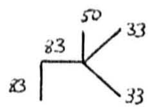
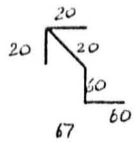
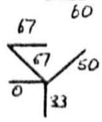
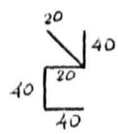
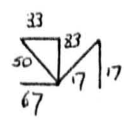
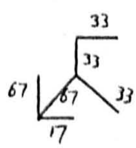
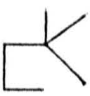
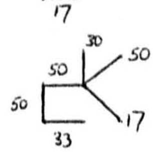
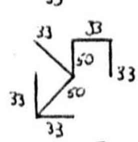
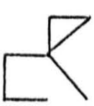
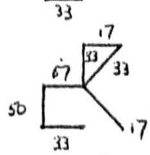
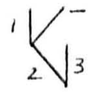
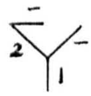
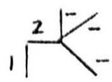
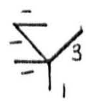
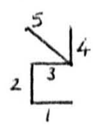
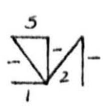
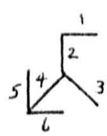
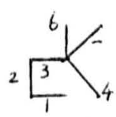
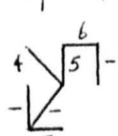
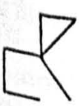
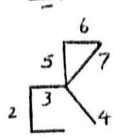
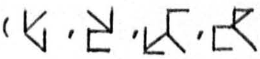
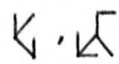
Figure	n	Line Percentages
	6	
	5	
	6	
	5	
	6	
	5	
	6	
	6	
	6	
	6	
	6	

Figure IIIt; Modal Line Orders for Correct Copies- Six Year Olds in Section A.

Figure	Immediate Condition n	Immediate Condition Line Order	Delayed Condition n	Delayed Condition Line Order
	6		0	-
	5		0	-
	3		0	-
	2		1	-
	6		0	-
	5		1	-
	5		0	-
	5		0	-
	5		0	-
	5		0	-
	3		0	-

Figures IIIs and IIIt above show no evidence that six year old subjects either postpone or omit the copying of isolated lines. In none of the eleven stimuli in Figure IIIs is the isolated line the least often included in delayed condition copies, and although a number of clear strategies emerge from the immediate condition copies in Figure IIIt there is no single example of a least-attached line being clearly postponed until last. These findings therefore represent a change in copying strategy with age, with the implication that the eight year olds organize their copies (to postpone isolated lines) in a way that six year olds do not.

Figure IIIt does show a number of figures () for which clear modal strategies are present for the six year olds copying in the immediate condition. The strategies used for the first two of these four figures favour a threaded progression path with the remaining oblique added last. The second two more complex of these four figures are separated into two distinct parts, with both the three-line 'arrow' and triangular parts drawn in an uninterrupted sequence. Study IV examines systematically the way in which enclosed parts are included in copying strategies. Interestingly, the strategies for the four and six-line figures of this group () are all but identical to those of the eight year olds in the immediate condition in Section B. This raises the question of the extent to which certain stimuli predispose themselves to being drawn with a relatively fixed stroke order regardless of subject age and copying condition.

From the limited amount of evidence presented in Figures IIIq, IIIr and IIIt it would seem that three factors contribute to the type of strategy employed for any one figure. These are the structural nature and complexity of the figure itself (and the extent to which the stimulus may lend itself to a preferred threading or part-use strategy), subject age and an immediate or delayed copying condition. Although evidence about the role of subject age in determining strategy has only been gathered piecemeal in Study III with a limited range of stimuli and small sample sizes, differences in copying strategies as well as in overall accuracy have been shown to exist as a function of the age of the subject.

Discussion

Study III has presented two types of analysis of copying skills drawn from two related and consecutive studies. The first section of Study III examined the developing accuracy with age of the reproduction of a series of geometric figures in two copying conditions. It was found that overall levels of copying accuracy were greater if the subjects aged between six and nine years copied each stimulus whilst it remained in view (the immediate condition) than if had to be memorized for a short time before being copied (the delayed condition). However, significant differences in copying success as a function of age were only present in the delayed condition, due to a ceiling effect in the immediate condition.

Also found to be a factor in determining whether the figure as a whole would be correctly reproduced was the number of component lines present within the figure. These had been varied systematically between four and seven lines in the first section of Study III, with the finding that stimuli possessing fewer lines were more likely to be copied correctly as a whole in both the immediate and delayed conditions.

On the basis of a more detailed analysis of individual copies made in Section A a further two groups of subjects aged approximately eight years repeated the experiment using only two figure complexity levels. The differences in overall levels of copying ability as a function of figure complexity and copying condition were replicated, but the central purpose of this second section was to examine in greater detail aspects of copying strategies that might contribute to a successful copy being made in either of the two copying conditions. It was found that a lesser number of strokes were employed in making correct copies in the delayed than in the immediate condition, with the hypothesis being presented that this represented a greater need to organize the reproductive strategy in the delayed condition.

Further analyses examined how such organization might occur. A descriptive, interpretative analysis was carried out on individual figure stimuli to discover whether certain stimulus features were typically omitted in incorrect copies, and also whether differences in strategy existed between the two copying conditions. Evidence was put forward to support the view that those lines in a stimulus figure that were the most isolated (i.e. those having only a single line-join with the remainder of the figure) were those lines that tended to be omitted in incorrect stimulus copies and drawn last in correct ones. The suggestion from this finding is that elements in the figure not central to the body of the stimulus as a whole by virtue of their being physically detached are disadvantaged in a reproduction task by being postponed in the order of copying. Equally importantly, the tendency to omit and postpone isolated lines was not found in a sample of comparable drawings made by the six year old subjects in Section A. This finding provides evidence that age differences are present in the copies made of certain stimulus-types between six and eight year old subjects.

To what extent can the two sections of Study III be interrelated to present a unified picture of the development and organization of copying skills? Section B represents an attempt to discover qualitatively what lies behind the quantitative trends found to exist in Section A. To date, few studies have taken into account the exact structural nature of the stimulus in invoking different copying strategies. Exceptions here include Nihei (1980) and Ninio and Lieblich (1975), but both of these studies make use of a small range of very simple stimuli that present few problems to the young child in a copying task. One subsidiary aim of the present study has been to systematically extend the range of figure complexities presented to child subjects in order to analyse more closely the nature of failure in copying skills. To this extent incorrect copies of stimuli represent a valuable source of information.

Any analysis of copying skills can not be totally isolated from the figures used as stimuli in the copying task itself, showing the value of a detailed figure-by-figure analysis of the production paths used. There is however, the danger of a dilemma in overemphasising the structural nature of individual stimuli in a copying task, in that any age trends derived from the use of such figures are liable to be regarded as stimulus-specific and not capable of extrapolation to a wider context. The solution to this dilemma would appear to be two-fold; firstly that a consistent framework should be used in deriving stimulus figures that can be employed across a range of studies, and that the principles used in figure generation should be made explicit. Secondly, more detailed analyses of copying accuracy and strategy based on individual figure stimuli should be primarily used to derive hypotheses about the nature of graphic organization that can be tested more rigorously in a formal context. Therefore, the fine-grained analyses in Section B of this study should be interpreted as predictive rather than explanatory.

STUDY IV

Introduction

Study III has shown that children between the ages of six and nine years organize their reproductions of geometric figures as a function of the complexity of the stimulus, the age of the subject and the need (or otherwise) to memorize the figure before it is reproduced. Study IV looks more closely at the methods by which adult subjects encode figure stimuli in memory in a delayed reproduction task. Study III also looked at the interrelationship between the drawing of certain parts of figures and accuracy of copying; the present study takes this analysis one step further to examine the relationship between part use and copying strategies.

The hypotheses in Study IV are derived largely from the series of studies reviewed in the section entitled 'The Encoding of Geometric Figures' in the Literature Appraisal. This section examined a number of studies which analysed the roles of visual and verbal processes in delayed recognition and reproduction tasks, with the general conclusion being drawn that verbal process are implicated in delayed reproduction tasks, usually taking the form of verbal descriptions of the stimuli employed (Reed, 1973). The most common experimental technique used to test the variety of hypotheses in these studies was the use of a secondary, intervening task between the perception and later recall of the stimulus. The rationale behind this approach is that an interpolated task in the same modality as that in which the central task is taking place will use the required processing capacity and interfere with the performance of this central task to a greater extent than an irrelevant interpolated task. This assumes that the processing necessary for the main task is modality-specific and not capable of being processed by alternative means. Thus if delayed figure reproduction is primarily a verbally-based task then verbal interference will lead to a greater detriment in copying performance than either a control group or one receiving a visual interference task. Study III has already demonstrated that some children spontaneously offer verbal descriptions of figure stimuli in a copying task. The present study uses an interference task design to examine the relative importance of verbal processes in what intuitively appears to be a largely visuo-spatial task.

To examine systematically the relative influence of visual and verbal processes in the encoding of figure stimuli adult, rather than child subjects are used. This is for two reasons; firstly, Study III has shown that even the oldest children of the age range tested (the nine year olds) correctly copied figures with five or more component lines at a less than 50% success rate, even when there is a minimal delay between the viewing and reproduction of the stimulus.

The second reason for employing adult subjects also comes from a number of the studies reviewed in the Literature Appraisal (e.g. Glanzer and Clark, 1964; Cohen and Granstrom, 1968a; Hayes, 1982; Gagné and Smith, 1962). A variety of hypotheses were tested in these studies, but one finding common to all is that an appropriate verbalization or description of the stimulus aids recall. The present study therefore not only includes visual and verbal interference tasks, but also a verbal description task to ascertain whether appropriate verbalization can aid recall by reproduction relative to a control condition. Conversely, it may be hypothesized that any interpolated task placed between the perception and reproduction of the stimulus will interfere with accurate recall, regardless of the nature of this secondary task. Adult subjects are employed in this study rather than child ones because adults are more likely to be able to provide accurate verbal descriptions of geometric figure stimuli than children.

The second section of Study IV continues with the analysis of reproductive strategies within the context of the examination of encoding methods given above. Previous studies in the thesis have found that certain stimulus features are identified and responded to differently; figures with symmetrical parts or those with two or more compound lines are drawn and started more quickly by adults than figures without these features (Study II). Furthermore, older children postpone or omit the least-attached lines where these are clearly present in a stimulus (Study III). The present study looks systematically at the way in which one obvious type of emergent part, that possessing enclosure, is included in adults' delayed copies. Given the previous findings in the thesis of a tendency to take account of emergent parts, it is expected in this study that enclosed parts will be identified and included in otherwise incorrect copies, and will also be drawn as 'units' (i.e. in an uninterrupted sequence) in both correct and incorrect copies. The study also examines the extent to which the lines comprising an enclosed unit are the first of the lines comprising the complete copy to be drawn for both correct and incorrect copies ('first units'). The use of uninterrupted stroke sequences placed first in the order of copying would attest further to the strategic use of enclosed parts.

The second analysis of strategy examines whether there is a higher incidence of the use of simple drawing rules for enclosed parts drawn as units than remaining lines in correctly drawn copies. Should this be so, then not only would enclosed parts be taken account of in terms of the order of drawing the complete copy, but they would also be further segregated from the remainder of the figure in terms of the use of consistent directional and starting behaviours. The drawing rules included here are the three start rules given by Goodnow and Levine (1973), namely the Top, Left and Vertical Start, and modifications of the progression rules which note the direction of drawing each of the single lines in four orientations (| , — , / , \ ) within enclosed units or remaining lines in the stimulus. These modified progression rules included drawing individual vertical lines from top to bottom (TB), horizontals from left to right (LR), left obliques from bottom-left to top-right (↗) and right obliques from top-left to bottom-right (↘).

The presence and use of four different types of enclosure is examined in Study IV. These four types include figures with four-line square parts, three-line right-angled triangular parts or those with 'complex' parts (figures with enclosed parts of more than four lines or of four lines organized in a non-square form). The final stimulus category includes figures without an enclosed part. Statistical analyses examine the differential accuracy with which the three figure-groups with enclosed parts are copied.

To summarize, Study IV employs intervening tasks between the perception and reproduction of a series of four types of stimulus figures to test the hypotheses that;

In comparison with a control group, copying will be least accurate with verbal interference, more so with visual interference, and more often correct than the control group with a verbal description task (accuracy: description > control > visual interference > verbal interference).

Enclosed parts of figures will be included to a high degree in incorrect copies, and drawn as units and first units in both correct and incorrect copies.

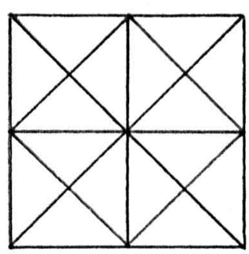
Rule use will be higher for enclosed units than remaining lines in correctly copied figures.

Method

Stimuli

The stimulus construction framework used in Studies II and III in the thesis was modified to facilitate the derivation of the greater variety of stimuli employed in this study. The modified framework, given below in Figure IVa, includes a further four lines forming the 'diamond' in the figure below.

Figure IVa; The Modified Stimulus Construction Framework.



Figures were randomly derived from the framework, with the sole constraints on construction, apart from the nature of enclosure within the figure as follows; no component lines in the figure should remain unconnected, no diagonal lines should intersect and no 'compound' lines (two adjoining lines in the same orientation) should exist. A total of 16 stimuli were constructed and presented to each subject, four stimuli with each type of enclosure (no enclosure, square, triangular and complex enclosure). These stimuli are given in Figure IVb overleaf.

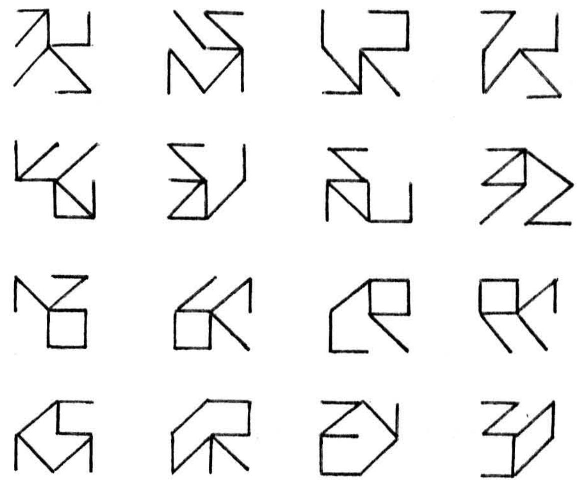
Figure IVb; The Sixteen Figure Stimuli

'No enclosure' Figures

'Triangular Enclosure' Figures

'Square Enclosure' Figures

'Complex Enclosure' Figures



The stimuli were drawn according to the principles outlined in the Experimental Design chapter, with each stimulus containing a total of eight component lines. These were formed into a randomly ordered A5 size booklet with one stimulus figure per page. Placed between each stimulus page were two further A5 pages, the first for the intervening task (as described below), and the second containing a centrally positioned 3x3 dot grid on which the subject reproduced each stimulus. This grid was the same size as the framework from which the stimuli were derived. These two pages served the further purpose of preventing subjects from seeing through to the next stimulus figure in the booklet.

Intervening Activities

Each of these activities was designed to take up a fixed length of time (20 seconds), yet to be capable of repetition without practice effects. Given these procedural demands the following tasks were employed;

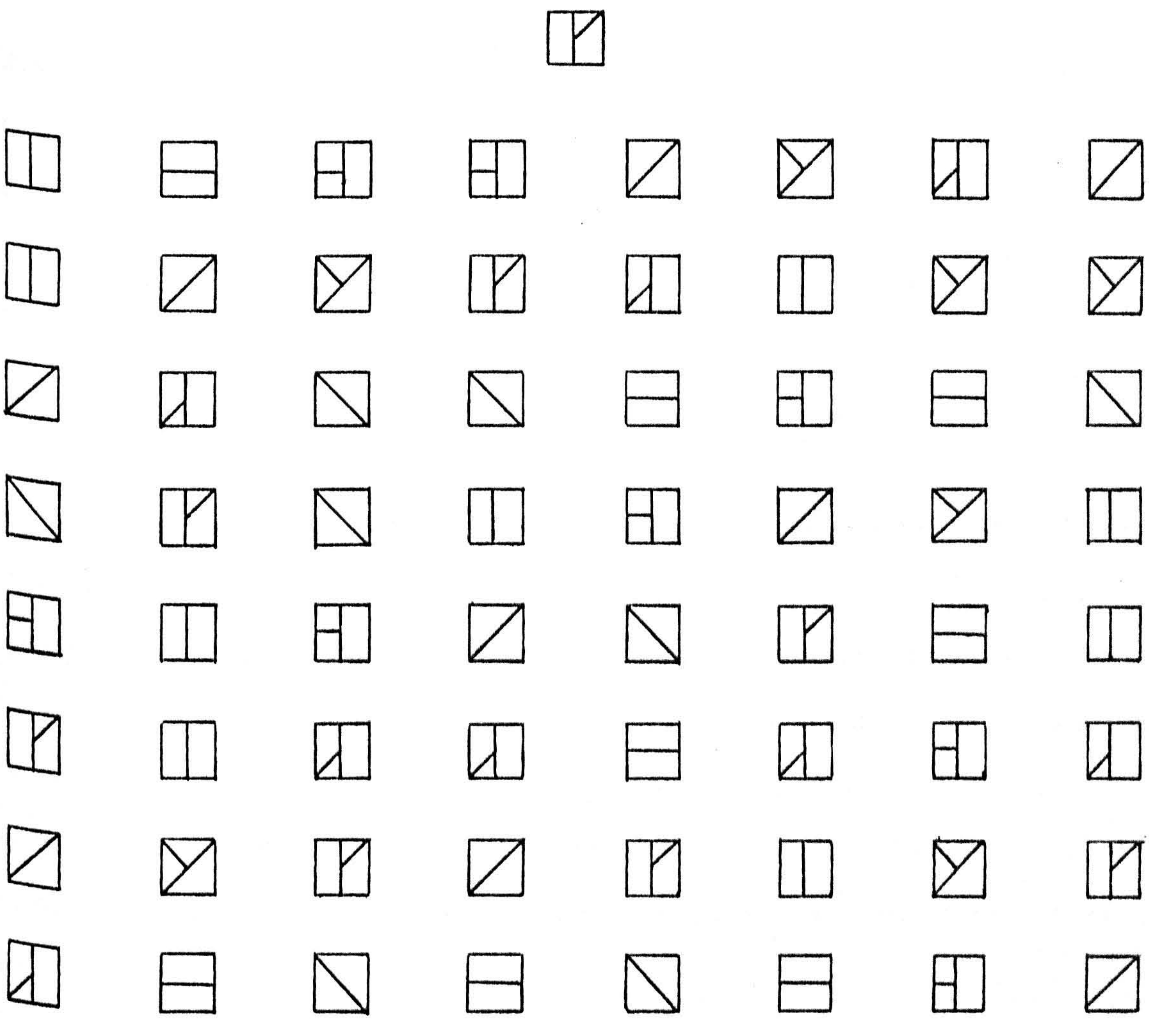
Verbal Interference: A randomly chosen three digit number was given centrally on the plain piece of paper after each stimulus page, the subject being asked to count backwards aloud, and as quickly as possible, from this number in units of seven.

