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A PROCESS ANALYSIS

OF THE SOLUTION STRATEGIES USED FOR PROBLEMS CONTAINED

IN THE MINNESOTA PAPER FORM BOARD TEST.

ALAN FORBES REID, M.A.(Melb), Th.M.(Harvard),

A Thesis
submitted to Deakin University as total
fulfilment of the requirements for the Degree of
Doctor of Philosophy.

School of education
September 1986
DEAKIN UNIVERSITY

CANDIDATE'S CERTIFICATE

I certify that the thesis entitled A PROGRESS ANALYSIS OF THE SOLUTION STRATEGIES used for problems contained in the Minnesota Paper Form Board Test and submitted for the degree of Doctor of Philosophy is the result of my own research, except where otherwise acknowledged, and that this thesis (or any part of the same) has not been submitted for a higher degree to any other university or institution.

Signed Signature Redacted by Library

Date 1st September 1986

(NB. This certificate should be bound in with the thesis to follow immediately after the title page).
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A PROCESS ANALYSIS OF THE SOLUTION STRATEGIES USED FOR PROBLEMS CONTAINED IN THE MINNESOTA PAPER FORM BOARD TEST.

SUMMARY

This thesis reviews progress toward an understanding of the processes involved in the solution of spatial problems. Previous work employing factor analysis and information processing analysis is reviewed and the emphasis on variations in speed and accuracy as the major contributors to individual differences is noted. It is argued that the strategy used by individuals is a preferable explanatory concept for identifying the cognitive substratum necessary for problem solving.

Using the protocols obtained from subjects solving The Minnesota Paper Form Board (Revised), a test commonly regarded as measuring skill in spatial visualization, a number of different strategies are isolated. Assumptions as to the task variants which undergird these strategies are made and tested experimentally. The results suggest that task variants such as the size of the stimulus and the shape of the pieces interact with subject variables to produce the operating strategy. Skill in problem solving is revealed in the ability to structure the array, to hold a structured image and to reduce the
number of answers requiring intensive processing. The interaction between task and subject variables results in appropriate or inappropriate strategies which in turn affect speed and accuracy.

Results suggest that strategy formation and usage are the keys to explaining individual differences and an heuristic model is presented to explain the performance of individual subjects on the problems involved in the Minnesota Paper Form Board. The model can be used to predict performance on other tests and as an aid to teaching subjects experiencing difficulties.

The model presented incorporates strategy variation and is consequently more complex than previously suggested models. It is argued that such complexity is necessary to explain the nature of a subject's performance and is also necessary to perform diagnostic evaluation.

Certain structural features of the Minnesota Paper Form Board are questioned and suggestions for improvement included. The essential explanatory function of the strategy in use makes the prevalent group administration approach suspect in the prediction of future performance in spatial or vocational activity.
CHAPTER 1: INTRODUCTION

The appearance of two evaluations of factor analytic studies of spatial aptitude (Lohman, 1979, Lohman and Kyllonen, 1983; McGee, 1979) marked a watershed in the research on spatial ability. Both are clear in noting that all factor analytic studies have identified mechanical-spatial factors that are distinct from other general and specific factors (Pellegrino and Goldman, 1983). However, both also point out that spatial aptitude is still a poorly defined construct after 70 years of investigation.

Reworking the data, evaluating the procedures, testing hypotheses as to the meaning of the factors identified led McGee to conclude that "although the debate over the existence versus non-existence of a spatial factor characterises much of the literature prior to 1930, a plethora of factor studies since that date have provided strong and consistent support for the existence of two distinct spatial abilities: visualization and orientation" (McGee, 1979). Lohman and Kyllonen (1983), found that in "attempting to summarise this work, it quickly became apparent that there were as many end-points as investigators". Re-analysis identified three spatial factors all of which involved mental transformations and which were labelled spatial relations, spatial orientation and visualization.
McGee (1979) amplified the definitions of his factors by characterising visualization as the ability to mentally rotate, manipulate and twist two and three dimensional stimuli. Orientation is concerned with the comprehension of the arrangement of the elements within a visual stimulus pattern and thus becomes "the aptitude to remain unconfused by the changing orientations in which a spatial configuration may be presented".

Lohman and Kyllonen noted that visualization as a spatial factor is involved in tests which share two important features: they are administered under relatively unspeeded conditions and seem to be more complex than those tests which load on spatial relations.

However, the important question is not "What are the factors?" but "What are the dimensions along which factors are arrayed?" because to simply list factors implies "more conformity and exactness than really exists". (Lohman & Kyllonen, 1983). The dimensions which are suggested in answer to the second question above are those of speed-power and complexity. To these Lohman and Kyllonen would add a third which they term "construction" or "synthesis". It is this additional dimension which introduces the idea of varying strategies for task solution which it will be argued in this thesis plays a primary role in identifying individual differences.
Some of these ideas are picked up by Pellegrino and Kail (1982) in the presentation of a process analysis of spatial aptitude (see Figure 1:1). Although they accept Lohman and Kyllonen's dimensions of speed-power and complexity they omit the strategy dimension and so conclude that the "important question is whether individual differences in performance on these various tasks reflect differential contributions of the speed and accuracy of executing specific cognitive processes". It will be argued later that this omission of Pellegrino and Kail is one which makes their process interpretation of spatial abilities incomplete.

An appreciation of the limitations of factor analysis is not new. Thurstone (1947) argued that factor analysis should be seen only as an exploratory method appropriate to an early stage in any investigation. The importance of factor analysis lies in the initial identification of important latent variables and what is produced is the "initial structural model" (Sternberg, 1985). Progress from this position requires the exploration of the psychological processes involved. Enter information processing theories! Thereby attempts are made to understand human activity in terms of mental processes that contribute to cognitive task performance. Among the major issues which emerge are speed of operating, accuracy in performance, the utilising of processes in solving various kinds of problems, how
FIGURE 1: Schematic representation of spatial ability. (From Pellegrino and Kail, 1982)
processes are combined to handle varying forms of information, and whether cognitive tasks are in fact solved in different ways by different individuals or simply by the execution of common processes at different rates.

Sternberg (1985) argues that information processing theorists must appreciate that there is more to processing than speed and accuracy although he sees that this emphasis "may reflect the heavy use of cognitive researchers of reaction time methodologies in which case method may be dictating theory (at least in part) rather than the other way round". Factor analysis and information processing theory, insofar as the former is concerned with structure and the latter with process, may ultimately be complementary in the search for insight and in guiding performance improvement. A psychometric test score related to factors may tell where an individual is at this moment (something like a still photograph) but unless it is known how he got there, it is of little use for future understanding. While yesterday’s photograph may be obsolete today it still offers a starting point.

On this analogy our starting point is to take one test and to analyse how an individual arrives at a final score. Most tests assume that all subjects presented with the test will solve the task in the same way. It is contended that different subjects often obtain a
similar test score by quite different methods, a proposition which had been hinted at by E.S. Barratt (1953) while Thurstone (1938) had already recognized that routine correlational analysis might obscure individual differences in solution strategy "when a test shows saturation with two or more factors we have no means of knowing by factorial analysis whether the several abilities enter into the test for every subject, or whether some subjects use one ability and other subjects use other abilities for the same performance. A STUDY WITH INDIVIDUAL SUBJECTS COULD REVEAL THESE DIFFERENCES, ESPECIALLY WHEN THE SUBJECTS INDICATE HOW THEY SOLVE EACH PROBLEM" (my italics).

As Lohman and Kyllonen note, Thurstone never pursued this line of investigation and instead turned his attention to the development of factorially "pure" measures of ability. Such attempts to find tests solved in the same way by all test takers has never really succeeded. French (1963) demonstrated that even simple tests such as the Cubes Test were sometimes solved in different ways by different subjects and Hunt (1974) analysed the Raven Progressive Matrices Test to show the existence of two separate algorithms for solution: a gestalt algorithm based on the manipulation of visual images and an analytic algorithm based on formal operations applied to sets and subsets of element features.
The present attempt to substantiate the hypothesis that subjects solve spatial problems in different ways involves selection of a particular psychometric measure, the Revised Minnesota Paper Form Board (Likert and Guasha, 1943) (hereafter referred to as the MPFB) which Anastasi (1976) refers to as "one of the best single measures of spatial aptitude". Having established the place of this test within the realm of factor analytic theory it will be our aim to develop an understanding of what this test measures. This will be done by developing a model which allows the "unpacking" of the processes involved in problem solution. It will also be shown how the test can be used for diagnostic purposes since we concur with Hunt's conclusion in relation to the Raven Progressive Matrices Test that "what we require are diagnostic tests which tell us a person's cognitive style in intellectual operations, rather than an index of a person's location in a static Euclidean model of mental power" (1974).

The remainder of this introductory chapter seeks to introduce the reader to the MPFB, put the test in historical perspective and to put forward the basic hypothesis of this dissertation: strategy variation between individuals is the best explanation of individual difference between individuals.

The Revised Minnesota Paper Form Board arose from Form Board tests included in the Thurstone battery and from
the Minnesota Mechanical Abilities Project of the 1930's. The present form of the test arose from the desire to administer the test as a group test which would measure spatial ability. In the Revised form (Likert and Quasha, 1943) the test was first reproduced in Australia in the early 1940s. There are two parallel forms of the test, DA and DB, the latter no longer in print.

The test consists of 64 multiple choice items. In each item the separate component shapes are presented first, followed by five complete figures, one of which is composed of the separate shapes. The number of component shapes ranges from two to five. The main test is preceded by eight practice questions "to allow candidates to become familiar with item types and procedures" (Revised Manual, ACER 1981). The five assembled figures presented as alternatives can usually be seen to consist of two figures which are readily identified as impossible, and two or three figures which vary in similarity although only one is the correct answer (Figure 1:2).

The items presented become increasingly more difficult as the number of pieces increases, the number of different pieces increases, and as more difficult shapes are used for both the pieces and the resulting figures. To solve a problem the subject may only have to join the pieces as they are presented congruently and then
Figure 1:2

REVISED MINNESOTA PAPER FORM BOARD TEST
(AUSTRALIAN EDITION)

PREPARED BY R. LIKERT AND W. H. QUASHA
NEW YORK UNIVERSITY

QUESTION BOOKLET DA

DO NOT MAKE ANY MARKS ON THIS BOOKLET
DO NOT TURN OVER OR OPEN THIS BOOKLET UNTIL YOU ARE TOLD TO DO SO

HOW TO ANSWER THE PROBLEMS

For each problem there are five answers given. One of these is right, but ALL the others are wrong. You have to look at the problem carefully and pick which of the given answers is right. You then MARK ON THE SEPARATE ANSWER SHEET the answer which you pick. The answers to some problems have been marked to help you.

The parts in most of the problems are taken from the Minnesota Paper Form Board Tests which appear in Paterson, Donald G.; Elliott, Richard M.; Anderson, L. Dewey; Toops, Herbert A.; and Heidbreder, Edna; "Minnesota Mechanical Ability Tests," University of Minnesota Press, pages 94-101. Used by permission.

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Published by Australian Council for Educational Research, Frederick Street, Hawthorn, Victoria, 3122, by arrangement with Wm. H. Quasha.
Look at the problems at the top of the page. There are eight of them, numbered from 1 to 8. Notice that they go across the page.

Look at Problem 1. There are two parts in the top left-hand corner. These two parts, when fitted together, will form one of the figures labelled A, B, C, D or E. When they are fitted together, they form the figure labelled E — so E is the correct answer.

Look at your answer sheet. Find the part headed PRACTICE, and look at Problem 1. E has been marked by a cross because it is the correct answer. Now try Problem 2. The two parts in the top left-hand corner fitted together make F, G, H, J or K. F is the answer. F is marked on the Answer Sheet. In Problem 3 the answer is M. Mark M on your Answer Sheet. In Problem 4 the answer is T. Mark T on your Answer Sheet.

Now do Problems 5, 6, 7 and 8. Mark your answers on the Answer Sheet.

Some of the problems inside the booklet are more difficult than these, but the idea is just the same. Sometimes the parts have to be turned around, and sometimes they have to be turned over, in order to make them fit.

Start with Problem 1 and go across the page. After you have finished the first line, go on to the next. Be careful not to go too fast, but do not waste time on any one problem.

DO NOT TURN OVER UNTIL YOU ARE TOLD TO DO SO
TURN OVER AND GO ON WITH PAGE 5.
If you finish before you are told to stop, go back and make sure that every answer is right.
compare the completed figure with the alternatives offered (as in the majority of practice examples) or it may be necessary to have regard to various transformations such as rotation or reversal in the process of searching. The test is timed at twenty minutes and the score is the number of items correct.

The original Manual (Manual, 1963) claims that the test is designed to "measure the ability of a person to perceive spatial relationships or to visualise how a number of separate sections would appear when combined to form a whole diagrammatic figure". The revised Manual (Manual, 1981) offers the test in order to "measure ability to mentally manipulate two dimensional shapes by requiring the individual to visualise how a number of separate shapes will appear when combined to form a single geometric shape". The Manual continues "successful performance depends critically on the perception of the correct proportions of a figure or pattern as well as the ability to re-orient shapes in order to fit them together into a whole".

The fact that the revised Manual can offer no further appreciation of what the test measures than the above and the following comment "factor analytic studies summarised in the American manual support the Revised Minnesota Paper Form Board as a valid measure of spatial visualization ability, and to a smaller extent, of general intelligence" is the major reason why this test
was selected. To refer to "spatial visualization" without definition really tells us nothing about the psychological concepts and processes involved nor about the strategies used by subjects in item solution. Should it be found that the test items vary item-to-item in solution strategy and that different subjects solve the same item in different ways the issue arises as to how valid this test may be in measuring "spatial aptitude" and, in fact, what "spatial aptitude" may be. There is also the issue of the meaning of similar scores and similar error patterns derived from different styles of cognition. Hence there is a need for a processing model by which the performance of individual subjects in the solution of particular items may be understood. Evidence for the resolution of these issues will be offered from introspective and retrospective reports and from experimental manipulations investigating the hypothesis that subjects often use different solution strategies and adapt these strategies to item demands.

Finally unless this approach is developed and proves fruitful the usefulness of the MPFB will continue to be defined by vague statements such as "the test is suitable for use, in conjunction with other procedures, for the selection of applicants for training in certain skilled trades, and as an aid in the vocational counselling of clients who may be contemplating such training" (Manual, 1981).
The MPFB has been frequently cited in factor analytic studies (Murphy, 1936; Brush, 1941; Estes, 1942; Barrett, 1944, Morgan, 1944; Wittenborn, 1945; Shuman, 1945; P.E. Barratt, 1953, E.S.Barratt 1955; Gavurin 1967) and has been reported to load on a variety of factors. Because of this lengthy history a brief review will be provided of how the test has been perceived by researchers.

To establish a context we begin with the work of E.S.Barratt (1953) who put forward the general thesis that one of the first steps in predicting "what" is being measured by tests of ability "should be an analysis of the problem solving process used by subjects, especially when these tests are used as a basis for defining factors".

For twenty years prior to Barratt’s statement this "what" of spatial tests had been loosely referred to as "mechanical aptitude" operationally used to refer to the set of characteristics which tend to make for success in mechanical work. Murphy (1936) was one of the first to complain that the tests then in use as tests of intelligence and mechanical ability were not built on a scientific basis due to the lack of information as to what constitutes a test of mechanical ability or a test of intelligence. As an example Murphy refers to the MPFB being called by its authors "a measure of mechanical aptitude" while the Revised Beta Examination
FIGURE 1: The plot of eighteen test vectors as points on a spherical triangle. (From Murphy, 1936)

P = Revised Minnesota Paper Form Board
B4 = Revised Beta Examination Paper Form Board.
had its fourth sub-test (a paper form board test) called "a non-verbal test of intelligence". Murphy set out to investigate the relationship between tests of mechanical aptitude and verbal and non-verbal intelligence.

From her correlation analysis Murphy was able to conclude that "the non-verbal tests are measuring the trait measured by mechanical aptitude tests to a greater extent than they are measuring whatever trait is measured by verbal intelligence". Her factor analysis went on to identify three primary abilities indicated by points on a spherical triangle (Figure 1:3): around A are grouped tests which seem to depend on the mental manipulation of relationships expressed symbolically, point B groups tests of speed of hand and eye co-ordination while point C seems "to be a factor calling for mental manipulation of spatial relations". The two form board tests P (Revised MPFB) and B4 (Revised Beta Examination Paper Form Board) are grouped at point C. From her analysis Murphy concludes that the MPFB depends on the "manipulation of spatial relations to a great extent, but also, to a lesser extent, on speed of hand and eye co-ordination".

During the 1940s attention turned to the nature of spatial aptitude with the emergence of a factor called "spatial visualization" which was seen as the "ability to judge the relations of objects in space, to judge shapes and sizes, to manipulate them mentally, and to
visualize the effects of putting them together or of turning them over all round" (Super and Crites, 1962). The work reviewed by Super and Crites found that mechanical aptitude is best seen as a composite of spatial visualization, perceptual speed and mechanical information.

Like Murphy these authors were also interested in the relation of mechanical aptitude and intelligence concluding that "in homogeneous groups there are variations in ability to visualize spatial relations that are quite independent of general mental ability and that, in heterogeneous groups the relationship between the two is positive but not high enough to make one useful by itself as a predictor of the other". When wide ranges of ability are in question, it is possible to classify subjects according to "general" ability but with fairly similar populations scores fail to predict success in certain types of activity. A situation which has continued until now! We shall return to this point in Chapter 7.

Super and Crites’ assessment of the work done on the MPFB in the years 1930 to 1960 concludes that the test "measures spatial relations, perceptual abilities and inductive reasoning, in that order, and although it measures spatial judgment by means of two dimensional media, this ability is the same as that measured by three-dimensional means". The latter conclusion had,
also, been reached by Estes (1942). In summary, the MPFB was seen as a valuable partial measure of "structural visualization" (Brush, 1944) involved in mechanical aptitude and in engineering aptitude. Interestingly Brush found that the test yielded better results when used as an individual test than when administered in group form.

During this time three important ideas as to the use of the MPFB were emerging. The first of these has already been commented upon in the work of E.S. Barratt. In seeking to explain the nature of the factors with which he was working he sought protocols from each subject regarding the method of problem solving. From these protocols he was able to adjust the definitions previously offered for the factors and to report that different strategies were being used for different problems within a test loading on a particular factor depending on the difficulty of the problem. By identifying strategies which varied from spontaneous (global) to part by part, by seeing that rotation was not a necessary process but could be by-passed if other cues were used, and by noting the way in which problem demands influenced strategy use, Barratt was able to enrich the statistical definitions with an understanding of psychological processes.

A second idea was developed by P.E. Barratt (1953) based on the work of Thurstone and others who suggested
an interpretation of the spatial group factor in terms of mental manipulation of visual imagery. His aim was to obtain more information on the role of imagery in the solution of problems of various kinds presented in a spatial medium.

Barratt identified three factors which he termed "Spatial Manipulation", as all the tests (including the MPFB) "appear to involve a capacity to manipulate visual imaginal processes", "Reasoning" as a second factor, and "Shape Recognition" where "a shape or configuration is held imaginally against competing shapes". Using questionnaire methods Barratt sought an "imagery" score for each test so that he was able to conclude that "facility in imagery is important in spatial manipulation, is less important in shape recognition tasks and is unimportant in spatial analytic reasoning".

Two types of image processing emerge from this approach. In manipulation a high order of control is called for, working with clear and well defined images and a strategy which allows control and "seeing" the image in different positions and "juggling" it into various places. On the other hand, shape recognition "seems to require imagery of a lower order, just sufficient to allow a direct comparison of shape to be made without any "juggling" or "manipulation" so that the degree of imagery control is minimal". The implications of this distinction for different
strategies will become apparent.

In this setting the MPFB was found to load on Factor I (Manipulation) and Factor III (Shape Recognition) which is understandable if we postulate that the imagery demands of the two factors are different because subjects are using two different strategies. For some strategies shape recognition is sufficient before moving to comparison between total images while for other problems and with other strategies manipulation of individually identified pieces is necessary for comparison. Unfortunately the author failed to develop these ideas beyond saying that "what seems to be critical between the two spatial factors is what the subject is required to do with his images". In hindsight it would seem that adoption of an analysis of processes approach would have been the logical progression from this tentative conclusion.

Imagery control, imagery vividness and the breadth of the image in restructuring were concepts which were returning as tentative explanations during this period (DiVesta, Ingersoll and Sunshine, 1971; Richardson, 1972; Paivio, 1978) and more and more were seen as major considerations in distinguishing between individual performances on spatial tests. They may well be the clue to the use of various strategies in spatial relations and spatial visualization tests.

A third idea was also emerging. This concerned the
dimensions along which differences in factors might lie. Michael, Zimmerman and Guilford (1954) argued that the difference between the two factors which they identified, Spatial Relations and Visualization, lay in the speed of response. The former demanded fairly rapid decisions, the latter a more deliberate and less automatic approach. These authors were also able to identify the presence of visual-motor reasoning in the responses of boys and a tendency by girls to verbalise their performance. Although they failed to come to definite conclusions about the involvement of these psychological processes in the solution of spatial problems the need for explanations which reached beyond factor analysis was becoming apparent.

The great difficulty for factor analysts was to bring the identified factors and the tests which they were using into some sort of exclusive relation since tests were found to load on both factors. The conclusion was that the factors were very similar in psychological terms and could not be as neatly distinguished as they were by statistical methods.

The approach which will be followed in this study is not to seek to establish the MPFB in relationship with some latent ability which is then claimed to be responsible for the observed variations among individuals on the test. Rather it is to seek to understand the test as a cognitive task which leads to
responses from individuals using different approaches. It is argued that the nature of these approaches will tell us more about "spatial aptitude" than approaches based on correlational analysis. By such an understanding it should be possible to ascertain cognitive weaknesses and strengths and thereby open possibilities for improvement.

The methods for drawing inferences about the ways in which individual's approach this test will involve content analysis of written and oral protocols, modelling of the material and testing of the model against other models proposed.

This historical review of the use of the MPFB over the past fifty years has been selective and has concentrated on three areas which seem to offer scope for development: the use of introspection to gain insight into the individual's activity, the role which imagery representation plays in the development of strategies and finally the dimensions along which all spatial factors and the tests which load on them may be arranged. Each of these areas will increase our understanding of how the test is processed and, in turn, generate new ideas for development of learning in a spatial context.
CHAPTER 2: A MODEL FOR PROCESS ANALYSIS OF SPATIAL VISUALIZATION.

As indicated above, factor analysis is limited to the identification of the major categories of mentation and groups of tests which seem to require the same skills. We have also suggested that a major source of inter-item and inter-test variance lies in the dynamic processes which individuals bring to bear on problems presented in tests. As Thurstone said nearly forty years ago "the factorial methods were developed for the study of individual differences but these individual differences may be regarded as an avenue to the study of the processes which underlie these differences" (1947).

An information processing analysis aims to elucidate the basic processes and the process co-ordination involved in solving a specific problem. The approach involves specifying, as completely as possible, what happens to an input after it enters the cognitive apparatus. By decomposing item solution into its composite mental operations it is possible to derive a conceptual infrastructure for a formal theory.

By identifying psychological indices within a target task it is possible to argue that individual differences result from the efficiency and effectiveness of the processes executed at the time, from the use of different processes, or from the ability to change these
processes.

An analysis of spatial ability requires identification of tasks which serve to define spatial ability, a model defining the relation of these tasks and the strategies which control process integration and sequencing. Finally, a method by which the model can be used as a basis for the analysis of individual differences is necessary.

Such an analysis has been conducted by Pellegrino and his associates (Pellegrino and Kail 1982, Mumaw and Pellegrino 1984, Pellegrino,Mumaw and Shute 1984, Pellegrino,Alderton and Shute 1984). The results highlight a number of issues which their work does not appear to have considered and which have arisen in our own investigation of the MPFB. We will report the results of replicating their experiments and then compare their models with an alternative.

The work of Pellegrino and his associates takes the MPFB test as the basis for their investigation of spatial visualization which they accept as a factor distinct from the factor termed "spatial relations". The model which they propose arises from a task analysis of the types of problem presented in the test and the dimensions which seem to underlie task difficulty and errors. Their approach, based on this factorial distinction, postulates that differences in simple spatial relations tasks are primarily associated with
FIGURE 2:1 A process model for the solution of MPFB problems (From Pellegrino & Kail, 1982)

Laboratory Form Board Item

\[ \begin{align*}
  n &= \text{total number of pieces} \\
  n_i &= \text{number of spatially displaced pieces} \\
  n_j &= \text{number of rotated pieces} \\
  RT &= n(e + c) + n_i s + n_j r + x
\]
measures of processing speed. Differences in task performance on visualization tasks reflect a larger number of component processes and/or more executions of individual processes.

Their task analysis of the MPFB identified the following points of variation:— the number of individual stimulus elements which must be processed, the similarity of the elements, and the number of mismatching pieces in the incorrect solutions. The approach hypothesises that the elementary processes include encoding, comparison, search, rotation and decision processes which are combined as shown in Figure 2:1.

The process model (shown in Figure 2:2) assumes an initial encoding of one of the pieces followed by a search for a potentially corresponding piece. When this possible match is identified, there is rotation to bring the two stimuli into congruence so that a comparison process can be executed. If the two pieces correspond and all the pieces have been examined and have given corresponding values, a positive response is executed. If all the pieces have not been examined then the entire process recycles for examination of another stimulus element until all are completed or a lack of correspondence has been found.

The material designed to test this model is taken from the MPFB together with other specifically designed
FIGURE 2:2 Example laboratory form board item and a process model for item solution. (From Mumaw and Pellegrino, 1984)

1. Encode Element i

2. Find Corresponding Element

3. Same Orientation?
   - Yes: Compare Elements
   - No: Rotate Element

4. Rotate Element

5. Are Elements Identical?
   - Yes: Reset Truth Index
   - No: Any Unchecked Elements?

6. Any Unchecked Elements?
   - Yes: Repeat
   - No: Respond Same

7. Respond Same

8. Reset Truth Index

9. Respond Different
items in the same format. Items from the MPFB which were based on size differences were deliberately excluded on the argument that in a simple same-different comparison test (that is without the aid of a number of options) such items are too difficult. In the Pellegrino experiment mismatches are characterised by changes in angles, in the number of sides and the relative proportions of the sides. It can be argued that in fact this approach negates a basic demand of the MPFB problems, namely, the ability to distinguish size differences.

In discussion, Pellegrino, Alderton and Shute, (1984) hypothesise that individual differences in spatial visualization tasks will be a function of accuracy in executing mental process rather than in speed of functioning. A related hypothesis is that these problems "require the execution and co-ordination of several processes with more information stored in the visual buffer - thus greater cognitive complexity may lead to strategy differences in problem solution as well as potential breakdowns of solution strategies with increased problem complexity". While the first of these hypotheses is developed, "the important question is whether individual differences in performance on these various tasks reflect differential contributions of the speed and accuracy of executing specific cognitive processes" (Pellegrino and Kail 1982), little is offered
in relation to the second hypothesis.

Subjects were presented with a same-different task in which the completed figure was presented on the left hand side and a number of pieces on the right hand side. The requirement was to identify the presentation as same or different. The pieces on the right hand side were presented in a variety of formats reflecting the hypothesised processes — wholistic, separated, displaced, rotated and rotated and displaced (Figure 2.3). The discriminability of the pieces was maximised in order to prevent confusion during the search stage of processing on the grounds that, if search as a process is based on gross characteristics of an element, the presence of similar elements will increase the chances of manipulating the wrong element. The fact that this could be a significant cause of error in the MPFB test seems to have been deliberately avoided by the authors.

The experimental results indicated that the simple additive structure implied in the model was confirmed with displacement items taking longer than wholistic which in turn were faster than separated. Rotated and rotated and displaced are taken together as it is claimed they did not differ although they were slower than the other processes. From the data the authors derive confirmation that the main processes are encoding, search, rotation, comparison and response. The faster items are explained as requiring fewer
FIGURE 2:3  Examples of the five positive trial item types. (From Mumaw and Pellegrino, 1984).

Rotated & Displaced
Encoding, Search, Rotation, Comparison, Response

Rotated
Encoding, (Search), Rotation, Comparison, Response

Displaced
Encoding, Search, Comparison, Response

Separated
Encoding, Comparison, Response

Wholistic
Encoding, Comparison, Response
processes thereby contributing to an additive latency model (Figure 2:4).

From the error data it is argued that there are various sources of processing failure. Failure to detect a match is influenced by the presence of a rotation component since the stimulus representation is distorted following rotation and comparison fails. Errors in the detection of a mismatch between similar but non-identical shapes usually occur in the presence of a large number of matching pieces suggesting that subjects resort to a global comparison under these circumstances. The likelihood of detecting a mismatch therefore decreases as the number of matching stimuli increase (Figure 2:5).