Visual Interference: A discrimination task, with a target of either a square, triangle or circle of size .7cm^2 positioned at the head of the page with 64 figures of similar outline shape below it. The subject had to cross off as many as possible of the lower figures with internal detail identical to that of the target within the 20 seconds allowed. The ratio of stimuli with internal detail similar to that of the target was 1:7. An example of the format of this task is given in Figure IVc.

Verbal Description: Having viewed each stimulus figure for 20 seconds, the subject removed it from sight by turning to the next (blank) booklet page, and was asked to provide a 'short, but accurate description of the figure 'as if someone else was going to re-draw the figure from your description'. Subjects were informed that 20 seconds would be allowed for this task.

Control: The subject was asked merely to look at the blank page following each stimulus for 20 seconds, but asked not to speak during this period.

Figure IVc; The Format of the Visual Interference Task.



Subjects

A total of 40 right-handed Undergraduate subjects of both sexes from the University of Keele served as subjects, all having volunteered to take part in a study on 'drawing ability'. The subjects were randomly assigned to each of the four intervening activity conditions. A between-subjects design with 10 subjects in each condition was used to eliminate any possible transfer of strategies had each subject served in all four conditions.

Procedure

The experimental procedure centred on a 2 x 20 second cycle for the viewing of each figure and the appropriate intervening task. The subject looked at each stimulus for 20 seconds, turned the page to the interference task, then after a further 20 seconds turned to the following page to reproduce each stimulus on the dot grid provided. Periods of 20 seconds were used due to the fact that a number of preliminary trials had established that this was the minimum approximate length of time in which an eight-line figure could be described in detail. No time limit was imposed for each reproduction. The subject informed the experimenter when each copy had been completed, and then continued on to the next stimulus figure.

Subjects were seated at a small desk with the stimulus booklet fixed centrally and at right-angles to the sides of the desk. Instructions to subjects varied according to the intervening condition, but all were told that each stimulus figure was to be as accurately drawn as possible, and was to use the dot grid given. A single practice copy using the appropriate intervening task was made with a further non-enclosed figure.

Data Collection and Analysis

The copies made by each subject were video-taped by means of a camera positioned in front of and above the subject. Analysis of the tapes noted the number, order and direction of strokes in each copy. Reproductions were scored on a 1/0 basis, with correct copies containing the appropriate number of component lines correctly positioned within the dot grid.

Results

Accuracy of Reproduction

Table IVd overleaf gives the mean number of each stimulus type correctly copied in each intervening condition (maximum score of four per subject per stimulus type).

T tests comparing each of the three filled intervening conditions against the control condition gave only a single significant comparison; reproduction was more accurate in the control than in the visual interference condition ($t = 2.14$, d.f. = 18, $P < .025$). Multiple t tests were used, rather than a single analysis (e.g. an ANOVA), because the latter type of test would have been inappropriate for the single comparisons against the control condition required by the hypothesis. Analysis of copying accuracy across the stimulus types using a one-way ANOVA gave $F = 11.64$, d.f. = 3, 117, $P < .01$. Post-hoc mean comparisons (Scheffé tests at 10% acceptance level) showed stimuli with square or complex enclosure to be more accurately copied than those with triangular or no enclosure. The following section of the results examines the extent to which enclosed parts were included in both correct and incorrect stimulus copies, regardless of the copying condition. Table IVe in the Appendix gives the full ANOVA table on which the above results are based.

Table IVd; Mean Number of Correctly Copied Figures for Intervening Condition and Stimulus Type. (max = 4)

	Intervening Condition				
	Visual	Verbal	Description	Control	Mean
Stimulus Type					
No Enclosure	1.7	1.8	1.7	2.3	1.9
Triangular Enc	1.4	2.1	1.5	2.1	1.8
Square Enc	2.2	2.3	2.9	3.5	2.7
Complex Enc	2.2	2.7	2.7	2.9	2.6
Mean	1.9	2.2	2.2	2.7	

The above results demonstrate that visual, but not verbal interference leads to a decrease in copying accuracy in comparison with an unfilled intervening period. Furthermore, there is no significant difference between the visual and verbal interference conditions ($t = .83$, $d.f. = 18$, $P = n.s.$). From this one can conclude that the primary processes involved in the delayed reproduction of geometric figures are visually-based ones, with no clear evidence being obtained about the role of verbal processes in this task. Subjects in all three conditions with filled intervening periods copied fewer figures correctly than subjects in the control condition, although as has already been stated, for two out of the three comparisons differences between the means were not significant. This implies that any interpolated task between the perception and reproduction of the stimulus figure causes a deterioration in performance regardless of the exact nature of this intervening task.

Table IVf in the Appendix gives eight examples (two from each of four stimuli) of the descriptions provided by a number of different subjects in the verbal description group. One correct and one incorrect copy are provided for each stimulus. Further analyses that could be carried out on these descriptions are outside the range of the present thesis, but could include an examination of the relationship between the naming and consequent inclusion of the enclosed parts and letter-like forms within the stimuli, and whether accurate descriptions are associated with accurate reproductions.

Part Use In Copying

This section contains two levels of analysis. It firstly asks whether the different types of enclosed parts (triangular, square, complex) were included in different proportions of otherwise incorrect copies of stimuli, regardless of whether these enclosed parts were drawn in uninterrupted line sequences. It secondly notes the proportions of each of the three types of enclosure being drawn as units and first units in both correct and incorrect stimulus copies. Differences in simple copying strategies (number of strokes used in copying, percentage use of start and progression rules) were tested for between the four copying conditions, but none were found. Henceforth data from the four copying conditions is combined in this and following sections of the results.

When stimuli were incorrectly copied, the three types of enclosed parts were included within the correctly copied portion of the reproduction in the proportions given below in Table IVg;

Table IVg; The Proportions of Enclosed Parts Included in Incorrect Reproductions.

	Sample Size	Percentage Inclusion Rate
Triangular Enclosure	89	59.6%
Square Enclosure	51	86.3%
Complex Enclosure	55	27.3%

The above table demonstrates that the rate at which enclosed parts were included within incorrectly drawn figures varies as a function of the nature of the part itself. A χ^2 test performed on the data above showed these proportions to differ significantly (χ^2 = 37.98, d.f. = 2, $p < .001$). It can be seen that square parts are over three times as likely to be drawn in an otherwise correct copy than complex parts. One possible interpretation for this finding centres on the fact that complex parts take up, on average, a larger proportion of the complete figure than square parts, and therefore any error in reproduction is more likely to include lines forming the complex part. Although this interpretation is a realistic one, it should be noted that triangular parts were less often included than square parts, although the former contain three lines to the latter's four. Thus discussion of the relative use of these enclosed parts also takes account of the extent to which an enclosed part is easily identifiable and used in the copy, including its being drawn as a unit.

Table IVh below gives the percentage of correctly and incorrectly drawn figures that both included enclosed parts and drew them as units or first units (with an enclosed part's lines being the first drawn of the complete copy). Also included are the sample sizes from which these percentages were derived and the values and significance levels of χ^2 tests performed between the different stimulus types.

Table IVh; Percentage of Correct and Incorrect Reproductions Drawing Enclosed Parts as Units and First Units.

	Enclosure Type							
	Triangular		Square		Complex			
% Drawing Unit	%	n	%	n	%	n	χ^2	sig
Correct copies	26.8	(71)	89.9	(109)	21.0	(105)	120.12	****
Incorrect "	27.0	(89)	82.4	(51)	20.0	(55)	53.80	****
% Drawing First Unit								
Correct copies	7.0	(71)	66.1	(109)	10.5	(105)	102.57	****
Incorrect "	4.5	(89)	70.6	(51)	18.2	(55)	76.52	****

Table IVh shows large and significant differences between the figure types in the tendency to include and draw enclosed parts both as units and first units. For each of the four measurement categories in Table IVg square parts are by the most often drawn in an uninterrupted sequence, including having been drawn as the first four lines in 70.6% of otherwise incorrect copies. In contrast, although Table IVg showed triangular parts to be included in 59.6% of incorrect copies, only 27.0% of these copies drew the triangle as a unit. Comparable decreases for both square and complex parts are far smaller across this measure. Similarly, a smaller proportion of triangular units were drawn as the first lines in both correct and incorrect copies than the remaining two figure types. It would seem, therefore, that although triangles are often identified and included in incorrect copies, this inclusion does not extend to the drawing of this particular type of enclosed part in an uninterrupted sequence.

Inspection of the results presented in Table IVd of the mean number of correctly copied figures with each of the intervening tasks, it can be seen that figures with square or complex parts were more often correctly copied than those with triangular or no enclosure. Figures with triangular parts do not tend to be amongst those most successfully recalled. Interestingly, although figures with complex parts were more likely to be correctly drawn, the complex enclosed parts themselves appear to be too detailed to be drawn as units. Thus complex parts appear to aid the memorability and consequent reproduction of the complete figure. Square enclosed parts serve better both as parts in themselves and as structures to aid the recall of the complete figure, possibly because the orientation of the lines forming a square are themselves easy to memorize.

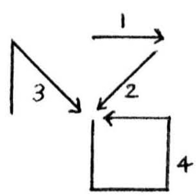
Rule Use In Copying

Examination of the use of copying rules is limited to correct reproductions of each of the four stimulus types. It is hypothesized that the identification and isolation of enclosed parts in terms of units will lead to these parts forming the focus of the drawing strategy for the complete figure, and hence be the lines more consistently structured with regard to the directional rules applicable to each line orientation. Rule use is therefore expected to be higher for the lines included in units than those remaining strokes forming the 'other lines' in a figure. This latter category also includes correct copies of stimuli without enclosed parts and all the lines from figures with enclosed parts where the part itself was not drawn as a unit. The following start and progression rules are included in the analysis;

Start Rules: Top Start
Left Start
Vertical Start

Progression Rules: Verticals top-to-bottom (TB)
Horizontals left-to-right (LR)
Left diagonals from bottom-left to top-right (↗)
Right diagonals from top-left to bottom-right (↘)

These categories modify those used by Goodnow and Levine (1973) by excluding Threading, inappropriate for the complex figures used in this study, and by including rules to take account of oblique lines. Analysis of the use of progression rules in the present study notes the proportion of, for example, vertical lines that are drawn downwards from the total sample of vertical strokes in the two categories of units and other lines, rather than whether each unit or series of other lines in a figure drew all the vertical downwards. Start rules, however, compare the extent to which any enclosed part drawn as a unit was itself commenced at, for example, a topmost point, regardless of whether the complete figure was started at the top. An example of these scoring methods is given for the copy below;



In this reproduction, the enclosed part was drawn as a unit and used all three of the Top, Left and Vertical Start rules. The single one of the other lines that was infact the first drawn of the complete copy used the Top and Left, but not the Vertical Start rule. If the enclosed unit had been the first drawn, the next drawn other line would have been included in the analysis of start rules. For the progression rules, the TB and LR rules were both employed for 1/2 strokes in the enclosed unit, and for the remaining lines in the copy the rule use scores would have been as follows; TB - 0/1, LR - 1/1, ↗ - 0/1, ↘ - 1/1. Table IVi gives the sample sizes and percentage use of the above rules. Sample size varies greatly in the analysis of progression rules (and in particular of the ↗ and ↘ rules) because of the relative lack of lines in these orientations within enclosed parts. The χ^2 tests compare the differing proportions of rule use between units and other lines, with the data summed across copying conditions and stimulus categories.

Table IVi; Rule Use in Correctly Drawn Figures: Units compared with Other Lines.

	Percentage Rule Use in					
	Units		Other Lines			
Rule	%	n	%	n	χ^2	sig
Top Start	82.4	(142)	30.3	(218)	91.38	****
Left Start	84.5	(142)	44.0	(218)	54.68	****
Vertical Start	62.7	(142)	40.8	(218)	15.56	****
TB	82.6	(258)	81.7	(672)	.04	n.s.
LR	86.8	(243)	82.2	(691)	2.46	n.s.
↗	60.0	(60)	72.9	(506)	3.79	n.s.
↘	100.0	(11)	94.0	(433)	.04	n.s.

Table IVi demonstrates that rules that govern the starting stroke when copying are used to a significantly higher degree in enclosed units than in other stimulus lines. Thus, although a correctly drawn figure may or may not have been started at the top, left or with a vertical, it is significantly more likely that any enclosed unit within the figure will have had its first line drawn using one or more of these start rules. The use of a consistent direction when drawing individual strokes is shown to be very high for both enclosed units and other lines in Table IVi, with the difference between the overall usage rates of the ↗ and ↘ rules possibly attributable to the fact that the ↘ direction for the right oblique can incorporate both Top and Left Start rules (as well as travelling in the preferred downwards direction), whereas the ↗ rule starts at the left, but not at the top of the line.

Conclusions about the use of simple drawing rules within more complex figures therefore takes note of the two different start and progression rule use categories. We have shown earlier that enclosed parts tend to be drawn as units. We have now shown that such units use Goodnow and Levine's start rules to a much greater extent that lines not in enclosed parts, even when such lines are the first to be drawn. The preferred use of starting rules in enclosed units does not extend to progression rules, where favoured directions of drawing do not take account of whether individual lines are included within enclosed units.

Discussion

Three aspects of geometric figure reproduction have been investigated in Study IV. These concern the relative influence of visually and verbally-based tasks interposed between the perception and reproduction of stimuli, the extent to which differing kinds of enclosed parts are included in otherwise incorrect copies and whether these parts are drawn in uninterrupted line sequences, and finally the levels at which simple drawing rules are employed in enclosed units when compared with remaining stimulus lines.

The results of Study IV can be summarized as follows; only subjects receiving a visual interference task recalled significantly fewer stimuli correctly than subjects in the control condition. No other differences in reproductive success were found between the four copying conditions. Stimuli with square or complex parts were more often recalled that those with triangular or no enclosed parts. Square parts were themselves most often included in incorrect copies and drawn as units and first units in both correct and incorrect copies. The use of start, but not progression rules was higher for lines included in the enclosed units of successfully drawn figures.

The hypothesis that a verbal interference task would cause a deterioration in copying performance in comparison with a control group was not supported, neither was the hypothesis claiming that the opportunity to describe each stimulus verbally before drawing it would improve the probability of it being drawn correctly. Thus the finding that a visual interference task did cause lower levels of correct copying goes against the conclusions drawn from a number of previous related studies. One interpretation of this finding is that the length of time given for the viewing of the stimuli or of the intervening tasks (20 seconds in each case) was too long for any verbally-based interference to be effective, possibly allowing the subject to encode the stimulus using a method not susceptible to such interference. For example, although Christie and Phillips (1979) found an interpolated 'counting backwards' task to cause interference in a delayed reproduction task, the presentation time used for the viewing of the stimulus in this study was 1.5 seconds rather than the 20 seconds used here.

At what point in the experimental procedure does the visual interference take place? If one assumes that the subject tries to 'make sense' of the stimulus in the 20 second viewing period prior to the intervening task, then any interference task can only be disrupting what has already been encoded. One hypothesis that follows is that a visual interference task will cause the subject to forget the nature, position and/or orientation of the enclosed parts found to be important in the delayed recall of these figure stimuli. Although this was not investigated systematically in this study a preliminary classification of the data according to this hypothesis shows no such effect. Table IVj in the Appendix notes part and unit use for correct and incorrect reproductions according to the nature of the intervening task, and across the four figure types that possess enclosure. Where χ^2 tests are possible, no significant effect is shown to support the view that lesser part identification and drawing takes place with visual interference.

The findings from the remaining analyses in Study IV are less equivocal, and demonstrate the ordered principles that operate behind the strategies employed when copying geometric figures. The study has considered the use of only one type of structural feature, that of enclosed parts, but found that these parts tend to be included and drawn in differing proportions as a function of the exact nature of the enclosure. Nevertheless, the presence of any type of enclosure was sufficient to ensure that when drawn as a unit, strategies which control the order, placement and direction of component lines were more highly used than for remaining lines in the stimulus. Thus enclosed parts have been shown by adult subjects to be segregated both in terms of preferred inclusion in a copy and of the higher use of common drawing strategies.

STUDY V

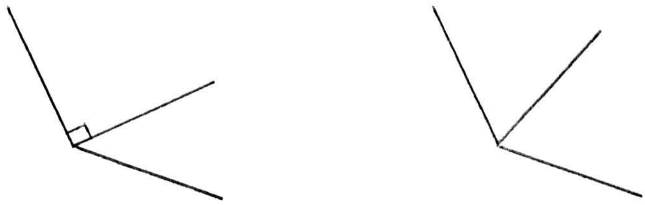
Introduction

The final study in the thesis stands apart from the previous studies in that its central aim is to test a single hypothesis derived from an area of research that has concentrated on one specific area of reproductive accuracy. Studies in this area have looked at the differential accuracy with which single lines in vertical, horizontal or oblique orientations have been reproduced within simple perceptual frameworks or from baselines themselves positioned in different orientations. A number of these studies have been reviewed in the 'Stimulus Orientation and Accuracy of Reproduction' section of the Literature Appraisal, including those examining the discrimination of similar simple stimuli within controlled frameworks.

As was stated in the Literature Appraisal, one of the single most enduring conclusions drawn from research in this area is the difficulty experienced with oblique lines drawn from a baseline. Ibbotson and Bryant (1976) found that 45^{o} obliques tended to be reproduced as more perpendicular than they infact were (the 'perpendicular error'), although this error was reduced in size when the baseline was vertical rather than horizontal or oblique (the 'vertical effect'). For Ibbotson and Bryant, the problems encountered in constructing oblique lines from baselines was not one or representing the complete figure accurately, but rather of specific difficulties with angles in certain orientations.

Bremner and Taylor (1982) tested the hypothesis that the young child's tendency to draw 45^{o} angles as more like 90^{o} angles is one of angle bisection; i.e. in the diagram below not only is the copy of CD more vertical than the model, it also bisects the angle ADB:

Using both straight and dog leg baselines in different orientations, it was found that the tendency to bisect angles existed even when the original stimulus contained a 90° angle, but only for dog leg baselines in an overall oblique orientation, i.e;

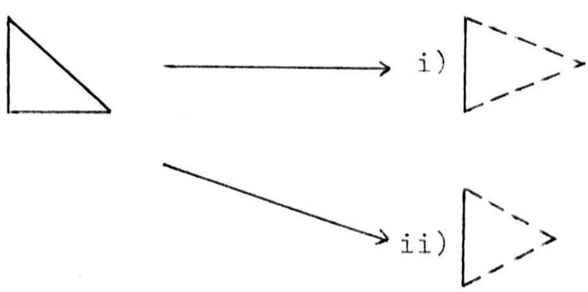


model copy

Bremner and Taylor's explanation of this finding is that children construct a more symmetrical version of the figure as a whole, with consequent effects on local angle errors. Bremner (1982) has further suggested that perpendicular errors and bisection effects operate separately, as a function of the positioning of the target line in relation to the baseline (at the middle or end of the baseline), and of the orientation of the baseline itself.

The present study examines the 'symmetry' hypothesis further, but employs a single, consistent stimulus type to this end. A right-angled triangle contains the necessary angular and linear elements essential to test the reproduction of 45° and 90° angles using one of the triangle's component lines as a baseline in a vertical, horizontal or oblique orientation. The singular advantages of using this stimulus are firstly that it is possible to test 45° or 90° angle reproduction within a geometric figure that has consistent relations between its internal angles, and secondly that this type of figure is one that is likely to have been encountered by younger children in their everyday drawing and copying. To prevent confusion the term 'oblique' henceforth refers to the overall orientation of a line relative to the (external) perceptual framework, but the hypoteneuse opposite the 90° angle in a right-angled triangle is called a '45°' line.

If Ibbotson and Bryant's findings are to be replicated using right-angled triangular stimuli () with one of the component lines presented as a baseline, the 45° lines drawn using vertical or horizontal baselines should have their angle size increased from the correct 45°. This would effectively change the symmetry of the complete figure drawn from one with an oblique axis of symmetry to one in which the axis of symmetry would tend toward the vertical or horizontal (example (i) in the diagram below), or even in an extreme case of angular distortion to an equilateral figure with three axes of symmetry (example (ii)). Both of these changes in the overall figure would leave a triangle with more salient and obvious symmetry than a figure with symmetry about an oblique axis (Palmer and Hemenway, 1978).



To test the symmetry hypothesis in a drawing task using right-angled triangular stimuli two methodological considerations are necessary. Firstly, only horizontal and vertical lines are used as baselines, as an oblique baseline leaves an already totally symmetrical triangle to be copied. Furthermore, an oblique baseline control condition is not employed here for the simple reason that both lines to be drawn are at 45° to this baseline, unlike vertical and horizontal baseline figures where one of the lines is at 90°. Only angle errors from the first line drawn from the baseline are those measured and taken into account, as the second line is contaminated by the first line that has been drawn. This may occur in a number of ways; by attempts to either preserve angle accuracy between the first and second lines drawn or between the second line and the baseline, or to maintain a correct orientation for the second line regardless of it joining the end-points of the first line and the baseline, or simply by joining the ends of the two lines already present.

Within the context of studying one particular aspect of oblique line reproduction, Study V goes on to analyse copying accuracy as a function of drawing individual lines to or from each baseline. By specifiying the direction of the first line drawn within the complete figure one is controlling in a simple manner the initial strategy with which the copy is reproduced. This is the first example in the thesis to date where direct control has been exercised on directional drawing strategies. The hypothesis here is that lines that are drawn from a baseline will be more accurate than equivalent lines drawn to a baseline. In the latter condition the point at which the line drawn joins the baseline must be planned for at the start of the stroke and monitored throughout, whereas when drawing from a baseline this aspect of the task can be resolved at the outset. It is expected that the extra dimension of planning needed when drawing to a baseline will lead to less accurate copying. Thus for each triangle orientation each first-line was drawn both to and from the baseline, with the specific instructions used to this effect given in the Method.

There are two possible causes of error, representational and reproductive. If the error is representational, this implies that the subject perceives the triangle as more symmetrical than it really is, but may draw accurately what is perceived. If the error is a productive one, then the subject would perceive the triangle accurately, but misrepresent it because of inappropriate copying strategies. Thus, the present study incorporates two tasks, a discriminative 'matching-to-sample' task and a normal copying task. If the discrimination task is error-free but the copying task is not, then the effect must be a productive one. If there is error on both tasks then a discriminative or perceptual effect is implicated. Bryant (1969) found that young children's 'successive' discrimination of single lines was less accurate than 'simultaneous' discrimination where the target line remained in view. The discrimination task in the present study compares performance in immediate and delayed presentation conditions, with subjects asked to distinguish between three triangular stimuli. Excluding the target stimulus of a right-angled triangle, the two remaining stimuli were right-angled triangles that had been distorted by being drawn with either a 10° increase or decrease at the intersection of the horizontal and vertical lines. The more symmetrical triangle in every case is the one with the 10° decrease at this intersection, with the remaining internal angles of the triangle consequently altered.

Although omitted from accuracy analysis because of first-line contamination, the direction of drawing of the second line is useful in assessing strategies used in the completion of the figure. This second analysis of copying strategy in Study V takes the form of noting the percentage of each age group that draws the second line in the consistent directions employed for the analysis of progression rules in Study IV. These were to draw verticals from top-to-bottom (TB), horizontals from left-to-right (LR), left obliques from bottom-left to top-right (↗) and right obliques from top-left to bottom-right (↘). As there exists only a single line in each stimulus triangle for which the direction of drawing is not fixed, the developmental analysis of directional preference for drawing individual lines provides a contrast to the foregoing examinations of levels of rule use within a larger figural context.

In summary, using right-angled triangular stimuli with a single horizontal or vertical line presented as a baseline, the following hypotheses are tested;

First-drawn lines will tend toward making the figure more symmetrical (with 45° angles to increase in size, 90° angles to decrease).

Strokes drawn to baselines are expected to be less accurate than equivalent strokes from baselines.

Simple directional rules are expected to be increasingly used with the non-directionally controlled second line drawn.

Correct performance on a discrimination task using right-angled triangular stimuli is expected to increase with age and in an immediate presentation condition, with discrimination errors selecting the more symmetrical of two distractor stimuli.

Method

Stimuli

Discrimination Task

This task consisted of a series of horizontally presented pieces of white A4 size paper bound at the top of each page into a booklet. At the top of each page was a centrally positioned right-angled triangle with its horizontal and vertical lines (both 5cm) themselves at right-angles to the paper edges. Underneath this figure were three further triangles with the same horizontal and vertical line size and in the same approximate orientation. One of these three was a right-angled triangle, one with its horizontal/vertical angle increased by 10°, and the third triangle with the same angle decreased by 10°. To prevent discriminations being based on the slight differences in height or width of the three figures, each stimulus was presented on a different horizontal plane (level, 5mm up or down) and was rotated by one of either -5°, -10°, $+5^{\circ}$ or $+10^{\circ}$ from true vertical. It is necessary to rotate as well as re-align the target stimuli to ensure that discrimination is based solely on the triangles' internal angles and not on the orientation of individual lines to the paper edges or other stimuli. Thus none of the stimuli presented any external match-mismatch cues (Bryant, 1974, Chapter 4). The order, horizontal position and level of rotation of each of the three figures was randomized to this effect. An example of the format of this task is given in Figure Va after the following two pages.

Two near identical booklets (I and II) were constructed using the above principles, each containing eight discrimination tasks (the four triangle orientations (◿ , ◺ , ◹ , ◸) in both an immediate and delayed presentation condition. Order of presentation conditions and use of either booklet I or II was balanced for each age group; two booklets being used to test that differences in discrimination performance between the immediate and delayed conditions could not be attributed to the layout and order of presentation in each booklet.

Copying Task

Each subject copied a total of 16 randomly ordered figures in a horizontal or vertical baseline condition; namely the four triangle orientations with each of the two remaining lines to be drawn first, both to and from the baseline. The figure to be copied was given on the left of a horizontally presented A5 piece of white paper, with horizontal and vertical line size of 5cm and at right-angles to the paper edges. Colour coding was used to indicate which of the stimulus lines was the baseline, first and second lines to be drawn. Throughout the booklet the baseline was black, the first line in green and the second line in red. Subjects' own copies were made in black pencil. To denote the starting point of the first line (to or from the baseline), a small black circle was put at the appropriate end of the green line. To the right of the stimulus on the booklet page was drawn the single black baseline in the appropriate orientation. No 'starting circle' was provided for this line. Between each stimulus page was placed a further blank page to prevent the viewing of following stimuli. An example of the layout of the copying task is given in Figure Vb below.

Figure Va; The Layout of the Discrimination Task.

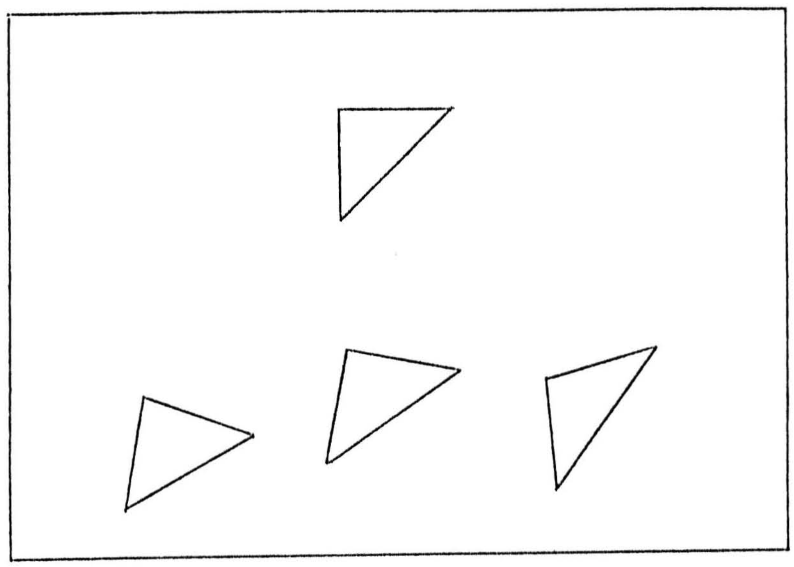
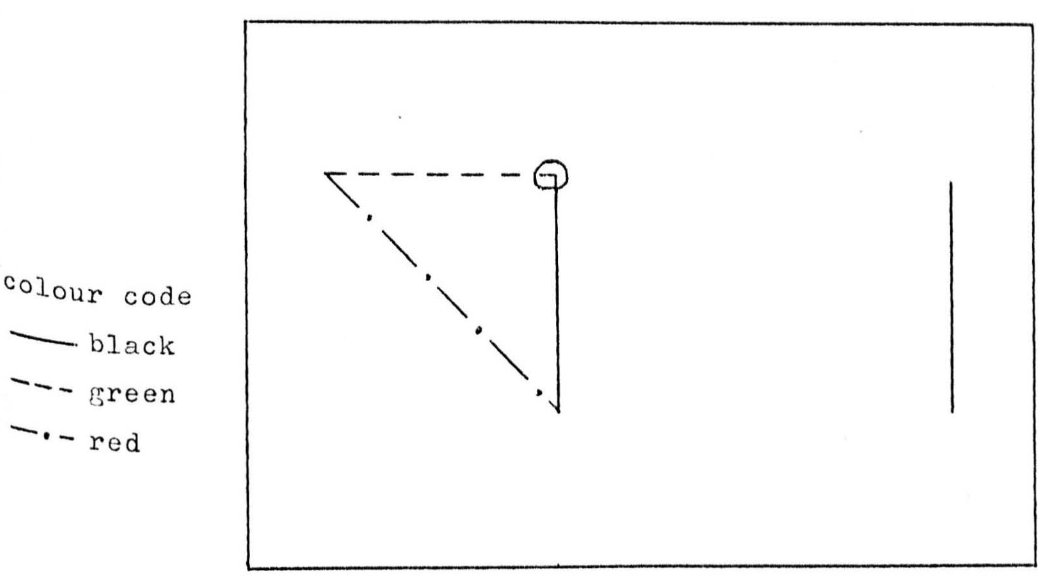


Figure Vb; An Example of the Copying Task using a Vertical Baseline.



Subjects

Three child and one adult groups participated in the study, each group containing 16 subjects. All subjects were right-handed to the extent of spontaneously picking up the pencil and drawing with their right hand, left-handers being excluded due to the differences in directional strategies employed by these subjects when drawing simple figures. The mean ages and standard deviations of the child groups were as follows in Table Vc;

Table Vc; Mean Ages and Standard Deviations of the Child Groups.

	Mean	Standard Deviation
Group A	5:10 years	2.5 months
Group B	6:9 years	2.7 months
Group C	8:6 years	3.2 months

The adult group (Group D) consisted of undergradute students from the University of Keele. All groups contained approximately equal numbers of males and females.

Procedure

Each subject participated in both the discrimination and copying tasks, but with the former task preceding the latter for each subject by three days. This time gap was to ensure that if subjects consistently selected a particular incorrect form of the triangle in the discrimination task, and then proceeded to draw similarly distorted figures, it would not be realistic to claim that the copying was influenced by recall from the discrimination task.

The discrimination task was itself preceded by a practice trial in which the target stimulus was presented in an array of grossly different figures, but in which the target itself was rotated by 10^{o}. The subject was informed that for future trials the aim was to select the figure that had 'exactly the same shape' as the target, regardless of rotation. For immediate presentation trials the target and three stimuli were seen concurrently, but for the delayed condition the target alone was viewed for five seconds, followed by the display of the stimuli without the target. No time limit was imposed for figure selection in either presentation condition.

At the front of the reproduction booklet three non-triangular stimuli were copied to familiarize the subject with the format of the task, the colour-based ordering of line drawing and the use of the 'starting circle'. The subject was told to draw the second red line 'in any direction you like'. Somewhat surprisingly this procedure was quickly grasped by the majority of even the youngest children, but whilst each copy was in progress vigilance on the part of the experimenter prevented potential starting-point errors. The booklet was fixed at right-angles in front of each subject to prevent rotation. The subject worked through the booklet at his or her own pace, and for each copy the experimenter noted the direction of drawing of the second line.

Scoring of angle errors for each copy was made in comparison with the baseline, and used the construction of a hypothetical straight line that joined the end-points of the line actually drawn by the subject. Angles were measured from this hypothetical line. When a line drawn continued beyond the baseline or second line, the intersection was used as the end-point from which the straight line was constructed.

Results

Discrimination Task

No differences in mean scores were found between subjects receiving discrimination task I or II, indicating that both formats of the task were of equal difficulty. The data from both formats of the task are combined in the tables below; Table Vd shows the mean number of correct discriminations made by subject groups under each presentation condition, with a maximum score of four (one for each triangle orientation) per condition.

Table Vd; Mean Discrimination Scores in Immediate and Delayed Conditions.