The latency data show a linear increase in RT as a function of the number of stimulus elements across all conditions. It is argued that the data are consistent with the assumption that processing is exhaustive for positive items and self-terminating for negative items. The exception found by Mumaw and Pellegrino was in performance on negative separated items "which suggests exhaustive processing of all elements before item rejection". The explanation for this is difficult to find especially as another paper by the same authors (Pellegrino, Mumaw and Shute, 1984) expressly notes that "on negative separated trials, the fusion process may result in forcing all the pieces into a whole even
FIGURE 2:4 Mean latencies as a function of trial type, item type and number of stimulus elements. (From Mumaw and Pellegrino, 1984)
FIGURE 2:5  Mean errors as a function of trial type, item type, and number of stimulus elements. (From Mumaw and Pellegrino, 1984)
though one of the elements is incorrect with respect to specific features such as size or angle. The result would be a higher error rate on such items”. The explanation is more likely to lie in the fact that the close similarity between the array and the separated one item different situation demands exhaustive processing. The method of presentation used in these experiments with the probe presented on the left hand side, is also likely to lead to decomposing the figure in this situation. In addition, when mismatch detection is relatively inaccurate or inefficient the number of processing cycles before correct rejection is a function of the number of stimulus elements and the failure to detect a match. From this it would be predicted that low ability subjects may take longer to process a negative item than a positive item thus clouding the clarity of the argument that negative item processing is self-terminating.

The authors develop the following conclusions about the differences between high and low ability subjects but make no comment on the possibility that subjects of the same ability may operate in different ways. (The comments in brackets will be looked at later as the bases of alternative hypotheses).

(a) Skilled individuals make fewer errors on problems involving stimulus rotation or transformation. (This assumes that skilled individuals do in fact rotate and
transform as often as others).

(b) Skilled individuals are more accurate in detecting mismatches between similar stimuli independent of the occurrence of rotation.

(c) Skilled individuals are faster at searching through an array to find corresponding stimulus elements. (This ignores the possibility of the nature of the search process being different rather than just more efficient).

(d) Skilled individuals are faster in encoding and comparison processes. (Alternatively they may execute these processes in different ways).

From their results the authors claim that skill in visualizing tasks is related to a number of features.

(a) The quality of the stimulus representation is one such feature since a more precise representation permits more rapid search and faster and more accurate decision making. It also allows the retention of enough information following manipulation to make an accurate comparison.

(b) The greater search speed of high ability subjects is best seen as a speed difference in locating a match piece and this, rather than speed of encoding, is the index of spatial ability.

(c) The choice of strategy plays a part since skilled subjects use a precise analytic mode of processing rather than a less analytic and partly wholistic or
global processing mode which generates errors on certain items.

(d) High ability subjects either have a perceptual or memory system which allows construction of representations containing or preserving more information over time ("hardware") or possess more efficient and better strategies for extracting important information when encoding stimuli for a particular cognitive task as a result of knowledge or attention differences ("software").

Mumaw and Pellegrino (1984) further argue that skilled performance on the MPFB is related to speed of rejecting incorrect alternatives which are totally dissimilar and that this is the greatest contributor to speed differences. Their model, however, fails to explain why this is so.

In conclusion, Pellegrino and his associates suggest that spatial aptitude is associated with the ability to establish sufficiently precise and stable internal representations of unfamiliar visual stimuli that can be subsequently transformed or operated upon with minimum information loss. Spatial relations and spatial visualization respectively reflect emphases on coding versus transformation processes within the system and single versus multiple/sequential transformations with the ability to co-ordinate and monitor the latter. What appears to be lacking is comment on an architecture
which can trigger knowledge of when a particular emphasis is appropriate.

This shortcoming is related to an issue which is not tackled adequately, namely, the nature of the strategies or algorithms which enable individuals to solve these particular problems. The issue raises a series of linked questions. Do individuals solve problems using the same strategy but vary in their speed and/or accuracy of execution? Do individuals differ in the emphasis which they place on executing the different components of the same algorithms or, alternatively, do they rely on different algorithms to solve specific problems? Pellegrino and Kail, (1982) are aware of these shortcomings. In fact Pellegrino (Mulholland, Pellegrino and Glaser (1977) presented a paper in 1977 on the information processing components necessary for solution of geometric analogies in which they specifically refer to strategic expertise. They conclude that "some items place severe demands on the processing resources and working memory capacity of an individual. Expertise ...... may include the ability to shift processing strategies in order to circumvent some of the memory problems that arise when using a strategy that is optimal for less difficult items. These adaptive characteristics of performance remain to be assessed". In the next chapter these questions will be explored in a series of experiments.
CHAPTER 3: ANALYSIS OF SUBJECTS' PROTOCOLS ON MPFB.

It will be recalled that E.S.Barratt (1953), as a follow up to factor analysis, sought to identify the problem solving processes involved in spatial tests by interviewing his subjects to discover their problem solving processes on problems typical of a variety of tests. His assumption was that "subjects were aware of some of the mental processes used to solve the problems and that they were able to communicate these thoughts to the investigator".

By using the protocols Barratt was able to formulate definitions for the factors which he identified. For the present discussion his most interesting discovery was that subjects used different approaches, which he called "part" and "whole", and varied strategies which worked with abstract symbolism or related figures to familiar and concrete images.

Further investigations showed that those using the part approach combined with abstract symbolism performed better on tests loading on the factor which he hypothesised to represent the ability to turn or rotate a given figure to correspond with another figure. On a second factor, defined as the "mental ability to see spatial relationships of objects involved in dynamic situations", Barratt found differences in subjects' approach to "easy" and "difficult" problems, differences
in the initial moves made by subjects, and a variation in the number of cues looked for and used. He also found some subjects who seemed to lack any consistent approach and gave up confused.

Barratt concluded that subjects' problem solving techniques might be a means of gaining insight into their scores, that teaching different problem solving techniques might be more effective with some subjects than with others and queried how generalizable these techniques or strategies might be for particular individuals.

The development of this approach to gaining information about the course of cognitive processes through obtaining protocols is analysed by Ericsson and Simon (1984). They identify two important dimensions of difference. The first is variation in the time of reporting since this determines from which memory the information is being drawn. This difference distinguishes reports involving "thinking aloud" while a task is being performed and retrospective reporting after the completion of the task directed processes. The second dimension distinguishes between reports involving intermediate inference and those which are a direct articulation of stored programs of a more general nature.

Asking for reports which are retrospective runs the risk that any retrieval operation is fallible and that
retrieved information will be corrupted by information previously acquired. To ask "How did you do this task?" is likely to receive a general rather than specific interpretation. Subjects are more likely to recall general programs applicable to all trials, and to generalize specific information derived from some trials. Retrospective review will regenerate processes used and this can be generalised to what they might have done or, in the light of present knowledge, what they should have done.

To ask a subject what he has been doing after a series of trials can be expected to produce a response containing general processes from retrieved selected episodes or a rationalisation based on what the subject now considers should have been done.

Although retrospective reporting may obscure changes in strategy or call forth only one particular type of approach, it does have the advantage of giving fairly generalised descriptions of the main strategies in use. Because retrospective reporting involves the retrieval of traces of connected episodic memory in long term memory (LTM) the reports can be combined into a single structure thought out after the event, or the reflection of a description of the subject’s cognitive processes already generated while working and reflecting the changes demanded by the task or by the individual conscious of his own limitations.
The aim of this chapter is to use the retrospective reports gathered in a number of experiments to propose a model. The reports contain both basic processes which operate without alternatives and strategies which are under the control of the subject and which allow aspects of the problems to be approached in different ways. The solution of a problem may necessarily demand encoding of the information, the way in which this encoding is accomplished and the time taken is likely to be an individual variant. From the expectation that subjects will conceive of the MPFB problems as "open" it is hypothesised that individuals will retrospectively report general plans which differ in format and execution.

It is also hypothesised that particular plans of action are chosen because of past experience, how "comfortable" a particular approach feels, the influence of previous examples and practice, and the way in which particular problems trigger "warnings" against certain approaches. It is possible that some plans, derived from past experience may have become virtually "automatic" and unavailable to introspection while unfamiliar problems will demand new approaches which are more easily recalled to consciousness. It is likely that retrospective reporting, occurring after the performance of a number of problems, reflects the most common "set" which a subject experiences while current
reporting during processing indicates how the unfamiliar is being tackled. If these two approaches yield complementary and compatible data then our confidence in what is happening will be increased.

A particular strategy may be chosen because of the nature of the processes being used and reflect the way in which these processes interact. Alternatively, strategy selection may be determined by representations employed in problem solving. Cooper (1982), for example, suggests that an analytic strategy may result from a memory representation which is composed of sub-units, parts or features while a wholistic strategy may be attributable to a memory representation including all of the information in a visual pattern. The former strategy will result in a sequential comparison, the latter a comparison performed in parallel and globally.

Selection of strategy or strategy change may also reflect an individual's perception of the relative difficulty of a problem. For example, when a subject experiences difficulty in labelling a piece this may create confusion or result in a change of strategy. Alternatively, selective attention by subjects to specific aspects of the stimulus may result in the adoption of different approaches.

Given the Pellegrino and Kail model (1982) outlined in Chapter 2, it would be expected that a study of the protocols of subjects performing the MPFB would reflect
a strategy which was analytic and exhaustive. This hypothesis is modified by Pellegrino, Mumaw and Shute (1984) who argue that "skill differences are also associated with differences in processing strategy. The major strategy differences may involve a precise analytic mode of processing versus a less analytic and partly wholistic or global processing for certain item types" the latter being typical of "lower skill individuals".

Five pilot studies were conducted to set the parameters for an investigation of the strategies available to individual subjects and the development of a model which would explain strategy use and strategy change in the performance of items from the MPFB.

PILOT STUDY ONE

Subjects and Method: The first attempt at investigation of the MPFB using retrospective protocol analysis involved asking 116 applicants for a certificate course in architectural drafting at a T.A.F.E. College, after completion of the test, to write down how they thought they had tackled the problems or to draw a flow-chart of their method of operation. This procedure was carried out at the conclusion of a standard test administration and the subjects were permitted to refer back to the
question sheet. The mean age of the applicants was 17.7 years and they were drawn from all parts of Melbourne since the college is one of only three offering this course in the metropolitan area. All had completed Year 11 of secondary schooling.

The selection tests included the MPFB, the Standard Progressive Matrices 1938 (1938), the Paper Folding Test from the French Battery (French et al. 1963) and the Surface Development Test from the French Battery (French et al. 1963).

Results and Discussion.

Some subjects simply listed the way in which the pieces were put together in an answer. The 85 protocols which were usable as retrospective reports can be grouped into three categories.

(1) The first category is defined by a strategy presented in the flow chart in Figure 3:1. The subject took one of the stimulus shapes, labelled in many cases as "the most unusual shape" or the "biggest shape" or "the easiest to recognize shape" or "a geometrically describable shape", and compared it with the first alternative answer asking "Is this shape present in the answer?". If the answer is "Yes" then the subject proceeds to compare other pieces of the stimulus array with that alternative until (a) all pieces are fitted, (b) a certain number are fitted, or (c) one of the pieces is found not to fit. When (c) occurs the subject
Figure 3.1 Flow chart of first strategy identified in Pilot Study One.

1. Encode stimulus
2. Choose piece from array
3. Go to answer to be considered
4. Find corresponding piece
5. Are pieces identical?
   - Yes
   - No: Take another piece
   - No: All pieces checked?
      - Yes: Choose answer
      - No: Go to next answer
repeats the whole operation with the next alternative answer and so on until a fit is found and chosen as the correct answer.

A variation of this strategy involved the subject first eliminating impossible answers before proceeding with the sequential comparisons. When (b) occurs the subject decides upon an acceptable threshold beyond which comparison is not necessary (self-terminating).

(2) The second strategy is presented in the flow chart in Figure 3:2. Like the first, it involves selecting one piece from the stimulus array characterised by the same descriptions or labels as Strategy 1. In this case, however, the subject applies the piece to each answer offered thereby eliminating some options. The strategy then requires the subject to take a second piece and apply that to those options which remain "live", or to all options. This is repeated with the remaining pieces until only one alternative remains. This is chosen as the correct answer. Some subjects indicated that on some occasions they used more than one piece at a time but always treated the information as if it were one unit. A few subjects reported making only a single pass and then deciding, on the basis of the presence of that piece in only one alternative, that that option was the answer.

(3) The third strategy may be loosely termed "global". Each example of this strategy involves an initial
Figure 3.2 Flow chart of second strategy identified in Pilot Study One

1. Encode Stimulus
2. Choose piece from array
3. Go to answer to be considered
4. Find corresponding piece
5. Are pieces identical?
   - Yes: All answers considered?
     - Yes: All but one eliminated?
       - Yes: Choose answer
     - No: Go to next answer
   - No: Take another piece
5. Eliminate
attempt to determine the answer by looking at the total array in the stimulus and all of the alternatives. The arrangement of the stimulus array is considered either as a single figure or as a relational structure and compared with the alternatives thereby eliminating wrong answers. It seems that subjects develop a structure which is distinguished by the fact that the relations among the elements are inseparable from the structure as such. Mandler (1982) refers to such structures as "coordinate structures", and defines them as "wholistic in the Gestalt sense in that the whole is different from the sum of its parts". In some cases where it was not possible to eliminate all but one alternative by this approach the subject switched to an analytic strategy and processed the remaining alternatives by means of strategy 1 or 2.

The results obtained by subjects using these varied strategies are presented in Table 3:1. Strategies 1 and 2 differ significantly from Strategy 3.

<table>
<thead>
<tr>
<th>Number of Ss</th>
<th>Strategy 1</th>
<th>Strategy 2</th>
<th>Strategy 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean score</td>
<td>46.7</td>
<td>49.0</td>
<td>42.9</td>
</tr>
<tr>
<td>Mean items complete</td>
<td>56.2</td>
<td>54.2</td>
<td>55.8</td>
</tr>
</tbody>
</table>

Strategy 1 and 2. t=1.63 n.s.
Strategy 1 and 3. t=1.78 p<.10 df 54
Strategy 2 and 3. t=3.75 p<.001 df 44
Grouping the subjects by MPFB strategy and correlating the scores with scores on the other tests administered gave the results set out in Table 3:2.

Table 3:2
Correlations between scores of subjects on MPFB grouped by strategy and other reference tests. (n=78)

<table>
<thead>
<tr>
<th>Reference Test</th>
<th>Strategy 1</th>
<th>Strategy 2</th>
<th>Strategy 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Paper Folding Test</td>
<td>.545***</td>
<td>.297</td>
<td>.529*</td>
</tr>
<tr>
<td>Surface Devel. Test</td>
<td>.434**</td>
<td>.476**</td>
<td>.487*</td>
</tr>
<tr>
<td>MPFB Items complete</td>
<td>.741***</td>
<td>.775***</td>
<td>.275</td>
</tr>
</tbody>
</table>

* p<.05    ** p<.01    *** p<.001

The strategies which are based on piece by piece comparison (Strategies 1 and 2) are significantly related to the number of problems completed within the time and to other tests generally defined as measures of spatial aptitude. The lack of correlation between the global strategy (Strategy 3) and the other tests suggests the possibility of processing which is different from the spatial processing demanded by the other reference tests.
PILOT STUDY TWO

Subjects and Method: The experiment was repeated with 51 applicants for a certificate of art course at a T.A.F.E. College in Melbourne. The subjects had a mean age of 19.8 years and most had completed Year 12 of secondary education with special studies in art. The subjects were given clear instructions to set out the way in which the problems had been tackled by either recounting the steps followed, or drawing a flow chart or imagining that they were instructing someone in the best method to be followed in order to solve the problems. Strategies 1 and 2 appeared as described above but two variants of the global strategy were identified.

Ten subjects did not give sufficient information in their response to be able to identify the strategy in use. This group had a mean score of 38.8/64 and the mean number of problems completed was 46.5. Compared with the means of identified strategy groups (Table 3:3) these were low suggesting difficulty in exercising a consistent strategy or confusion in operation.

Strategy 2 appears to produce marginally more accurate results than Strategy 1 (t=1.54, df22, p<.20) probably because the latter strategy involves the danger of accepting a closely similar answer without checking through all alternatives whereas Strategy 2 requires working through all alternatives. There are also some
lower accuracy of the global strategy.

Table 3:3
Mean performance of art course applicants on MPFB.

<table>
<thead>
<tr>
<th>Strategy</th>
<th>Number of Ss</th>
<th>Mean score</th>
<th>Mean items complete</th>
</tr>
</thead>
<tbody>
<tr>
<td>Strategy 1</td>
<td>11</td>
<td>46.3</td>
<td>53.9</td>
</tr>
<tr>
<td>Strategy 2</td>
<td>13</td>
<td>50.8</td>
<td>54.6</td>
</tr>
<tr>
<td>Strategy 3</td>
<td>17</td>
<td>46.6</td>
<td>54.4</td>
</tr>
</tbody>
</table>

Differences not significant.
The variations of Strategy 3 are marked by the following:

(3A) The first variation involves structuring the pieces into a total representation and then comparing this with the answers. The sequence of steps is indicated in the flow chart in Figure 3:3.

(3B) The second variation involves looking for an alternative in which the answer "jumps out". The processing sequence is presented in Figure 3:4.

The relative frequency of adoption of strategy types appears to be consistent in the two studies. Approximately two thirds of the subjects employed piece by piece strategies. The remainder used some form of strategy requiring a global representation of a total figure or structure. There is some suggestion that the piece by piece strategy is more accurate for the architectural drafting applicants but there is no evidence of one strategy being quicker than another as the results are reported in mean scores and mean number of problems completed.
Figure 3.3 Flow chart of strategy 3A identified in Pilot Study Two

1. Study problem
2. Scan answers
3. Mentally construct pieces to whole
4. Does constructed image equal an answer?
   - Yes: Check with pieces
   - No: Change to strategy 1 or 2
5. Choose answer
Figure 3.4 Flow chart of strategy 3B identified in Pilot Study Two.
Variations in speed and accuracy occurred within strategy groups. The protocols suggest, however, that subjects who are unable to articulate their processing tend to perform more poorly in speed and accuracy.

PILOT STUDY 3

Pilot studies 1 and 2 sought to itemise the operations which were involved in the solution of MPFB problems. As such, these studies set out the internalized, organized and co-ordinated sets of actions which lead to the solution of the problems. Operational thinking is, however, presumably dependent upon more fundamental processes. The approach adopted in Pilot Study 3 is aimed at exploring to what extent it is possible to identify these more fundamental processes from the protocols. It is hypothesised that any mental task may be conceptualised as comprising an input, elaboration and output phase. The strengths and limitations of individuals within these phases will directly affect the availability of particular strategies for problem solving.

Subjects and Method: 72 applicants for a certificate course in computer operating were asked to detail their method of approach to the problems presented in a previously administered MPFB. The subjects ranged in age from 16 to 45 with a mean age of 19.3 years.
small number of mature age students were seeking entry to part-time study. The subjects had all passed Year 11 of secondary education.

Results and discussion.

All of the retrospective reports mentioned an orienting stage with emphasis on expressions such as "look at", "look carefully", "quickly look". A number of subjects amplified these "looking" expressions with references to particular referents such as shapes, pieces, sizes, "samenesses" or the overall problem.

After this orienting phase the "looking" takes on a specific purpose which was probably best summed up by the subject who described this stage as one in which the individual must "consider the problem - ask questions". This questioning was exemplified in various types of activity which can be summarised as follows:

(a) Mental activity involving processing described as "visualizing", "taking the pieces into memory", "forming a mental image", "fitting the pieces together in one's mind", "placing the shape in my mind", "memorising shape and size", "imagining the shapes put together", "rearranging the shapes in one's mind", "putting together all the pieces in my mind", and "matching up physically in my mind to get the answer".

(b) Identification of one piece with special characteristics described as "the main piece", "largest/smallest piece", "strangest", "unique"
or some other characteristic of shape and size fitting the requirements of "a shape I could recognize straight away".

(c) Exploration of a relationship between pieces such as identity, similarity, symmetry, or other characteristics such as "meeting at a point".

Discussion with individuals of their performance on the MPFB revealed that those who performed well were conscious of careful preparation during this input/encoding phase and subsequent difficulties can often be traced back to it. Some individuals who progressed to a later phase without first establishing adequate control over the stimulus experienced difficulty distinguishing pieces, became unsure of what to do next and began to engage in trial and error operating. The subjects who seem to have the greatest range of options are those who organize the data according to some scheme, place it in context, and having anticipated difficulties which might arise are prepared to adjust to them.

Tentative attempts made to train subjects in consistency of encoding produced an initial slowing of processing but an increase in accuracy. An example of this was subject P.C. whose initial trial on the MPFB resulted in 34 errors in the 64 problems although he completed the test in 22 minutes, 70% of which was working time. After a further three unguided attempts
at the MPFB the subject’s error score was still 29 and there was no reduction in completion time. The subject was then instructed in a strategy which involved looking for one piece in the stimulus array, concentrating on getting it "under control" and then asking such questions as "How does this piece compare with others in the array? Can it be given an identification label? How is it going to be found in the alternatives offered? How does this problem compare with previous problems?"

After two forty five minute training sessions the MPFB was repeated. Performance time increased to 35 minutes, 80% of which was working time but errors dropped to 11. Further training results similar to these will be reported in Chapter 8.

The protocols suggest that this stage is followed by an elaboration or solution phase. A number of features appear to be crucial components of this second phase:

(a) The first is skill in establishing a relationship between stimulus and answer which can identify "same", "similar", or "different". It appears that this can either be a visual skill in seeing a relationship between two items which can be rapidly carried out within a particular context, or it can be a judgmental and inferential skill "that leads to propositioned, abstract and logical thinking" (Feuerstein, 1979).

(b) Another crucial skill seems to be the ability to put pieces together in a meaningful way having regard to the
final shape desired. This process seems to require a wholistic understanding since subjects typically describe it by such expressions as "picture in your mind pieces on top of answers", "rearrange the pieces in your mind", "group shapes".

(c) Another highly relevant visual skill appears to be the ability to visually transport one piece onto an answer, "jigsawing", in an almost physical way so that the piece covers the corresponding piece in the answer. This is then held, often by finger pointing, while the process is repeated until enough of the answer is covered to be confident that a match or a mismatch has been discovered.

(d) Finally, the ability to select a relevant cue to define the problem also seems to make for a more adequate solution since some cues allow more rapid elimination of answers than others. Choosing a shape which is common to all answers adds nothing to the solution process and wastes time.

The protocols suggest that the major difficulties encountered in this second phase include inappropriate piece choice, failure to hold images in a transformed position, inability to see reasons for eliminating a possible answer on grounds of visual comparison or relational qualities and limitations in "building up" or constructing pieces into a shape.

A number of subjects concluded their processing with
a final check before indicating a response. They described this last phase in such phrases as "ensure identical", "try the whole thing", "assume this to be the only possible answer", and "choose what becomes obviously correct".

Finally it was found that the ten best performers used about half the propositional expressions compared with the ten poorest performers. This may reflect fewer processes being used resulting from more skilled operation and lends some support to the contention of Ericsson and Simon (1984) that "we should expect the verbalizations of highly skilled individuals to be less complete than those of less skilled ones". Ericsson and Simon accept the suggestion of Schneider and Shiffrin (1977) that the growth of skill can be viewed as the development of successively "higher level codes and organizations of lower level processes" which can in turn result in curtailment of processing or "automatization" thereby accounting for subjects being unaware of working mismatch strategies or of the reasons why they are operating in a less than exhaustive fashion.

These exploratory studies, based on acquisition and analysis of retrospective protocols, gave rise to a number of hypotheses.

(a) Subjects' retrospective reports enable discrimination of those who work with pieces and those
who work in a more global fashion using relationships to "see" a total unit which is used to reject mismatches very rapidly. There appears to be a relatively stable relationship between the two approaches in that the former can follow the latter but rarely the reverse.

(b) The classification of strategies in this way does not imply that all individuals using one strategy are faster or more accurate than those using other strategies but that within strategies there are individual differences.

(c) A relationship exists between the level of performance and the ability to introspect on processing. Slower and less accurate responses to items are associated with confused verbal protocols.

(d) Subjects seem to change processing strategies under the influence of the specific context or because the strategy in use does not generate a confidence level sufficient for the individual's satisfaction.

(e) Ability to add information to the basic encoding either in terms of past experience or information, or by the organization of the information gained from the stimulus seems to determine the choice and subsequent control of a strategy and give flexibility of operation.

(f) Protocols can be used to indicate the underlying cognitive prerequisites necessary for the operation of particular strategies. Failure to perform may be due to deficits in these underlying prerequisites which either
preclude certain strategies or limit the strategy in use.

These introductory pilot studies suggest that protocol analysis is a useful and valid tool for investigating the strategies in use in solving MPFB problems and identifying the cognitive substratum necessary for such problem solving. The collection of a large amount of group data should give a base for developing a model which can be tested on individual subjects.

**PILOT STUDY 4**

The inter-relation between the cognitive substratum and the demands of the problem may be defined as the "complexity" of the problem. Variation in complexity is hypothesised to be directly related to the errors made by individual subjects and the time to complete the problem. This proposition was tested in the following experiment.

**Subjects and Method:** Two groups of subjects were chosen from Year 12 students who had volunteered for the experiment. All subjects were aged between 16 and 20 and were randomly assigned to two groups.

The first group (n=20) were shown a sheet containing all the pieces from the problems 25 to 40 of the MPFB (DA) (Figure 3:5). The subjects were asked to identify
Look at each of the 24 shapes above. Decide which 5 shapes you think are the SIMPLEST and number them (1) to (5) - (1) being simplest.

Decide which 5 shapes you think are the most COMPLEX and number them (24) to (20) - 24 being the most complex.

Rate the shapes from (6) to (19) in order - simplest to most complex (19).
the 5 simplest figures and rate them 1 to 5 and then to identify the 5 most complex shapes and rate them 20 to 24. The subjects were then asked to rate the remaining pieces in order of complexity (simple to complex) from 6 to 19.

The second group (n=14) followed the method of Vitz and Todd (1971) for determining the complexity of simple geometric figures. Figures were enlarged and presented on cards randomly. After viewing the 24 cards the subject was asked to divide the cards into two piles: the 12 figures judged to be simplest, the 12 judged to be most complex. As with the first group the subjects were allowed to use any definition of "simple" or "complex" which they wished. The subject then ranked the 12 simplest from 1 (simplest) to 12. The first 8 were recorded and the rest mixed with the remaining 12. From these 16 the subject was asked to put aside the 4 most complex. The remaining 12 were ranked simplest to most complex and ranking 9 to 16 recorded. The remaining 4 plus the 4 previously put aside were then ranked 17 to 24.

Results and discussion.

The rankings achieved by the two groups correlated .921 (p<.001) and the pieces were assigned a complexity ranking. It appears that figures classed as simple are all easily labelled geometric figures while the most complex are figures which are geometrically complex and
unfamiliar and thus have no easily applied label. The major variations in individual rankings were in the middle range with little variation at the simple and complex ends of the spectrum.

From this ranking, values were assigned to each problem. Ranking 1-5 was assigned a value of 1, 6-10 a value of 2, 11-14 a value of 3, 15-19 a value of 4 and 20-24 a value of 5. Applying these values to the total correct configuration in each problem 25-40 a complexity value for the total problem was achieved.

The complexity values for the problems were compared with the percentage errors resulting in problems 25 to 40 from 741 subjects who completed the MPFB (DA). These subjects came from Year 11, Year 12 and apprentice subjects (mean age 16.9). These data were collected in 1979. A second comparison was made with the errors in problems 25 to 40 made by 633 subjects who were applicants for certificate courses in 1984 and who completed the MPFB (DA). The results are set out in Table 3:4.

The first group of subjects was younger and less able and it could be argued that they were more likely to be following a piece by piece strategy while the more skilled certificate applicants would be likely to follow a strategy which was not dependent upon the total complexity arrived at by taking all pieces into consideration.
Table 3.4
Comparison of complexity value of total problem and the percentage of errors made on that problem by two groups of subjects.

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>25</td>
<td>4</td>
<td>3.4</td>
<td>2.0</td>
</tr>
<tr>
<td>26</td>
<td>14</td>
<td>23.6</td>
<td>17.6</td>
</tr>
<tr>
<td>27</td>
<td>6</td>
<td>11.2</td>
<td>5.1</td>
</tr>
<tr>
<td>28</td>
<td>6</td>
<td>20.9</td>
<td>22.5</td>
</tr>
<tr>
<td>29</td>
<td>5</td>
<td>11.3</td>
<td>8.7</td>
</tr>
<tr>
<td>30</td>
<td>5</td>
<td>13.2</td>
<td>8.9</td>
</tr>
<tr>
<td>31</td>
<td>11</td>
<td>20.1</td>
<td>11.6</td>
</tr>
<tr>
<td>32</td>
<td>5</td>
<td>15.8</td>
<td>12.0</td>
</tr>
<tr>
<td>33</td>
<td>3</td>
<td>11.2</td>
<td>8.4</td>
</tr>
<tr>
<td>34</td>
<td>7</td>
<td>10.5</td>
<td>10.2</td>
</tr>
<tr>
<td>35</td>
<td>8</td>
<td>20.1</td>
<td>13.4</td>
</tr>
<tr>
<td>36</td>
<td>16</td>
<td>29.6</td>
<td>21.6</td>
</tr>
<tr>
<td>37</td>
<td>6</td>
<td>24.4</td>
<td>21.7</td>
</tr>
<tr>
<td>38</td>
<td>6</td>
<td>22.8</td>
<td>19.2</td>
</tr>
<tr>
<td>39</td>
<td>12</td>
<td>22.4</td>
<td>16.0</td>
</tr>
<tr>
<td>40</td>
<td>22</td>
<td>23.8</td>
<td>19.6</td>
</tr>
</tbody>
</table>

Correlation between complexity value and the percentage errors for the 741 subjects was .662 (p<.01) and for the 633 subjects .524 (p<.05).
There is one striking anomaly in the results reported in Table 3:4. Problem 28 (see Figure 1:2) shows a low value of complexity and a high error rate in both groups. It could be argued that while the problem is composed of two simple geometric figures there are two alternative answers which are very close to correct although only one is identical.

It is therefore concluded that complexity of the individual pieces and the resultant figures composed of these figures is closely related to the errors made by subjects in completing the MPFB.

To test the relation of complexity and the time taken to complete the problem, the subjects who completed the ranking of pieces for complexity were also timed individually on problems 25-40 and their times correlated with the complexity values shown in Table 3:4. The correlation between time taken and the complexity value was .8686 (p<.001).

In general, the results suggest that the perceived complexity of the pieces involved in the problems affects both time to complete and the errors made in the solution of these problems and is a crucial element in task solution.
PILOT STUDY FIVE

It remains to consider the factors which may cause a change in strategy.

Cooper (1980) argued for a programme of research to identify the qualitative differences which emerge in simple visual information processing tasks. The first objective of such a programme is to identify patterns of performance and to sketch the type of processes and process combinations which produce them. This would be followed by a more detailed analysis of the underlying strategies.

The pilot work reported above has identified three strategies. They might be labelled in accordance with Sternberg’s (1977) terminology.

Strategy 1 - Sequential option scanning. This involves taking one piece and checking in the first answer "Is it there?". If "Yes" proceed to check other pieces in that answer until complete or until one piece does not fit.

Strategy 2 - Alternating option scanning. One piece is taken and checked against each answer, eliminating those without this piece. The process is repeated on the remaining answers with the next piece and so on until only one answer remains.

Strategy 3: Global. The subject attempts to determine the answer by using the total figure or relationships between the pieces.
It could be hypothesised that Strategy 1, being self terminating and aided by the structure of the test, could be expected to be marginally faster than Strategy 2. Strategy 2 however, should be more accurate since it involves consideration of all the alternatives. Strategy 3 could be less accurate than the other two approaches due to the inaccuracy of the total construction.

Cooper suggests (1982) that one way of gaining insights into the various strategies is to identify the strategy being used by particular subjects and then change the nature of the task in a way that will affect the operation of one strategy type. If the change affects performance in only one type of subject then (a) the modified task demands "reflect certain features of the natural comparison strategy of the subjects whose performance remains the same" and (b) the processing strategy adopted by the subjects whose performance does change will show how effectively they can adapt to new demands. This methodological suggestion provided the basis for the final pilot study in the preliminary series of experiments.

**EXPERIMENT**

To test these propositions it was decided to change the nature of the task so that subjects employing Strategy 2 were no longer able to use this approach. This could be done simply by reducing the number of
alternatives to one. Since, however, it would be expected that this would not distinguish Strategies 1 and 2 it was also decided to change the nature of the task to require the subject to remember the problem piece rather than being able to return to it to refresh memory again for a further comparison.

It was hypothesised that subjects who have difficulty in remembering the piece with which they are working will tend to use Strategy 1 as it does not require the piece to be retained in memory as long. Subjects employing Strategy 2, being able to hold a piece for a longer time to complete five comparisons would be more likely to move in the direction of Strategy 3 than revert to Strategy 1. Realization that they only have to retain a piece in memory for a short time would tend to give them confidence to try remembering a number of pieces at the same time and to attempt a global comparison. Since a global comparison (Strategy 3) requires an understanding of relations as well as retaining images of a number of pieces it would be expected that it would result in an increase in the error rate. Subjects already employing the Strategy 3 approach should not be affected since they should be able to employ the same approach as when working with the stimulus array present.

Subjects and method: Eight subjects whose strategy could be clearly identified on the MPFB administration were
selected. Each subject was shown a card which consisted of the normal stimulus array of a problem taken from the MPFB. The subject was instructed to study the pieces of the stimulus array for as long as they wished. When the subject indicated that he/she was ready the card was removed and replaced by another card on which appeared one of the five alternatives given in the test for that problem. This step was repeated with two other alternatives. The three chosen for presentation were the correct answer, the most nearly correct answer and in each trial the answer least likely to be correct. In each case the subject was asked to indicate whether the answer offered was correct or not.

Ten problems were used and the alternatives were presented in random order. The sequence comprised thirty trials in all. The time taken to study each of the pieces was recorded, and the answer noted.

Results and Discussion.

The subjects were drawn from the group of architectural drafting applicants discussed in Pilot Study 1 and were selected on the basis that their strategy could be clearly identified and was distinguished from the other strategies. The subjects obtained the accuracy results on the MPFB shown in Table 3:5.

The results obtained on the thirty trials with the experimental procedure are presented in Table 3:6.
Table 3.5
MPFB results of eight subjects used in Pilot Study 5.

<table>
<thead>
<tr>
<th></th>
<th>Strategy 1</th>
<th>Strategy 2</th>
<th>Strategy 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>n=2</td>
<td>n=3</td>
<td>n=3</td>
<td></td>
</tr>
<tr>
<td>Mean score</td>
<td>48.0</td>
<td>50.0</td>
<td>41.5</td>
</tr>
<tr>
<td>Mean completed</td>
<td>57.5</td>
<td>58.7</td>
<td>61.5</td>
</tr>
<tr>
<td>Per cent correct</td>
<td>83.5</td>
<td>85.2</td>
<td>67.5</td>
</tr>
<tr>
<td>(Percent correct total sample n=85)</td>
<td>83.1</td>
<td>90.3</td>
<td>76.9</td>
</tr>
</tbody>
</table>

Table 3.6
Results on experiment for Ss grouped by strategy.

<table>
<thead>
<tr>
<th></th>
<th>Strategy 1</th>
<th>Strategy 2</th>
<th>Strategy 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>n=2</td>
<td>n=3</td>
<td>n=3</td>
<td></td>
</tr>
<tr>
<td>Mean encoding time</td>
<td>185 secs</td>
<td>120 secs</td>
<td>122 secs</td>
</tr>
<tr>
<td>Mean correct</td>
<td>25.5 (85%)</td>
<td>20.7 (69%)</td>
<td>18.5 (62%)</td>
</tr>
<tr>
<td>Mean frequency failure to select correct answer</td>
<td>0</td>
<td>1.3</td>
<td>2.5</td>
</tr>
<tr>
<td>Mean frequency select similar answer</td>
<td>4</td>
<td>6.3</td>
<td>6.5</td>
</tr>
<tr>
<td>Mean frequency select least likely answer</td>
<td>0.5</td>
<td>1.7</td>
<td>2.5</td>
</tr>
</tbody>
</table>

Strategy 1 subjects appear to have maintained their strategy and continue to perform at about the same level of accuracy. The errors which those employing this strategy make appear to involve failure to identify close alternatives. A possible explanation is that the image which they form of the piece for comparison blurs quite quickly and prevents accurate comparison with minor differences. It is also apparent that Strategy 1 subjects take considerably longer to encode the material.

Strategy 3 subjects appear to maintain their strategy
and the major cause of errors is attributable to failure to have a clear enough figure in memory to compare to the offered answer so that they reject correct answers, and fail to distinguish close answers. At times they may even lose the global figure entirely and simply guess.

Strategy 2 subjects seem to be pushed by the task requirements and, perhaps, their estimate of their own ability, in the direction of Strategy 3 rather than Strategy 1. They show an error pattern consistent with the employment of Strategy 3.

CONCLUSIONS FROM THE PILOT STUDIES.

The pilot studies have identified three basic strategies which are used by subjects and the influence which strategy choice exercises on performance on the MPFB. The investigation of the influence of complexity and strategy choice have also contributed insights into performance.

In addition to the hypotheses developed at the conclusion of Pilot Study 3 it can also be argued that strategies seem to be affected by the ability of the subject to retain an image of the piece or constructed figure. Although results obtained by Strategy 2 on the MPFB administration differ little from those of Strategy 1 subjects, the process which they employ probably entails a great deal of backwards and forwards checking of individual pieces. If, for example, a piece is
compared to all five alternatives in order it is likely that the image is "refreshed" several times. This hypothesis could be tested by eye-movement experiments.

It is also likely that the time taken by the backwards and forwards scanning of subjects using Strategy 2 is offset by the greater time taken by Strategy 1 subjects to encode. As a consequence the two strategies produce similar results but are quite different in their execution. Obviously the number of subjects is insufficient for firm conclusion but the results are suggestive and are given as an example of how strategies which produce apparently similar performance do so in different ways.

These introductory pilot studies suggest that investigation of strategy usage is a valid dimension in exploring performance on the MPFB and that complexity of the material presented within the problem will have the effect of producing variation in strategy usage.

The pilot studies have fulfilled the function of clearing the ground and identifying the major issues which will now be explored by the use of larger numbers of subjects and investigating their protocols. Confirmation of the task analysis will allow the development of a model which will be experimentally tested.
PROTOCOL INVESTIGATION

Subjects and Method: 709 applicants for certificate courses at a Melbourne T.A.F.E. College who had been given the MPFB as part of the selection battery participated in this experiment. The subjects, aged between 16 and 25, were required to have completed year 11 and were applying for courses in electronics, computer operating, architectural drafting and engineering.

Each subject was given a sheet containing three of the test problems (Figure 3:6) chosen as representing varying levels of difficulty. The percentage error rates for these problems obtained by the 666 subjects regarded as "live" (43 subjects did not complete half the test and were excluded from the error analysis) were 8.4%, 16.0% and 19.6%.

The subjects were asked to explain to an imaginary naive subject how the test should be tackled being provided with the three problems as reminders of the range of items and assistance in considering whether the problems should be tackled in different ways. The subjects were also given several statements which could serve as guides to recall and were asked to indicate the features which determine the relative difficulty of problems.

The procedure was aimed at eliciting protocols which would reflect the material already systematised and
Below are three problems from the test you have just completed. Please describe the steps you followed to solve these problems. (Imagine you are explaining the steps to follow to someone who has never tried them before).

(Some of the statements you might add answers to:

"I started by ____________________________"

"I worked with this shape because ____________________________"

"I found some problems easier than others because ____________________________"

"I feel the hardest part of the test was ____________________________"

"I assume doing this test helps the examiners know ____________________________"

Figure 3:6 Instrument used to gather protocol data.
stored in long term memory (LTM). Alternatively, if the subjects reworked the problems the protocols would provide material from short term memory (STM) representing a verbal encoding of their current activity. This verbal encoding should reflect the order in which thoughts were generated. Confusion in the protocol would reflect confused thinking at the time of processing.

It was also assumed that by asking the question "How did you do these problems?" the subjects would be prompted to work through the examples asking themselves "What am I doing?". This would discourage omission of information about processes which may have become "automatic".

Despite the inherent limitations of the procedure it was anticipated that the data obtained would provide an indication of the subjects' general strategy. It was accepted that the protocols may be a reflection of how the subjects tackled the three problems presented rather than the whole test but this was accepted since the problems are reasonably representative of the total set of problems. The problems were also sufficiently different to identify the subjects who realise that they have to tackle the problems differently. As we have already noted, protocols gathered in this manner risk reflecting "what I should have done" rather than "what I did".
Results and Discussion.

Since the protocols were gathered as part of a selection process administered to different groups at different times Table 3:7 sets out the mean scores on the MPFB for each group.

Table 3:7
Mean scores and standard deviations of subject groups.

<table>
<thead>
<tr>
<th>Applicant Group</th>
<th>Mean score</th>
<th>Mean items completed</th>
<th>Error rate</th>
<th>Percent complete</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electronics</td>
<td>44.6 (8.3)</td>
<td>51.7 (8.8)</td>
<td>13.7%</td>
<td>11.7%</td>
</tr>
<tr>
<td>Building</td>
<td>45.0 (9.1)</td>
<td>51.1 (8.7)</td>
<td>12.0%</td>
<td>9.3%</td>
</tr>
<tr>
<td>Mech Engin.</td>
<td>45.5 (9.9)</td>
<td>53.4 (9.9)</td>
<td>14.8%</td>
<td>25.7%</td>
</tr>
<tr>
<td>Computer Op.</td>
<td>41.9 (8.8)</td>
<td>52.3 (9.4)</td>
<td>19.9%</td>
<td>18.7%</td>
</tr>
<tr>
<td>Arch. Draft.</td>
<td>47.9 (8.2)</td>
<td>56.4 (7.7)</td>
<td>15.0%</td>
<td>31.0%</td>
</tr>
<tr>
<td>Total</td>
<td>45.0 (8.5)</td>
<td>53.2 (8.4)</td>
<td>15.3%</td>
<td>19.2%</td>
</tr>
</tbody>
</table>

Between means for electronics and drafting t=4.4, p<.001. Between computer operators and architectural drafting t=6.6, p<.0005. Between computer operators and electronics t=3.1, p<.0005.

Because of this difference between the three major groups a three part analysis of the protocols was carried out. Part one consisted of 281 applicants for post-Year 11 courses in electronics, the second part consisted of 200 applicants for courses in architectural drafting, and the third part considers the computer operator applicants.
The categorizing of the protocols in each major group flows from an attempt to understand the approach taken by each subject. Consequently the initial groupings reflect the approaches rather than the strategies reported by individuals. These approaches have been grouped in ways which offer the greatest insight into the data and only then are these groupings compared with the hypothesised strategies, and the different approaches reconciled into strategy categories.
PART 1. ELECTRONIC APPLICANT PROTOCOLS.

Nine approaches to problem solution were identified in the first group of protocols. They will be illustrated with extracts from statements by the subjects to provide a direct "feel" for the type of performance. With each extract the number of items correct and number completed by the subject are given in brackets. After presenting the approaches, they will be related to the previously identified strategies.

APPROACH 1: Working with pieces and all alternatives.

A typical protocol for this approach was "started by finding a piece, trying to use one which was easy to remember - tried to find it in the answers - I then used a second shape to identify the correct answer" (53/53) or "I started by looking at the main shape, the largest piece. Then seeing which one it will fit into, then the other shapes by comparing sizes and trying the different combinations until you can picture in your mind all the pieces put together" (35/36).

The number of subjects following this approach was 13 and, in general terms, they followed the pattern of Strategy 2 previously discussed (See Figure 3:2).

APPROACH 2: Working with pieces and one alternative in turn.

This approach reflected the previously identified Strategy 1 (Figure 3:1) which is to take a piece and when found in an answer, add the remaining pieces to see
if it is correct. In practice, it is not always easy to
discriminate Strategies 1 and 2 in subjects’
performance. A protocol clearly exemplifying this
approach was "pick one shape and match with the shape in
one of the boxes. Then put the other shapes into the
same diagram and see if they are the same size" (42/45).
Approach 2 appears to be followed by 12 subjects.

APPROACH 3: Working with pieces.

A number of subjects used pieces in a "jigsawing"
method which involved overlaying pieces or using space
as recounted in the following extract. "Start by
placing the largest blocks side by side or whatever and
having a look at the space left. This space may have
been in the middle of the two blocks or joins at the
outside. The shape of the space left will match either
the piece left or the last pieces combined" (33/39).
This type of approach was common to some 13 subjects.

APPROACH 4: Right to left, whole figure to piece
comparison.

In view of the approach taken by Mumaw and Pellegrino
(1984) in their experiments subjects were identified who
appeared to work from the completed whole by breaking it
up and then comparing the pieces. Four of these were
identified. There was, however, some indication that
the choice of the answer from which to work backwards
may have been conditioned by a rapid scan resulting in
elimination of some answers and selection of one as the
most appropriate with which to work. An example of this approach is provided by the following protocol: "I looked at the answers to get an idea of what the shape would look like when put together. Step two was to pick one answer and compare its shapes with the one you are given. Step three, if the shapes are the same, that’s the answer, if not then repeat step two with another alternative until answer found" (55/57).

APPROACH 5: Identifying relationships.

This approach appeared to be based on identifying some particular relationship within the pieces given and then using this relationship to eliminate answers. This approach was reported by 4 subjects. An example was the following: "I looked for a figure containing no rectangles and no symmetry ... I then used the largest shape - I selected answer by comparing sizes of shapes relative to each other" (43/47). From this it can be seen that it was an approach which was useful in eliminating unsatisfactory answers but which required checking by matching pieces to be finally successful.

APPROACH 6: Approaches which specifically mentioned a change in approach depending on the nature of the problem.

This seems to be a more general approach than that reported in Approach 5 and is dependent on the demands of the problem. Examples of this type of approach are: "For the easier ones it is quickest to identify the
correct choice by looking to see which contains the same given pieces. For the harder ones it is best to eliminate the options which have the wrong pieces. Sometimes choices can be eliminated easily and in others the correct choice is obvious" (45/48).

Another subject suggested: "step one, go through each answer and find the ones with shapes identical to those in the question. Step two, if this does not work, try to put the object together without looking at the answers and then find the answer which fits your answer" (50/54).

On the easier questions one subject "picked out without eliminating" but for harder problems "worked by elimination" (46/64).

The most enlightening protocol reflecting this change in approach gives insight into why and when change in approach takes place (writer’s emphasis added): "Look at the basic shapes and MEMORISE them. Try and get a basic picture IN MIND to match with the answer. On the hard questions WHERE YOU CAN'T IMAGINE THE SHAPE, it is necessary to get the pieces and fit them into each square until you find the shape all the pieces fit into" (47/53). Ability to memorise, hold images and work with such images are crucial factors in performance.

Two other approaches hint at a more global approach to the problems presented in the MPFB.

APPROACH 7: Construction of the pieces followed by
This approach was used (a) only with the easier problems or (b) with all problems as a general approach. The goal of this approach is to build up a picture of the total figure constructed from the stimulus array and then to compare this constructed figure with the answers which are offered. An example of this strategy applied to the simpler problems "first put two triangles together to form a square, next place this square which you have formed under the other square and line these edge to edge along the rectangle. Rotate it to get the answer" (32/39).

The second group reported in more general terms such as "start with the biggest shape, then in my head I put the pieces together and see if it makes the same shape as the answers. If it doesn’t then you note how the lines are and see if you can see one the same. If not I turn it upside down or left to right inside out until you see the same shape as the one in the answers" (39/56), or "I attempted to picture how the pieces fit together in my mind. I then searched for a combination that matched this picture" (52/59). The role of imaging is reflected in the protocol of the subject who reported "I started by drawing a picture of the shape in my mind then by looking at the other shapes (answers) I chose the one I thought suited the most" (43/48).

APPROACH 8: Study-eliminate-match.
This approach was reported by 26 subjects. Examples from the protocols of these subjects were — "I started off by looking at the given shapes — looked at shape and size — then looked through the answers — narrowed them down to one or two and then went through these carefully" (48/59) or "I examined the shapes to be aware of comparative size. When I had quickly eliminated those boxes which were not feasible, I looked at those left and imagined the shapes in that position to see if it was the answer. This method was used with harder questions as they were more complicated. Often in easier questions the answer could be seen at a glance without wasting time on elimination of other answers" (43/44). One clear protocol reported "I started to piece together ... looked for peculiar shape easy to recognize. Step 2 was to have a quick look over the answers and either count them for a second look or discard them. I then had a careful look at the two or three obvious ones and picked one which fitted the description" (45/47). This approach was summed up by one subject who wrote "observe basic shapes and make a quick comparison with the answer. If a shape does not appear or there is an extra shape in the answer, then dismiss as an impossibility. Step two — take any particular shape and try in all the possible positions and see if it matches. Again dismiss any answer where there is no possible way the shape could fit. Keep
repeating step two until there is only one possible answer left" (47/52).

APPROACH 9: Basis of performance unclear.

There was a group of 27 protocols which did not lend themselves to identification of underlying processes. The protocols were confused or did not offer enough information on which to classify them according to the approaches already noted.

The results obtained by the subjects identified as following particular approaches were compared in Table 3:8.

Table 3:8
Means and SDs for MPFB performance by approach.

<table>
<thead>
<tr>
<th>Approach</th>
<th>Number</th>
<th>Mean correct</th>
<th>Mean completed</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Part approach (Strategy 2)</td>
<td>131</td>
<td>47.1 (7.9)</td>
<td>53.1 (8.3)</td>
</tr>
<tr>
<td>2. Part approach (Strategy 1)</td>
<td>12</td>
<td>44.5 (11.2)</td>
<td>54.2 (10.0)</td>
</tr>
<tr>
<td>3. Part approach (Jigsawing)</td>
<td>13</td>
<td>39.7 (11.3)</td>
<td>48.9 (8.8)</td>
</tr>
<tr>
<td>4. &quot;Backwards comparison&quot;</td>
<td>4</td>
<td>48.0 (8.3)</td>
<td>50.5 (8.5)</td>
</tr>
<tr>
<td>5. Relationships identified</td>
<td>4</td>
<td>45.5 (4.8)</td>
<td>52.0 (8.1)</td>
</tr>
<tr>
<td>6. Strategy change identified</td>
<td>11</td>
<td>46.4 (2.4)</td>
<td>52.7 (6.3)</td>
</tr>
<tr>
<td>7a. Easy Problem construction</td>
<td>36</td>
<td>41.1 (8.8)</td>
<td>50.5 (9.3)</td>
</tr>
<tr>
<td>7b. Systematic construction</td>
<td>18</td>
<td>41.8 (7.1)</td>
<td>50.9 (8.0)</td>
</tr>
<tr>
<td>8. Study-eliminate match</td>
<td>26</td>
<td>44.9 (5.6)</td>
<td>51.9 (7.6)</td>
</tr>
<tr>
<td>9. Unidentifiable confused</td>
<td>27</td>
<td>41.3 (7.4)</td>
<td>47.8 (7.4)</td>
</tr>
</tbody>
</table>
The main point of interest in these results is that the lowest results in number correct and number completed are the two groups who experienced difficulty in stating what they were doing (Approaches 3 and 9). This is consistent with the previous suggestion that the ability to generate verbal descriptions of process when faced with a problem is crucial for the solution of problems and the ability to monitor progress. This inability to generate descriptions should not be confused with the previous point that highly skilled individuals often report in shortened forms. These latter exhibit curtailment of expression but are always able to return to a fully consistent reporting when queried.

It is also apparent from the results that a Part approach (Strategy 2) which begins with an identified piece and then searches for this piece in all alternatives thereby eliminating some answers, and which repeats this process with other pieces until an answer is chosen, is, by far, the most common approach.

There is no significant difference in performance between the Part approach/Strategy 2 (1) and the Study-Eliminate-Match approach (8) \( (t = 1.7 \text{ df } 155) \) or between the Part approach and the change of approach \( (6). (t = .7 \text{ df } 140) \). However there is a significant difference \( (t=3.43 \text{ df } 183) \) between the means for the
number correct of the Part approach (1) and the Construction approach (7) suggesting important performance differences between Part and Global approaches. There is, therefore, some evidence that a Part approach will give an advantage over global approaches in total results but allowance must be made for the confounding effects of speed and accuracy variations in individual performance.

The overall results suggest that there are two major approaches to these problems - a Part approach and a Global approach with the latter being varied to include a part approach in more difficult problems. Crucial performance factors are the ability of the subject to memorise individual pieces and to group configurations and work with them at various levels of complexity.

Comparison of the results obtained by subjects in the MPFB with their results in mathematics and mechanical reasoning tests reveals that the highest results in these tests are obtained by groups which employ relational and change-depending-on complexity approaches in the MPFB. This supports the contention of McGee (1979) that it is not the raw score but the method of operation which carries the predictive power in a spatial visualization test. The method of operation is related to the ability to perceive configurations and retain these as mental patterns.
PART 2: ARCHITECTURAL DRAFTING APPLICANT PROTOCOLS.

The applicants for architectural drafting performed better in the standard administration of the MPFB in both speed and accuracy. As these applicants are expected to have skill in graphics and to be spatially acute this is to be expected. It gives the opportunity to investigate the processing of a highly competent group. The group obtained a significantly higher mean score and 31% of the group completed the test compared with 11.7% of the electronics applicants and 18.7% of the computer operator applicants.

The protocols were surveyed and divided roughly into two groups on the basis of the processing of the pieces within the problem. The two groups comprised (a) those who reported considering all the information given (the Whole Approach) and (b) those who concentrated on parts of the information (the Part Approach). Within each group it was possible to distinguish individual variations in tactics but the subjects’ overall approach to the problems, or their strategy, appeared basically to fall within one or other of these categories.

The Whole Approach.

This approach was marked by three characteristics:
(a) some activity in relation to all the pieces,
(b) a process of elimination performed rapidly, and
(c) a matching process which confirmed or identified the answer.
The checking part of this approach is not always applied.

Some examples of this approach are:
"I started to solve the problems by first visualising and arranging the shapes in my mind. Next, I quickly went through all the possibilities and chose the one I thought was the more logical. Then I studied the square of shapes very carefully, arranging, sorting and finally coming up with the right answer" (55/56).

"First I looked at the shapes and the number of similar ones. Then I looked at the alternative answers and found 2 or 3 of them could apply. From the ones I chose I compared the sizes of each piece and marked the one that fitted best" (44/47).

"Try to visualise the shapes in your head. Scan to see any of the alternatives are similar and how many there are of these. If this quick method cannot be adopted, take a closer look and try to place each shape on the corresponding shapes. Once this is done the problem should work out systematically" (50/50).

"Look at pieces ... quickly memorise their various shapes and dimensions ... quickly construct the pieces into a model ... try to eliminate those answers I consider obviously wrong thus narrowing the field to choose from - usually left 2 - look more closely at sizes and angles of component parts until satisfied that everything fitted to my satisfaction" (46/55).
"First visualise the pieces being used. Quickly look over each answer, then take the one that looked closest. I then started to match up the shapes" (40/53).

This process of elimination and then matching can also apply where only one piece is taken as evidenced by this comment: "I chose a shape or two shapes which were distinctive from the others in relation to the irregularity of their form. The choices were usually reduced to about two. By then examining the remaining pieces the correct answer could be determined" (58/59).

Obviously this could be claimed to be more of a piece by piece strategy akin to Strategy 2 but the willingness to emphasise removing mismatches rather than matching puts it into the Whole Approach.

What characterises this approach is that certain alternatives are quickly eliminated on the basis of a mismatch, after which, if the answer is not immediately available, it is obtained by a process of matching piece by piece thereby either eliminating the remainder or matching to completion. The crucial characteristic of this mismatch strategy is elimination, very much more rapidly than in Strategy 2, usually by utilizing an overall picture of the problem. The Part Approach.

This approach differs in two ways from the Whole Approach: firstly, the amount of work done on the total problem is much less with an emphasis on one particular
piece initially, followed by the other pieces in successive stages. Secondly, the major thrust with the single piece is to look for a match. This contrasts with the Whole Approach which initially involves consciously looking for a mismatch. Careful interpretation is required because, as already indicated, looking for a match can create an impression of seeking to eliminate as in the Whole Approach when in fact the elimination is attributable to a different process. This point will be covered later in a discussion of Target and Context controlled search.

The following are "pure" examples of this approach.

"I found the biggest and easiest to find shape. Located it. Then took the second biggest and located it. Then the small pieces just fell into place" (49/64).

" Took biggest piece - find which answers had the exact size. Chose one smaller shape. Find in answers" (53/64).

"Take one shape, usually most abnormal (biggest, smallest, many-sided) - imagined that shape fitting into the five answers. If that fitted, then took another (piece) that looked different in some way and repeated" (56/64).

"Look at biggest shape - look at answers and see which has a shape the same as the largest. Then find the next largest shape and go through the same process. Repeat the process until you build up the correct shape"
Another way of characterising this sequential approach is not so much as looking for a match but rather as a "discarding", or, as one subject described it, "a cancellation approach". This aspect is illustrated in some further examples.

"Choose a particular approach - discard those answers in which this piece could not be found. Do this with one or two pieces until solution is found" (45/51).

"Which answer had the appropriate piece? Take another piece - eventually cancel out four answers" (61/64).

"Take each shape one by one and try to fit them into the answers - when a shape does not go into a box, I eliminate that box until I find the box which fitted all the shapes perfectly" (54/64).

"Started by taking one of the shapes, usually the biggest shape, then go through each box eliminating those that do not agree with the shape I have. I then choose another shape and do the same process. After doing this with every shape, you should only be left with one box" (61/64).

This Part Approach is by far the most common approach representing over 60% of the subjects. Within this approach it is rare to find either a complete checking of pieces with all the answers, except for the first piece, or to find the checking of all pieces with the chosen answer. Most reports suggest terminating at
various confidence levels, from finishing when two pieces fit to a rapid check of the remainder.

A number of protocols, such as the following, reveal an overlap between Whole and Part approaches.

"I chose one piece at a time checking to see it it was present in each shape in its correct form. In this way I was able to eliminate certain answers ALMOST IMMEDIATELY. Final choice after comparing the form and size of its surrounding pieces" (40/42).

The clue to the different approaches lies in the amount of work related to the total picture and in how fast the elimination is accomplished.

Many subjects seemed to reduce the comparison time through creating a larger chunk by joining two pieces together or taking two pieces at the same time and proceeding through a matching strategy. The following is an example:

"Look at the shapes. Imagine what they would look like when they are made into a certain shape. With this shape in mind, look through the answers and find out which one matches the one in your mind" (57/63).