	Age Group (n = 16 per cell)			
Condition	A	B	C	D
Immediate	1.50	1.50	2.69	3.56
Delayed	1.50	1.13	2.50	3.50

One-way ANOVAs performed on Table Vd demonstrate increasing accuracy in discriminative ability for both immediate and delayed conditions (immediate condition, $F = 13.95$, d.f. = 3,60, $P < .001$; delayed condition, $F = 21.99$, d.f. = 3,60, $P < .001$), with Scheffé tests (10% acceptance level) showing significant single comparisons in the immediate condition to lie between Groups A or B vs C or D, and in the delayed condition between A or B vs C or D, and C vs D. Tables Ve and Vf in the Appendix give the full ANOVA tables. Thus the adult group discriminated more accurately than the oldest child group in the delayed presentation condition only. Related-sample t tests carried for each age group found no differences in discriminative accuracy between the immediate and delayed conditions. This result is not totally surprising with regard to Groups A and B, who appear to be operating at about a chance level, but not so for Groups C and D, who are more accurate in their discriminations.

Of greater concern to the present study is an examination of the errors made in the discrimination task, and whether these lie in a consistent direction. Incorrect discriminations necessarily selected triangles with component angles toward a more symmetrical figure ('+') or away from such a figure ('-'). Table Vg shows the sample sizes and frequencies of each subject group making '+' and '-' discrimination errors.

Table Vg; Frequency of '+' and '-' Errors in the Discrimination Task.

	Immediate Condition		Delayed Condition	
Age Group	'+' errors	'-' errors	'+' errors	'-' errors
A	21	19	18	40
B	26	14	35	11
C	13	8	17	7
D	4	3	4	4

To discover whether subjects of different ages reported differing proportions of '+' and '-' discrimination errors, a 'positive discrimination score' was calculated for each subject on the basis of the number of '+' errors minus '-' errors in each of the immediate and delayed conditions. A two-way ANOVA performed on this data revealed a significant age effect ($F = 4.26$, d.f. = 3, 60, $P < .01$), but no differences as a function of the discrimination condition ($F = .42$, d.f. = 1, 60, P = n.s.). No interaction between the age and condition variables was reported ($F = 1.01$, d.f. = 3, 60, P = n.s.). Table Vh in the Appendix gives the full ANOVA table. There is thus a difference with age in the tendency to make directional discrimination errors, with Scheffé tests (10% acceptance level) showing significant mean comparisons to lie between the six year old and both the five year old and adult groups. As Table Vg shows, it is the six and eight year olds that report a high level of '+' errors across the immediate and delayed conditions, 71% and 67% respectively.

The conclusion drawn from the discrimination task results is that the youngest age group (A) appeared to find the task as a whole rather difficult, responding at a 'chance' level in both the immediate and delayed conditions. This group also reported a lower level of '+' incorrect discrimination errors. Conversely adults were very accurate, leaving little error data. However, Groups B and C do show that when discrimination errors were made, they were made more often in the direction of the symmetry hypothesis.

Copying Task

T tests were carried out for each age group and line orientation to examine differences in accuracy between strokes drawn to or from baselines. Only three out of the 16 tests were significant, but these were all in the direction of to errors being greater than from errors. Thus the hypothesis predicting differences in this aspect of copying performance is not supported, and data from these two conditions is henceforth combined in the analysis of overall error levels.

Table Vi below gives the mean directional angle errors for the first line copied using both the horizontal and vertical baselines. All angles given are the internal angles measured between the first line and the baseline. Data is summed across the four triangle orientations and for lines copied to and from the baseline. For each line the expected error direction supporting the symmetry hypothesis is given, as is the direction ('+' for increased angle size, '-' for decreased size) of the mean for each subject group and the standard deviation.

Table Vi; Mean Directional Angle Errors for First-drawn Lines.

	Subject Group (n = 8 per cell)			
	A	B	C	D
V baseline, O drawn (+)	-2.11°	-6.97°	-5.03°	-1.02°
s.d.	6.56	2.61	2.21	1.46
H drawn (-)	-2.86°	$-.72^\circ$	-1.33°	$-.38^\circ$
s.d.	6.15	1.31	2.78	.28
H baseline, O drawn (+)	$+8.85^\circ$	$+9.02^\circ$	$+7.14^\circ$	$+1.58^\circ$
s.d.	5.38	6.35	3.56	1.29
V drawn (-)	$+1.08^\circ$	-1.74°	$-.61^\circ$	$-.77^\circ$
s.d.	2.87	3.83	.58	.99

A three-way ANOVA was performed on the data comprising Table Vi with the three variables of age group, baseline (vertical or horizontal) and the angle of the first line drawn (45^{o} or 90^{o}). This latter category pools data from the two 90^{o} angle conditions (verticals drawn from horizontal baselines and vice versa), both of which have '-' expected error directions. Main effects were found due to baseline condition ($F = 75.15$, d.f. = 1, 56, $P < .001$) and the angle of line drawn ($F = 13.10$, d.f. = 1, 56, $P < .001$) but not for age group ($F = 1.12$, d.f. = 3, 56, P = n.s.). Significant age group x baseline interactions ($F = 5.90$, d.f. = 3, 56, $P < .001$) and line drawn x baseline interactions ($F = 39.38$, d.f. = 1, 56, $P < .001$) were also noted. Scheffé tests revealed a large number of significantly different paired comparisons in the age group x baseline interaction, of which the majority (15/20) could be explained by differences between the vertical and horizontal baseline conditions. Inspection of Table Vi shows mean error to decrease for both baseline conditons across angle type as a function of age, with the exception being the mean of -2.49^{o} reported for the youngest age group with a vertical baseline, which is lower than both the means of -3.85^{o} and -3.18^{o} given by the six and eight year olds respectively. A clear pattern of results emerged from the analysis of the line drawn x baseline interaction; the four significant paired comparisons being accounted for by 90^{o} lines being drawn more accurately than 45^{o} lines with both vertical and horizontal baselines. The age groups were further implicated in a complex triple interaction with both baseline and line drawn conditions ($F = 4.15$, d.f. = 3, 56, $P < .01$). Table Vj in the Appendix gives the complete ANOVA table.

Analysis of the direction of angle errors in Table Vi shows a trend to reduce the size of 90^{o} angles in 7/8 cases reported, but that the mean directional errors for 45^{o} lines only supports the symmetry hypothesis for horizontal but not vertical baselines. However, in only 3/8 horizontal baseline cases and in none of the vertical baseline cases do these mean errors achieve significance using Z tests. Thus the symmetry hypothesis in its pure form is rejected in favour of one which notes the greater accuracy with which 90^{o} lines are drawn, and explains the direction of 45^{o} line errors in terms of the baseline orientation. Although no simple age effect has been found, age does enter into the age x baseline x angle type interaction, as well as the age x baseline interaction. There does appear to be a trend for copying to become more accurate; a non-directional analysis of the mean errors reported by the four age groups in Table Vi shows the 4.61^{o} reported by the six year olds to fall to 3.53^{o} at age eight and to $.94^{o}$ by adulthood. Interestingly, however, the five year olds are more accurate than the six year olds, giving a mean error across angle and baseline type of 3.73^{o}.

There is limited support here for a version of the 'vertical effect', a concept invoked in previous studies of single line reproduction using baselines as visual aids (Ibbotson and Bryant, 1976). In the present study 45^{o} angles tend to be reduced in size from vertical baselines and increased in size from horizontal ones, the net effect of which is to draw 45^{o} lines as more vertical than they infact are.

Directional Strategies

Although the direction of the first stimulus line to be drawn was controlled, the subject was free to draw the second vertical, horizontal or oblique line in either of the two possible directions. The following analysis of the simple choice of directionality ('rule use') is at two levels; firstly a comparison of changes in rule use between the subject groups, and secondly an examination of the 'theoretical probability' of each rule being used. Table Vk overleaf gives the percentage use of each of the four simple directional rules appropriate to each of the four line orientations, together with a χ^2 value associated with changes across the subject groups. Data are summed across baseline conditions and figure orientations.

Table Vk; Percentage Rule Use for Second-drawn Lines.

Subject Group (n = 64 per cell)

Rule	A	B	C	D	χ^2 (3 df)	sig
TB	81	66	70	75	4.35	n.s.
LR	56	59	66	92	23.75	***
↗	39	34	44	70	19.95	***
↘	70	70	59	88	12.83	***

Table Vk shows that with the exception of the 'TB' rule (draw verticals from top to bottom), rule use varies significantly as a function of subject age. For these remaining three rules, the general trend is for rule use to increase with the age of the subject, in line with the findings of Goodnow and Levine (1973). The 'TB' rule is used widely by even the youngest subjects, and the difference between the levels of rule use for the two oblique lines ('↘' more than '↗'), can be attributed to the right oblique (\) itself embodying two rules ('top start' and 'left start'), whereas a conflict exists in the left oblique (/) between the use of a 'left start' rule and an unpopular 'draw upwards' rule.

The present examination of rule use has centred on the use of simple directional rules for single lines within more complex figures. It may, however, be reasonable to assume that the 'theoretical probability' of a rule being used for these second drawn lines is also dependent on the position of the pencil immediately after having drawn the first line. For example, drawing <u>to</u> the baseline with the first line will ensure that the pencil is lifted to start the second line, but drawing the first line <u>from</u> the baseline will leave the pencil at the appropriate line-end to follow a rule in 2/4 triangle orientations, and at the inappropriate end in the remaining 2/4 orientations. This holds for the vertical, horizontal and both oblique lines. By assuming that an enforced pencil lift will leave, in theory, an equal or near-equal probability of a rule being used or not ('equal' probability), and that a first stroke finishing at the appropriate start point will increase the chance of a rule being used ('high' probability) or vice versa ('low' probability), Table Vl below re-examines the rule use data across subject age to test this 'high-equal-low' probability hypothesis. Sample size varies in this analysis as the data in the first-line <u>from</u> category is divided equally into the 'high' and 'low' probability classes.

Table V1; Percentage Rule Use as a Function of Theoretical Probability.

	Theoretical Probability				
Rule	Equal (n = 128)	High (n = 64)	Low (n = 64)	χ^2(2 df)	sig
TB	70	84	67	5.77	n.s.
LR	69	86	50	19.13	***
↗	46	75	20	38.49	***
↘	74	91	48	28.87	***

Table Vl shows the analysis of rule use in terms of 'theoretical probability' to be a valid one, with all four rules showing a trend in the direction of the hypothesis. The single rule for which this trend is not significant is the 'TB' rule, found here to be used at a 67% level even where the pencil is left at the bottom of the vertical after drawing the first stroke. Taken with the findings of Table Vk this particular result attests to the strength of the 'TB' rule. Although Table Vl does not examine rule use for individual subject groups, a further examination of the data revealed 13/16 of the individual analyses (four subject groups tested for each of the four rules) to be in the expected direction of rule use in the 'high' probability category to be greater than that in the 'equal' category, and for this to be in turn higher than the 'low' probability class.

An analysis of percentage use of copying rules within each theoretical probability level and across the four drawing rules was performed as a function of subject age. Table Vm overleaf reallocates the data from Table Vl according to these criteria, also giving χ^2 values and significance levels for tests performed between the subject groups. These show that at each probability level (equal, high, low), significant differences in percentage rule use exist as a function of subject age, with adults more consistent in directional rule use than the remaining three child groups. For example, when the pen was 'correctly' positioned for a rule to be followed (high probability), the ensuing stroke was in the predicted direction in 62/64 examples reported by adult subjects. This demonstrates again the high level of consistency with which adults employ simple directional rules, and the relative susceptibility of younger subjects to factors likely to decrease levels of rule use.

Table Vm; Frequency of Rule Use as a Function of Subject Age and Theoretical Probability.

Equal Probability (n = 128 per age group)

Subject Group	Rules Used	Rules Not Used	% Rule Use	χ^2(3 df)	sig
A	72	56	56		
B	78	50	61	16.24	***
C	81	47	63		
D	101	27	79		

High Probability (n = 64 per age group)

Subject Group	Rules Used	Rules Not Used	% Rule Use	χ^2(3 df)	sig
A	53	11	83		
B	49	15	77	11.47	***
C	51	13	80		
D	62	2	97		

Low Probability (n = 64 per age group)

Subject Group	Rules Used	Rules Not Used	% Rule Use	χ^2(3 df)	sig
A	22	42	34		
B	31	33	48	23.29	****
C	21	43	33		
D	45	19	70		

Discussion

The central findings of Study V are as follows; in a discrimination task those subject groups with a mean age of 6:9 and 8:6 years tended to make discrimination errors of selecting triangles which could be described as being more symmetrical than the correct stimulus of a right-angled triangle. However, evidence from the copying task found no simple 'symmetrical' effect, but rather that in the context of copying a right-angled triangle with the horizontal or vertical line presented as a baseline, the first-drawn 45^{o} line tended to be drawn more vertically than it infact was. An overall analysis failed to show any simple age differences in reproductive accuracy, but did find an interaction between baseline orientation and the type of first line drawn, with 90^{o} lines being more accurately drawn than 45^{o} lines in both vertical and horizontal baseline conditions.

The expected increase in 45^{o} angle size when drawn from vertical lines was not therefore supported, and the symmetry hypothesis rejected in its present form. Examination of the use of simple directional rules for the second-drawn line found increasing use with age of all but the 'draw verticals from top to bottom' rule, itself used highly by the youngest subject group, and further analysis vindicated an examination of rule use in terms of the 'theoretical probability' due to the final position of the pencil in the previously drawn line. To what extent do these findings concur or conflict with previous research in the area?

Explanations of the results from the discrimination task and comparisons with similar previous tasks are difficult but possible. In such comparisons care must be taken in accounting for differences both in the task procedure and the nature of the discriminative stimuli. Although

Bryant (1969) found immediate (or 'simultaneous') discriminations to be both very accurately made, and to be at a higher level than delayed ('successive') discriminations, the stimuli used in the present study are both more complex, and furthermore present none of the match-mismatch cues found to influence single line discrimination in Bryant's study. It would seem that these differences would be strong enough to account both for the lack of immediate/delayed condition differences in the present study and the fact that these findings do not replicate those of Bryant. This does not, however, prove the present discrimination task level to be insensitive to age as the result noting a preference for 'symmetrical' errors by Groups B and C shows. Unlike the discrimination task no simple differences in reproductive accuracy as a function of subject age were found in the copying task.

Is the explanation of this effect in the discrimination task in terms of 'symmetry' an appropriate one? The way in which these findings are labelled affects both the interpretation of results and future research in the area. To be called a 'symmetry' effect puts emphasis on the global features of the figure as a whole, although Palmer (1980) and Palmer and Bucher (1982) have noted that the perception of equilateral triangles is facilitated by both local and global levels of symmetry. For the copying task, an interpretation in terms of 'angle bisection' is not appropriate for the stimuli in the present study, but the findings from the copying task reject a global analysis in terms of symmetry, in favour of one which takes account of the specific biasses and distortions present in drawing and discriminating lines with baselines as visual aids. The tentative conclusion here is that a form of the 'vertical effect' may exist using these triangular stimuli. Another interpretation of the results from the copying task would be to regard the distortions of oblique angles using vertical baselines as intrinsically different from those using vertical baselines. A number of studies have demonstrated that single line reproduction from vertical baselines is more accurate than that from horizontal baselines (Berman, Cunningham and Harkulich, 1974; Ibbotson and Bryant, 1976), which may well be associated with the early development of the concept of 'vertical' noted by Freeman (1980) in representational drawings of people. Further investigation in the area of internal angle distortion would benefit from the inclusion of rotated baselines in the experimental design to control for the fact that all 45^{o} lines copied in this study were also at 45^{o} to the paper edges.

To what extent do the methods and results presented in Study V concord with those given in the previous four studies in the thesis? The present study has been the first to employ both child and adult subjects to compare directly copying accuracy and strategy as a function of age. Secondly, Study V is the only study to have included a discrimination task to examine the relationship between the nature of the representation of the stimulus and any consequent errors in its reproduction. Examination of copying errors to date has tended to be at a more global level compared with the present study, noting the frequency and type of stimuli that are correctly and incorrectly drawn, as well as those parts of stimuli that are included or omitted. The examination of angle errors in Study V represents a micro-analysis of one aspect of graphic skill that has been shown to be susceptible to distortion and error, and the present study has furthermore shown that for the structurally simple stimuli used here directional preferences in drawing are both present and employed at different levels by subjects of differing ages.

The use of a discrimination task in the present study produced interesting, though somewhat unexpected results, with some evidence for 'symmetrical' triangles to be preferred when discrimination errors are made. There was no evidence, however, that immediate discrimination is more accurate than delayed discrimination for the stimuli employed here. A further surprising result was that no simple age effects were found in the copying task itself, although biasses as a function of the type of baseline and line drawn were noted. One hypothesis to explain the lack of increasing reproductive accuracy with age is that the copying task itself was a relatively simple one to complete 'successfully', with only two lines to be drawn for each reproduction and with no memorization of the stimulus or its orientation necessary. Furthermore, the immediate visual framework surrounding each stimulus (the paper edges) provided a high level of contextual information shown to used by younger children in a number of studies of simple graphic reproduction (e.g. Brittain, 1976; Berman, 1976; Berman et al, 1974).

The methods by which drawing strategies have been examined in Study V also differ from previous studies in the thesis. Although Study IV also examined directional preferences for single lines, these were within more complex stimuli than those used in the present study. Here, each subject was presented with a choice of drawing direction for only a single line within each triangular stimulus. It was found that not only were age differences present for three out of the four directional rules (with adults being more consistent than the three child groups), but that the notion of the 'theoretical probability' of a rule being used was a valid one, at least for the simple directional choices presented here. Studies which have made use of simple drawing rules for the teaching of early handwriting skills (e.g. Kirk, 1981; Simner, 1981) may well be able to maximise the efficiency of rule-based instruction if the relationship between preferred starting points and stroke directions is explored more fully.

CONCLUSIONS

The aim of this final chapter is to present a short summary of the thesis. This summary takes the form of answers to a number of different questions relevant to the research within the thesis as a whole. These questions are at a number of levels, from descriptions of general findings to theoretical speculations about the processes that influence the development of copying strategies.

Do children change their copying accuracy with age?

Three studies addressed themselves to this question. In the first of these (Study I), two children aged between six and seven years were given a range of simple and complex figures to copy, as well as the complete series of upper and lower case letters. These two children copied each of these stimuli at least four times during the space of one year, during which period both children started to receive formal handwriting practice. It was hypothesised that this formal practice would influence their copies of the figures, making them more accurate and more likely to be produced with an increase in the use of 'drawing rules'. Although the methods for assessing the accuracy of a copy were rigorously controlled, it was unexpectedly found that the mean number of errors made when copying each type of stimulus did not decrease for these two children for the year in question, a period found by previous research to be one of quite rapid change in the organization of graphic behaviour.

However, a further study that employed a group design rather than an individually-based longitudinal one (Study III), found that children between the ages of six and nine years old did copy correctly a higher proportion of the figure stimuli given to them as they got older, but only when they needed to draw each figure from memory. The older children in this sample could also copy successfully those figures with a greater number of component lines than could the younger children, regardless of whether or not each figure did or did not need to be memorized before it was drawn.

The final study in the the (Study V) also examined the accuracy with which children of differing ages were capable of copying, but it did this from a rather different experimental standpoint. Here it was found that the size of the distortions made when reproducing the first of two lines from a baseline did not simply decrease as subjects got older, but that copying accuracy was influenced by a number of factors which included the orientation of the baseline itself and that of the other single line that was drawn. This experiment was designed to examine in detail one specific feature of children's copying with simple stimuli, that is that when copying 45^{o} lines from a baseline these lines tend to be drawn as more perpendicular than they really are. This finding has been shown to be a stable one in previous studies, but also has been shown in Study V to be influenced to some extent by the exact nature of the task given to the subjects.

How can the findings from these three studies be reconciled, when only two of the three find age-related differences in copying accuracy? Methodologically, the studies differ in two ways. Firstly, all three studies use different ways of assessing the accuracy of reproduction. The first study mentioned examined the mean number of different sorts of errors made when copying single stimuli, the second used a correct/incorrect measure to assess whether each copy had been successfully made, and the final study noted the level of error in terms of angular distortion. The study that assessed copying accuracy in terms of the mean number of errors per stimulus found no age differences, although there is no intrinsic reason why this method should be less sensitive than the other two methods used.

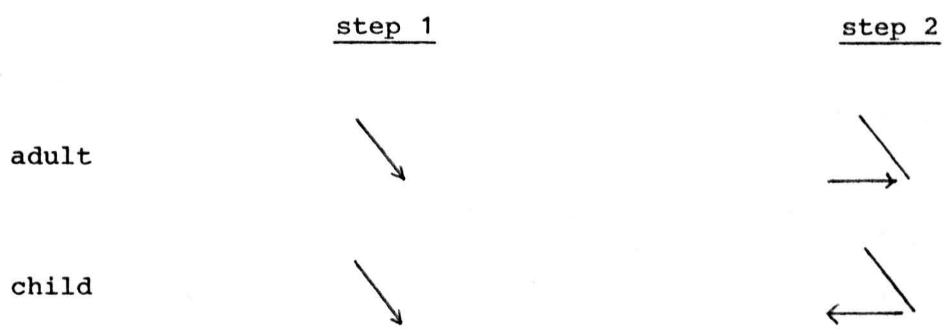
More importantly, the three studies also differed in the way subjects were selected and used. Only Study I, the study finding no age differences, used an individually-based and longitudinal design. Studies III and V both employed groups of subjects of different ages. More reliable trends in copying accuracy may have emerged from Study I if the two subjects had been tested over a longer period of time, or if a larger group-based design had been used. What did emerge from this study, as will be discussed shortly, was the high level of consistency with which the two subjects copied each group of stimuli, rather than any statistically significant changes in accuracy of reproduction. To discover age-related accuracy changes using Study I's methodology and the two subjects in question, the test period would have needed to be perhaps one year earlier, at which point in time both Emma and Shona would probably have been incapable of making any interpretable attempt at copying the more complex figures.

Do children change their copying strategies with age?

The same three studies (Studies I, III and V) also combined a developmental examination of copying strategies with that of reproductive accuracy, with different conclusions being drawn from each of the three studies. The Literature Appraisal outlined what was seen at that point as the clearest and most influential method of describing the strategies for copying simple figures, this being the six drawing rules of Goodnow and Levine (1973). These rules governed the points and directions for initial strokes made when copying (Top Start, Left Start, Vertical Start) and the direction and methods for combining further strokes (Verticals Top-to-bottom, Horizontals Left-to-right, Thread). The first study in the thesis found that for simple figures the two subjects used these rules (and in particular start rules) to an unexpectedly high degree at the first test session, leaving little opportunity for an increase in overall levels of rule use.

For more complex figure stimuli, the progression rules in particular were found not to be used at a high level at any of the four test sessions used in this first study. This does not imply, however, that the two subjects adopted an unstructured approach to the copying of these complex figures, rather that the measurement of drawing strategies simply in terms of drawing rules was inappropriate for these stimuli. Both Emma and Shona were found to be consistent in the strategies used for multiple copies of simple and complex figures, both in the short term ('within-session') and long term ('between-session'). What was partly concluded from this study was the inadequate sensitivity of Goodnow and Levine's drawing rules for complex figures.

Later studies in the thesis took this criticism into account, and explored new ways to describe copying strategies in detail. The second section of Study III, for example, found that those lines in a stimulus that were clearly identifiable as forming only a single connection with the remainder of the figure ('isolated lines') tended to be omitted by eight year olds from incorrect reproductions and postponed in the order of drawing in correct ones. Six year olds subjects, however, did not display this level of organizational behaviour, reflecting qualitative differences in the copying strategies of two age groups. Further age-related differences in the tendency to employ certain copying strategies were found in the final study. This study found that the trend to employ a consistent direction when copying a single line in a very simple stimulus not only increased with age (from six years to adulthood), but that adults were also more likely to employ a consistent stroke direction, regardless of whether or not the pen was already positioned at a point that would facilitate following this direction. For example, adults were more likely than any of the child groups to reposition their pen and draw a horizontal line in the more usual left-to-right direction, even though the pen had previously been placed at the right-hand end of this line. In this situation, a six or eight year old would be less likely to reposition the pen to enable left-to-right drawing, but would rather just draw from right-to-left (see diagram).



What can be concluded from these examples? Firstly, the methods used to assess this consistency need to be sufficiently sensitive to allow age-related changes to be detected. Secondly, it appears that with age children become more consistent in their drawing strategies, and in particular in their use of preferred directions for single lines.

How does this increased consistency with age arise? Goodnow and Levine's (1973) conception of the copying task as a form of problem solving is useful here. With age and through relevant experience comes a fluency in the 'knowing how to' aspects of solving problems, what Goodnow

(1972) described as the 'tricks of the trade'. In this article, Goodnow took the general concept of 'rules' for problem solving as being derived from experience relevant to the task in question. For an increased consistency in copying strategies to come about, one can therefore assume that practice with other graphic tasks leads gradually to the fluency, consistency and relative ease with which older children and adults have been shown in this thesis to copy simple stimuli or simple parts of more complex stimuli. Relevant experience in this case would be associated with the practice of simple motor programmes. These would gradually allow larger 'chunks' of behaviour to be performed. Examples within the area of graphic skills include the development of writing, printing and drawing, which emerge from the spontaneous scribbling and drawing of patterns found to exist before the development of representational skills (Kellogg; 1969, 1979).

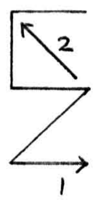
How does the nature of the task affect the way subjects copy?

Apart from studying the effect of different stimulus complexities on reproductive accuracy and strategy, two different experimental designs have been used to suggest how the nature of the task might affect the way subjects copy. Copying has taken place either with the stimulus remaining in view (immediate copying) or with a delay between perception and reproduction (delayed copying). This latter condition forces the subject to memorize the complete figure before a correct copy can be made, whereas in immediate copying continual comparison between the original and the ongoing reproduction can occur. How do these differences in the copying task influence reproductive strategies?

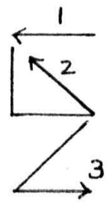
Two studies in the thesis employed delayed copying tasks, either singly or in combination with a more common immediate copying task, Study III with children and Study IV with adults. The first of these found not only that copying was more accurate in an immediate condition for each age group tested, but that the two copying conditions induced differing strategies. One of the methods used to assess copying strategies was to note the number of strokes used in each correct copy. It was found in Section B of Study III that a smaller number of individual strokes were used by subjects copying in the delayed condition. This was hypothesised as being caused by the memorization of stimuli in the delayed condition being to some extent in terms of parts rather than single lines. This higher level of organization in memory was then reflected in the drawing process which produced these parts in uninterrupted stroke sequences.

Study III found further differences in strategy as a function of immediate or delayed copying beyond the number of strokes used. These differences centred on the order of reproduction of component lines within stimuli. However, partly because of small sample sizes, only a small proportion of the stimuli used revealed distinct differences as a function of the copying condition. For example, those eight year olds who correctly copied the  figure in the immediate condition tended to draw in a complete sequence from the top to the bottom of the figure, finally adding in the top oblique line. Subjects in the delayed condition appeared to draw the triangle as a complete unit, finally adding in the bottom two lines. The diagram below gives a simplified version of the strategies from these two conditions.

immediate



delayed



One explanation to account for these differences is that the former top-to-bottom strategy is controlled predominantly by the ease of producing downward movements (a motor factor), whereas the second type of strategy involves a higher level of perceptual analysis which is then reflected in the final order of drawing and which places less emphasis on motor considerations.

Experimental differences within a delayed copying task were used in Study IV on adult subjects to examine exactly how figure stimuli were memorized in a task of this kind. A number of previous studies had suggested on the basis of results from the use of visual or verbal interference tasks that verbal processes were influential in the delayed recall of figure stimuli due to the formation of structural descriptions of each stimulus. Study IV employed visual and verbal interference tasks placed between the perception and reproduction of each stimulus, as well as a 'verbal description' condition designed to aid the formation of structural descriptions and to aid accuracy of reproduction relative to a control group. Infact, no effect on copying accuracy was found due to either of the verbally-based tasks, with the subject group receiving visual interference being the only one with significantly worse drawing accuracy than the control group.

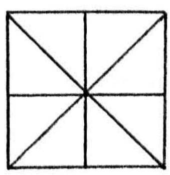
The redundancy of verbal processes here may have been due to methodological differences between this study and the previous studies with which it was being compared. Previous studies tended to have shorter periods for the initial viewing of the stimulus and smaller delays between viewing and reproduction (e.g. Christie and Phillips, 1979). A shorter time period would mean that subjects would be less likely to have the opportunity to employ alternative methods of representing the stimulus to themselves prior to reproduction. Thus verbal encoding may only be important if other forms of memorization are not possible. Further analyses within Study IV went on to consider in greater detail the methods with which adults organized their delayed copying strategies, regardless of the type of interpolated task that they had been given. Study IV was also designed to highlight the different kinds of parts of stimuli that were isolated and drawn, and it this area to which attention is now given.

How does the nature of the stimulus affect the way subjects copy?

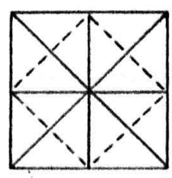
Study III showed that children were more likely to copy correctly figures with fewer, rather than a greater number of lines. Nonetheless, the upper limit on the number of component lines which children can successfully cope with is lower than that for adults, especially when children are forced to memorize the figure. Therefore the study of strategy when copying complex figures has concentrated almost exclusively on adults. Two studies within the thesis, although employing different methodologies, collected data on adults' copying strategies for these more complex figures.

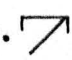
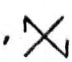
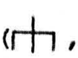
The first of these, Study II, differed from the second, Study IV, in that the former used a speeded immediate copying task and the latter used a delayed one with the interpolated tasks described earlier. It is possible to compare the findings that emerged from these studies, however, as both employed a similar framework from which stimulus figures were derived. For Study II this was based directly on that used by Palmer (1977), with Study II itself testing hypotheses on copying tasks generated from Palmer's perceptually-based study. Study IV's stimulus framework was modified to allow for a larger range of stimuli to be derived. The diagram below shows both of these frameworks. Stimuli were constructed by randomly selecting a fixed number of interconnecting lines from the framework.

Study II



Study IV



The copying task employed in Study II required subjects to make speeded reproductions of six-line figures, but failed to find any advantage in the overall speed of drawing or the time taken to start the drawing when 'Good' (Gestalt) parts were present within the figure. However, the adults did respond differently to the figures as a function of their structure, although not in the way that was originally controlled for. It was found that faster starting and copying was elicited by those stimuli which contained two or more compound lines (e.g. , ) or that were symmetrical as a whole about the vertical or horizontal axis or that possessed both features (, ). These features made the stimulus as a whole more simple and hence easier to recall when drawing, even though Study II did not use a delayed reproduction task. The simplicity of these figures would make it less likely that subjects would need to refer back to the original whilst copying or to spend as long in initially viewing the figure. It can be seen from these examples, however, that structural features of parts of figures (compound lines) are often those that contributed to the symmetry of the figure as a whole.

The extent to which certain stimulus parts aid the reproduction of the complete figure was more rigorously controlled in Study IV. Here, stimuli with four types of enclosed parts (square, triangular, 'complex' or no enclosed parts) were presented to subjects in the delayed copying task that has been outlined above. At a number of levels of analysis square parts were those found to aid the copying process as whole, being most often included in otherwise incorrect reproductions and also being copied as a unit within the complete figure. In addition, directional drawing rules were employed in the drawing of the enclosed parts. These directional drawing rules were simplified versions of Goodnow and Levine's progression rules, and governed the drawing of each of the four simple stimulus line orientations (horizontal, vertical, left and right oblique).

The essential difference between these directional rules and the previous progression rules was the way in which they were classified as having been used or not. Goodnow and Levine's measurement of progression rules was in terms of every line of particular orientation being drawn with the predicted direction before the progression rule in question was counted as being employed. This 1973 study also rather simplistically included all oblique lines as verticals for the analysis of copying strategies. To give a hypothetical example of these differing methods of assessing the use of consistent stroke directions, in a figure with three vertical lines (e.g. ) all three verticals would need to be drawn from top-to-bottom before Goodnow and Levine would state that the vertical progression rule had been used. The more flexible and sensitive method used in Study IV (and continued in Study V) was to note the proportion of vertical lines actually drawn in this manner.

Using this method it was found that directional rule use was higher for the enclosed parts that had already been isolated and drawn as units within the complete figure, regardless of the nature of the enclosure itself. Similarly, the three start rules were used at a higher degree for these units. It was concluded that adults' copying strategies for complex figures occurred at a number of different levels, from the perception of enclosed parts in the figure, to the drawing of these parts in uninterrupted stroke sequences together with the high proportion of rule use for these parts. This summary of the findings represents a considerable advance in the knowledge of the organization of adults' graphic behaviour with controlled stimuli, yet it does not contradict Goodnow and Levine's findings of high adult rule use for simple figures in immediate copying that stimulated in part the research contained within the thesis.

How do these studies improve on previous research?

This question has been answered in part in the previous section by noting the rigorous control that has been exercised in the design of figure stimuli. This consistency has facilitated increased sensitivity in the methods used in classifying copying strategies, and has also permitted comparisons to be drawn between studies in the thesis. Comparison of stimuli and hence strategies both with and between previous studies is less easy because of the lack of uniformity in figure design. For example, the papers by Ninio and Lieblich (1976) and Nihei (1980) have similar aims in attempting to categorize globally the strategies employed by young children when copying very simple figures. However, further comparison between the strategies outlined by the two sets of authors is difficult as both use different sets of stimuli. It is not unreasonable to question whether Ninio and Lieblich's analysis in terms of 'degrees of freedom' for drawing the | , —, ⊥ figures remains applicable to the still simple stimuli used by Nihei (┐, └ , [, ⫯). A further example is Goodnow and Levine's (1973) examination of rule use for the figure stimuli employed by Graham et al (1960). Interestingly, the stimuli that Goodnow and Levine omitted from this original sample were precisely those that did not lend themselves easily to the rules derived to account for copying behaviour in that they were circular in design (○ , ↄ , C). Although circular stimuli also cannot be derived from Palmer's framework, the latter method does represent a consistent approach to stimulus design lacking in previous research.

The thesis has also attempted to make quantifiable sense of qualitative data. One example here has been the use of incorrect copies as a source of information about the copying process as a whole. Rather than merely concentrate on the level of correct copies and strategies in making these, Study III examined the distinctive features of failed reproductions, and what they could tell us about the way children ordered the strokes within a copy. It was found not only that incorrect copies tended to omit isolated lines, but also that these were postponed in the drawing order for correct copies. Here, an examination of the nature of copying failure led to further analyses which were informative about successful copying.