Another variation of the Part Approach involves terminating the matching process as soon as the pieces are believed to match an answer as in this example:

"Choose any shape - fit to answers. As soon as the first shape fits you take the second, third and fourth shapes" (52/57). The danger of this approach is that
the subject will make an error by failing to check through all alternatives. It will be recalled that this is a feature of Strategy 1 whereas Strategy 2 requires such checking.

There were also some subjects who worked "backwards" from answer to problem, for example:

"Look at pieces. Look at each answer in turn beginning at a particular section of the answer and looking back at the individual pieces to see if the section was one of them. If it was, I would continue onto the next section (of the answer) until I checked all the sections and pieces. This process continued until I had eliminated the four incorrect solutions or found a correct formation" (60/64).

An important aspect of the Part Approach is the choice of a particular piece, usually, as we have already noted, the biggest or the smallest. The subjects gave reasons for this choice. The largest piece was chosen because it was "easier to place and find", creates the biggest proportion of the area first making it easier to position smaller pieces", is "least complicated", and just "simplest".

A number chose the "distinctive" shape because it was "most visible in the solutions", "varied considerably and therefore easiest to find", "allowed identification in close patterns", "easier to remember" or "would look the same upside down thereby making the problems
The smaller shapes were chosen "because you could picture them in your mind longer" while the circular shapes "were harder to distinguish". What some respondents called "basic" or "pure" shapes were those "easy to put together". Whatever choice was made was justified on the grounds of capacity to remember, to identify, to "see" and to work with.

Since the results to this point have not consistently identified one approach as more accurate or quicker than another the subjects were divided into four groups on the basis of the strategies which they appeared to use.

Table 3:9 presents the results.

Table 3.9
Results of architectural drafting Ss by strategy.

<table>
<thead>
<tr>
<th>Strategy</th>
<th>Number</th>
<th>Mean score</th>
<th>Mean completed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pure part-approach</td>
<td>117 (60%)</td>
<td>48.9</td>
<td>57.1</td>
</tr>
<tr>
<td>Pure whole-approach</td>
<td>16 (8%)</td>
<td>49.5</td>
<td>55.1</td>
</tr>
<tr>
<td>Construction plus matching</td>
<td>29 (15%)</td>
<td>47.6</td>
<td>55.8</td>
</tr>
<tr>
<td>Relationships plus matching</td>
<td>33 (17%)</td>
<td>45.9</td>
<td>56.6</td>
</tr>
</tbody>
</table>

Between Pure part-approach and the other three approaches t=1.69, p<.10 df194. Other comparisons n.s.

Once again it is apparent that the Part Approach is the most common with two thirds following this approach.

From the protocols it was possible to gain information on three other matters which have been raised previously. The first of these concerns the reasons for subjects changing strategies. The data
offer two accounts of strategy change.

There is evidence for inter-problem change whereby the demands of a problem compared with other problems created a change in strategy. This was most apparent where the problem contained four and five different and unfamiliar pieces. These problems, unlike others, could not be tackled by putting pieces together or they lacked a readily applied label. However, some problems of the five unfamiliar pieces variety could still be solved quickly if a clue is picked up such as "all pieces of the octagon meet at a mid-point". Obviously one of the skills in doing MPFB problems lies in the ability to use previous knowledge to identify a clue of this nature. An example of this inter-problem change is given by the subject who writes of harder problems "I use an error method by placing each bit into each answer .. if it did not fit I went on. I did this because there is NO LOGICAL SYSTEM TO WORK IT OUT" (writer's emphasis).

There is also evidence for intra-problem change in which the subject changes strategy within a problem when it becomes apparent that a strategy will not work. This was usually confined to attempts to eliminate answers by mismatch. When the processing complexity had reached a certain level, the subject had to switch to a more successive match strategy. An example of this was "I chose the largest shape and found which answers it fitted. Then I took the next largest and tried to fit
it. Sometimes I would eliminate answers by seeing shapes within them which could not possibly be correct. Mainly I judged the sizes of the shapes when fitting them together" (52/58).

Two matters remain to be considered:

Some subjects score very poorly on the test. The protocols of subjects who performed poorly were looked at carefully. Two difficulties emerge. First, some subjects try to form images and are unable to do so. The following are examples taken from poor performers.

"I started by trying to fit the shapes into the shape of the answers and then visualising the sizes of the shapes which make the answer - compare visualized image with the answers" (18/30).

"I pictured the measurements of the shapes .. imagined to myself a specific figure" (28/63).

"Look at the unpuzzled shapes and try to imagine the measurements of them" (30/46).

"Fewer shapes made it easier to visualize the correct shape .." (36/64).

These are interesting in that a number of subjects who scored low on the test actually finished the test. Their attempts to work with visual images allowed them to scan but they were not able to hold the image nor were the images clear enough for the rapid processing which subjects sought.

The other area of apparent difficulty lies in
rotating pieces. This is clearly related to difficulties in image formation. Examples of this difficulty are provided by these subjects:

"Looked at main shape given and turned it in all different directions" (29/55).

"I used angles, length of sides, actual size to decide which was correct to match with the problem. This was used with shapes that were turned over or upside down" (37/60).

"Rotate the shapes in your mind" (29/41).

These protocols suggest that the major difficulties for low scoring subjects lie in image formation, the rotation of images and confusion in comparing them.

Finally, the protocols give the opportunity to explore why subjects define some MPFB problems as more difficult than others. Apart from items already mentioned such as the number of pieces, the number of different pieces and the degree of rotation required, the protocols suggest that the other main sources of individual difficulty were:

(a) Differences in size both of the pieces offered in the array ("it is hardest when most of the shapes are of the same or nearly the same size") and of the answers offered ("it was hardest when there were a number of answers which could be right except for very marginal differences in angle, size or area"). This suggests that problems are difficult, not so much because of the
number of shapes but because of the inability of subjects to make distinctions on the basis of size differences. The former comment was made by a subject following a Part Strategy and the latter by one initially attempting to mismatch.

(b) The nature of the shape was raised as a contributor to difficulty by comments about the easier problems having "basic shapes", that is shapes which are easy to put together and "simple and easy to remember". The more difficult problems elicited comments such as "shapes with many curves were the hardest", and "it is harder when shapes lack a distinct shape".

(c) The idea of "manageableness" was raised a number of times in relation to the question of problem difficulty. The ability to fit the shapes together, to manipulate them, to do things with them visually contributed to being able to manage shapes as distinct from just identifying them.

Taken together, these reports of relative problem difficulty suggest that a crucial difference between problems regarded as being easy or difficult lies in the ability to see a relation between the pieces, the ease with which they can be labelled, and their ease of being distinguished from other similar shapes. These, rather than the actual number of shapes, contribute to difficulty.
PART 3. COMPUTER OPERATOR APPLICANT PROTOCOLS.

The applicants numbered 151 with a mean age of 21.7 years. As part of the selection tests the Computer Operator Aptitude Battery (1974) was completed. The Battery consists of three sub-tests: Sequence Recognition (which tests the speed of the subject in visualizing the order in which a scrambled set of time related events should occur), Format Checking (tests skill in perceiving whether arrangements of numbers and letters conform to specified formats), and Logical Thinking (tests ability to analyse logical relations within problems and visualise solution in stepwise form).

The MPFB scores produced the following correlations with these tests:

- Sequence Recognition: 0.2954
- Format Checking: 0.3031
- Logical Thinking: 0.2835

All correlations were significant (p<.001). There is a zero order correlation between age and performance on the MPFB (r = -0.0832). This was looked at because this was the sample which had a wider range of age.

The subjects' protocols can be categorised in the now familiar way, those who follow a piece by piece matching approach and those who follow other approaches. The range of strategies and mean results are reported in Table 3:10.
Table 3:10
Results of computer operator Ss by strategy.

<table>
<thead>
<tr>
<th>Strategy</th>
<th>Number</th>
<th>Mean score</th>
<th>Mean completed</th>
<th>Error Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Strategy 1</td>
<td>19 (13%)</td>
<td>40.2 (9.7)</td>
<td>53.5 (8.7)</td>
<td>25%</td>
</tr>
<tr>
<td>Strategy 2</td>
<td>83 (53%)</td>
<td>44.2 (7.9)</td>
<td>53.5 (8.6)</td>
<td>22%</td>
</tr>
<tr>
<td>Total Piece</td>
<td>102 (66%)</td>
<td>43.5 (8.4)</td>
<td>53.5 (8.6)</td>
<td>24%</td>
</tr>
<tr>
<td>Global</td>
<td>24 (16%)</td>
<td>39.8 (8.6)</td>
<td>47.2 (10.7)</td>
<td>21%</td>
</tr>
<tr>
<td>Confused</td>
<td>27 (18%)</td>
<td>36.4 (10.7)</td>
<td>49.5 (12.5)</td>
<td>26%</td>
</tr>
</tbody>
</table>

Difference between means for Piece and Global strategies is t=20.4, p<.001, df 124.

The majority of subjects appear to adopt an approach involving taking a piece, usually one which is easily identified, and matching this to the alternative answers. Failure to match this piece allows some answers to be eliminated before a second piece is taken and the process repeated with the remaining answers. As one protocol describes it: "Take a large shape - take away the ones (answers) that don't fit this shape - do the same with the other shapes on the answers you have picked - answer" (39/40).

And again "I started by choosing one shape from the selection. I then applied it to each box, seeing which it would fit. After a few boxes had been disqualified I then began with another shape, repeating the same process until one box was left" (51/56).

Some minor variations on this approach involve using more than one piece at a time:
"I pick two given shapes from the question - I see or pick boxes where these shapes aren't - in the remaining answer I get one of those two shapes I picked - see if it matches - if it matches only one I go to the other box left - I see if the two pieces are the same" (52/54).

This subject short circuits the program. The result is akin to amalgamating strategies 1 and 2.

Rotation appears most frequently in those "jigsawing" the pieces, that is, overlaying pieces on the answer. One subject commented that "shapes with more than four sides were found difficult to orient" (48/60), and another "the more and the smaller the shapes, the harder I found them to do" (51/57). While seeking a match one subject was "also looking if it could have been turned over or changed in position" (45/63) and another stated "I feel the hardest part of the test was picking the shapes out, when you put them together, you had to turn them around the other way or on the side" (35/36).

These protocols suggest two distinct demands. First finding the relevant piece and then rotating to congruence, both demands adding to the difficulty of the problem as the pieces become smaller or as the number of pieces occupying the problem space increase. The comparison of pieces was summed up by one subject "I found some problems easier than others because some didn't have a lot of information which needed to be
comprehended" (36/43). Position, orientation and size all determine the "information needed to be comprehended" for piece by piece strategies.

Strategy 1 is most often found in conjunction with "jigsawing". "It's like a jigsaw puzzle, you have the end result and must put it in terms of different shapes to get it" (34/51). There is some indication that Strategy 1 is less accurate than Strategy 2. This may be attributable to failure to check all possible alternatives.

This group produced more "confused" subjects than the other groups. Confused subjects are those who are unable to report an approach which explains their activity. As with the other groups, these subjects perform poorly with less problems attempted and more errors. Examples of their protocols are:

"I started by choosing the correct shape and to match them up with the examples given. I try more than one method of doing something and to match together what I thought went right" (37/64).

"Do these only by imagination and comparison of size" (23/64).

The Global Approach was reported by few subjects but,
for those who did, it involved the following characteristics:

(a) Organization of the array. "I started by looking for the most likely organization of the shapes" (46/47), "Try to fit each shape together, knowing (in mind) that you will eventually make up the shape of the answer" (34/40), and "Try to make the shape yourself" (47/64).

(b) A "mind" activity. "I rearranged each pattern in my head in all different positions" (26/42) or "In my mind I placed the shapes into the same final shape - this method does not always work as you might construct the image in your mind in a different way (to the answer)" (54/64) and "I mentally juggled the pieces around and when the problem presented too many pieces to juggle around I looked for obvious errors" (37/43).

(c) Quick elimination. "I quickly look at all the answers to omit some, then compare and work with answers which look right and find differences and similarities" (42/48). Another protocol said "This helped me to eliminate the incorrect shape . . if it did not then I looked further and tried to compare the size and shape of each individual piece" (29/41).

The whole strategy is summed up by one subject "look at components given, look how they can be fitted together, survey the alternatives, eliminate those obviously not similar" (42/59).
CONCLUSION

It will be recalled that five pilot studies were instigated for the purpose of investigating the strategies which are available to subjects tackling the MPFB, the difficulties which are raised by particular strategy use, how complexity relates to the demands of particular problems and what happens if a strategy is not available to a particular subject.

Confirmation of the tentative conclusions suggested by the pilot studies was sought by an investigation of large groups of subjects reporting their processing as they saw it. From this investigation a number of conclusions can be drawn and these will be reported now in preparation for the development of a model which will be subsequently tested by experiment.

The protocol data reported in this chapter allows the drawing of a number of conclusions.

(a) Two basic approaches were identified throughout the protocol analysis. These can be termed the Whole and Part Approaches. The Whole Approach is characterised by work on the total problem and by an ability to develop a clear representation of the nature and relationship of the various pieces involved. The Part Approach demands a successive matching process based on the working of a piece by piece strategy which proceeds until a particular level of confidence in an outcome is reached or continues exhaustively. In their pure form the
performance latencies produced by the Whole Approach are independent of the number of items to be processed while those for the exhaustive Part Approach will increase linearly with increasing items.

(b) The protocols suggest that the distinction between the two approaches lies in the amount of information which can be held in memory. This, in turn, is dependent on individual ability to chunk, label and generally relate pieces to a whole. Complexity is not just a matter of numbers of pieces but rather of how well the pieces can be handled by the individual skill of the subject.

(c) The type of organization which is amenable to the Whole Approach may range from a totally constructed image to a single piece which is seen in a field of relationships and which is thus made "whole" for the purposes of comparison aimed at rejecting a mismatch. Since individuals appear to be conscious of differing abilities to organize material and to hold this material clearly, strategy choice and change may be a result of self assessment.

(d) The features determining relative difficulty, such as in size and shape variations and "manageableness", are differences which can, to some extent, be over-ridden by past experience, geometrical knowledge and image generation skills. However, there may be some upper limit of sustainable difficulty which applies to
each individual and which governs the speed and accuracy of processing as well as strategy choice and execution.

The stage which has been reached in protocol investigation demands the development of a model which reflects the strategies which have been identified and an understanding of the ways in which subjects may switch strategies.
CHAPTER 4: A MODEL FOR THE PROCESS ANALYSIS OF THE MPFB.

The background which has been developed from the pilot studies and the protocol investigation will now be used to develop a task analysis of the MPFB from which a model will be structured aimed at explaining subject performance on this test.

The MPFB is a test which is defined by Mumaw and Pellegrino (1984) as a measure of spatial visualization and is used for this purpose. Therefore it seems a hollow warning by these authors that "the unsystematic nature of the problems of the MPFB make it impossible to validate assumptions concerning the processes involved in this test". It is intended to seek to undertake a process analysis of the MPFB. The rationale for this approach is that it is essential to identify the processes involved to provide a basis for interpretation of individual performance on the test and, indeed, to justify its existence and use.

It is accepted that the MPFB is not a "pure" test of visualization but lies somewhere on a continuum between spatial relations at one end and tests which load highly on spatial reasoning at the other. The approach to be adopted will resemble that of Pellegrino and his associates in identifying the tasks which are involved in the solution of the problems and then developing a
model representing the way in which these tasks are integrated. It will differ from their approach, however, by being concerned with the test as such rather than with an idealized model of visualization. Particular emphasis will be placed on the way in which strategies integrate and order the processes which provide the basis of the model. This analysis will enable investigation of the sources of individual differences in performance on the MPFB and also incorporating the insights suggested by the previous pilot studies and protocol analysis.

THE TASK ANALYSIS

It will be recalled that the typical MPFB problem, as illustrated in Figures 1:1 and 4:1, consists of an array of two dimensional pieces and five completed figures. If the pieces are put together correctly they produce one and only one of the figures presented. The subject's task is to determine which of the five alternatives is the correct figure. A subject's score on the test as a whole is the number of items completed correctly within a specified time, usually twenty minutes.

MPFB problems vary on a number of dimensions.
(a) The number of pieces varies between two and five and within this variation the number of identical pieces can vary between one and five. Discriminability is also affected by the similarity of the pieces which vary by
Figure 4:1  Examples of typical MPFB problems.
angle and length of sides.
(b) The shape of the completed figure varies from a square to a hexagon and includes circles, trapeziums, triangles and rectangles together with occasional figures which are not easily labelled.
(c) The pieces in the array differ in their perceived complexity with the simpler figures being easily assigned geometric labels while those which are classified as complex are neither geometric figures nor can they be given a pictorial label. Pilot study 4 (Chapter 3) showed that pieces varied considerably in their complexity rating and also that the completed figures were seen to vary in complexity.
(d) Since the space used for presenting the array remains constant and is always filled by the pieces, the elements in a two piece display are viewed as being larger than the individual elements in a five piece array. As a result the size of the pieces must be added to the list of dimensions of variation.
(e) The nature and the number of mental transformations which have to be performed on the stimulus pieces in order to arrive at an answer vary. There are two types of transformation. In some cases pieces have to be rotated to bring them into congruence with the alternative to which they are being compared; in others pieces have to be reversed or turned over before comparison can be effected. The number of
transformations to be made depends upon the unfamiliarity of the stimuli and the strategy being used by the subject.

(f) Another important dimension of variation is the degree of difference between each of the alternatives presented and the pieces in the stimulus array. In some problems the differences between each of the five alternatives and the array is quite small. As a result each alternative is a possible answer. In other problems it is clear to the subject that as many as three of the alternatives are so different from the array that they are not worthy of serious consideration. In the former situation the problem is regarded as particularly difficult by all subjects while the latter identifies subjects who are capable of rapid rejection of obviously incorrect options so that their processing time may be concentrated on those alternatives which are obviously "live". The difficulty of distinguishing between completed figures which are very similar to the stimulus array, usually having only two pieces different, and those which are identical appears to be the cause of most errors.

(g) Problems vary in the demands which they place upon subjects to adopt adequate strategies for solution. More complex problems may create situations where strategies in use with simpler problems will no longer be adequate and change is demanded. If this change is
not made then the error rate will rise appreciably. For other subjects increasing demands will be revealed in increased latency to solution as the problem becomes more complex, less familiar or contains pieces which cannot be readily labelled or "handled".

Any model proposed must be able to explain the ways in which these task variants interact with the processes which are operating. Already it is apparent that some variables are task-related: the number of pieces, the number of different pieces, the number of pieces to be processed to completion which can vary from the number of pieces, the complexity of pieces and figures, the transformations to be made and the number of similar solutions presented. Other variables are subject related: the strategy used, the ability to change strategies between and within problems, and the ability of the subject to name, recognize, imagine, form as a representation, store in visual working memory, reason about geometric form, "see" relationships and organize processing to cope with time constraints.

THE MODEL

The proposed model is based on a number of hypothesised processes: encoding, organization, strategy choice and decision processes. The model to be described is intended to provide an information processing account of the MPFB which offers an heuristic statement of the nature of the processing involved and
which differs when compared with the Pellegrino model. The aim of the model is explanation of individual and group performance. The model makes the following assumptions about the processes involved.

(a) The processing involved in the encoding stage depends on the discriminability of each stimulus and the difficulty of retrieving codes for it (Banks and Flora, 1977). Eysenck (1978) proposes that the general distinctiveness attained in the encoding phase "will vary inversely with both the similarity and the number of prior encodings". It is argued that greater effort expended at the point of encoding will lead to better memory performance (Horton and Mills 1984), since it enables the pieces to be brought "under control" by identifying cues, labelling appropriately and noting relationships. All of these processes make for a clearer and more manageable elaboration of the stimulus.

The extent of the encoding processes depends on the instructions, past experience, familiarity and practice. Individual differences in encoding are revealed by variations in descriptive ability, in the quality of visual transportation, in the ability to combine shapes and in the degree of attention necessary. The particular strategy in use may also affect the degree of clarity required at the encoding stage, for example, simple outlines or fully developed images. Einstein and Hunt (1980) consider encoding to be related to
relational processing and item-specific processing and argue for the value of combining the two types of processing to produce the best recall.

It is possible that "good" encoding eliminates the need for the search process proposed by Mumaw and Pellegrino (1984) which is based on gross characteristics of the encoded element such as relative size, number of angles and overall shape and is followed by a more detailed comparison. If the processes of relational encoding and item-specific encoding are combined there may be need for only one comparison and the solution process as a whole is speeded up appreciably.

(b) The ability to see all of the encoded material as a whole organized into the "best" or "simplest" form may be identical to "the old Gestalt idea that Ss will structure a pattern in a way that minimises its complexity" (Reed, 1973). Pomerantz (1981) views it somewhat differently, however, and suggests that the most appropriate model "would be one in which separate subsystems of pre-attention struggle independently to achieve a stable organization of a figure based on one grouping rule or another. If enough of these sub-systems 'vote' for the same organization, then the pattern will be organized quickly and predictably and seen as good configuration". The ability to see the possibilities for organization may be the single most
important factor in determining subsequent strategy.
(c) The Pellegrino model incorporates only one strategy option, that of exhaustive serial and analytic processing. On this basis individual differences are limited to variations in the speed and accuracy with which individual processes are performed at the encoding and elaborating stages. While they admit that there may be differences in strategy which "reflect less analytic modes of processing in lower skill individuals" (Mumaw and Pellegrino, 1984) there is no systematic investigation of the nature of the strategies which may be in use. The model to be presented seeks to remedy this omission by incorporating a number of strategic options. These will now be reviewed.

Figure 4:2 presents a flow chart defining the processing basis of the strategic options. It should be noted that this presentation does not seek to be an algorythmic statement but rather an heuristic explanation of data arising from both macro and micro studies. In this sense the expression "flow chart" must be seen in a broad sense as a statement which arises from an analysis of the environment and the way in which the mind has been shaped to meet that environment. It is not an attempt to present what Neisser (1976) calls a "hypothetical model of the mind" but seeks to show that various paths to solution may be followed in practice with satisfactory results. As such it is a model which
Figure 4:2 A heuristic model for the solution of MFB problems.

START

ENCODE ARRAY

SCAN ANSWERS

ORGANIZE STRUCTURE

IS STRUCTURE EVIDENT?

YES

NO

SELECT ANSWER

IS AN ANSWER LEFT?

NO

NO

YES

YES

NO

ELIMINATE

PLACE ON LIST

IS AN ANSWER LEFT?

NO

NO

YES

NO

NO

YES

CHOOSE ANSWER

HOW MANY ANSWERS ON LIST?

N = 1

N = N + 1

ID CHECK NECESSARY?

NO

NO

YES

CHOOSE PIECE FROM ARRAY

COMBINE TWO OR MORE PIECES TO FORM ONE UNIT

IS AN ANSWER LEFT?

NO

NO

YES

COMBINE TWO OR MORE PIECES TO FORM ONE UNIT

IS AN ANSWER LEFT?

NO

NO

YES

CHOOSE PIECE FROM ARRAY

FIND CORRESPONDING PIECE

SAME ORIENTATION?

NO

NO

YES

ELIMINATE

ARE PIECES IDENTICAL?

NO

NO

YES

预备件或回答策略?

NO

YES

TAKING ANOTHER PIECE FROM ARRAY

ARE PIECES IDENTICAL?

NO

NO

YES

TAKE ANOTHER PIECE FROM ARRAY

PREPARED TO ACCEPT?

NO

NO

YES

总确认次数?

NO

NO

YES

PREPARED TO ACCEPT?

NO

YES

TAKE ANOTHER PIECE

PREPARED TO ACCEPT?

NO

YES

PREPARED TO ACCEPT?

NO

YES

TAKING ANOTHER PIECE FROM ARRAY
seeks to understand the performance of subjects on the MPFB "as this occurs in the ordinary environment and in the context of natural purposeful activity" (Neisser, 1976). The flow chart is a description of information processing space from which individual activity emerges.

The explanation of this flow chart will be amplified using comments drawn from the protocol analysis bank gathered from subjects reflecting on their method of operating and used earlier. Where the comments refer to specific problems from the MPFB the number of the problem is indicated, otherwise the quoted comment is of a general nature.

As the flow chart indicates, the process of encoding the array sets the conditions for a decision on strategy options (A). Key decision points in the flowchart are indicated by letters. If the subject is able to see the possibility of a structural configuration it is likely that the next step will be to organize the data along these lines (B). ("I looked at what I had to make up and then arranged the pieces to make this shape. After this I skimmed through the answers") The ability to "see" a possible structure establishes a level of confidence leading to an attempt to organize the material. If the organization is successful the subject is launched on Strategy 3. The attempt to achieve this organization may fail ("This problem - DA35 - was harder
because of the difficulty in working out how a square would go”). (Figure 4:3) Failure leads to the abandonment of Strategy 3 in favour of an alternative strategy. ("I couldn’t understand -DA19- it so I started to look for a big bit. When identified I picked up another bit and kept comparing until I got an answer"). (Figure 4:3).

Strategy 3 allows the elimination of alternative answers on the basis of detecting a mismatch (C). It is assumed that the mismatch strategy is able to bring the essential structural features, without superfluous material, into contact with the answers thereby allowing rapid elimination. Because of the nature of this structural image it fails to hold its clarity and integration for a long period and is "lost" after one run. ("Having quickly constructed the pieces into a model, I would then look at all the examples and try to eliminate those examples which I considered obviously wrong").

The rapid elimination of alternatives leaves the possibility for three outcomes.

(1) All but one alternative is eliminated thus allowing an immediate answer to be achieved (D) (Commenting on DA26 a subject reported "Four outside bits with an identifiable middle piece, checked each answer moving left to right and then down. Only one answer not eliminated. Other pieces must fit this so didn’t
check") (Figure 4:3).

(2) While several alternatives are eliminated there remains more than one possibility (E). ("This eliminating usually left about two remaining models, I would then closely look again at the model to be constructed and looking more closely at the various angles and sizes of the component parts continuing until I was satisfied that everything fitted." - DA12) (Figure 4:3).

(3) Only one alternative seems viable but the subject's level of confidence in its accuracy is not sufficient for it to be chosen immediately as in the first outcome. Checking of the potential result is required (F). ("Built up a pattern of the array and then checked. With one answer I checked by using the middle sized bit" DA14) (Figure 4:3).

The second and third outcomes of Strategy 3 require an approach which confirms one of several alternatives or the single most likely alternative as the answer. Such an approach requires a strategy change to an analytic piece by piece strategy (G). Failure to make this strategy change results in the type of processing reported by a subject ("I eliminated those that it definitely wasn't. I like the proportions of answer L. That looks kind of right. I'll make a guess on it" - DA19, and on DA 37 "answer X looks about right. I'll check the other two possibilities. If I was in a hurry
Figure 4:3. Examples of MPFB problems referred to in the text.
I wouldn't bother to check and I'd then be wrong." (Figure 4:3).

The alternative approach (Strategies 1 and 2) is an analytic piece by piece comparison which allows the subject to concentrate on a specific part of the array, mastering its size, shape and angles (H). ("Take the biggest piece and compare to each answer" DA40). (Figure 4:3) A difficulty experienced by some subjects was apparent in the following protocol of a subject ("a ripper. These shapes don't mean anything to me. I can't put a name to any of them. If I knew enough about geometry I could pick each of these shapes, give it a name, flash the names in my mind and go whizzing around trying to find these" - DA50) (Figure 4:4).

Occasionally, before the comparison commences, identical pieces are fitted together to create a new "piece" usually because it is easier to handle or work with as a unit (I). This step is illustrated by a subject's protocol. ("There are three cones the same size so I put them together and then compared with answers" - DA58) (Figure 4:4).

Next, the subject proceeds to match the encoded piece to a piece in one of the answers open for consideration (J). The answer chosen by those beginning with an analytic strategy is most frequently the first answer. For subjects switching to an analytic strategy from the global strategy (G) only a single or short list
of answers remain to be considered.

Depending on the skill of the subject this approach may or may not involve rotation of a piece into congruence. (K). It is usually found that "jigsawing" requires rotation ("match over the answers with the pieces by rotating them and placing on top of the solution") or the subject may make an image comparison which is less likely to require rotation ("all answers have a long triangular bit. I am only worrying about shape and size. Not rotating or turning over" - DA52) (Figure 4:4).

From Figure 4:2 it can be seen that the early stages of this strategy involve the comparison of one piece from the array with one piece in the first answer considered (L). If this piece does not match, the answer is eliminated. Thereafter there are a variety of possibilities dependent upon the number of live answers (which includes answers not yet considered). If there is then only one answer left (M), as may occur if the global strategy has left only two possibilities or only one answer to be checked, then the subject may accept the answer without further processing or proceed to a strategy of complete or partial checking of the answer with the remaining pieces. If the subject eliminates all of the remaining answers (N), a situation most likely to arise where a mistake has meant the elimination of the correct answer during the global
Figure 4.4. Examples of MPFB problems referred to in the text.
processing, then it is necessary to restart and proceed on an analytic strategy from the beginning. As noted, this happens if the global strategy has produced alternatives which do not stand up to checking.

If more answers remain to be processed or there is more than one live answer remaining, one of two strategies may be adopted. The subject may proceed to compare the originally chosen piece with the next possible answer and repeat until all answers are checked, thereby eliminating some answers and keeping others as "live" (P) ("I took the big rectangle with the right angle and looked for this piece. Four answers were left. Taking the isosceles triangle and comparing this piece with the remainder left two. Checked the last bit" - DA42) (Figure 4:4).

Alternatively, the subject may decide to complete checking of a live answer with the next available piece from the array until the answer is accepted or rejected (R) ("I took the biggest piece. Put it on top of an answer. Then with the other pieces covered everything up and everything went in" - DA23) (Figure 4:4).

The decision as to which strategy is followed depends upon the subject's preference to follow a piece or answer strategy. The piece strategy (Strategy 1) leads the subject to take another piece from the array and compare it with the live answer under consideration. The answer strategy (Strategy 2) depends on the
"availability" of the image of the original piece being compared. The availability is determined by the brightness, the familiarity, the ease of labelling the piece under consideration or the ability to "refresh" the image from the original array. The piece is then compared with answers still to be considered. This explains why subjects may start with the "largest" or "most easily identified piece" and use this to follow Strategy 2 but when the piece taken from the array becomes small, difficult to label or to distinguish the subject may change to Strategy 1 to complete the processing. As the flow chart shows it is possible to follow Strategy 1 and not process all the answers to be considered. This may lead to acceptance of a close alternative rather than the identical answer.

The extent of processing is determined by the degree of confidence sought by the subject before making a decision. The points at which this decision to accept an answer is taken on the basis of confidence are indicated in the flow chart by the letter S. For some subjects processing will be exhaustive with all pieces being checked while other subjects are prepared to terminate after the processing and checking of a number of pieces. ("Too many bits for the mind to encompass, get three of the five bits to fit and that'll be enough" - DA42, a method further described as "a risk taking method, having got two pieces to fit, the other bits
look O.K. - this way reflects my personality, I take risks when there is a fair chance of success" - DA24) (Figure 4:4).

From the model two major deductions can be made. In relation to errors it is likely that the global strategist using Strategy 3 eliminates too many mismatches thereby omitting the correct answer. This leads to an error recorded at point (D) or the subject being left with no alternative at point (N). If it does not lead to the elimination of enough obviously wrong answers, its value as a strategy is limited. Piece by piece strategies depend upon the accurate matching of pieces so that errors result in Strategy 1 from a false match, a false acceptance or the failure to check all answers to be considered and in Strategy 2 from a failure to adequately compare pieces or failing to check sufficient pieces with live answers.

Assuming random order in processing pieces, increasing reaction time with increasing array size would be expected since increasing the array size logically increases the complexity of the problem and the number of comparisons to be made. The model suggests that the increase in reaction time with increasing array size is not necessarily linear because:

(a) If Strategy 3 is successfully followed there is a rapid reduction in the number of answers to be processed.
(b) The combination of pieces in the array, which usually appears to be possible in arrays of four or fewer pieces, may reduce processing to as few as one comparison plus optional checking.

(c) The level of confidence may be such that processing is terminated before all pieces are compared.

(d) Finally, a perceptual cue may be available which over-rides the issue of the number of pieces in the array. Problem DA40, for example, has five pieces but since they all meet at a point this provides a focal characteristic that limits the processing demands. (Figure 4:3).

The lack of symmetry or other relation between the pieces, the smaller size of pieces in the array and the lower familiarity of the shapes seems to make five piece problems generally immune to the shortcuts noted. Consequently, the time taken for five piece problems is likely to be a gauge of exhaustive, piece by piece comparison. Where there is a linear increase with increasing pieces to five it would be expected that the subject follows this processing route exclusively; a sharp increase in latency between arrays with four and five pieces suggests that the subject can no longer use the shortcuts available and switches to a more exhaustive piece by piece comparison. This difference between subjects is an indication of variations in individual skill.
Pellegrino and his associates report a linear increase in reaction time with increasing array size. This is consistent with a model of exhaustive search and comparison of all pieces. The alternative model proposed suggests that in the MPFB it is not so much the search for a piece as the search for an appropriate answer with which to work that is crucial. It will be argued in the next chapter that this distinction arises naturally from the variations in the format of the presentation of problems and from the strategy used.

The model described presents the various approaches or routes available to subjects. It indicates that an appreciation of the strategy in use and the ways in which shifts in strategy take place is essential for the understanding of an information processing model. It is argued that crucial points in problem solution are the structuring of the array, the ability to hold this structured image, the number of answers to be processed and the clarity of the individual image.
CHAPTER 5: THE TESTING OF THE MODEL

This chapter has two aims: to develop an experimental substantiation of the model outlined in the previous chapter and to distinguish the various processing parameters tapped by the varied types of problem encountered in the MPFB.

The experimental design is based on the use of items from the MPFB both in the standard form and in an altered form aimed at isolating the processes required to cope with the test. Our concern is with an evaluation of the MPFB and the development of data on the range of strategies used by subjects in the solution of these problems.

Pellegrino and Mumaw (1984) and Pellegrino and Kail (1982) report investigations of laboratory tasks developed from the MPFB since "Paper Form Board items are found on a variety of spatial ability batteries and are most commonly associated with the visualization factor of general spatial ability." (Pellegrino and Kail, 1982). They are concerned to offer a process analysis of spatial visualization and, as has been noted, produce an algorithmic model of this assumed factor.

In contrast, the work reported here is intended to produce an heuristic model of the activities of subjects when confronted with the demands of the test items of
The differences in this approach from that of Pellegrino will not allow generalization of the results to the spatial visualization factor but they will permit an evaluation of the actual test items. Any comparison of the results of the present study with those of Pellegrino must take account of these procedural differences.

Figure 5:1 sets out the altered stimuli developed from the MPFB for use in the experiment and those items developed by Mumaw (Pellegrino and Mumaw, 1984). Several differences require explanation.

(1) Presentation.

The method of presentation is different. The MPFB problems place the array on the left hand side and the complete figure on the right hand side. In contrast, the task variants used by Pellegrino place the constructed problem on the left hand side and the "broken" array on the right hand side. In determining identity between the two, subjects, due perhaps to a left to right bias, tend to break up the total figure in order to look for individual items. It will be recalled that Pellegrino takes the view that an element must first be encoded from the context of the "whole" figure and then searched for in the array. This physical layout emphasises an analytic strategy and, thus, disadvantages subjects who are able to process more
globally. Evidence from the protocols previously reported suggests that subjects rarely move from the constructed figure to the pieces when the pieces are presented in the standard form of the test.

This difference in presentation is tentatively supported by differences in the RT of two small groups of subjects (n=3) who were used to trial the material to be used in Experiment 5:1. The materials were presented in the MPFB format and the Pellegrino format and the differences in RT for wholistic, separated, displaced, rotated and rotated and displaced item types and for positive and negative conditions were all significant at p<.10 (Wilcoxon rank-sum statistic).

The decomposition of a figure to select a piece (Pellegrino format) takes longer in all variants, possibly because this type of presentation forces a more analytic strategy and more exhaustive processing rather than beginning with a piece and using certain structural rules to terminate processing before all pieces have been compared. In short, the Pellegrino presentation method encourages the use of an algorithm rather than a heuristic approach. It is quicker to "see" a figure in an array which allows construction than in one which begins with the constructed figure and works towards individual comparison by decomposition.

It is emphasised that these results are only indicative being drawn from a pilot experiment. However
there does seem to be a difference due to the way in which the problem is presented.

(2) Rotation.

The reported protocols and proposed model suggest the possibility that rotation may be an optional process. For example, a subject, discussing rotation, claimed that "there are times when rotation is unnecessary. These are times when the piece has a specific characteristic such as symmetry, when the piece can be given a name, for example right-angled triangle, or when by putting two pieces together a new shape can be developed which has either of these characteristics".

Apart from those MPFB problems which require reversal of the pieces (a condition not included in Pellegrino's experimental items) it appears probable that the need for rotation is not generated by the angle of divergence from congruence but by the unfamiliarity of the shapes involved, the "density" of the array, and/or the strategy used especially "jigsawing" which always requires rotation. Where a piece has specific characteristics rotation may not be necessary. It also appears likely that problems with small numbers of pieces are solved by means of images which can be easily rotated while the larger arrays are solved by analytic reasoning and rotation of pieces to congruence is unnecessary. Both the model and the experiments used by Pellegrino and Mumaw imply that rotation will always be
used for conditions where pieces are not congruent thus making rotation a required rather than an optional process.

(3) Size differentiation.

The major thrust of the MPFB is the evaluation of skill in discriminating matches and mismatches based on size differences while a similar but not identical shape is maintained. Where figures offered as alternatives differ in shape only, mismatch decisions are faster and error rates lower. The test material used by Mumaw deliberately omits the type of MPFB problems which depend upon discrimination of size differences for solution. This omission is inappropriate in evaluating the MPFB.

The aim of the present study is the development of a process model of the MPFB and the items developed to test the model and elucidate the processing variables seek to reflect the nature of the demands of the MPFB test. The use of variations from MPFB type problems by Pellegrino and Mumaw casts doubt on their model as a representation of the processing involved in this test.

The proposed model of MPFB performance gives rise to the following predictions.

(a) Choice from a range of strategies is a key variable. Accordingly, it is predicted that there will be variation in the time to complete problems which differ in the number of pieces but this variation will be
affected by the strategy in use and any strategy changes involved in the processing.

A closely related prediction is that individual subjects will show variations in reaction time with increasing numbers of pieces up to and including four pieces and that all subjects will show a common pattern of latency increase with five piece problems since subjects will tend to adopt a common strategy at this point.

Such a prediction differs from the results reported by Pellegrino and Mumaw (1984) who found that reaction time increases linearly with an increase in the number of pieces. This finding is consistent with the adoption of an analytic strategy by all subjects and its exhaustive application to the specific arrays in individual problems.

(b) Accuracy in problem solution is related to the ability of a subject to use a strategy consistently and, if necessary, to change strategy. The key points of strategy change are indicated by points (A), (N) and (T) in the model (Figure 4:2). The "confidence" points (S) in the model determine the degree of processing required to generate solutions that represent self-terminating or exhaustive outcomes.

(c) Differences in the strategies being used by individuals will be most apparent in the solution of problems where there is a large variation between the
array and the answer. Subjects committed to a global strategy in which mismatches are the key events will produce mean reaction times which are lower than subjects using an analytic strategy. This will be particularly marked in problems composed of two to four pieces.

(d) Where the stimulus array and an answer to be processed are very similar but not identical, the difference in reaction times between individuals will be a reflection of skill. Skilled individuals will be more capable of distinguishing differences in size, structure and area and will produce mean reaction times consistently lower than in the identification of arrays and answers which are the same. Inefficient processing will result in a reaction time pattern for similar but not identical arrays and answers which matches that for arrays and answers which are identical.

(e) The group latency results obtained will differ from the model proposed by Pellegrino which predicts a linear increase with an increase in the number of pieces, and processes which are additive. This is because the results will reflect the influence of the varied strategies being used by individual subjects.

(f) The presentation of actual MPFB problems along with variations designed from these problems in the one answer format described above will produce a significant correlation confirming that the hypothesised tasks
(encoding, organization, search and rotation) are a consistent reflection of the demands of the MPFB test processing. It is also predicted that error scores obtained from the one answer format and those derived from the total five alternative answer format of the MPFB test will correlate positively. Such findings would confirm the relevance of results achieved in the one answer format tasks of the experiment to the total MPFB test.

EXPERIMENT 5:1

Subjects and method. The subjects were 20 students enrolled in courses at the Box Hill College of TAFE aged between 17 and 25 who volunteered to take the test. The mean age was 19.8 years.

Each subject initially completed the alternative form of the MPFB (DB) with each problem timed separately. The subjects represented a wide range of ability with scores ranging from 23/64 to 54/64 with a mean of 45.7 and SD of 9.6.

At the completion of the test each subject was asked to explain their method of operation.

Materials and Design: Four variables were incorporated into the stimulus design (Figure 5:1):

(1) the number of elements or pieces in the stimulus
FIGURE 5:1 Stimuli adjusted from MPFB problems. Reid stimuli on the left hand side, those of Mumaw on right.

Rotated and Displaced

Rotated

Disconnected

Separated

WHOLEISTIC

ORIGINAL MPFB PROBLEM
array was varied from 2 to 5 and the number of different pieces in the stimulus was varied from 1 to 5.

(2) The form of presentation was the one answer format shown in Figure 5:1. The answers were varied to give a correct answer (same), a similar but incorrect answer and an answer which was obviously incorrect. The last of these was the answer from the five alternatives of the MPFB problem which was chosen as correct least often by 666 subjects completing the MPFB. This possibility was assumed to be the answer which was most different from the correct answer and most easily eliminated. It was designated N2. The most frequently chosen incorrect answer from the same sample was designated N3. This answer was assumed to be the alternative most likely to be confused with the correct answer and therefore closest in structure to the correct answer. The correct answers were designated P1 (Figure 5:2).

(3) The shape of the completed figure was selected from the range of MPFB problems and varied between circle, square, trapezium, rectangle and hexagon (Figure 5:3).

(4) The positioning of the pieces in the stimulus array was varied. Pieces were presented as a whole (Wholistic), as marginally separated (Separated), with no piece holding the same relative position in the array as it did in the answer while retaining the same orientation (Displaced), with the pieces rotated between 75 and 150 degrees counter clockwise and in one case the
Figure 5.2 Examples of arrays adjusted from the MPFB to tap trial type (Positive, N2, N3) and item type (Wholistic, Separated, Displaced, Rotated, Rotated and Displaced and original problem from MPFB.)

Positive Wholistic

Positive Separated

Positive Displaced

Positive Rotated

Positive Rotated-Displaced

Positive MPFB

N2 Wholistic

N3 Wholistic
Figure 5:3 The twelve MPFB problems which formed the basis for the adjusted arrays used in Experiment 5:1.

Two piece problems

Three piece problems

Four piece problems

Five piece problems.
pieces reversed but retaining the same positioning as in the answer (Rotated), and, finally, with pieces different in both orientation and position (Rotated and Displaced). The original problem from the MPFB was also included as a control (FB).

These variables were incorporated into the twelve problems depicted in Figure 5:3. They were chosen from the MPFB (DA), three having 2, 3, 4, and 5 pieces respectively. Their MPFB problem numbers are 1, 28, 11, 27, 32, 37, 38, 15, 39, 42, 26, 40. The array of pieces in each problem was rearranged to meet the positioning requirements for the conditions stated above – whole, separated, displaced, rotated, and rotated-displaced. The original array was also included. These prescriptions resulted in 216 trials composed of 72 positives (the array equals the answer), 72 N2 items (the array was different from an obviously incorrect answer) and 72 N3 items (the array was different from the answer but the differences were marginal). The two negative conditions were included to compare results when the probe was grossly different and when it was very similar but not identical. In the majority of cases the difference between N2 and N3 lies in the number of different pieces – N2 usually consists of all different pieces, N3 usually differs in one or two marginally different pieces.

The trials were arranged individually on 6 inch by 4
inch cards in the format of the MPFB with the array placed on the left hand side and the completed figure on the right hand side. The subject was timed by stop watch from the moment of presentation until the response "same" or "different".

The trials were randomised so that no trial involving one particular problem followed a trial based on the same problem and positives and negatives were also randomised.

Procedure: The subjects took the test individually in a session lasting about 30 minutes. The procedure to be followed was explained to each subject and two problems which had been constructed to cover all conditions were used as trial items. Feedback was given after each practice trial item whether correct or incorrect and where an error was made that item was repeated. Subjects were allowed to control the rate at which the problems were presented and to continue with each problem until a response was given.

RESULTS

The results will be reported in two sections. The remainder of this chapter covers the group results while individual results will be discussed in Chapter 6.

Accuracy.

The overall error rates for positive, N2 and N3 trials were 6.8, 3.8, and 10.8 per cent respectively.
Table 5:1 sets out the number of errors made by the 20 subjects by item type and condition. Table 5:2 shows errors as a function of item type, condition and the number of stimulus pieces in the array.

Table 5:1
Errors by item type and condition.

<table>
<thead>
<tr>
<th>Condition Type</th>
<th>W</th>
<th>S</th>
<th>D</th>
<th>R</th>
<th>RD</th>
<th>FB</th>
</tr>
</thead>
<tbody>
<tr>
<td>Positive</td>
<td>6</td>
<td>9</td>
<td>14</td>
<td>28</td>
<td>25</td>
<td>39</td>
</tr>
<tr>
<td>N2</td>
<td>9</td>
<td>13</td>
<td>8</td>
<td>4</td>
<td>12</td>
<td>9</td>
</tr>
<tr>
<td>N3</td>
<td>17</td>
<td>37</td>
<td>25</td>
<td>27</td>
<td>24</td>
<td>35</td>
</tr>
</tbody>
</table>

Relation between item type and condition, Chi squared = 29.1, df =10, p<.01.

The results raise a number of points. First, errors in positives, i.e. failure to detect a match, are related to the presence of the rotation component with its major effect being in those arrays composed of 2 or 5 pieces (Table 5:2). For the N2 trials, i.e. those involving an obvious mismatch, the majority of errors are made in the four piece arrays. Most errors (51%) occur in the N3 trials which involve detecting a mismatch between two items with similar but not identical structure and/or shape. Particularly noteworthy is the high number of errors in the separated and displaced items in N3 trials in comparison with these item types in the positive trials.

Even within the groups of array problems which have
Table 5:2
Errors as a function of number of pieces in array, item type and condition. Number of trials = 60.
(P = Same, N2 = Distinctly different, N3 = Similar but not identical).

<table>
<thead>
<tr>
<th>Item type</th>
<th>Number pieces</th>
<th>Condition</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>P</td>
<td>N2</td>
</tr>
<tr>
<td>WHOLISTIC</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Two</td>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td>Three</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Four</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>Five</td>
<td>1</td>
<td>5</td>
</tr>
<tr>
<td>SEPARATED</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Two</td>
<td>4</td>
<td>2</td>
</tr>
<tr>
<td>Three</td>
<td>0</td>
<td>3</td>
</tr>
<tr>
<td>Four</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>Five</td>
<td>2</td>
<td>4</td>
</tr>
<tr>
<td>DISPLACED</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Two</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>Three</td>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td>Four</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>Five</td>
<td>7</td>
<td>3</td>
</tr>
<tr>
<td>ROTATED</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Two</td>
<td>11</td>
<td>0</td>
</tr>
<tr>
<td>Three</td>
<td>3</td>
<td>0</td>
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<tr>
<td>Four</td>
<td>4</td>
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<td>Five</td>
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<td>1</td>
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<td>ROTATED AND DISPLACED</td>
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<td>Two</td>
<td>7</td>
<td>1</td>
</tr>
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<td>Three</td>
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<td>1</td>
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<tr>
<td>Four</td>
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<td>8</td>
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<tr>
<td>Five</td>
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<td>2</td>
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<tr>
<td>FORM BOARD</td>
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<td></td>
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<tr>
<td>Two</td>
<td>10</td>
<td>2</td>
</tr>
<tr>
<td>Three</td>
<td>5</td>
<td>1</td>
</tr>
<tr>
<td>Four</td>
<td>3</td>
<td>6</td>
</tr>
<tr>
<td>Five</td>
<td>21</td>
<td>0</td>
</tr>
<tr>
<td>TOTAL (possible = 360)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Two</td>
<td>37</td>
<td>7</td>
</tr>
<tr>
<td>Three</td>
<td>16</td>
<td>7</td>
</tr>
<tr>
<td>Four</td>
<td>16</td>
<td>25</td>
</tr>
<tr>
<td>Five</td>
<td>53</td>
<td>15</td>
</tr>
</tbody>
</table>
FIGURE 5.4 Error rates resulting from Experiment 5.1 on all trials, compared with error rates of subjects taking the MPFB test (n=666) and comment on the results.

Base line problem.
All trials: Error rate 0.3%
MPFB performance: Error rate 0.9%

All trials: Error rate 9.2%
MPFB performance:
Error rate 6.0%
Major difficulties in the R and RD positives due to the need for a reversal to generate the correct answer.

Major difficulty is the R positive trial (6 errors) suggesting problems rotating large piece. R positive also has the longest mean latency - 5.0 secs - of the designed trials. FB positive has 9 errors and a mean latency of 5.72 secs. (errors excluded)

All trials: Error rate 19.7%
MPFB performance: Error rate 19.2%
91% of the errors are made in N2 (27%) and N3 (64%). Size comparison between A and B breaks down especially in the Separated and Displaced types.

All trials: Error rate 5.3%
MPFB performance:
Error rate 6.8%
50% of the errors occur in N2 condition i.e. false choice of Y especially in RD item.

All trials: Error rate 12.7%
MPFB performance: Error rate 16.0%
Size comparison difficulties in the N3 condition for all item types except Displaced. Rotation to congruence adds to size differentiation difficulties.
All trials: Error rate 3.7%.
MPFB performance: Error rate 5.1%.
Little difficulty due mainly to cue of symmetry.

All trials: Error rate 4.3%.
MPFB performance: Error rate 12.0%.
As with 28, and 27 the errors are mainly in the positives.

All trials: Error rate 13.7%.
MPFB performance: Error rate 21.7%.
80% of trial errors occur in the N3 condition (that is, distinguishing X and Z) supporting proposition that size comparison is a major problem in some MPFB problems.

All trials: Error rate 14.7%.
MPFB performance: Error rate 17.6%.
Major difficulties encountered in N3 Separated and FB positives.

All trials: Error rate 10.7%.
MPFB performance: Error rate 29.1%.
Major difficulty is in the positive condition brought about by rotation to congruence.

All trials: Error rate 10.3%.
MPFB performance: Error rate 19.6%.
Most errors occur in item types requiring rotation.

r between all trials and MPFB performance = .6712 (p<.02)
the same number of pieces there is variation in the number of errors. The individual problems produce varying error rates as can be seen from Figure 5:4. Problem 2 provides a performance baseline for encoding, solution and response. The rotation process in Problems 11 and 28 is apparent although it should be noted that Problem 11 demands a reversal rather than rotation and the errors only occur in the positives. Problem 28 presents difficulty in rotating the large section to congruence for comparison and this is borne out by the errors made by 666 subjects on the actual MPFB test. The three piece Problems 27 and 32 appear to present little difficulty but Problem 37 reveals the effects of the difficulty of detecting marginal size differences in the N3 condition. Size comparison is also apparent in the four piece Problems 38 and 39. The five piece problems show varying difficulties. Problem 26 suggests there is difficulty finding the pieces, the total comparison of Problem 42 presents difficulty and the rotation process in Problem 40 suggests that the lack of symmetry and label-ability of the pieces demands rotation.

Latency:

Mean latency data was computed for the 20 subjects in each condition and item type. Figures 5:5 and 5:6 show the processes graphed for the the number of pieces and the reaction time. Figure 5:5 excludes errors.
Figure 5.5 Mean latency data as a function of trial type, item type and number of stimulus elements for 20 subjects. (Errors excluded)

**POSITIVES**
- W = Holistic
- S = Separated
- D = Displaced
- R = Rotated
- RD = Rotated-Displaced
- FB = MFB problem

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**NEGATIVES 2**

---

**NEGATIVES 3**
Figure 5:6 Mean latency data as a function of trial type, item type and number of stimulus elements for 20 subjects (Errors included).

W = Wholistic, S = Separated, D = Displaced, R = Rotated, RD = Rotated-Displaced, FB = MPFB problem.
Figures 5:7 and 5:8 give the regression lines for the various process item types with, respectively number of pieces and reaction time. Figure 5:7 excludes errors.

Table 5:3 contains the mean latency data for the positive and negative conditions and item type as a function of the number of stimulus pieces while Table 5:4 presents slopes and $r$ squared values for the same data.

The $r$ squared values reported by Mumaw and Pellegrino (1984) are much higher although there is no comparative figure for rotated and rotated-displaced since their report combines both processes on the grounds that there is little difference between the two processes. Figure 5:9 shows the regression graphs reported by Mumaw and Pellegrino (1984) emphasising the linear increase in reaction time as a function of the number of stimulus elements in the array. The increased time and the "fanning" of the process item types is quite apparent. From Figure 5:7 it is clear that the results reported from this experiment do not indicate the "fanning" of processes consistent with an additive processing model.

The degree to which there is a correlation between the problems taken directly from the MPFB (called Form Board in the experiment) and the redesigned problems which seek to reflect the processing involved in MPFB tasks is set out in Table 5:5.
Figure 5:7 Regressions of latency data as a function of trial type, item type and number of stimulus elements for 20 subjects (Errors excluded).

W = Wholistic, S = Separated, D = Displaced, R = Rotated, RD = Rotated - Displaced, FB = MPFB problem.
Figure 5:8 Regressions of latency data as a function of trial type, item type and number of stimulus elements for 20 subjects (Errors included). W = Wholistic, S = Separated, D = Displaced, R = Rotated, RD = Rotated-Displaced, FB = MPFB problem.
Table 5:3
Mean latency data for positive and negatives conditions and item types as a function of number of pieces. Ss = 20. Errors excluded.

<table>
<thead>
<tr>
<th>Item type/Condition</th>
<th>Number of Pieces</th>
<th>Two</th>
<th>Three</th>
<th>Four</th>
<th>Five</th>
</tr>
</thead>
<tbody>
<tr>
<td>WHOLISTIC</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>P</td>
<td>2.62</td>
<td>3.30</td>
<td>3.75</td>
<td>4.63</td>
<td></td>
</tr>
<tr>
<td>N2</td>
<td>2.60</td>
<td>2.92</td>
<td>4.31</td>
<td>3.71</td>
<td></td>
</tr>
<tr>
<td>N3</td>
<td>1.88</td>
<td>3.59</td>
<td>3.47</td>
<td>4.37</td>
<td></td>
</tr>
<tr>
<td>SEPARATED</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>P</td>
<td>4.35</td>
<td>3.02</td>
<td>4.22</td>
<td>6.94</td>
<td></td>
</tr>
<tr>
<td>N2</td>
<td>2.50</td>
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<td>4.82</td>
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</tr>
<tr>
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<td>2.40</td>
<td>4.71</td>
<td>4.42</td>
<td>6.38</td>
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</tr>
<tr>
<td>DISPLACED</td>
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<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>P</td>
<td>3.68</td>
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<td>5.96</td>
<td>13.06</td>
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</tr>
<tr>
<td>N2</td>
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<td>5.90</td>
<td>7.16</td>
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<tr>
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<td>2.93</td>
<td>5.33</td>
<td>5.42</td>
<td>8.42</td>
<td></td>
</tr>
<tr>
<td>ROTATED</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>P</td>
<td>5.52</td>
<td>5.73</td>
<td>6.18</td>
<td>9.78</td>
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</tr>
<tr>
<td>N2</td>
<td>3.03</td>
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<td>4.65</td>
<td>7.57</td>
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<td>8.56</td>
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<td>ROTATED-DISPLACED</td>
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<tr>
<td>P</td>
<td>4.52</td>
<td>5.64</td>
<td>6.42</td>
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<td>FORM BOARD</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>P</td>
<td>4.42</td>
<td>4.97</td>
<td>5.68</td>
<td>9.86</td>
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<td>6.10</td>
<td>6.27</td>
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<td>N3</td>
<td>3.25</td>
<td>4.44</td>
<td>5.74</td>
<td>8.74</td>
<td></td>
</tr>
</tbody>
</table>

Table 5:4
Slope and r squared values of least squares regression lines by condition. Errors excluded. (Corresponding values from Mumaw (1984) in brackets).

<table>
<thead>
<tr>
<th>Item type</th>
<th>Positive Condition</th>
<th>Positive</th>
<th>N2</th>
<th>Positive</th>
<th>N2</th>
<th>Positive</th>
<th>N2</th>
<th>Positive</th>
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<th>Positive</th>
<th>N2</th>
<th>Positive</th>
<th>N2</th>
</tr>
</thead>
<tbody>
<tr>
<td>W.</td>
<td>.65</td>
<td>.64 (.78)</td>
<td>.47</td>
<td>.14</td>
<td>.73</td>
<td>.37</td>
<td></td>
<td>W.</td>
<td>.65</td>
<td>.64 (.78)</td>
<td>.47</td>
<td>.14</td>
<td>.73</td>
</tr>
<tr>
<td>S.</td>
<td>.79</td>
<td>.41 (.99)</td>
<td>.93</td>
<td>.52</td>
<td>1.16</td>
<td>.64 (.98)</td>
<td></td>
<td>S.</td>
<td>.79</td>
<td>.41 (.99)</td>
<td>.93</td>
<td>.52</td>
<td>1.16</td>
</tr>
<tr>
<td>D.</td>
<td>2.89</td>
<td>.71 (.98)</td>
<td>1.42</td>
<td>.66</td>
<td>1.65</td>
<td>.79 (.88)</td>
<td></td>
<td>D.</td>
<td>2.89</td>
<td>.71 (.98)</td>
<td>1.42</td>
<td>.66</td>
<td>1.65</td>
</tr>
<tr>
<td>R.</td>
<td>1.32</td>
<td>.37</td>
<td>1.34</td>
<td>.60</td>
<td>1.61</td>
<td>.64</td>
<td></td>
<td>R.</td>
<td>1.32</td>
<td>.37</td>
<td>1.34</td>
<td>.60</td>
<td>1.61</td>
</tr>
<tr>
<td>R-D.</td>
<td>2.21</td>
<td>.67</td>
<td>1.58</td>
<td>.82</td>
<td>1.50</td>
<td>.71</td>
<td></td>
<td>R-D.</td>
<td>2.21</td>
<td>.67</td>
<td>1.58</td>
<td>.82</td>
<td>1.50</td>
</tr>
<tr>
<td>FB.</td>
<td>1.71</td>
<td>.58</td>
<td>1.11</td>
<td>.53</td>
<td>1.68</td>
<td>.68</td>
<td></td>
<td>FB.</td>
<td>1.71</td>
<td>.58</td>
<td>1.11</td>
<td>.53</td>
<td>1.68</td>
</tr>
</tbody>
</table>
FIGURE 5:9  Mean latencies as a function of trial type, item type and number of stimulus elements. (From Mumaw and Pellegrino, 1984)
These data support the view that the test problems reflect the processes involved in MPFB test items.