The inclusion of actual examples of reproductions in Studies I and III has served as a background to the more formal analysis of copying strategy. Although these examples were not examined in detail in either study, they do provide an insight into the nature of the final graphic product and of the particular distortions and errors that tended to be made. A qualitative analysis of such copies, possibly longitudinally and in terms of the addition or omission of figure parts, would help draw the comparison between geometric figure reproduction and other representational graphic skills. Representational drawings not only provide a valuable source of information about the development of graphic and spatial skills, but they are of intrinsic interest, perhaps because children's drawings provide what appears to be a naive, simplistic and appealing view of the world. However, as Freeman (1980) has shown, the levels of organization and planning that exist in the youngest child's drawing of, for example, a human figure, demonstrate that a considerable level of planning and organizational technique exist even at this early stage. It is the analysis of process rather than product that helps the correspondence to be made between representational and non-representational graphic skills.

What more do we now know about copying strategies?

The description of strategies within the five studies contained in the thesis has been matched by an analysis of how these strategies arise, how they develop with age, and the best way that they can be categorized and examined. The approach within these studies has been a multi-level one, analysing within the specific design of each study the factors influential in determining copying strategies. What have we learned from this approach?

The simplest answer to this question is that with age, copying strategies become more consistent. However, beyond this response lies a host of other factors that have been the subject matter of the studies contained within the thesis. The precise structure of the stimulus to be copied and the nature of the copying task itself are two crucial variables influencing the copying response. Complex figures have not only been found to be more difficult to copy correctly for children of any age, but the analysis of strategy for these figures needs an approach that is sensitive to the complexity level of the stimulus itself. As has been shown, beyond the level of very simple stimuli subjects tend to organize their reproductions in terms of stimulus parts, with the enforced memorization of stimuli before reproduction increasing the level of part use.

REFERENCES

Abercrombie, M.L.J. (1970). Learning to draw. In K.J.Connolly (ed.), Mechanisms of Motor Skill Development. London: Academic Press.

Appelle, S. (1972). Perception and discrimination as a function of stimulus orientation: the oblique effect in man and animals. Psychological Bulletin, 78, 266-278.

Askov, E.N. & Greff, K.N. (1975). Handwriting: copying versus tracing as the most effective form of practice. Journal of Educational Research, 69, 96-98.

Askov, E.N., Otto, W. & Askov, W. (1970). A decade of research in handwriting - progress and prospect. Journal of Educational Research, 64, 99-111.

Attneave, F. & Arnoult, M.D. (1956). The quantitative study of shape and pattern perception. Psychological Bulletin, 53, 452-471.

Attneave, F. (1957). Physical determinants of the judged complexity of shapes. Journal of Experimental Psychology, 53, 221-227.

Attneave, F. (1968). Triangles as ambiguous figures. American Journal of Psychology, 81, 447-453.

Bayrakter, R. (1979). An analysis of various copying errors in young children. Unpublished D.Phil thesis, University of Sussex.

Beagles-Roos, J. & Greenfield, P.M. (1979). Development of structure and strategy in two-dimensional pictures. Developmental Psychology, 15, 483-494.

Beery, K.E. (1968a). Form reproduction as a function of complexity. Perceptual and Motor Skills, 26, 219-222.

Beery, K.E. (1968b). Geometric form reproduction: relationship to chronological and mental age. Perceptual and Motor Skills, 26, 247-250.

Beittel, K.R. (1972). Mind and Context in the Art of Drawing. New York: Holt, Rinehart & Winston.

Bender, L. (1938). A Visual Motor Gestalt Test and its Clinical Use. New York: American Orthopsychiatric Association.

Berman, P.W. (1976). Young children's use of the frame of reference in construction of the horizontal, vertical and oblique. Child Development, 47, 259-263.

Berman, P.W., Cunningham, J.G. & Harkulich, J. (1974). Construction of the horizontal, vertical and oblique by young children: failure to find the 'oblique effect'. Child Development, 45, 474-478.

Bernbaum, M., Goodnow, J.J. & Lehman, E. (1974). Relationships among perceptual-motor tasks: tracing and copying. Journal of Educational Psychology, 66, 731-735.

Birch, H.G. & Lefford, A. (1968). Visual differentiation, inter-sensory integration and voluntary motor control. Monographs of the Society for

Research in Child Development, 32, no. 110.

Boswell, S.L. (1976). Young children's processing of asymmetrical and symmetrical patterns. Journal of Experimental Child Psychology, 22, 309-318.

Bremner, J.G. & Taylor, A.J. (1982). Children's errors in copying angles: perpendicular error or bisection error? Perception, 11, 163-171.

Bremner, J.G. (1982). Errors in children's copies of angular figures: perpendicular effects and bisection effects? Unpublished paper; author at Department of Psychology, University of Lancaster.

Brittain, W.L. (1976). The effect of background shape on the ability of children to copy geometric forms. Child Development, 47, 1179-1181.

Bryant, P.E. (1969). Perception and memory of the orientation of visually presented lines by children. Nature, 224, 1331-1332.

Bryant, P.E. (1974). Perception and Understanding in Young Children. London: Methuen.

Casperson, R.C. (1950). The visual discrimination of geometric forms. Journal of Experimental Psychology, 40, 668-681.

Christie, D.F.M. & Phillips, W.A. (1979). Simple drawing and pattern completion techniques for studying visualization and long-term visual knowledge. Memory and Cognition, 7, 360-367.

Cohen, R.L. & Granstrom, K. (1968a). The role of verbalizing in the memorizing of conventional figures. Journal of Verbal Learning and Verbal Behavior, 7, 380-383.

Cohen, R.L. & Granstrom, K. (1968b). Interpolated task and mode of recall as variables in STM for visual figures. Journal of Verbal Learning and Verbal Behavior, 7, 653-658.

Cohen, R.L. & Granstrom, K. (1970). Interpolated task and mode of recall as variables in STM for visual figures. Journal of Verbal Learning and Verbal Behavior, 7, 653-658.

Cohen, R.L. (1966). Effect of verbal labels on recall of a visually simple figure: recognition vs recall. Perceptual and Motor Skills, 23, 859-862.

Coleman, E.B. (1970). Collecting a data base for reading technology. Journal of Educational Psychology Monographs, 61, Part 2.

Connolly, K.J. (1968). Some mechanisms involved in the development of motor skills. Aspects of Education, 7, 82-100.

Connolly, K.J. & Elliot, J. (1972). The evolution and ontogeny of hand function. In N. Blurton Jones (ed.), Ethological Studies of Child Behaviour. Cambridge University Press.

Deregowski, J.B. (1971). Symmetry, gestalt and information theory. Quarterly Journal of Experimental Psychology, 23, 381-385.

Di Leo, J.H. (1971). Young Children and their Drawings. London: Constable & Co.

Dreman, S.B. (1974). Directionality trends as a function of handedness and of reading and writing habits. American Journal of Psychology, 87, 247-253.

Edwards, B. (1981). Drawing on the Right Side of the Brain. London: Souvenir Press.

Ericsson, K.A. & Simon, H.R. (1980). Verbal reports as data. Psychological Review, 87, 215-251.

Fehrer, E.V. (1935). An investigation into the learning of visually perceived forms. American Journal of Psychology, 47, 187-221.

Feldt, L.S. (1962). The reliability of measures of handwriting quality. Journal of Educational Psychology, 53, 288-292.

Ferguson, G.A. (1976). Statistical Analysis in Psychology and Education. Tokyo: McGraw-Hill.

Fisher, C.B. & Heincke, S. (1982). Children's memory for oblique orientation: a matter of degree? Child Development, 53, 235-238.

Fisher, C.B. (1979). Children's memory for orientation in the absence of external cues. Child Development, 50, 1088-1092.

Freeman, N.H. (1980). Strategies of Representation in Young Children. London: Academic Press.

Furner, B.A. (1969). The perceptual-motor nature of learning in handwriting. Elementary English, 46, 886-894.

Gagné, R.M. & Smith, E.C. (1962). A study of the effects of verbalization on problem solving. Journal of Experimental Psychology, 63, 12-18.

Gardner, H. (1980). Artful Scribbles. London: Jill Norman.

Garner, W.R. & Clement, D.E. (1963). Goodness of pattern and pattern uncertainty. Journal of Verbal Learning and Verbal Behavior, 2, 445-452.

Garner, W.R. (1970). The stimulus in information processing. American Psychologist, 25, 350-358.

Garner, W.R. (1978). Aspects of a stimulus: features, dimensions and configurations. In E.Rosch & B.B.Lloyd (eds.), Cognition and Categorization. New Jersey: Lawrence Erlbaum Associates.

Gesell, A. & Ames, L.B. (1946). The development of directionality in drawing. Journal of Genetic Psychology, 68, 45-61.

Gibson, E.J., Gibson, J.J., Pick, A.D. & Osser, H. (1962). A developmental study of the discrimination of letter-like forms. Journal of Comparative and Physiological Psychology, 55, 897-906.

Glanzer, M. & Clark, W.H. (1964). The verbal loop hypothesis: conventional figures. American Journal of Psychology, 77, 621-626.

Goodenough, F.L. (1926). Measurement of Intelligence by Drawings. New York: Harcourt, Brace & World.

Goodnow, J.J. & Levine, R.A. (1973). 'The grammar of action': sequence and syntax in children's copying. Cognitive Psychology, 4, 82-98.

Goodnow, J.J. (1972). Rules and repertoires, rituals and tricks of the trade: social and informational aspects to cognitive and representational development. In S.Farnham-Diggory (ed.), Information Processing in Children. London: Academic Press.

Goodnow, J.J. (1977). Children's Drawings. London: Fontana.

Goodnow, J.J., Friedman, S., Bernbaum, M. & Lehman, E.B. (1973). Direction and sequence in copying: the effect of learning to write in English and Hebrew. Journal of Cross-Cultural Psychology, 4, 263-282.

Graham, F.K. & Kendall, B.S. (1946). Memory for Designs Test. St. Louis: Washington University Press.

Graham, F.K. & Kendall, B.S. (1960). Memory for designs test: revised general manual. Perceptual and Motor Skills, 11, 147-188.

Graham, F.K., Berman, P.W. & Ernhart, C.B. (1960). Development in preschool children of the ability to copy forms. Child Development, 31, 339-359.

Greenberg, J.W. (1972). Synthesis and analysis of visually perceived forms. Perceptual and Motor Skills, 34, 735-741.

Handel, S. & Garner, W.R. (1966). The structure of visual pattern associates and pattern goodness. Perception and Psychophysics, 1, 33-38.

Hanfmann, E. (1933). Some experiments on spatial position as a factor in children's perception and reproduction of simple figures. Psychologische Forschung, 17, 319-329.

Hayes, D. (1982). Handwriting practice: the effects of perceptual prompts. Journal of Educational Research, 75, 169-172.

Herrick, V.E. & Okada, N. (1963). The present scene: practices in the teaching of handwriting in the United States - 1960. In V.E.Herrick (ed.), New Horizons for Research in Handwriting. University of Wisconsin Press.

Hirsch, E. & Niedermeyer, F.C. (1973). The effects of tracing prompts and discrimination training on kindergarten handwriting performance. Journal of Educational Research, 67, 81-86.

Hochberg, J. & McAlister, E. (1953). A quantitative approach to figural goodness. Journal of Experimental Psychology, 46, 361-364.

Hochberg, J. (1974). Organization and the gestalt tradition. In E.C.Carterette & M.P.Friedman (eds.), Handbook of Perception, Volume 1. London: Academic Press.

Huttenlocher, J. (1967). Discrimination of figure orientation: effects of relative position. Journal of Comparative and Physiological Psychology, 63, 359-361.

Ibbotson, A. & Bryant, P.E. (1976). The perpendicular error and the vertical effect in children's drawings. Perception, 5, 319-326.

Ilg, F.L. & Ames, L.B. (1964). School Readiness. New York: Harper & Row.

Jarman, C. (1973). Is children's handwriting neglected? Where, 76, 5-8.

Jarman, C. (1979). The Development of Handwriting Skills. Oxford: Basil Blackwell.

Jeffrey, W.E. (1966). Discrimination of oblique lines by children. Journal of Comparative and Physiological Psychology, 62, 154-156.

Kellogg, R. (1969). Analyzing Children's Art. Palo Alto: Mayfield.

Kellogg, R. (1979). Children's Drawings, Children's Minds. New York: Avon.

Kirk, U. (1978). Rule-based instruction: a cognitive approach to beginning handwriting instruction. Unpublished thesis, Columbia University Teacher's College.

Kirk, U. (1981). The development and use of rules in the acquisition of perceptual motor skill. Child Development, 52, 299-305.

Lehman, C.L. (1973). Handwriting legibility - a method of objective evaluation. Visible Language, 7, 325-344.

Lewis, E.R. & Lewis, H.P. (1964). Which manuscript letters are hard for first graders? Elementary English, 41, 855-858.

Lewis, E.R. & Lewis, H.P. (1965). An analysis of errors in the formation of manuscript letters by first grade children. American Educational Research Journal, 2, 25-35.

Lowenfeld, V. & Brittain, W.L. (1966). Creative and Mental Growth. New York: Macmillan.

Maccoby, E.E. & Bee, H.L. (1965). Some speculations concerning the lag between perceiving and performing. Child Development, 36, 367-377.

Maccoby, E.E. (1968). What copying requires. Ontario Journal of Educational Research, 10, 163-170.

Miller, G.A., Galanter, E. & Pribram, K.E. (1960). Plans and the Structure of Behavior. New York: Holt, Rinehart and Winston.

Miller, S. (1975). Experimental Design and Statistics. London: Methuen.

Mitchelmore, M.C. (1978). Developmental stages in children's representation of regular solid figures. Journal of Genetic Psychology, 133, 229-239.

Moxley, R. (1975). Acquisition of writing skills. Visible Language, 9, 225-248.

Naeli, N. & Harris, P.L. (1976). Orientation of the diamond and the square. Perception, 5, 73-77.

Newland, T.E. (1932). An analytic study of the development of illegibilities in handwriting from the lower grades to adulthood. Journal of Educational Research, 26, 249-258.

Nihei, Y. (1980). Developmental change in motor organization: covert principles for the organization of strokes in children's drawing. Tohoku Psychologica Folia, 39, 17-23.

Ninio, A. & Lieblich, A. (1976). The grammar of action; 'phrase structure' in children's copying. Child Development, 47, 846-50.

Ninio, A. (1979). On the testing of Piaget's hypothesis of topological primacy in representational space by copying geometric figures. Human Development, 22, 385-389.

Nisbett, R.E. & Wilson, T. de Camp. (1977). Telling more than we know: verbal reports on mental processes. Psychological Review, 84, 231-259.

Olson, D.R. (1970). Cognitive Development. London: Academic Press.

Palmer, S.E. & Bucher, N.M. (1982). Textural effects in perceived pointing of ambiguous triangles. Journal of Experimental Psychology; Human Perception and Performance, 8, 693-708.

Palmer, S.E. & Hemenway, K. (1978). Orientation and symmetry: effects of multiple, rotational and near symmetries. Journal of Experimental Psychology; Human Perception and Performance, 4, 691-702.

Palmer, S.E. (1977). Hierarchical structure in perceptual representation. Cognitive Psychology, 9, 441-474.

Palmer, S.E. (1980). What makes triangles point: local and global effects in configurations of ambiguous triangles. Cognitive Psychology, 12, 285-305.

Peck, M., Askov, E.N. & Fairchild, S.H. (1980). Another decade of research in handwriting: progress and prospect in the 1970s. Journal of Educational Research, 73, 283-298.

Piaget, J. & Inhelder, B. (1956). The Child's Conception of Space. London: Routledge & Kegan Paul.

Pigram, J.S. (1979). An investigation into plan use in geometric figure copying: a part-replication and extension of Goodnow and Levine's 'grammar of action' study. Unpublished degree thesis, Portsmouth Polytechnic.

Pomerantz, J.R. (1977). Pattern goodness and speed of encoding. Memory and Cognition, 5, 235-241.

Pomerantz, J.R., Sager, L.R. & Stoever, R.J. (1977). Perception of wholes and of their component parts: some configural superiority effects. Journal of Experimental Psychology; Human Perception and Performance, 3, 422-435.

Rand, C.W. (1973). Copying in drawing: the importance of adequate visual analysis versus the ability to utilize drawing rules. Child Development, 44, 47-53.

Reed, G.F. & Smith, A.C. (1961). Laterality and directional preferences in a simple perceptual-motor task. Quarterly Journal of Experimental Psychology, 13, 122-124.

Reed, S.K. (1973). Psychological Processes in Pattern Perception. London: Academic Press.

Reed, S.K. (1974). Structural descriptions and the limitations of visual images. Memory and Cognition, 2, 329-326.

Reed, S.K. & Johnsen, K.A. (1975). Detection of parts in patterns and images. Memory and Cognition, 3, 569-575.

Robson, C. (1973). Experiment, Design and Statistics. Harmondsworth: Penguin.

Rock, I. & Leaman, R. (1963). An experimental analysis of visual symmetry. Acta Psychologica, 21, 171-183.

Rock, I., Halper, F. & Clayton, T. (1972). The perception and recognition of complex figures. Cognitive Psychology, 3, 655-673.

Rudel, R.G. & Teuber, H.L. (1963). Discrimination of direction of line in children. Journal of Comparative and Physiological Psychology, 56, 892-898.

Scher, A. & Unruh, W.R. (1983). On the codes and processes involved in identity judgements of oblique lines. British Journal of Developmental Psychology, 1, 99-107.

Sekuler, R.W. & Rosenblith, J.F. (1964). Discrimination of the direction of line and the effect of stimulus alignment. Psychonomic Science, 1, 143-144.

Siegel, S. (1956). Nonparametric Statistics. Tokyo: McGraw-Hill.

Simner, M.L. (1981). The grammar of action and children's printing. Developmental Psychology, 17, 866-871.