Table 5:5
Correlation between the MPFB problems and the experimental items.

<table>
<thead>
<tr>
<th>Item Type</th>
<th>Condition</th>
<th>Positives (P)</th>
<th>Negative 3 (N3)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wholistic (W)</td>
<td></td>
<td>.527</td>
<td>.534</td>
</tr>
<tr>
<td>Separated (S)</td>
<td></td>
<td>.624</td>
<td>.654</td>
</tr>
<tr>
<td>Displaced (D)</td>
<td></td>
<td>.764</td>
<td>.787</td>
</tr>
<tr>
<td>Rotated (R)</td>
<td></td>
<td>.684</td>
<td>.671</td>
</tr>
<tr>
<td>Rotated-Displaced (RD)</td>
<td></td>
<td>.709</td>
<td>.698</td>
</tr>
</tbody>
</table>

All correlations significant P<.001, df 239

DISCUSSION OF GROUP RESULTS

The accuracy results raise the question of the nature of the relationship between rotation and errors in positive trials. The processes underlying the results can be characterized in terms of the model. It seems likely that most subjects tackle the easier trials on a global basis probably using an approximate image constructed from relationships of the stimulus array pieces with the result that some items are falsely rejected. With the more difficult items, especially those involving five different pieces, rotation is probably attempted as part of an analytic strategy but controlling the image representation of an unfamiliar
piece in the midst of other unfamiliar pieces creates distortion sufficient to produce a mismatch. In the simpler figures the difficulty is in synthesising the pieces into a figure, in the more complex problems there is difficulty in visual transportation. This construction difficulty appears to be related to variations in ability. High ability subjects, as assessed on the basis of total performance on the reference test, have an error rate of about 4% on two piece positive problems while for lower ability subjects the error rate rises to 25 per cent. Errors appear to be related not so much to rotation but to the skills necessary for construction. Absence of these skills leads to false rejection of positive items.

Accurate performance on N2 trials should be achieved by one simple mismatch and it can be assumed that errors arise either through carelessness or through failure of the subject to exercise sufficient concentration when the number of pieces rises to four. This is probably the numerical upper limit for rapid elimination of grossly dissimilar stimuli. Failure to appreciate different demands as complexity increases leads to errors.

The difficulties in identifying similar and identical configurations are apparent in the results of the N3 condition which reveal a sharp rise in errors on item types requiring processing. Mumaw and Pellegrino
(1984) found a similar situation when dealing with closely similar trials and explained the results as follows: "When the stimuli are oriented the same (as in the separated and displaced conditions) and have a similar but non-identical shape, and occur in the context of a large number of matching pieces, subjects may use a global comparison process which often leads to errors". This is certainly an explanation for some subjects but, as an examination of individual results will reveal, it may also be a function of the inability of some individuals to develop completed figures of a quality sufficient to allow comparison. Although it may be attributable to a failure to perceive individually different pieces within a group of identical pieces it may also be a reflection of a larger difficulty, the inability to construct a total figure. This latter explanation is given some support by the high error rate in the rotation conditions with three and four pieces. When rotation is required in the comparison of similar but not identical figures there is an added complication in building a total figure.

With N3 errors the explanation may lie in a failure to adequately distinguish almost identical configurations. Consequently, what may be constructed for comparison is guessed at. The realisation of the difficulties in such construction with increasing numbers of pieces is probably a signal to the more
skilled subjects to change strategies to a more analytic piece by piece operation. The less skilled fail to recognize this need for change.

Over all error data are approximately the same in the present experiment and that of Mumaw (1984). He postulates two sources of processing failure or inefficiency, namely the detection of a match between corresponding stimuli and the detection of a mismatch between similar but non-identical stimuli. Mumaw argues that the proposal of two different processing sources of inefficiency is supported by zero correlations between individual subject error rates on positive and negative trials. The results of the present study yield a correlation of -.3147 (t=4.1) between error rates of subjects on positive and negative trials suggesting that the proposal made earlier of inappropriate strategy usage under certain conditions may be a more valid interpretation. Furthermore, unlike the Mumaw and Pellegrino model, the alternative model allows incorporation of an explanation at the strategy usage level.

There appears to be no significant relationship between ability, as measured by the MPFB, and errors made in detecting a match. When the high and low performers are separated (n=4 for each group) the results are reported in Table 6:1. The significant difference is in failure to detect a mismatch in the N3
condition where high ability subjects made 18 errors compared with 48 by low ability subjects. Ability is reflected in mismatch detection.

The present results differ from those of Mumaw and Pellegrino in the reaction time data reported above. These results provide no support for an additive model since the regression graphs do not substantiate increased time with the assumed introduction of more processes. The $r$ squared results are, however, not high enough to interpret the regressions with confidence. For this reason the data is more adequately reported in the form of reaction time means. These show results which are basically independent of hypothesised processes. All positives reflect a similarity of reaction time when there are from two to four pieces and then a rapid rise in all results between four and five pieces. N2 results expressed as means are more linear but N3 results, while faster than the positive results, display basically the same pattern as positives.

There is some suggestion in the results that the processes which take longer in the simpler problems are those which require transformations but as the number of pieces and complexity of the problems increase the search for pieces prior to comparison assumes the major role (Table 5:6).

The difference in the results between Positives and N3 suggests that there is a different set of processes
active in determining a match and identifying a mismatch. An increase in search time in the positives, compared with other processes, as the number of other pieces increases and creates a jumble of figures, seems reasonable considering that the number of pieces is unlikely to increase the transformation time once the pieces are identified. The increase in transformation time, while not being as great as that of search, is there and can be explained on the grounds that more subjects are resorting to transformations, rather than using substitute processes which can flow from the use of relational cues at a simpler stage, or are switching to a more analytic strategy which increases the time to solution.

Table 5:6
Mean reaction time as function of item type and number of pieces. Errors excluded.

<table>
<thead>
<tr>
<th>Condition</th>
<th>Pieces</th>
<th>Item type</th>
<th>Displaced</th>
<th>Rotated</th>
<th>Rotated/Displ.</th>
</tr>
</thead>
<tbody>
<tr>
<td>POSITIVES</td>
<td>Two</td>
<td>3.68</td>
<td>5.52</td>
<td>4.52</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Three</td>
<td>5.11</td>
<td>5.72</td>
<td>5.64</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Four</td>
<td>5.96</td>
<td>6.18</td>
<td>6.42</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Five</td>
<td>13.10</td>
<td>9.78</td>
<td>11.62</td>
<td></td>
</tr>
<tr>
<td>NEGATIVE 3</td>
<td>Two</td>
<td>2.93</td>
<td>2.99</td>
<td>3.14</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Three</td>
<td>5.33</td>
<td>5.08</td>
<td>5.19</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Four</td>
<td>5.42</td>
<td>4.45</td>
<td>4.69</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Five</td>
<td>8.42</td>
<td>8.56</td>
<td>8.32</td>
<td></td>
</tr>
</tbody>
</table>
It would have been predicted that the slope for N2 data would have been flatter and lower than N3 on the grounds that one elimination run should be sufficient to remove N2 items from consideration. Surprisingly this is not so. A possible explanation is that some subjects are unable to rapidly eliminate those items which are obviously different since they are using the same strategy of matching as in determining positive matches. The possibility of the adoption of elimination strategies by most subjects is supported by the lower reaction times for negatives in the two piece type problem. Many subjects, however, appear to be unable to sustain this strategy with larger numbers of pieces.

The increase in search time between four and five pieces can also be explained by the hypothesis that it is at this point that image representation breaks down. This suggests the more general proposition that spatial images have capacity limitations and that there comes a time when it is no longer possible to encode sufficient material to make a valid comparison. In short there is evidence for a system of levels to which even those skilled in spatial representation must resort at a certain point. As most problems of five pieces are of a nature and degree of unfamiliarity that prevents formation of a combined image, the subject is forced to move at this point to a unit evaluation devoid of relations as cues
or of the capacity to chunk into sub-assemblies. This forced advance to a new level creates a change in strategy for those who have been able up to this point to rapidly eliminate and so cut down the working space needed for problems having up to four pieces. The new level of operating may move totally from image comparison to a reasoning or propositional basis.

The results in Table 5:7 suggest that high ability subjects are able to cope with image construction longer than low ability subjects and do not resort to transformations as readily.

As the number of pieces increases, the search time of skilled subjects increases but such subjects appear to manage to cope with activity which forces the lower skilled into transformations.

Table 5:7
Mean RT by item type as function of high and low ability. Positive condition. (n = 4).

<table>
<thead>
<tr>
<th>Number of Pieces</th>
<th>Item type</th>
<th>Ability</th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>High</td>
<td>Low</td>
<td>High</td>
<td>Low</td>
<td>High</td>
</tr>
<tr>
<td>Two</td>
<td>Displaced</td>
<td>2.25</td>
<td>3.36</td>
<td>2.67</td>
<td>3.59</td>
<td>2.65</td>
</tr>
<tr>
<td></td>
<td>Rotated</td>
<td>2.78</td>
<td>4.13</td>
<td>3.38</td>
<td>4.60</td>
<td>3.02</td>
</tr>
<tr>
<td></td>
<td>Rotated-Displaced</td>
<td>4.11</td>
<td>4.78</td>
<td>3.80</td>
<td>5.65</td>
<td>3.89</td>
</tr>
<tr>
<td></td>
<td></td>
<td>7.08</td>
<td>9.34</td>
<td>5.75</td>
<td>8.54</td>
<td>7.93</td>
</tr>
</tbody>
</table>

Another possible source of variations in processing time lies in the way in which subjects operate their processing - exhaustively or in a self-terminating manner. It appears logical to postulate that positives will be processed exhaustively and that negatives will
produce termination after a number of elimination runs. If this is so it would be expected that reaction times for negatives would be shorter than reaction times for positives in all conditions. Table 5:3 indicates that this is generally the case.
CHAPTER 6. THE ANALYSIS OF INDIVIDUAL SUBJECTS

The group data support the view that it is usually quicker to eliminate (detect a mismatch) than to identify a match and that the demands of more difficult problems are such as to require solution by a qualitatively different strategy even among high ability performers.

The major hypothesis centred on the proposed model is that it provides a basis for the explanation of differences in results in terms of differences in strategies arising from interaction between variations in task demands and individual abilities. The ability to decide when to change strategy is considered to be a crucial determinant of skilled performance. This chapter seeks to investigate individual data to determine whether performance is critically affected by the strategy being used.

The analysis of individual data will address the following range of questions. How well does the group data reflect individual processing? How adequately can individual data be explained by the model suggested by the group data? What, if any, are the basic performance differences between high and low ability subjects and can any differences be reconciled with the proposed model? To what extent are individual differences due to strategy differences or are they attributable solely to...
variation in ability to process information in a set format? Are any variations in error structure between individuals consistent with employment of different strategies or do such variations merely reflect the same processes operating more rapidly or more accurately? Is variation in speed of process execution sufficient to explain individual differences?

It will be recalled that the group data with errors excluded failed to replicate the results obtained by Mumaw and Pellegrino (1984) for latency by item type and process. The group data showed a flat progression from two to four pieces for all processes in the positives and then a rapid rise from four to five pieces, a shallow progression for N2 with increasing numbers of pieces, and a "step-up" progression for N3. The regression lines indicated no "fanning" by process and there was a difference between the rotation and rotation-displaced conditions.

Error rates for the 20 subjects varied on both the positive and negative types. For positive trials the error range was 3 to 19 per cent, for the N2 trials 0 to 14 per cent, and for the N3 trials 0 to 44 per cent.

In order to compare individual performance with the group data, graphs were prepared for each individual subject showing mean latency data as a function of process and number of stimulus pieces (Appendix). Since each subject took the MPFB (DB) on an individually timed
basis before participating in the experiment it is possible to compare individual experimental results with performance on the reference test.

The individual data will be reviewed in relation to
(a) high and low ability as measured by the reference test;
(b) individual differences in the error structure;
(c) individual differences in reaction time.

High and Low Ability Individuals.

From the 20 subjects who participated in the experimental tasks high and low ability performers were separated on the basis of their scores on the MPFB (DB). Each group comprised 4 subjects. The mean for the high ability subjects was 54.8/64 (range 57-54) and for the low ability subjects was 34 (range 23 to 40). Tables 6:1 and 6:2 respectively present the error performance for the high and low ability groups and the slopes for each process condition.

Table 6:1
Errors of high and low ability performers as function of condition.

<table>
<thead>
<tr>
<th>Condition</th>
<th>High Ability</th>
<th>Low Ability</th>
</tr>
</thead>
<tbody>
<tr>
<td>Positives</td>
<td>22 (47%)</td>
<td>24 (29%)</td>
</tr>
<tr>
<td>N2</td>
<td>7 (15%)</td>
<td>11 (13%)</td>
</tr>
<tr>
<td>N3</td>
<td>18 (38%)</td>
<td>48 (58%)</td>
</tr>
<tr>
<td>Total</td>
<td>47</td>
<td>83</td>
</tr>
<tr>
<td>Total error rate</td>
<td>16.3%</td>
<td>28.8%</td>
</tr>
</tbody>
</table>

The difference between the groups was significant only for the N3 condition (p<.10) (Wilcoxon Rank Sum Statistic).
The difference in errors and in mean slope between high and low ability performers on the reference test lies in the skill in solving N3 problems.

Table 6:2
Mean slopes of high and low ability Ss as function of item type and item condition.

<table>
<thead>
<tr>
<th>Item type</th>
<th>Positive condition</th>
<th>N3 Condition</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Ability</td>
<td>High</td>
</tr>
<tr>
<td>-------------</td>
<td>--------------------</td>
<td>------</td>
</tr>
<tr>
<td>Wholistic</td>
<td></td>
<td>.25*</td>
</tr>
<tr>
<td>Separated</td>
<td></td>
<td>.53</td>
</tr>
<tr>
<td>Displaced</td>
<td></td>
<td>1.49</td>
</tr>
<tr>
<td>Rotated</td>
<td></td>
<td>1.02</td>
</tr>
<tr>
<td>Rotated-Displ.</td>
<td></td>
<td>1.45</td>
</tr>
</tbody>
</table>

* p<.10, ** p<.025 (Wilcoxon Rank Sum Statistic).

The mean latency data as a function of trial type, item type and number of stimulus elements for high and low ability subjects are set out in Figure 6:1. From this data it is apparent that the structure of performance on positive trials by the high and low ability subjects is basically similar except that for the low ability subjects the processing is performed more slowly and rotation may be more of a difficulty. Both groups on positives show the familiar pattern with a sharp rise between four and five pieces in the stimulus array. The high ability group is faster although the positive errors for both groups are about the same.

There is, however, a difference in the errors on the positives which should be noted. While Table 6:1
Figure 6.1. Mean latency data as a function of trial type, item type and number of stimulus elements for high and low ability subjects.
W = Wholistic items  S = Separated items
D = Displaced items  R = Rotated items
RD = Rotated and Displaced  FB = Form Board items.

HIGH ABILITY

POSITIVES

NEGATIVE (2)

NEGATIVE (3)

LOW ABILITY
indicates high and low ability subjects make about the same errors, the major difference is in the displaced condition where the high ability subjects make 7 errors compared with the low ability subjects who make two. Taking the latency and error data for positives together suggests that high ability subjects, being significantly faster, are less accurate in their searching perhaps due to the nature of the image being searched.

The major difference in latencies between the two groups lies in the detection of a mismatch. The issues are whether low ability subjects are working at a much slower rate but engaging in the same processing as the high ability subjects, whether they are processing at the same rate but repeating the processing two or three times or whether high and low ability subjects are using different strategies to determine a mismatch.

A likely hypothesis appears to be that low ability subjects are employing the same processes in match and mismatch detection while the high ability subjects are using different processing strategies which result in the detection of a mismatch between two and three times faster than detection of a match.

Before reaching any conclusions about the nature of the differences between high and low ability subjects, it is necessary to evaluate the hypotheses of Mumaw and Pellegrino (1984). It will be recalled that they postulate that skilled performers make relatively fewer
errors on problems requiring transformation. They reason that the skilled are capable of producing a more precise representation which in turn permits more accurate and rapid decision making when the stimulus requires manipulation. Table 6:3 indicates the differences in the errors of high and low ability subjects in the rotated and rotated and displaced conditions.

Table 6:3
Errors of High and Low Ability Ss by trial condition and number of pieces. Rotated and rotated-displaced item types.

<table>
<thead>
<tr>
<th>Pieces</th>
<th>High Ability</th>
<th>Low Ability</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Condition</td>
<td>P</td>
</tr>
<tr>
<td>Two</td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>Three</td>
<td></td>
<td>3</td>
</tr>
<tr>
<td>Four</td>
<td></td>
<td>3</td>
</tr>
<tr>
<td>Five</td>
<td></td>
<td>4</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>11</td>
</tr>
</tbody>
</table>

The results suggest that Mumaw's explanation is only applicable to the similar but not identical condition (N3). The representation constructed by high ability subjects may break down at the point where they have to switch to a more analytic strategy from a rapid elimination approach. This may occur with more than 4 piece arrays. The interesting point is that while positive errors total about the same, which might be expected if both groups were doing the same processing, the low ability subjects have difficulty dealing with both two and five piece arrays while the high ability
subjects make their errors across the array range. This could be due to both groups seeking to construct the array but the low ability group find that they fail even with two piece problems while the high ability group seek to keep such a strategy going through to five piece arrays. Low ability errors on five piece problems reflect the difficulty of this group in making comparisons in the context of a number of pieces.

The status of strategy usage as a major variable is further supported when another hypothesis put forward by Mumaw is considered. He suggests that the skilled are more accurate in detecting mismatches between similar stimulus arrays independent of transformations. On this basis it would be expected that the high ability subjects would have fewer errors in N3 trials for wholistic, separated and displaced process conditions insofar as these do not involve transformations. Table 6:4 presents the relevant results.

Table 6:4
Errors of High and Low Ability Ss in the wholistic, separated and displaced types as function of condition type.

<table>
<thead>
<tr>
<th>Condition</th>
<th>High ability</th>
<th>Low ability</th>
</tr>
</thead>
<tbody>
<tr>
<td>Positive</td>
<td>7</td>
<td>4</td>
</tr>
<tr>
<td>N2</td>
<td>4</td>
<td>8</td>
</tr>
<tr>
<td>N3</td>
<td>7</td>
<td>24</td>
</tr>
</tbody>
</table>

Significances based on Wilcoxon Rank Sum Statistic.

Low ability subjects clearly make more errors than
high ability subjects on similar stimulus arrays independent of transformations. A possible explanation is that in these situations the skilled are using a strategy which allows for rapid and accurate elimination. On the other hand the low ability subjects may be looking for matches within a piece by piece strategy and the reason for their difficulty lies in inability to match similar but different pieces.

Finally, Mumaw argues for two hypotheses related to speed as the distinguishing factor between skilled and unskilled performance. Skilled subjects are considered to be faster at searching through an array to find corresponding stimulus elements and also faster at encoding and comparing. If Mumaw's assumptions that the displaced condition reflects search time and the wholistic condition reflects encoding and comparison time are accepted, it would be expected that the high ability subjects would perform more quickly throughout the items. Table 6:5 sets out the data.

Table 6:5
Mean RT of High and Low Ability Ss on wholistic and displaced item types as function of trial condition.

<table>
<thead>
<tr>
<th>Condition</th>
<th>Wholistic Ability</th>
<th>High</th>
<th>Low</th>
<th>Displaced Ability</th>
<th>High</th>
<th>Low</th>
</tr>
</thead>
<tbody>
<tr>
<td>Positive</td>
<td></td>
<td>2.03</td>
<td>2.60</td>
<td>3.96*</td>
<td>5.35</td>
<td></td>
</tr>
<tr>
<td>N2</td>
<td></td>
<td>1.71**</td>
<td>2.79</td>
<td>2.52***</td>
<td>4.61</td>
<td></td>
</tr>
<tr>
<td>N3</td>
<td></td>
<td>1.95***</td>
<td>3.57</td>
<td>2.94**</td>
<td>5.29</td>
<td></td>
</tr>
</tbody>
</table>

* p<.10  **p<.05  *** p<.025 (Wilcoxon Rank Sum)

Except in the Wholistic positive trial type high
ability subjects are consistently quicker than low ability subjects yet it is this process that reflects encoding and comparing.

There is no significant differences between the time taken to encode and compare matches and mismatches for either group. The only significant difference is that the high ability group appear to be faster in searching out a mismatch.

The differences noted above suggest that it is not so much variations in speed of performing the same processes that distinguish high and low ability subjects but rather processing differences. These differences may arise from greater skill of high ability subjects in picking a mismatch with confidence and in making the decision more quickly. Also, while their encoding may be faster it is hypothesised that, more importantly, it is of a different quality and enables faster comparison because it is more structured and related. High ability subjects may, also, be more flexible in their processing varying from an exhaustive to a self terminating approach depending on the demands of the problem. It is possible that their positive errors are due not to speed as such but rather to unwise decisions on when to finish processing.

If some subjects were terminating processing too quickly, or in terms of the model, were not using the "hold" basket wisely, and the mismatch strategy was
being pushed to serve as a final arbiter of same or different, then it would be expected that these individuals would make errors at points demanding more care to avoid rejecting a match.

This possibility is supported if we consider errors made by high and low ability subjects on five piece stimulus arrays. High ability subjects tend to make errors by falsely rejecting a match (58% of errors) while the low ability subjects make the majority of their errors by falsely accepting a similar but not identical answer (74% of errors).

An appealing explanation of this result is that the unskilled lack the ability to detect slight differences between pieces especially when the array reaches a certain degree of complexity while the highly skilled make their errors because they are using an inappropriate strategy and expecting this strategy to cope with increasing complexity. The data discussed in this section suggest that there is a qualitative difference in the processing employed by high and low ability subjects. This qualitative difference appears to arise not from employing the same processing more quickly but from using a different range of processes which permit processing to be varied to meet the demands of each situation. The remaining two sections of this chapter will be devoted to further investigation of this range of processes.
Error Structure

The nature of the errors of the twenty subjects provides an indication of the strategy being used by each subject. The twenty subjects can be divided into three groups on the basis of the nature of their errors on the experimental task. Seven subjects mainly made errors on the positives, seven mainly made errors on the N3 items and six had errors spread evenly. The means for these three groups on the MPFB (DB) were 52, 41 and 45 respectively. It should be stressed however that the groups are dis-similar not only in the direction of their errors but also in the number of errors made. The group which makes the majority of errors on the positives averaged 11.8 errors. Those making the majority of their errors on the negative similar (N3) averaged 27.3 errors. The middle group averaged 12.1 errors.

Taking the groups making errors predominately on positives and those doing so on negatives, the mean reaction times for subjects within these groups are significantly different in the positive wholistic, separated, displaced, rotated and rotated-displaced processes. All subjects making errors on positives are faster at detecting a mismatch in all processes while those making the majority of errors through failure to pick a mismatch take longer to detect a mismatch than to pick a match in the wholistic and separated processes.
and in some cases in the other processes.

Subjects in the first group may take longer to process positives because they are unable to confirm a match by rapid elimination and their errors arise because they must change to a match strategy using one or two pieces. It could also be that this group has difficulty in constructing a complete figure and comparing this with the answer. For this group the establishing of a match demands a more exhaustive strategy. They do better on the MPFB because the presence of five alternatives assists in correcting a false rejection by forcing a further look at the options, one of which must be correct.

Subjects making errors in the negative conditions appear to be able to compare two identical items correctly but find difficulty in comparing similar items. If this group is using exclusively a matching piece by piece strategy then they may be having difficulty with comparisons which require greater concentration, create a situation where the processing is repeated "just to be sure" or take longer and lead to the image fading and comparison which lacks clarity. The image they are using may be very individual and precise but lacks the support of relational structure to allow quick elimination. This group may also lack the support of the alternatives in the MPFB since having chosen an answer it is not generally tested against the
other alternatives and possibly corrected.

Subjects making approximately equal numbers of errors on positives and negatives tend to take about the same amount of time to process in both conditions.

Skill in detecting a mismatch quickly by elimination appears to be an essential component of efficient processing even if it means that there is a possibility of making positive errors. As noted above those making positive errors in a "pair" presentation are likely to be helped by the presentation of more alternatives and so their initial error will be corrected. No such support is given to those mistaking a mismatch for the correct answer since that generally means that the subject will move on to the next problem.

The structure of the MPFB actually aids those subjects who seek to eliminate mismatches because of the variation in the test in the number of obviously incorrect alternatives. Those working an efficient mismatch strategy should be able to quickly reduce the set of alternatives to one or two items to be looked at more closely.

A close examination of the MPFB (DA) problems in the light of the error data obtained from 666 subjects permitted an assessment of how many "close" alternatives might be chosen as correct when they are only approximately so and how many alternatives could be eliminated as clearly inadequate.
The results indicate that a skilled subject using an elimination by mismatch strategy can reduce 38 of the 64 problems to the correct answer alone or to two alternatives only. For the mismatch strategist there are only 6 problems which cannot be reduced to less than five alternatives by a rapid mismatch scan.

Although it may be argued that the skilled are faster at searching through an array to find corresponding stimulus elements (Mumaw and Pellegrino, 1984), it seems much more reasonable to suggest that the speed is not the result of a positive matching process but the result of the ability of the subject to reduce the working requirements by rapidly eliminating a number of alternatives. The present structure of the MPFB favours those following this strategy while those following a search, find, orient, compare strategy will be considerably slower if they elect to follow this strategy and apply it to all alternatives in the exhaustive processing mode suggested by the Mumaw model. Subjects who do not follow an exhaustive processing approach, however, run the risk of choosing an incorrect answer.

The danger of the mismatch strategy is that too many alternatives will be eliminated and where more than a single alternative remains the choice will become something of a guess. This was apparent with one of the subjects who made 25 errors on the MPFB test while
completing it in 12 minutes. On the 216 items of the experimental task, however, he made only 8 errors. This can be explained by suggesting that on the MPFB he was working too fast and eliminating too much thereby leaving himself only one incorrect answer. However, when faced with a "pair" comparison he was able to apply the strategy to a single alternative so that the elimination processing was more controlled and open to being checked.

This section has indicated that a more detailed analysis of errors to show in what direction they are made — on positives, negatives or equally — provides a valuable indication of the way in which the subject is processing the problem. If the subject is detecting a mismatch accurately and more rapidly than a match then it can be hypothesised that he is using a different strategy from the subject who is making mistakes on the negatives and taking longer to do it. The errors of such a subject will be on the positives either because he tries to determine the answer by mismatching alone or because he fails to realise that a matching strategy is slower and this must be allowed for in determining the answer. This mismatching or elimination of needless material appears to be an essential ingredient of efficient and effective spatial processing.
Performance time.

The last approach to individual differences involves considering the results of the 20 subjects in terms of performance time on the experimental task.

Two groups of subjects were identified. The first group was composed of the five subjects with the longest performance times on the task. For this group, individual mean latency data and regression graphs were prepared for positive and negative trials in each processing condition and for increasing stimulus array size. The data are presented in Figures 6:2 to 6:6. Assuming that time is a relevant variable and using it to identify the major difficulties experienced by these subjects is hypothesised to give insight into the difficulties that subjects experience on the MPFB. Although such an approach does not lend itself to statistical analysis it is believed that it will further understanding of the proposed model.

Subject L.B.

This subject showed no apparent consistent strategy in approaching the MPFB and on the five piece items usually gave up after one or two minutes claiming that "I have the pieces I am looking for in my mind but can’t find them". This was substantiated by her finger movements which suggested great difficulty in finding the piece she was working with in the answers offered.

It became obvious that there was no memory for
previous searches on the same problem as she repeated her finger movements in identical fashion after giving up and starting again. She would often stare at a problem seemingly unable to decide where to go next. On the MPFB she was able to solve most of the problems up to four pieces despite the length of time and the haphazard approach but five piece problems defeated her totally.

The scattered pattern in the accompanying mean latency graph shows the difficulty clearly (Figure 6:2). In the positive condition the subject takes a long time to identify even a two piece problem and performance time in general increases with increasing numbers of pieces. The drop in performance time in four piece arrays may be due to the ability to see that some pieces are the same. Even when she finds the pieces, rotation is a problem and it is a reasonable assumption that this is due to rotating to congruence. The difficulty she experienced in the five piece MPFB problems is explained in the rapid increase in search time with a five piece array in the experimental task. The search time is double that required for the other processes and reflects great difficulty in finding a designated piece embedded in a figure composed of five different and relatively small pieces. Her difficulty results in the subject running and re-running the search-and-compare process until she does arrive at an answer. The fact
Figure 6:2. Subject LB. Mean latency as a function of trial type, item type and number of stimulus elements.
that this eventually works with an "array and answer" presentation is seen in the fact that she has only a 5% error rate. But when confronted with five alternatives to process it can be seen why the demand becomes too great. While able to mismatch grossly different answers presented as two pieces the introduction of a three piece figure immediately increases the time required by as much as five times in some conditions. In fact this is almost harder than discriminating the similar but different items. This suggests that a totally different figure cannot be taken in as well as the pieces of a figure which is almost the same.

The picture which emerges is that of a subject putting in a great deal of "work" to arrive at an answer due to inability to integrate information and/or to hold that information in a short term working memory which integrates the information to the point of posing questions for the next run which approximates to a developing insight (learning). The term "working memory" is used here not as an "architectural" term but to indicate processing capacity limitations. Difficulty in recognizing a total figure is also an apparent cause resulting in the need to decompose and process a figure as separated pieces. There is no evidence that the subject improved with practice.

This picture suggests that adequate processing capacity is essential for fast and consistent
performance using clues from past experience and knowledge to build up the answer. Such difficulties not only make for very slow operating but raise the question of whether the subject is able to build on any previous knowledge which she might have developed.

Subject R.M.

An essential process in spatial perception is the ability to hold an image for the purpose of comparing it with a similar or identical representation. If a subject experiences difficulty in performing such a process, it will be very difficult to identify a structured image made up of a number of pieces such as we have in the wholistic and separated conditions of the experiment. The structured image will tend to fade and the subject will have to start again.

This type of difficulty appears to explain the performance of Subject RM. The subject is relatively fast and accurate at detecting differences in the N2 and N3 conditions and exhibits the familiar rise with the introduction of five piece arrays (Figure 6:3).

However, when identification of "same" figures is involved there is a significant increase in performance time especially in encoding and comparing as this is reflected in the wholistic condition. The subject’s processing seems to become "paralysed" by some items which cannot be processed whole and yet cannot be broken into constituent units. This is seen in the time to
Figure 6:3 Subject RM. Mean latency as a function of trial type, item type and number of stimulus elements.
perform two piece problems in the positive trial conditions. Table 6:6 illustrates the difficulty.

Table 6:6
Mean time to perform two piece problems in positive and negative conditions by item type. (Errors in brackets).

<table>
<thead>
<tr>
<th>Item type</th>
<th>Positives</th>
<th>N2</th>
<th>N3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wholistic</td>
<td>11.9 secs(2)</td>
<td>3.3</td>
<td>2.0</td>
</tr>
<tr>
<td>Separated</td>
<td>14.7</td>
<td>5.3</td>
<td>3.4</td>
</tr>
<tr>
<td>Displaced</td>
<td>6.8</td>
<td>3.4</td>
<td>3.2</td>
</tr>
<tr>
<td>Rotated</td>
<td>11.8 (1)</td>
<td>3.0</td>
<td>4.4</td>
</tr>
<tr>
<td>Rotated-Displ.</td>
<td>16.7</td>
<td>4.6</td>
<td>3.5</td>
</tr>
</tbody>
</table>

Positives and N2 p<.005, Positives and N3 p<.005.
(Wilcoxon Rank Sum Statistic).

Two aspects of this data are arresting. First, the very long time taken to identify two figures the same (wholistic) and the errors made, with the same being true for the separated items; and second, the way in which, excepting rotation, the subject is able to correctly see a difference in the N3 trials more quickly than in the N2 grossly dissimilar comparison.

The subject seems to be unaware that whole figures can be compared as wholes and the only way he can operate is to dismantle the structure and then compare it piece by piece. The difficulty in comparing an obviously dissimilar figure seems to lie in an inability to grasp the presented figure as a unit or to see that its relational structure is quite different when given only the pieces. The subject can "see" small differences but not large ones because his perception is
confined to a limited area of the stimuli. It is not a case of "failing to see the wood for the trees" but failing to see the other trees for the one tree which is the focus of attention.

Dealing with identity is very difficult for the subject and 14 of his 20 errors are made on positive items (representing 19.4% of all positives). Identity requires holding two aspects of an item at a time and this renders it a very difficult task. The subject is conscious of this and commented while doing the MPFB that he "did one piece at a time but on reflection should have scanned the lot". The pattern of results suggests that he might be unable to "scan the lot" and this may explain why Subject RM is a very slow reader and his writing can become bogged down in the middle of a sentence so that he can neither start again nor go forward to a conclusion.

This type of interpretation of a single individual performance suggests that the MPFB type problem when used as a diagnostic tool gives insight into more general difficulties. Understanding processes may help in cutting across content categories, as suggested by Goldner (1957).

Subject J.M.

This subject shares some features with those already considered. He takes a long time on the positives and makes 9 of his 10 errors on these items. He also
Figure 6:4 Subject JM. Mean latency as a function of trial type, item type and number of stimulus elements.
experiences difficulties in building up a whole image and holding it. On the other hand he lacks the skill of Subject R.M. in making rapid distinctions when similar items are involved. As Figure 6:4 indicates, there is no consistency in the negative condition results.

Performance time for the positives increases consistently with increasing pieces in the array and transformations appear to be difficult and take longer than the finding of a piece.

On the MPFB the subject worked with his fingers tracing many recycles of the data until he ended up waivering between two final answers for some time. On one occasion he stared at two answers and appears to rerun a comparison over and over until he finally "grabbed" an answer. The variations in latencies for the wholistic and separated conditions suggests that this subject also had difficulty working with unit figures and that they were being broken up into their component pieces. The subject believed that he was employing a systematic piece by piece comparison strategy. On this basis, his difficulty would appear to be in the number of times he has to run this strategy before he can arrive at an answer with any confidence.

Subject T.T.

This subject was both the slowest and most inaccurate of the 20 subjects on the MPFB. He explained his approach to the MPFB by claiming to "pick the
largest, smallest or most unusual piece to work with, and to try to find the chosen piece in the solutions, after which another piece is taken and the process repeated". From the protocols we have seen that this is quite a common and acceptable strategy. Why then does it result in this case in a very low score on the MPFB (23 correct out of 64) and a high error rate on the experimental test (13% with 8 errors on positives, 3 on N2 and 16 on N3)?

What was apparent in watching his performance on the MPFB was that the subject was working with the first alternative which contained the chosen piece, checked in another piece and if it looked possible, accepted that answer. This approach is both self-terminating and does not involve any working through the alternatives once an alternative that looks vaguely right is seen. This adaptation of Strategy 1 without its safeguards may account for the number of subjects who perform the MPFB quickly, usually finishing all 64 problems, but achieve very low scores.

Turning to the experimental task results (Figure 6:5) the subject fits the pattern of having difficulties with the separated and wholes in the positive trials and thus having difficulties with identifying total figures. The separated trials in N2 and N3 are associated with long performance times suggesting that the subject is either decomposing them into their individual pieces or
Figure 6:5 Subject TT. Mean latency as a function of trial type, item type and number of stimulus elements.
trying to "fuse" them into a whole and then finding that he can't cope with total figures of this nature. Comparing pieces after rotation is a real difficulty for this subject supporting the view that subjects like Subject TT have difficulty holding an image especially after transformation.

Subject W.Mc.

The results for this subject (Figure 6:6) suggest that he is able to eliminate mismatches fairly fast. While he was working the subject continually talked to himself labelling each piece with which he was working and then looking for a piece which could carry a similar label. While this appears to help with the grossly different pieces, fine distinctions become perceptual discriminations and this seems to slow down the subject especially in the positive trials with arrays greater than three pieces. Finding the piece being worked with generally appears to be the slowest processing step, possibly because the labels are verbal and after verbal comparison are converted to visual images.

The results suggest that even among subjects taking a long time there are processing differences. The length of processing is not a cause of difficulty but rather a symptom of underlying processing problems which have to be compensated for if a level of accuracy is to be achieved. From the results it appears that slow
Figure 6:6 Subject W.Mc. Mean latency as a function of trial type, item type and number of stimulus elements.
performance is indicative of the following difficulties on both the experimental task and on total performance on the MPFB:

(a) An unstable and blurred short term memory makes it very difficult to hold an image long enough to work effectively. Many subjects compensate by using finger movements in an attempt to hold their place in the processing cycle or by giving a verbal label to the piece with which they are working. The latter may help with gross differences but apart from giving a "benchmark" for progress is not helpful for fine distinctions.

(b) The lack of a systematic strategy is apparent to some extent in all subjects resulting in a number of processing runs before ending in what might be a guess. The error rates suggest that these longer latency subjects try to put off guessing as long as possible but with the more complex problems may finally give up especially on the MPFB problems.

(c) The major difficulty experienced by these subjects lies in working with whole figures or with separated figures which can be readily collapsed into wholes. All the subjects seem to experience difficulty in comparing wholes or in constructing whole figures for comparison. They seem to consciously decompose figures rather than work with wholes. The subjects, therefore, lack the perception of a total structure and the skill to integrate information into larger units.
(d) This inability to integrate information has two important consequences. It seems that such subjects have difficulty holding even two pieces together to make a comparison. It also restricts their ability to work backwards and forwards between pieces and wholes since both have to be reduced to single units. Both of these aspects of information integration are crucial features in effective spatial visualization.

The second group of individual subjects to be considered are those who worked quickly and accurately completing the reference test in 12 minutes or less and whose performance on the experimental test was not only quicker but showed a different pattern to those discussed above.

Subject J.S. (Figure 6:7)

In completing the MPFB this subject commented that for her there were two types of problems. With the first type she was able to glance at all the options and discount a number of them, take a particular piece and distinguish the correct answer by a matching process. The second type comprised those problems which required taking one piece from the beginning. Solution of the former group of problems was assisted by being able to take two identical problems or by seeing that the pieces were related in some way.

This subject makes 6 of her 9 errors in the N3
FIGURE 6.7 Subject JS. Mean latency as a function of trial type, item type and number of stimulus elements.
conditions and half of them were in the separated condition. This suggests that if the one run mismatch strategy is going to break down it will do so at points where there is a close similarity between the answer and the almost correct answer. The long search time in the N3 trials up to four pieces suggests that the major problem for the subject is making a distinction between similar and identical and the sharp drop in search time (N3) for five pieces indicates a change of strategy to piece by piece comparison. The marginal rises in positives between four and five pieces and in N2 at the same point supports this. The change of strategy is dependent on the presence of a number of jumbled pieces without clues as to their relationship. This forces a change to a slower and successive strategy.

The sensing of any difficulty in the mismatching strategy alerts the subject to the need for instituting some form of hold for uncertain answers to enable them to be more adequately searched. Subject A.R. (Figure 6:8)

Another approach is reported by this subject in which he seeks to "build up a figure from the pieces and then compare this figure with the answers in a one run process". If this cannot be done then "the most unusual shape" is matched to the answers allowing elimination. The skill appears to lie in the ability to identify "the unusual" so that on most occasions one run is
Figure 6:3 Subject AR. Mean latency as a function of trial type, item type and number of stimulus elements.
sufficient.

For this subject the majority of errors are made in falsely rejecting positives in the more complex problems. This suggests that the constructed figure is not precise enough or cannot be held together after a certain point giving what the subject refers to as variations which seem "to be out of focus". If the subject is pushing a visual image to the limit then this "out of focus" comment takes on meaning due either to the complexity of the pieces or to the final complexity of the whole. The mean latency data for this subject show how little influence an increasing number of pieces has upon this strategy.

Subject H.S. (Figure 6:9)

A final example of a flexible and quite fast strategy is given by Subject H.S. who reports being aware of two strategies. In the first "some answers just came to me. I scanned and the eyes would fix on one answer, that was it". The subject continued "it seemed that my eyes stick to one answer - the answer jumps out". When the subject is unable to get this effect she resorts to one piece and works a piece by piece match strategy.

The flat positive mean times between two and four pieces suggest that she is working quickly with identifying answers but the skill breaks down with the introduction of five pieces. It might be expected that
Figure 6.9 Subject HS. Mean latency as a function of trial type, item type and number of stimulus elements.
the mismatches would be dealt with even more rapidly when the answer "didn't jump out" but surprisingly the negative trials are not appreciably faster than the positives although the N3 trials do present a somewhat similar pattern to the positives.

In this group, although the members have fairly similar accuracy and speed results, there is variation in strategy. The strategy range comprises scanning to eliminate a mismatch followed if necessary by piece by piece comparison, the construction of a base figure on which match or mismatch is determined and a strategy which allows answers to "jump out". The similar feature is the ability of each subject to change strategy when the need arises.

Subject D.K. (Figure 6:10)

Subject DK is added to this group to avoid the misconception that the most common strategy of taking a piece and matching it to each answer thereby allowing the elimination of several answers and then taking another piece and repeating the process to lead to an answer cannot be executed rapidly. This subject was able to use a matching strategy to achieve one run on all negatives and in the positive separated and wholistic conditions. The mean time graphs show the negatives at about half the time of the positives. The displaced-rotated condition is the most demanding process in the positives.
Figure 6:10 Subject DK. Mean latency as a function of trial type, item type and number of stimulus elements.
Speed in processing can be the result of very efficient "hardware" processing or it can arise from the quality of the "software" which is introduced in the form of strategy control. These results suggest that some faster and more accurate subjects are using flexible processing which reduces demand on working space and hence time. The absence of this flexibility throws the subject back onto patterns of processing which are generally relevant to all subjects, namely piece by piece comparison which itself varies in its exhaustiveness.

It was the aim of this analysis of individuals to develop answers to a number of questions. These will now be reviewed.

The difference between high and low ability performance appears to be attributable to the employment of different and flexible strategies by those who operate well. This analysis is based on the error data which show a different pattern and slopes which, while showing the same pattern in positives, differ quite markedly in negative trials. Taken together it can be argued that while the positives may look alike in mean times and slopes the strategy is different both in the positives and quite obviously in the negatives. Errors made by high performers in the experimental test arise because of failure to check adequately. This only happens in some cases and yields a pattern similar to
poor performers but quicker.

The speed differential may be explained by a reduction in the required working. In the case of mismatching negatives this is done accurately and rapidly by high ability subjects by means of their mismatching strategies. Poor performers continue with a matching to rejection strategy which becomes difficult when it is necessary to distinguish similar from identical and is influenced by increasing numbers of pieces.

The second issue is raised by the question whether the difference between individuals is due to variations in strategy usage or to variation in the speed of performing the various processes within a single strategy? The results reported suggest two conclusions. Performance varies due to the use of different strategies rather than to the speed of processing the elements of one strategy, although this does vary as well. Secondly, the skilled performer is able to be flexible when it comes to mixing strategy use in varying circumstances. The variation between the strategies of high and low performers supports these proposals although the results suggest that there are variations in processing even within the two groups.

How valid is it to see "speed of operation" as a major variable? Certainly, on the surface, speed of operating seems to be a major variable and subjects do
appear to vary in their ability to perform what appears to be the same process. However, what may be more important is what we might call the mix of the processes so that these are performed in different ways which makes for different strategies. The confidence level also affects the number of processing runs so that self-terminating processing can give the impression of speed when compared with exhaustive processing although the actual processing may occur more slowly. In this case it is not a matter of speed but amount to be completed. This can be affected by a reduction of the processing required or an increase in the integration of the information.

The type of error being made has a direct effect on MPFB performance since false rejections can be corrected where a number of alternatives are still "live" but false acceptance cannot be corrected. In the experimental tasks the type of error being made is a clue to the form of strategy being used since errors tend to occur at the limits of a mismatch strategy but can occur at any point on a match strategy. They are directly related to the varied forms of encoding and comparison being used by particular strategies.

Finally the variations between individuals reported in this chapter cast doubt on the value of group data as a valid explanation of a generalized model. The proposed model based on strategy variation is better
able to explain individual differences than a model which assumes a common strategy performed more or less efficiently by different individuals reflecting differences in processing speed and accuracy alone.
CHAPTER 7: THE MODEL APPLIED TO INDIVIDUAL PERFORMANCE ON THE MPFB.

Previous chapters have reported work which has questioned the validity of group performance as a means of substantiating a model for the MPFB and urged an understanding of the processing of components by individual subjects. It has been established that within group results there are variables which reflect skill in processing, error profile and performance time. It has also been argued that the way in which search, transformation and comparison are combined together by each individual creates differences in individual performance on MPFB type problems. Subject’s performance on MPFB type problems has been investigated by analysis of the processes involved including the way in which these are co-ordinated into strategies and the number of cycles of processing required. Generally, performance is consistent with the proposed model but performance on the actual MPFB test has not been considered in relation to the model. This chapter reports an experiment with the actual MPFB test aimed at determining whether individual performance on the test is consistent with the proposed model.

Analyses of group-collected retrospective protocols (n=666) and of individual protocols have identified two major strategies open to individual performance, the
ways in which data can be organized and the reasons for strategy difference and change (Figure 4:2). It was concluded that strategy choice and change is a dimension of individual difference and a model is required which is compatible with variation and change in strategies and can account for individual differences in them.

If the model proposed offers a structure onto which individual flow charts, as heuristic statements of processing derived from MPFB test performance, can be projected then the model’s general and individual explanatory power will be greatly increased. There is also need to further investigate the reasons for individuals adopting differing strategies and the linked question of the relationship between terminating and exhaustive processing in performance. Finally, the psychological concepts which underlie processing of MPFB problems and the degree to which these are generalized to the concept of spatial visualization require further consideration.

It is hypothesised that group data, analysed by simple correlation methods, fail to tap the rich diversity of subjects' performance on the MPFB. Without a knowledge of this diversity any comparison of effective performance on tests such as the MPFB with performance on other tests will lack predictive power.

It is also anticipated that the proposed model will be able to account for performance on the MPFB test by
Figure 7:1  Problems 25 to 40 of the MPFB
(Reduced to 70% of actual size used)
Mean complexity rating appears under each problem.
relying on strategy use and strategy change as the major variables. However, it is not anticipated that consistently superior individual performance will be associated with one particular processing path.

EXPERIMENT 7:1

Subjects: Thirteen subjects in the final stages of the first year certificate of Architectural Drafting at the Box Hill College of T.A.F.E. volunteered to take part in the experiment. The subjects were aged between 17 and 21 with a mean age of 18.5 years.

Procedure: Each subject in the group completed the MPFB (DA) and was timed on the middle sixteen problems (numbers 25 to 40) (Figure 7:1). These were to constitute the problems used in the subsequent experiment. All the subjects had completed the test ten months earlier as part of the selection procedure for entrance to the course.

Two weeks later each subject took part in three individually administered tests:

(a) The subject was given 16 problems, numbers 25 to 40 from the MPFB. Each problem was presented separately on a 6 by 4 inch card and was individually timed.

(b) The subject was presented with one of ten cards on each of which appeared the pieces of a particular MPFB problem arranged in random order (Figure 7:2). The 10 problems used were drawn from the 16 problems numbered
Figure 7:2  Examples of the encode and identify experiment included in Experiment 7:1. The pieces to be encoded appear on the LHS, the pieces of the five answers including the encoded pieces are on the RHS.
25 to 40. The subject studied these pieces as long as he wished and the time was recorded. The card was then removed and replaced with a card containing all the pieces from the five answers offered by the MPFB for that particular problem. The subject was required to indicate those pieces which had been previously shown as part of the stimulus array. Response time and number correctly identified were noted.

(c) The subject was presented with a pack of 24 cards (Figure 7:3) each containing an enlarged drawing of a piece taken from the 16 problems, numbers 25 to 40 of the MPFB, and representing all the shapes used in these problems. After viewing the cards, the subject was asked to divide the cards into two piles, the 12 pieces judged "simplest" and the 12 judged "most complex". In making a judgment about simplicity-complexity the subject was instructed to use their own definition and no guidance was given. The subject then ranked the 12 simple cards from simplest to most complex. The first eight rankings were recorded. The remaining four were mixed with the 12 remaining cards and from these the subject chose the four considered "most complex". The remaining twelve were then ranked simplest to most complex and rankings 9 to 16 were recorded. The remainder were then ranked 17 to 24. Each ranking was given a value as follows: 1-4 = 1; 5-8 = 2; 9-12 = 3; 13-16 = 4; 17-20 = 5; 21-24 = 6. These values were then
Figure 7:3 A. Examples of the cards used to determine complexity rating in Experiment 7:1.
The complexity values given to each piece in the Experiment 7:1 by the thirteen Architectural Drafting subjects and the resultant values applied to each total problem.

<table>
<thead>
<tr>
<th>Problem</th>
<th>Complexity Values Assigned to Each Problem Considering All Pieces and Different Pieces Only.</th>
<th>Complexity Values Assigned to Each Problem Considering Only Considered MFB Problem.</th>
</tr>
</thead>
<tbody>
<tr>
<td>1/25</td>
<td>4/18</td>
<td>6/16</td>
</tr>
<tr>
<td>2/26</td>
<td>18/18</td>
<td>6/16</td>
</tr>
<tr>
<td>4/28</td>
<td>17/7</td>
<td></td>
</tr>
<tr>
<td>5/29</td>
<td>6/4</td>
<td></td>
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<td>6/30</td>
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<tr>
<td>10/34</td>
<td>10/7</td>
<td></td>
</tr>
<tr>
<td>11/35</td>
<td>12/6</td>
<td></td>
</tr>
<tr>
<td>12/36</td>
<td>16/1</td>
<td></td>
</tr>
<tr>
<td>13/37</td>
<td>7/7</td>
<td></td>
</tr>
<tr>
<td>14/38</td>
<td>6/0</td>
<td></td>
</tr>
<tr>
<td>15/39</td>
<td>14/10</td>
<td></td>
</tr>
<tr>
<td>16/40</td>
<td>29/29</td>
<td></td>
</tr>
</tbody>
</table>
Figure 7.4  The "four-in-a-row" presentation corrected for bias of twenty problems taken from the MPFB. Problems 1-16 in this presentation are MPFB problems 25-40. Problems 17-20 in the presentation are MPFB problems 41, 42, 44 and 48. Problems A, B, C and D are practice items.
applied to the pieces in problems 25 to 40 of the MPFB to give a complexity value for each problem as viewed by each subject. (Figure 7:3B).

A week later each subject repeated the initial 16 problems presented in the form of a stimulus array plus four alternative answers. The relative positions of the answers had been corrected for bias since analysis of the MPFB test had established that in the first 32 problems of the MPFB (DA) the first of the five alternatives offered was correct 12 times and only once in the second half of the test. (Figure 7:4). The test also included four additional problems (numbers 41, 42, 44 and 48) the last of which did not offer a correct decision. The subject was asked to itemise the steps followed to solution, to indicate any differences in operating with various problems and any difficulties which were encountered.

RESULTS

The thirteen subjects scored a group mean of 52.5/64 correct and 57.9/64 completed at the time of selection and ten months later a group mean of 54.9/64 correct and 63.9/64 completed. Correlation of individual scores over the period was .355 (t=1.26, n.s.) and for number completed .425 (t=1.55, n.s.).

The group was given a number of selection tests at the time of the first administration of the MPFB and the
group means from these tests and from the experimental group were compared as set out in Table 7:1.

The group participating in the experiment is more highly skilled spatially than the total group.

Table 7:1
Mean results of Ss in experiment 7:1 compared with all applicants on a battery of selection tests.

<table>
<thead>
<tr>
<th>Test</th>
<th>Experiment 7:1 Ss</th>
<th>All applicants</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(n =13)</td>
<td>(n = 89)</td>
</tr>
<tr>
<td>MPFB (DA)</td>
<td>52.5 (SD 8.4)</td>
<td>47.6 (8.5)</td>
</tr>
<tr>
<td>Prog.Stand.Matrices</td>
<td>50.0 (3.2)</td>
<td>48.1 (4.4)</td>
</tr>
<tr>
<td>Paper folding test</td>
<td>15.9 (1.4)</td>
<td>11.8 (3.4)</td>
</tr>
<tr>
<td>Surface Devel.Test</td>
<td>51.3 (6.6)</td>
<td>39.6 (13.0)</td>
</tr>
</tbody>
</table>

The experimental group results for the three administrations of the 16 problems (Numbers 25-40) are given in Table 7:2.

Table 7:2
Group means for experiment 7:1 Ss on three administration of MPFB. Problems 25 to 40.

<table>
<thead>
<tr>
<th>Administration</th>
<th>Mean time</th>
<th>Mean errors</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Within MPFB test</td>
<td>215 secs (SD 29)</td>
<td>1.8</td>
</tr>
<tr>
<td>2. Individually tackled</td>
<td>105 secs (SD 31)</td>
<td>2.5</td>
</tr>
<tr>
<td>3. Four alternatives</td>
<td>198 secs (SD 53)</td>
<td>0.9</td>
</tr>
<tr>
<td>bias removed.</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Between 1 and 2 t = 3.3, p<.01, between 2 and 3 t = 2.3, p<.05. Between 1 and 3 n.s.

The mean latency for individual administration of the MPFB problems on separate cards is significantly less than that for the group administration of the problems. This may be attributable to an administration in context being given more care than an individually presented
problem or to distractions in group administration. The "four in a row" presentation is only marginally faster than the MPFB format and is not significant since, as might be expected, the removal of bias in the location of the answers counterbalances the reduction by one of the alternatives to be dealt with. The mean errors for the three administrations suggest that performance on the "four in a row" although not faster is more accurate than the normal administration (p<.10) possibly because all alternatives are considered. The individual administration while faster tends to be less accurate than the "four in a row" (p<.02).

The averaging of group data conceals very broad variations within it. This is exemplified by the three variables of number of pieces in the array, number of different pieces in the array and the complexity value given to each problem by individual subjects. Table 7:3 shows how these vary when the 13 subjects are considered individually.

Table 7:3
Correlation range for 13 Ss between RT and number of pieces, number of different pieces, and complexity rating of the problems in Experiment 7:1.

<table>
<thead>
<tr>
<th>Correlation</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>RT and number of pieces</td>
<td>.173 to .804</td>
</tr>
<tr>
<td>RT and number of different pieces</td>
<td>.583 to .946</td>
</tr>
<tr>
<td>RT and complexity rating</td>
<td>.092 to .899</td>
</tr>
</tbody>
</table>

For some subjects there is little relation between the number of pieces in a problem and the time taken for
solution (terminating processing) nor is there a relationship between the complexity of the pieces and the time taken to solution. The number of different pieces affects some subjects more than others. The nature of the processing appears to be diverse and demands a subject by subject investigation combining individual results with the verbal protocol data on subject’s processing methods. Such an investigation will permit an examination of the effect of individual strategy on the other variables in problem performance.

The second part of the experiment explored the relationship between time taken to encode the array, time taken to identify the encoded pieces and accuracy of the outcome. Table 7:4 present the results.

Table 7:4
Means for the 13 Ss in array encoding, identifying time and accuracy.

<table>
<thead>
<tr>
<th></th>
<th>Mean time to encode array</th>
<th>Mean time to identify pieces</th>
<th>Mean percentage correct</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>57.9 secs (SD 20.8)</td>
<td>55.5 secs (SD 18.8)</td>
<td>67.4%</td>
</tr>
</tbody>
</table>

Taken as group results it would seem that subjects took about the same amount of time to encode the pieces in an array as to identify them in a random group and that the average accuracy was about two thirds. However there was considerable individual variation, with some subjects taking longer to encode than identify and others the reverse. The number correctly identified ranged from 24 to 12/27. Analysis of individual results and protocols indicates that greater time given to
encoding is more frequently associated with subjects who appear to operate a piece by piece strategy while those taking about the same time for encoding and identification tend more to the use of global strategies. Once again group results fail to indicate the variability displayed by individual subjects.

The third part of the experiment concerned complexity and here the results were more uniform although some problems appeared to be more complex for some subjects than for the majority. Figure 7:1 includes the mean complexity rating for each problem. The mean complexity score given to each problem correlated with the number of pieces in the problem (.755 p<.001) and with the number of different pieces in each problem (.834 p<.001) The group results suggest that complexity is dependent on the nature of pieces and increases with the number of pieces and especially with increasing numbers of different pieces. However, individual correlations between latencies and problem complexity vary and there is some evidence to suggest that the more global strategies are more affected by problem complexity than are the piece by piece strategies.

In order to explore the results more fully each individual’s data will be further analysed and heuristic flow charts representing individual performance will be developed from the verbal and written protocols.
Table 7:5
Time (in seconds) for 13 Ss to complete the three administrations of the MPFB problems 25 to 40 and the time to encode and identify in Experiment 7:1. Errors in brackets.