Somerville, S.C. (1983). Individual drawing styles of three children from five to seven years. In D.R.Rogers & J.A.Sloboda (eds.), The Acquisition of Symbolic Skills. New York: Plenum Press.

Sommers, P.van. (1983). The conservatism of children's drawing strategies: at what level does stability persist? In D.R.Rogers & J.A.Sloboda (eds.), The Acquisition of Symbolic Skills. New York: Plenum Press.

Sovic, N. (1979). Some instructional parameters related to children's copying performance. Visible Language, 13, 314-330.

Stennett, R.G., Smythe, P.C., Hardy, M. & Wilson, H.R. (1972). Developmental trends in letter printing skill. Perceptual and Motor Skills, 34, 183-186.

Strayer, J. & Ames, E.W. (1972). Stimulus orientation and the apparent developmental lag between perception and performance. Child Development, 43, 1345-1354.

Taylor, M. & Bacharach, V.R. (1981). The development of drawing rules: metaknowledge about drawing influences performance on nondrawing tasks. Child Development, 52, 373-375.

Thomassen, A.J.W.M. & Teulings, H.L.H.M. (1979). The development of directional preference in writing movements. Visible Language, 13, 299-313.

Townsend, E.A. (1951). A study of copying ability in children. Genetic Psychology Monographs, 43, 3-51.

Vitz, P.C. & Todd, T.C. (1971). A model of the perception of simple geometric figures. Psychological Review, 78, 207-228.

Werner, H. (1948). Comparative Psychology of Mental Development. New York: Follett Publishing Co.

Williams, J.P. (1975). Training children to copy and discriminate letter-like forms. Journal of Educational Psychology, 67, 790-795.

Williamson, A.M. & McKenzie, B.E. (1979). Children's discrimination of oblique lines. Journal of Experimental Child Psychology, 27, 533-543.

Winer, B.J. (1970). Statistical Principles in Experimental Design. London: McGraw-Hill.

Wright, C.D. & Wright, J.P. (1980). Handwriting; the effectiveness of copying from moving versus still models. Journal of Educational Research, 74, 95-98.

Young, R.M. (1978). Strategies and the structure of a cognitive skill. In G.Butterworth (ed.), Strategies of Information Processing. London: Academic Press.

APPENDIX

Table Ia; The Error Checklist of Lewis and Lewis (1965).

1) Reversal of a letter

2) Partial omission of a letter

3) Addition of an unnecessary part

4) Incorrect relationship between parts

5) Incorrect size of letter or part of letter

6) Incorrect placement relative to line

7) Misshapenness

8) Rotation of a letter

9) Retracing after initial construction

10) Total omission

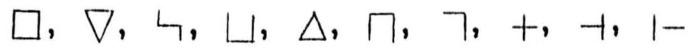
Table Ib; The Expanded Checklist used in Study I.

	Error Category	Criteria/Comments
1)	First oblique drawn too vertically	Stimulus must have oblique
2a)	Unnecessary retracing over line(s)	
b)	Faulty retracing over line(s)	Where retracing is possible
3)	Breaks in the copy	Not join underextension
4)	Faulty positioning of joins	
5a)	Overextension at line join	5a) and b) both possible
b)	Underextension at line join	in same reproduction
6a)	Whole figure too large	6a) and b): 5mm error
b)	Whole figure too small	allowed
7)	Upper/lower case replacement	Where the two versions are structurally different
8)	Rotation of stimulus copy	Sufficient to distort
9)	Stimulus reversal or reflection	
10)	Copy unrecognizable from the original	
11)	Omission of line or part of line	Not due to faulty line join
12)	Lines not uniformly straight or curved	
13)	Addition of line or part of line	
14a)	Incorrect baseline placement- above	14a) and b): 1mm error
b)	Incorrect baseline placement- below	allowed
15)	Misshapenness	Incorrect spatial relationship between lines or parts

Table Ic; The Checklist Error Categories.

Stimulus Formation:	Errors 1 to 7, 9 to 13, 15.
Stimulus Position:	Errors 8 and 14.
Global Production:	Errors 6 to 10, 14 and 15.
Part Production:	Errors 1 to 5, 11 to 13.

Table Id; Figure Stimuli included in the Analysis of Rule Use.

Simple Figures		Sample Size
Top Start		10
Left Start	" " " " " " " " " "	10
Vertical Start	" " " " " " " " " "	10
T-B	" " " " " " "	7
L-R	" " " " " " "	7
Thread	" " " " " " "	7

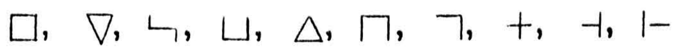
Complex Figures		
Top Start		11
Left Start	" " " " " " " " " " "	11
Vertical Start	" " " " " " " " " "	10
T-B	" " " " " " " " " " "	11
L-R	" " " " " " " " "	9
Thread	" " " ", 	5

Table Ie; Letter Stimuli included in the Analysis of Rule Use.

Upper Case Letters		Sample Size
Top Start	all	26
Left Start	all	26
Vertical Start	not C, K, M, N, O, S, V, W, X, Y	16
T-B	not C, O, S	23
L-R	A, E, F, H, I, L, T, Z	8
Thread	not A, C, E, F, H, I, K, O, Q, T, X, Y	14

Lower Case Letters		Sample Size
Top Start	all	26
Left Start	not i, l	24
Vertical Start	not c, e, k, l, o, s, v, w, x	17
T-B	not c, e, o, s	22
L-R	e, f, t, z	4
Thread	not c, f, i, j, k, l, o, t, x	17

Table Ij; Figure Stimuli included in the Analysis of Consistency of Rule Use.

Simple Figures		Sample Size
Top Start		10
Left Start	" " " " " " " " " "	10
Vertical Start	" " " " " " " " " "	10
T-B	" " " " " " " " " "	10
L-R	" " " " " " " " " "	10
Thread	" " " " " " "	7

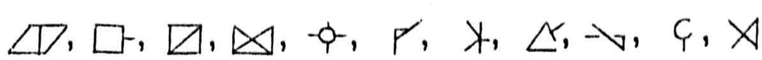
Complex Figures		Sample Size
Top Start		11
Left Start	" " " " " " " " " " "	11
Vertical Start	" " " " " " " " " "	10
T-B	" " " " " " " " " " "	11
L-R	" " " " " " " " "	9
Thread	" " " ", 	5

Table Ip; Mean Number of Errors Committed for each Stimulus Group.

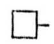
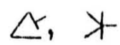
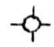
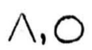
	Figures				Letters		
	Simple		Complex		Upper Case		Lower Case
	2.63		5.38	V, Z	2.00	v	1.25
	3.00		6.00	S	2.13	l, i	1.38
	3.13		6.75	L	2.38	s	1.63
	3.38		7.00	U	2.50	c	1.88
	3.63		7.13	T, C	2.75	b, h, j, w	2.13
	3.75		7.38	A, F, W	2.88	u	2.38
	5.13		7.75	H, I, J	3.25	m, o, x, z	2.50
	5.25		8.13	X	3.38	q, r	2.63
	5.38		9.38	D	3.50	n	2.88
	5.50		12.25	K, R, Y	3.63	t	3.13
	5.63			E	3.68	e	3.38
	6.38			G	3.75	y	3.50
	9.25			M	3.88	a, d, p	3.75
				O	4.00	f	4.00
				N	4.13	g	4.63
				Q	4.50	k	4.88
				B	4.63		
				P	5.00		
mean n. errors	4.81		7.56		3.32		2.74

Table IIe; Mean Length of Time Taken to Start Drawing G and NG Figures.

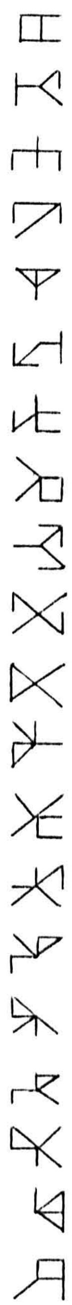
	Time Taken (Seconds)					
	First Copy		Repeat Copy		Mean Value	
Subject	G	NG	G	NG	G	NG
S1	2.07	1.95	1.64	1.92	1.86	1.94
S2	1.90	1.58	2.32	2.09	2.11	1.81
S3	1.54	1.38	1.10	1.12	1.34	1.27
S4	1.41	1.23	1.46	1.34	1.44	1.29
S5	1.63	1.53	1.53	1.57	1.54	1.55
S6	1.84	1.64	1.67	1.56	1.76	1.60
S7	1.07	1.03	.88	1.04	.98	1.04
S8	1.30	1.24	1.37	1.22	1.34	1.23
S9	.98	1.05	.92	.91	.95	.98
S10	1.77	1.64	1.95	2.40	1.86	2.02
Mean	1.55	1.43	1.48	1.52	1.52	1.47

Table IIg; Mean Length of Time Taken to Draw G and NG Figures.

	Time Taken (Seconds)					
	First Copy		Repeat Copy		Mean Value	
Subject	G	NG	G	NG	G	NG
S1	7.65	6.92	7.08	6.37	7.37	6.68
S2	6.47	5.27	7.41	6.24	6.94	5.71
S3	5.08	5.14	4.25	4.11	4.71	4.68
S4	3.75	3.22	4.33	3.49	4.04	3.36
S5	4.63	3.98	4.42	4.44	4.53	4.21
S6	7.50	6.43	6.07	4.92	6.79	5.68
S7	3.30	2.63	2.91	2.34	3.11	2.49
S8	5.18	4.48	4.34	3.91	4.76	4.20
S9	2.47	1.92	2.19	1.70	2.33	1.81
S10	5.84	5.31	8.62	7.33	7.23	6.32
Mean	5.19	4.53	5.16	4.49	5.18	4.51

Table IIh; Stimulus Ranking of Mean Starting and Drawing Times (Seconds) and Consistency Values (CVs).

			To Start Drawing		To Draw		Consistency	
Order	G/NG	—	Figure	Time	Figure	Time	Figure	CV (max=6)
1	NG	—		1.27		3.16		5.70
2	G	—		1.33		3.44		5.25
3	NG	—		1.36		3.52		5.20
4	G	—		1.38		3.80		5.10
5	NG	—		1.39		4.11		5.00
6	G	—		1.46		4.15		4.93
7	NG	—		1.47		4.21		4.75
8	NG	—		1.48		4.55		4.70
9	G	—		1.48		4.73		4.65
10	NG	—		1.50		4.89		4.60
11	NG	—		1.51		4.89		4.57
12	G	—		1.51		4.99		4.56
13	NG	—		1.52		5.23		4.45
14	NG	—		1.54		5.23		4.44
15	G	—		1.57		5.39		4.30
16	G	—		1.58		5.69		4.25
17	G	—		1.59		5.71		4.05
18	G	—		1.60		5.79		3.80
19	NG	—		1.60		6.02		3.35
20	G	—		1.71		6.58		3.30



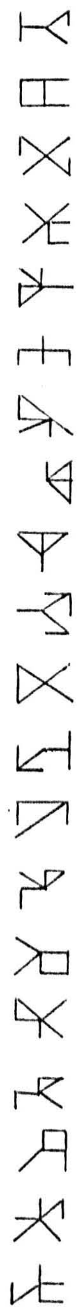


Figure IIk; Percentage Length of Time Taken for Drawing Units in G Figures.

Figure

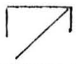
						
40.6	50.1	49.3	54.3	51.6	47.8	44.8
41.8	40.7	48.0	52.0	48.0	29.9	37.2
43.1	41.1	40.4	62.3	32.4	43.4	46.8
40.9	44.5	47.0	54.5	28.3	45.3	37.1
34.8	43.4	44.3	72.7	47.9	49.5	56.9
41.4	57.7	59.1	57.0	53.3	50.7	39.0
34.3	51.7	49.6	58.4	22.8	55.4	38.2
33.7	42.6	52.9	50.9		41.0	40.6
38.6	43.1	39.9	57.8		43.8	
33.4	58.2	43.2	65.5		45.5	
	41.1	38.5	58.9		54.1	
	37.3	45.9	61.7		70.5	
	39.9	44.2	59.6		43.7	
	35.5	41.8			51.4	
	40.6	45.7			44.0	
		72.9			53.9	
		59.3			37.1	
		40.9			38.0	
		40.6				

Table IIIe; Two-way ANOVA Table for the Immediate Copying Condition.

	Sum of Squares	df	Mean Square	F
Age Condition	15.36	3	5.12	2.94
Error	34.88	20	1.74	
Figure Condition	6.28	3	2.09	4.84
Age x Figure Interaction	9.01	9	1.00	2.31
Error	25.96	60	.43	
Total	91.49	95		

Table IIIh; Two-way ANOVA Table for the Delayed Copying Condition.

	Sum of Squares	df	Mean Square	F
Age Condition	69.46	3	23.15	13.42
Error	34.50	20	1.73	
Figure Condition	47.21	3	15.74	33.52
Age x Figure Interaction	23.62	9	2.62	5.59
Error	28.17	60	.47	
Total	202.96	95		

Table IIIi; Values Obtained from Immediate/Delayed Condition T Tests.

Age Group (Years)		Number of Lines in Figure (df = 10; 1 tail tests)			
		4	5	6	7
	6	11.18****	4.29***	4.60****	5.22****
	7	4.78****	5.27****	10.14****	10.38****
	8	6.07****	5.68****	8.03****	13.00****
	9	2.00**	4.02***	5.22****	10.38****

Table IIIk; Two-way ANOVA Table for the Copying Condition/Figure-Complexity Analysis.

	Sum of Squares	df	Mean Square	F
Copying Condition	398.23	1	398.23	129.19
Error	64.68	21	3.08	
Figure Condition	26.48	1	26.48	15.10
Condition x Figure Int.	13.00	1	13.00	7.42
Error	36.75	21	1.75	
Total	539.14	45		

Table IIIm; Mean Number of Strokes in Correct Copies of Four-line Figures.

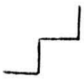
Figure	Condition	n	Mean No. of Strokes
	Immediate	10	2.40
	Delayed	6	1.33
	I	11	1.64
	D	9	1.00
	I	11	2.36
	D	4	1.00
	I	11	2.73
	D	3	2.33
	I	11	2.91
	D	6	2.83
	I	11	2.00
	D	9	2.11
	I	11	2.91
	D	6	2.67
	I	11	2.45
	D	8	2.13
	I	11	3.36
	D	6	3.33
	I	11	2.82
	D	5	2.40

Table IIIn; Mean Number of Strokes in Correct Copies of Six-line Figures.

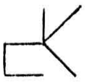
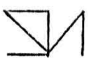
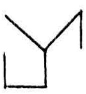
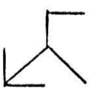
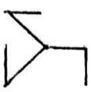
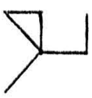
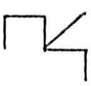
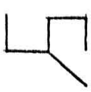
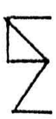
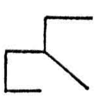
Figure	Condition	n	Mean No. of Strokes
	Immediate	9	4.22
	Delayed	1	4.00
	I	9	3.67
	D	1	1.00
	I	11	3.36
	D	4	3.00
	I	11	4.55
	D	4	3.75
	I	11	3.36
	D	0	-
	I	9	3.67
	D	2	1.50
	I	11	3.45
	D	8	2.25
	I	11	3.27
	D	4	2.25
	I	11	3.73
	D	3	2.67
	I	11	3.27
	D	3	2.33

Figure IIIu; The Twenty Copies made by a 6:4 Year Old in the Delayed Condition: Four-line Figures

Stimulus (half-size) Copy (original size)

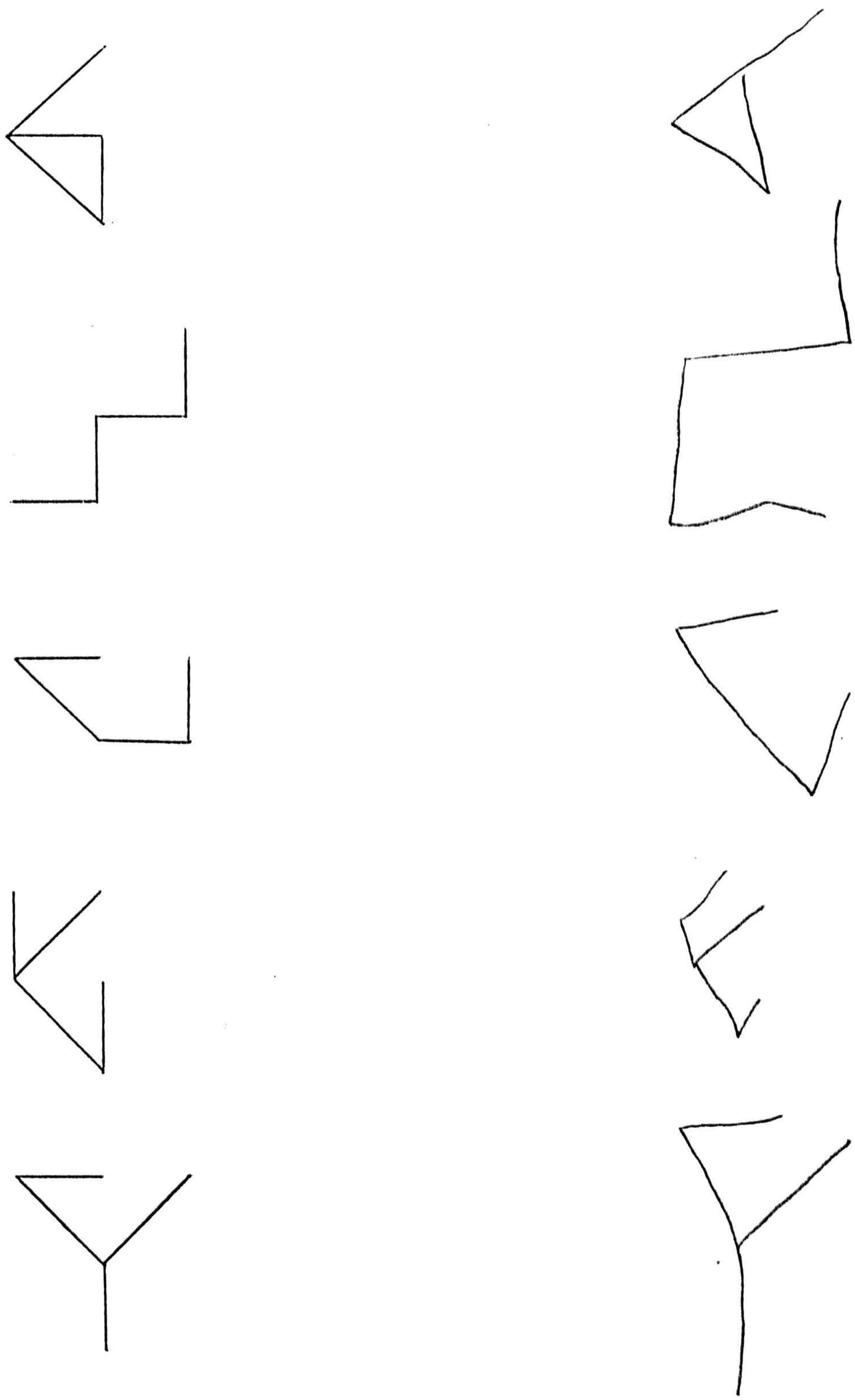


Figure IIIu Continued; Five-line Figures

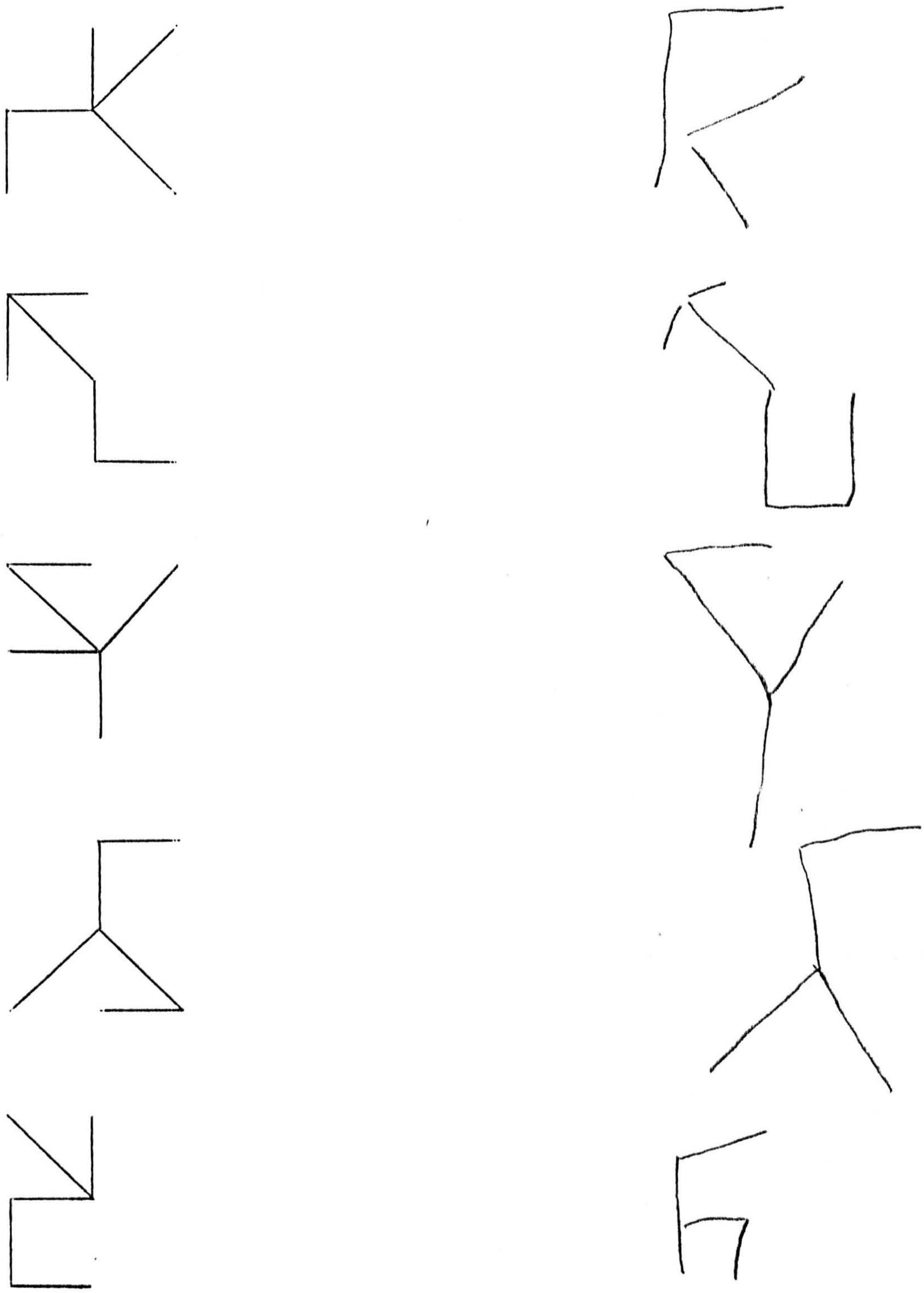


Figure IIIu Continued; Six-line Figures

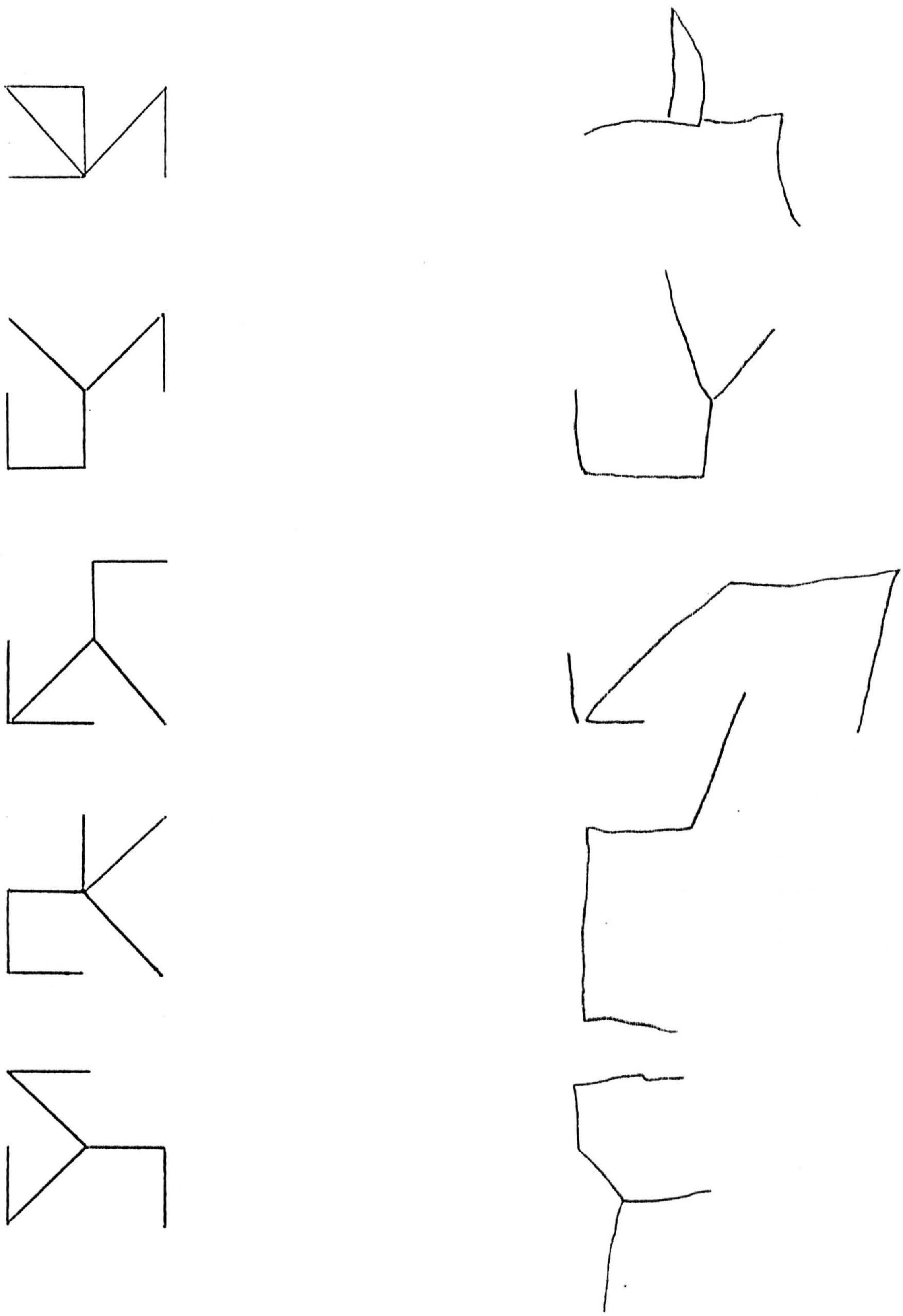


Figure IIIu Continued; Seven-line Figures

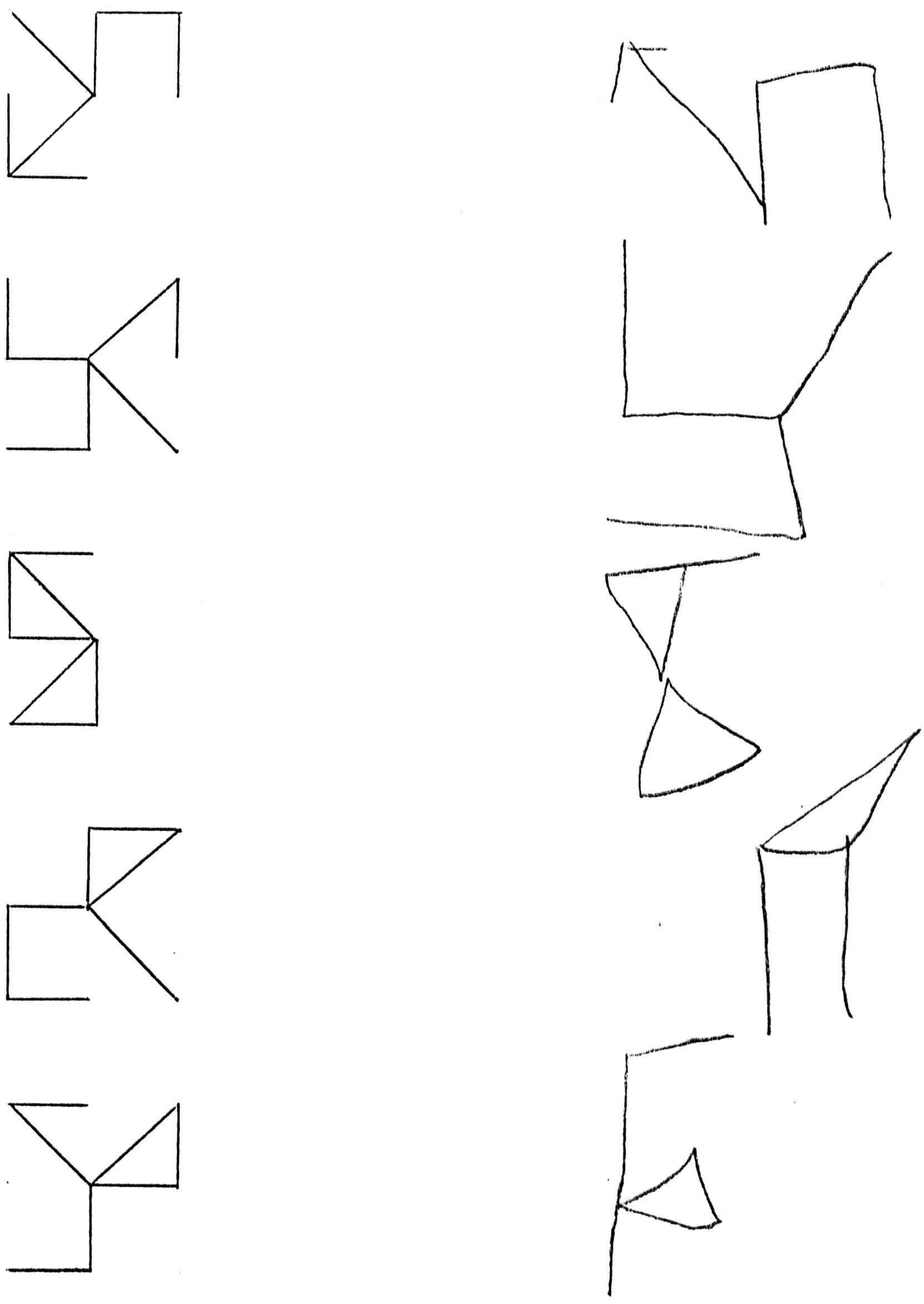


Table IVe; One-way ANOVA Table between Figure Types.

	Sum of Squares	df	Mean Square	F
Figure Type	29.30	3	9.77	11.64
Subjects	124.49	39	3.19	
Residual	98.28	117	.84	
Total	252.07	159		

Figure IVf; Examples of Verbal Descriptions with Correct and Incorrect Reproductions.

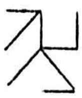
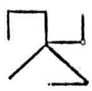
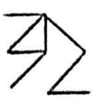
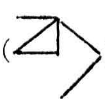
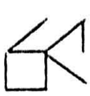
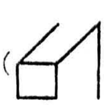
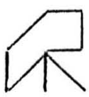
Figure	Correct/Incorrect	Description
	Correct	'There's an arrow at the top and three sides of a square, and at the bottom it looks like a triangle but half of the bottom is missing.'
	Incorrect ()	'Three sides of a square open at the top at the right-hand side, from the lower point of the left-hand side an almost complete triangle.'
	Correct	'Left-hand side was the corner of a three-dimensional cube with a view of the back line, right-hand side was three lines drawn in a very rough Z shape.'
	Incorrect ()	'Small open square top-left, open side to the left. Diagonal line from the right-hand top-corner point down to the right.'
	Correct	'A square bottom-left, two diagonal lines up from the two top corners, one down from one of the lines.'
	Incorrect ()	'There's a square in the bottom left-hand corner, with two parallel diagonal lines going off to the top

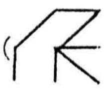
Figure IVf; Continued ...

two corners, and an incomplete triangle on the right.'



Correct

'An arrowhead at the bottom pointing up, three sides of a trapezium on the left and three sides of a square on the right.'

Incorrect ()

'The figure looks like two insides of a rectangular box; one small side, one long side, with three lines radiating from the corner.'

Table IV j; Enclosed Part and Unit Use in each Intervening Condition.

a) Enclosed parts drawn in incorrect copies.

	Part				
Condition	drawn	not drawn	% Part Use	χ^2	sig
Control	19	16	54		
Visual Interference	33	29	53	1.84	n.s.
Verbal Interference	28	21	57		
Verbal Description	32	17	65		

b) Enclosed units drawn in correct copies.

	Unit				
Condition	drawn	not drawn	% Unit Use	χ^2	sig
Control	8	13	38		
Visual Interference	2	12	14		
Verbal Interference	6	15	29	- (sample size too small)	-
Verbal Description	3	12	20		

c) Enclosed units drawn in incorrect copies.

	Unit				
Condition	drawn	not drawn	% Unit Use	χ^2	sig
Control	5	14	26		
Visual Interference	8	18	44	3.84	n.s.
Verbal Interference	2	17	11		
Verbal Description	9	16	36		

Table Ve; One-way ANOVA for Immediate Condition Discrimination Scores.

	Sum of Squares	df	Mean Square	F
Age Groups	48.38	3	16.13	13.95
Error	69.38	60	1.16	
Total	117.75	63		

Table Vf; One-way ANOVA for Delayed Condition Discrimination Scores.

	Sum of Squares	df	Mean Square	F
Age Groups	54.69	3	18.23	21.99
Error	49.75	60	.83	
Total	104.44	63		

Table Vh; Two-way ANOVA Table for Positive Discrimination Scores.

	Sum of Squares	df	Mean Square	F
Between Subjects				
Age Variable	28.16	3	9.39	4.26
Error	132.31	60	2.21	
Within Subjects				
I/D Variable	.78	1	.78	.42
Age x I/D	5.66	3	1.89	1.01
Error	111.56	60	1.86	
Total	278.47	127		

Table Vj; Three-way ANOVA Table for Directional Angle Errors.

	Sum of Squares	df	Mean Square	F
Between Subjects				
Variable A (Age)	41.13	3	13.71	1.12
Variable B (Baseline)	916.74	1	916.74	75.15
A x B	216.00	3	72.00	5.90
Error	439.16	36	12.20	
Within Subjects				
Variable C (Line Type)	219.22	1	219.22	13.10
A x C	49.50	3	16.50	.98
B x C	659.27	1	659.27	39.38
A x B x C	208.45	3	69.48	4.15
Error	937.50	56	16.74	
Total	3686.97	107		