<table>
<thead>
<tr>
<th>Subject</th>
<th>MPFB Test</th>
<th>Individual</th>
<th>Four in a row</th>
<th>Encode</th>
<th>Identify</th>
</tr>
</thead>
<tbody>
<tr>
<td>M.S.</td>
<td>165 (3)</td>
<td>97 (0)</td>
<td>250 (0)</td>
<td>54</td>
<td>45 (7)</td>
</tr>
<tr>
<td>W.M.</td>
<td>240 (1)</td>
<td>75 (2)</td>
<td>187 (0)</td>
<td>52</td>
<td>63 (10)</td>
</tr>
<tr>
<td>S.A.</td>
<td>-</td>
<td>162 (3)</td>
<td>-</td>
<td>118</td>
<td>85 (10)</td>
</tr>
<tr>
<td>G.H.</td>
<td>210 (1)</td>
<td>77 (1)</td>
<td>239 (1)</td>
<td>44</td>
<td>33 (8)</td>
</tr>
<tr>
<td>I.H.</td>
<td>255 (1)</td>
<td>180 (2)</td>
<td>292 (0)</td>
<td>71</td>
<td>82 (3)</td>
</tr>
<tr>
<td>J.A.</td>
<td>195 (3)</td>
<td>115 (1)</td>
<td>255 (2)</td>
<td>53</td>
<td>36 (15)</td>
</tr>
<tr>
<td>T.P.</td>
<td>255 (2)</td>
<td>97 (2)</td>
<td>180 (1)</td>
<td>39</td>
<td>31 (7)</td>
</tr>
<tr>
<td>A.R.</td>
<td>180 (1)</td>
<td>75 (3)</td>
<td>130 (2)</td>
<td>50</td>
<td>51 (11)</td>
</tr>
<tr>
<td>P.B.</td>
<td>210 (1)</td>
<td>73 (5)</td>
<td>123 (2)</td>
<td>38</td>
<td>46 (7)</td>
</tr>
<tr>
<td>C.P.</td>
<td>210 (5)</td>
<td>90 (4)</td>
<td>147 (0)</td>
<td>54</td>
<td>49 (9)</td>
</tr>
<tr>
<td>T.B.</td>
<td>240 (1)</td>
<td>120 (2)</td>
<td>183 (2)</td>
<td>46</td>
<td>51 (10)</td>
</tr>
<tr>
<td>G.K.</td>
<td>195 (1)</td>
<td>122 (4)</td>
<td>180 (0)</td>
<td>69</td>
<td>82 (8)</td>
</tr>
<tr>
<td>J.B.</td>
<td>225 (3)</td>
<td>82 (3)</td>
<td>210 (2)</td>
<td>65</td>
<td>67 (10)</td>
</tr>
<tr>
<td>Means</td>
<td>215 (1.8)</td>
<td>105 (2.5)</td>
<td>198 (0.9)</td>
<td>58</td>
<td>56 (9)</td>
</tr>
</tbody>
</table>
Individual subjects will be considered in an order which reflects a movement from the purest examples of a piece by piece strategy to the most global approaches.

Before considering each individual separately Table 7:5 sets out the results of the 13 subjects on the three attempts at the MPFB problems.

The first six subjects appear to use some variant of the piece by piece strategy while the remaining seven employed some variant of construction or rapid elimination. "4 in a row" appears to take less time for the latter group, possibly because they are able to eliminate quickly and therefore gain the advantage of having to consider one less alternative.

The individual results of the thirteen subjects will now be reported. In each case the subject’s protocol will be interpreted by mapping the account of the processing onto the heuristic model.

Subject M.S. (Figure 7:5)

This subject performed well on all tests at the time of selection into the architectural drafting course.

Progressive Standard Matrices 51/60
Paper Folding Test (French) 17/20
Surface Development Test (French) 56/60
MPFB 54/57

Protocol: (For each subject the protocol report is
generalized to reports on Problems 3 and 15, the former consisting of three equal pieces which need only to be put together and the latter consisting of four unequal and dissimilar pieces Figure 7:4. Each protocol is a verbatim account in the subject's own words. All protocols are reported in the Appendix).

Problem 3. Step 1. Look at the shapes.
   2. Look at alternate finished shapes.
   3. Look back at the sizes of each shape.
   4. Determine the larger sizes.
   5. Rotate the shapes to a shape similar to the four alternatives.
   6. Select your answer.

Problem 15. Step 1. Look at the shapes.
   2. Pick out largest shape.
   3. Choose, out of the four alternative answers, answers with the largest shape.
   4. Look at smaller shapes.
   5. See which of the chosen in Step 3 have similar smaller shapes.
   6. Select your answer.

All other four and five piece problems included an additional step to the process outlined for Problem 15. This step was inserted following step 2. Step 3: rotate and join the largest shape to similar shapes in the four alternatives.

The flow chart which reflects his method of
Figure 7.5 Model of performance of Subject MS.
operation on the MPFB problems (indicated by shading in the relevant parts of the total heuristic model) clearly shows the strategy which he was using consistently and efficiently. His account of what he was doing involved looking at the shapes and grading them from largest to smallest, then looking at the answers. He then took the largest shape and rotated it if necessary. "Choose from the possible answers those with the same shape". If this did not give one answer then the subject took the smallest shape and investigates "which of those chosen above has a similar smallest shape". If only one answer was left it was selected, if more than one remained the process was repeated with the next piece until only one answer was left. For this subject this was a consistent approach. The flow chart for Subject MS is the closest fit to the Mumaw and Pellegrino model (1984).

If this strategy is being used consistently then it would be expected that:

(a) there would be a linear relation between the time taken and both the number of pieces and the number of different pieces. Figure 7:6 indicates such a progression. This was the nearest to the results of Mumaw who obtained consistently high R squared values throughout his data.

(b) there would be a correlation between the time taken and the number of rotations which would be made using the largest piece, then the smallest piece and, where
Figure 7:6. Performance of Subject MS showing mean latency and regression for number of pieces and number of different pieces in MPFB problems individually presented.
there was still more than one alternative, using another piece. The result was .7514 (p<.001).

(c) there would be a correlation between the latency and the number of pieces processed to reach solution using the largest, then smallest and, if still more than one alternative remains, the next piece. This assumes terminating processing. The result was .8081 (p<.001).

(d) there would be a high co-efficient of multiple determination using number of pieces, number of different pieces, complexity of the problems and the number of transformations to be made as variables correlated with time. The result was .926.

The major difference between this subject and the Pellegrino model is that the number of pieces to be processed to reach an answer is not equal to the number of pieces in the problem but approximates more closely to the number of different pieces.

While considering the performance of each subject on the MPFB problems the results obtained in the encoding-identifying experiment will be incorporated.

In seven of the ten problems in the encoding-identifying experiment the subject took longer to encode than identify. This proved a satisfactory method for him giving a score of 20 out of a possible 27. His approach therefore appears to involve carefully encoding the figures before commencing to identify.
Subject W.M. (Figure 7:7).

The results on the standard tests for this subject were:

- Standard Progressive Matrices 49/60
- Paper Folding Test (French) 13/20
- Surface development Test (French) 55/60
- MPFB 63/64

Protocol:

1. Look at the jumbled sections.
2. Go through the assembled shapes.
3. Pick one of the jumbled sections and try and match it to the choice of the assembled shapes.
4. Do the same with each of the separate jumbled sections.
5. Pick that answer which has all the sections in it.
6. Match the assembled shape with each section as a check.

This method was used each time. Problem 16 was the most difficult for me because the shapes were a lot alike and in trying to match the individual sections they looked the same and were harder to match.

This subject followed a standard piece by piece identifying strategy. It involved looking at the stimulus figures, scanning the answers and then taking one piece and "matching it to the assembled shapes'. If this procedure is followed with each piece in turn, it should be possible to pick the answer which has all the shapes in it with other alternatives being eliminated as
Figure 7:7 Model of performance of Subject WM.
Figure 7:8. Performance of Subject WM showing mean latency and regression for number of pieces and number of different pieces in MPFB problems individually presented.
the processing proceeds. The subject adds a variation by then "matching the assembled shape with each piece as a check" - presumably a type of reverse checking. While this may appear to be a nearly exhaustive operation there is a difference between the correlations for number of pieces and latency (.552 p<.05) and number of different pieces and latency (.817 p<.001). This suggests that the processing terminates before all pieces are checked. The safeguard lies in the checking method which allows a quick check on all pieces in the chosen answer working from the answer. Performance is shown in Figure 7:8.

The subject noted a difficulty when the pieces were "a lot alike" which made matching individual pieces a difficulty because "they looked the same". This would explain difficulties in the encoding-identifying experiment and why he took longer to identify pieces than to encode them and why the accuracy level is lower than the other subjects (total latencies for the experiment were 52 seconds to encode, 63 seconds to identify, score 17/27). In some ways it is surprising that this subject did not adopt Strategy 1, however he discovered a checking method which resembles Strategy 1 but uses only one considered answer.

This is further supported when the mistakes which he makes on the encoding-identifying experiment are considered. Errors are most frequent when the subject
has to deal with three or more pieces. He seems aware of this limitation and compensates for it.

Subject S.A. (Figure 7:9).

The results of this subject on the selection tests were:

- Progressive standard Matrices 51/60
- Paper folding Test (French) 15/20
- Surface Development Test (French) 44/60
- Minnesota Paper Form Board 51/64

Protocol: Step 1: Look at the problem.
2. Look at the answers.
3. Shuffle the pieces around in your mind to suit each answer.
4. Then check to see if each piece in the answer is the same size and shape as in the question.
5. Do this to each answer until you find the one that fits.

This was the general method and is elaborated when the unsolvable problem 20 is discussed:

Step 1. Look at question.
2. Look at A (first answer).
3. Take biggest piece. Find in A. Note in A.
4. Take biggest piece. Look in C. Fits.
5. Take triangle (top right) Fits in C.
6. Take triangle (bottom left). Fits in C.
7. Take rectangle (bottom right) Fit C? No
8. Go back to biggest piece. Doesn’t fit D.
Figure 7:9 Model of performance of Subject SA.
Figure 7:10. Performance of Subject SA showing mean latency and regression for number of pieces and number of different pieces in MPFB problems individually presented.
Doesn’t fit B.

9. Checked all pieces into C. Out.

10. Must be A.

This subject has difficulty "grasping" the nature of the stimulus items and consequently each answer is tackled until it can be eliminated. Evidence for this difficulty is not simply provided in the verbal protocol. The subject took appreciably longer to encode the pieces and to identify them in the encoding-identifying experiment than other subjects. The reported strategy is a piece matching process in which the piece chosen is oriented, each piece in the stimulus is compared with the answer until rejected or until the level of confidence is sufficient to allow acceptance. If the answer is rejected the process is repeated with the next alternative. However the subject is not consistent in his choice of starting piece so that on turning to the next alternative he may begin with a different piece to the previous run. This is an example of Strategy 1.

The orienting of the piece to allow comparison as a necessary process is exemplified in his protocol on Problem 3 which consists of three equal segments of a circle; "shuffle the pieces in my mind to suit the answer" before "checking to see if each piece in the answer is the same size and shape as in the question". There is no use made of the symmetry of the pieces and
the ease with which they might be put together. The difficulty which piece array complexity presents for this subject is evidenced by the very high correlations between complexity and latency (.837 p<.001) and between the complexity of a problem and the number of different pieces (.889 p<.001). For this subject to adopt Strategy 2, which involves continuing with one piece through all of the alternatives, would increase the risk of "losing" the piece before completion of the process. The process is presented in Figures 7:9 and 7:10.

An interesting aspect reported by the subject was in the last problem of "4 in a row". This is the problem which has no correct answer. The confusion is evident in the quoted extract from his protocol.

Subject G.H. (Figure 7:11).

His results on the standard selection tests were:

- Progressive Standard Matrices 43/60
- Paper Folding Test (French) 16/20
- Surface Development Test (French) 55/60
- Minnesota Paper Form Board 38/55

Note the lower scores in both the PSM and the MPFB than any of the subjects previously considered. However on repeating the MPFB 10 months later he scored 62/64 in the specified time. It could be that his initial attempt was marked by a more global approach as indicated by the high number of problems attempted.
Protocol:

   2. Count the number of shapes in the first diagram on the LHS of the page.
   3. Study these shapes, their size and shape.
   4. Look at the shapes to the right of this first diagram labelled D, B, A, E, respectively.
   5. Go back to the first diagram.
   6. Ask yourself questions. For example: are these shapes the same size? Are they the same shape?
   7. If these shapes are the same size, look at the shapes to the right of the first diagram and pick out the one made up of the shapes all the same size.
   Answer D.
   8. To check your answer, study the other shapes, that is B, A, and E and look for similar qualities. This will certify your decision.

Problem 15. 1. Look at the problem.
   2. Study the shapes in the square on LHS.
   3. Rearrange these shapes in your mind while looking at the squares J, G, F, and H, still referring back to the first diagram.
   4. Look at the size and shape of the pieces.
   5. Look for these shapes in each of the squares.
Figure 7:11 Model of performance of Subject GH.
Figure 7:12. Performance of Subject GH showing mean latency and regression for number of pieces and number of different pieces in MPFB problems individually presented.
correlation between latency and the number of different pieces is .670 p<.01. Performance is set out in Figure 7:12.

In discussing complexity the subject commented "irregularity doesn’t necessarily have to be complex" but that complexity may be seen as due to a "certain combination of curves, angles and straight lines". The correlation between complexity and time to complete the 16 problems (.092) is the lowest of any subject. This suggests that Subject GH is not affected by complexity of the individual pieces in the problem. This is probably due to the subject’s concentration on regularities and relationship and the decision on strategy is governed by the result of this investigation.

In setting out the flowchart for this subject the position is necessarily complex because of the distinct use of two processing paths depending upon the ability of the subject to see in each problem a relationship between the pieces of the array which will facilitate solution.
Subject I.H. (Figure 7:13).
The results on the selection tests for this subject were:

Minnesota Paper Form Board 47/48
(This was the only test completed by this applicant who joined the course late).


2. Does D fit?
3. Does B fit? No. Shapes aren’t the same.
5. Does E fit? No. All three shapes are different.
6. D must fit. All shapes in problem are same. All three shapes in D are the same.

Problem 15: Step 1. Look at the shapes.

2. How many triangles? One. Can’t be F.
3. How many identical shapes? None. Can’t be F or G.
4. Check sizes of various pieces. Are they the same dimensions? No. One piece of J doesn’t match that of the problem.
5. H must be right because F, G, J don’t fit.


2. Compare one piece with the same corresponding shape in all the boxes.
3. Box U has small triangle, one side
curved, two sides equal. Should be one side curved, two sides not equal. Box R too big. Box Q not curved enough. T must be right.

Subject IH produced the longest latencies of all of the subjects in each of the three sets of trials. Can an understanding of the strategy that seems to have been followed explain this result? In working through the problems the subject appears to adopt the approach of identifying some characteristic of the stimulus array as a whole rather than a particular piece and compares this characteristic with each answer in turn. In this way characteristics, such as number of triangles or identical shapes, play the part of a piece in the piece by piece strategy (Strategy 2). When no further overall characteristic is available or identified, pieces are then employed in the comparison.

An example of this subject’s mode of operation is seen in the protocol for Problem 15 where he starts with the triangle and matches this to the answers. This allows elimination of alternative F which has two triangles. Then there is a search for those alternatives which have identical shapes (two the same). By this means he eliminates alternatives F and G, the latter wrongly. The next step is to check the sizes of the shapes with the answers. Each new method of comparison is used exhaustively and previous eliminations are ignored. While this may make for
Figure 7:13 Model of performance of Subject IH.
Figure 7:14. Performance of Subject IH showing mean latency and regression for number of pieces and number of different pieces in MPFB problems individually presented.
accuracy it also becomes a lengthy, serial and exhaustive strategy very dependent upon the ability to continue to find characteristics for comparison until an answer is achieved. There are no short cuts for this subject.

The drawback of this method is that the characteristic chosen and other characteristics may not be mutually exclusive. As a result the subject is forced to process all answers exhaustively on each occasion. The characteristic of the number of triangles and the number of identical shapes in problem 15, for example, do not lead to an initial elimination of answer F so that this incorrect answer is processed twice. Eventually after two or three exhaustive runs the subject becomes aware that some answers are being consistently rejected and the correct answer is the only one left. While this is a long method it is perhaps the only method available for this subject if each possible answer is to be compared since a characteristic is more easily retained for comparison than a specific shape.

In the encoding-identifying experiment this subject achieved the highest number of correct answers with identifying taking longer than encoding (Total latency for encoding 71 seconds, identifying 82 seconds, 24/27 correct). This result is consistent with the subject encoding a characteristic rather than a piece and then identifying that characteristic in the selection of
pieces. The characteristic is more easily held than the actual piece although the identification may take proportionally longer because of exhaustive runs. This is seen in Figure 7:14 where this subject takes longer than any other subject with MPFB problems involving three to five pieces.

Subject J.A. (Figure 7:15).
The selection test results for this subject were:

- Progressive Standard Matrices 50/60
- Paper Folding Test (French) 17/20
- Surface Development Test (French) 39/60
- Minnesota Paper Form Board 45/46

Protocol: Problem 3: Step 1. I looked at the shapes.

2. Then I quickly look at the shapes with the letters beside them (the answers).

3. I looked at the first shape again.

4. I looked at each answer in turn.

5. I looked then at the first shape and tried putting it together to make one of the shapes.

6. D looked like the shapes put together.

Problem 15. Step 1. Looked at the shapes.

2. I looked for a shape - the biggest.

3. I tried to see if that shape was on one of the other shapes (the answers).

4. When I found one I checked if the other shapes were the same.
5. If they are not the same I check another lettered shape until I find one that matched all the shapes.

This subject follows a piece by piece approach which contains an early variation. If the pieces can be put together into a total shape this construction is used as a single piece and is compared with the answers to produce an answer. If the array is complex then the subject chooses the most characteristic piece, usually the biggest and proceeds "to see if that shape is contained in one of the answers". When an answer containing the piece is found "I checked if the other pieces were the same". Such an approach tends to be exhaustive in the number of pieces checked but not necessarily exhaustive in the number of answers.

A clue to the reasons for the choice of this strategy is given by the subject's results in the encoding-identifying experiment (Total latencies were encode 53 seconds, identify 36 seconds, score 12/27). While the time to encode is close to the group average of 58 seconds, the identification time is very quick (group average 56 seconds) and the number correctly identified is by far the lowest of all subjects. The difficulty of holding the encoded image in order to find and identify the pieces is seen in these results showing the limited time he apparently felt he had to find the pieces. Appreciation of his individual limitations
Figure 7:15 Model of performance of Subject JA.

[Flowchart diagram showing the process of encoding, choosing pieces from an array, organizing structure, and selecting answers.]
Figure 7:16. Performance of Subject JA showing mean latency and regression for number of pieces and number of different pieces in MPFB problems individually presented.
appears the most likely reason for the adoption of this approach (Strategy 1). See Figure 7:16 for comparison of RT with increasing pieces and different pieces.

As soon as a possible match is found this is the answer in the easier problems because all pieces are contained in "THE piece" being used for comparison. Where there are more pieces to be considered the subject proceeds to check the other shapes with each alternative until he can accept or reject it. If it can be accepted, that is the answer. If it is rejected, the process is repeated with the next possible answer. This approach explains why the "4 in a row" presentation takes longer than the standard five alternatives of the MPFB. The latter contain a number of first or second place answers and the former is corrected for this bias.

The difficulty of holding a piece in memory seems to be the crucial factor in distinguishing users of Strategy 1 and Strategy 2. Strategy 1 allows renewal of the memory image before proceeding to the next alternative. The subject is prone on the standard administration to make errors by choosing an incorrect answer when it is followed by the correct answer. (On the 64 problems of the MPFB 7 of 9 errors occur before the correct answer would have been considered). His chunking may also be inaccurate thus leading to errors.
Subject T.P. (Figure 7:17)

Selection test results were as follows:

- Progressive Standard Matrices: 51/60
- Paper Folding Test (French): 16/20
- Surface development Test (French): 50/60
- Minnesota Paper Form Board: 49/54

With this subject there is also a distinction between the approach used for "easier" problems (3, 9, 11, 13 Figure 7:1) and "harder" problems (12, 15, 16 Figure 7:1). (See complete protocol in the Appendix).

With the former there is an organization of the pieces in the array into a total figure (Point B in chart). However the process differs from the preceding subject in that this figure is compared to the answers in turn to see if it is different and a single remaining alternative is chosen as the answer. If the problem is "harder" then he proceeds to "take apart each answer (in your head) and look to see which parts are the same as the pieces in the array". If they are all the same then that answer is chosen. If they are not, the subject proceeds to the next alternative and repeats the process. This procedure continues until the answer is found. The flowchart (Figure 7:17) is very similar to Strategy 1 except that the piece is taken from the answer (See point R) and not from the array (shaded areas).

In the encoding-identifying experiment it is
Figure 7:17 Model of performance of Subject TP.
Figure 7:18. Performance of Subject TP showing mean latency and regression for number of pieces and number of different pieces in MPFB problems individually presented.
apparent that the subject is very fast at identifying pieces and does so with reasonable accuracy. (Encoding 39 seconds, identification 31 seconds, 20/27 correct) It can be hypothesised that breaking up a figure and holding the pieces to identify them by comparison with the problem pieces is feasible. He may also have adopted this strategy because the most difficult problems for him were those which had pieces he found difficult to fit into the completed puzzle. For him the answer is to work the other way and to break up the puzzles so that the pieces can be compared out of context. This approach appears to work adequately (Figure 7:18).

It should be noted that this subject and the previous subject seem to have adopted strategies designed to cope with appreciated difficulties. Subject J.A. has difficulty remembering pieces and so adopted Strategy 1; Subject T.P. has difficulty in constructing figures and so adopts a strategy which allows him to by-pass this demand. In general, finding an alternative approach to skirt individual processing weaknesses appears to be a frequent occurrence.

Subject A.R. (Figure 7:19).

This subject was a repeat from the previous year and so she did not take the selection tests.

Subject A.R. differentiates between two types of
problems which generate two types of activity although the strategy is basically the same - construction of the array pieces and comparison of wholes. The types of problem are consistently distinguished on the basis of complexity. For the simpler problems she looks at the pieces, scans the answers, returns to the problem and makes the pieces up into a whole figure which is then compared with the answers. On the other hand, with the more complex problems, the strategy adopted involves looking at the pieces of the problem, registering their shapes, then transferring attention to the answers "breaking each one into its separate shapes". The next step is to go back to the stimulus array and "keeping in mind the alternatives, put the separate pieces together". This was followed by "glancing back at each of the alternatives and deciding which picture it (the constructed image) correspond to". (See Appendix for total protocol).

At first glance this looks very much the same as already seen except that the complex figures (answers) cannot be dealt with as "wholes", are broken into their constituents and, presumably, put together again thus giving the subject valuable and needed "construction experience". Where there is a simple figure the bare outlines are sufficient to allow the construction of the problem pieces so that a wholistic comparison can be made. With a complex figure an analysis (and
Figure 7:19 Model of performance of Subject AR.

START

ENCODE

ARRAY

SCAN

ANSWERS

ORGANIZE

STRUCTURE

I

SELECT

ANSWER

YES

NO

IS AN

ANSWER

LEFT?

YES

NO

ELIMINATE

ANSWER

NO

DOES

ANSWER

LOOK

WRONG?

PLACE

ON

LIST

YES

NO

IS AN

ANSWER

LEFT?

YES

NO

E

M

PREPARE

TO

ACCEPT?

YES

NO

PREPARE

TO

ACCEPT?

YES

NO

WHICH

PIECES

OR

ANSWER

STRATEGY?

NO

PREPARE

TO

ACCEPT?

YES

NO

ARE

PIECES

IDENTICAL?

NO

PREPARE

TO

ACCEPT?

YES

NO

SAME

ORIENTATION?

NO

PREPARE

TO

ACCEPT?

YES

NO

ROTATE

SAME

ORIENTATION?

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PREPARE

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Figure 7:20. Performance of Subject AR showing mean latency and regression for number of pieces and number of different pieces in MPFB problems individually presented.
re-synthesis) of the figure is necessary before the problem pieces can be integrated for a similar wholistic comparison. This indicates that even within apparently similar strategies there are differences.

The additional step is related to the subject’s definition of complexity. Simplicity is related to "equal-ness", "even-ness" and "sequence" and complexity to irregularity and the shape of lines, especially small "pointy" and comparatively large enclosed spaces. Failure to detect a regular or common shape is the signal to move from one strategy to another. Simple shapes make an answer which can be easily constructed and held for comparison. Irregular shapes in an answer demand dissection. There is a zero order correlation between latency and complexity in simple problems where the first strategy is used, but rises in the problems employing the second strategy to an overall correlation of .6623 p<.01. For the three problems definitely following the second strategy (13,15,16) the correlation between latency and complexity is .75.

Complexity seems to be the trigger for strategy variation but both processes aim to create the circumstances for a wholistic match and to that extent are similar. The advantages of this construction comparison are seen in Figure 7:20 which shows short RTs for the more complex problems but the influence of four or more different pieces is apparent.
It would be expected that this approach would encourage errors in similar figures because the construction lacks the clarity or accuracy to make fine distinctions. This is consistent with her performance on the MPFB test where 9 errors in 64 problems are all explicable in terms of inaccurate construction.

Subject P.B. (Figure 7:21).

This subject was also a repeat from the previous year and did not take the selection tests except the MPFB (61/64).

Protocol: Problem 15: Step 1. I looked at the shapes given on the left.

2. I fitted the shapes together to form a picture in my mind.

3. I looked to the right hand side and glanced at the four given made up shapes.

4. I then eliminated the given answers J, G, and F because the shapes given to make up these three shapes were different from those given on the LHS.

5. I checked out shape H and chose.

(See Appendix for total Protocol).

The strategy adopted appears to be basically global involving looking at the shapes given and then putting those pieces "together in my mind to form a picture". When he had achieved this constructed image, the subject "glanced at the made up shapes". "I then eliminated all
but one of the given answers because the pieces making up these shapes were different". In this sense it is a mismatching strategy using a constructed image (B) compared with the alternatives to derive the answer. There is a check (F) with the more difficult problems. In the simpler problems the subject saw "that the pieces given to make up the answers were different" or "noticed that this answer was right". In these cases the constructed image is used to eliminate all but the correct answer (D).

The natural inclination of the subject to a global strategy is illustrated in his comment on Problem 20 (the problem without solution): having put the pieces together "I looked at the four solutions. After looking closely I realised that there was no correct answer". This is concluded without resort to any matching piece by piece strategy to check.

This is a fast strategy. Subject PB was fastest of the 13 subjects on the individually administered and "4 in a row" trials. There is a danger, however, that errors will result from missing the correct answer. This is illustrated in his performance on the total MPFB where 11 errors included 9 which arose from choosing an answer which came AFTER passing the correct answer. Having missed the correct answer he tends to select the nearest correct answer as he comes to the end of the alternatives and fails to check that answer. This
Figure 7:21 Model of performance of Subject PB.
Figure 7:22. Performance of Subject PB showing mean latency and regression for number of pieces and number of different pieces in MPFB problems individually presented.
supports the hypothesis that the global strategy is a "one run" strategy from which one cannot return to check. Consequently although the subject in his protocol claims to be checking, the best interpretation is that if he has established a firm conviction as to the correct answer this step is not followed. As already indicated the global strategy leads to successful detection of close and correct answers but the constructed image does not hold up to lengthy comparison especially when the answer is apparently obvious. The majority of the errors are in three piece problems which, with care, should have been constructable and comparable. From this data it would appear that the subject does resort to a check with the more difficult problems but does not realise that this check should have been instituted earlier in the test sequence. Performance is set out in Figure 7:22.

Subject PB seems unwilling or unable to change his strategy. It is perceived complexity which appears to increase solution time. In Problem 16, for example, he says "I found this to be the most complex because the shapes were all alike and roughly the same size, and the solutions were all alike ... took a little longer than the rest to complete". There is a zero order correlation between the number of pieces and latency for the simple problems but with the four most complex the correlation is .781. Similarly the correlation between
the complexity he assigns to the pieces of the problem and the latency is .426 for the simple problems and .984 for the difficult or most complex. Multiples correlation analysis shows that complexity taken together with increasing numbers of pieces is significantly correlated with the latency for this subject. In the encoding-identifying experiment this subject has the fastest encoding time (encode 38 seconds, identify 46 seconds, score 20/27) and it is a reasonable assumption that he is sacrificing accuracy for speed of starting and concluding.

Subject C.P. (Figure 7:23).

On the selection tests this subject achieved the following results:

- Progressive Standard Matrices 53/60
- Paper Folding Test (French) 8/20
- Surface Development Test (French) 40/60
- Minnesota Paper Form Board 40/48

Compared with the other subjects these are poor results and should be borne in mind when we look at his strategy and performance on the experiment.

Protocol: (See Appendix for total protocol).

Problem 15: Step 1. Look at the shapes on LHS.

2. Compare sizes of shapes in left hand column to right hand column.

3. Decide nature of shapes if put together.
Figure 7:23 Model of performance of Subject CP.
Figure 7:24. Performance of Subject CP showing mean latency and regression for number of pieces and number of different pieces in MPFB problems individually presented.
4. Imagine the overall shape.

5. Decide which answer matched the imagined shape.

6. Check to make sure you are right.

The subject believes that he put the pieces together consistent with the answers offered and then compared this construction with the answers (I). This comparison of total shapes differs from the mismatch strategy since it does not seek to eliminate answers but to derive the correct answer. (Figure 7:23). The pressure is not to develop a more adequate working space for future processing but to determine the answer. This is not a viable strategy for this subject and he makes 9 errors out of 29 three piece problems, 7 errors in 22 four piece problems and 6 errors out of 8 five piece problems on the first trial involving the total MPFB.

If we look at Subject CP’s performance on the two spatial tests from the French battery it can be hypothesised that he has difficulty with spatial rotation and transformation. Such difficulties translated into a strategy which seeks to construct a spatial image of a total figure from a number of pieces presents limitations and it can be presumed that the construction which this subject uses for matching purposes is likely to be inaccurate. It seems that the subject is unaware of his personal limitations or it could be that that he realises that piece by piece
comparison involving a number of transformations is even more difficult for him. Whatever the reason when the problems reach the greatest complexity and have the most pieces he is placed in a situation of almost guessing at the result. This conclusion is supported by his choice of an answer in problem 20 which has no equivalent to the array. The difficulty would appear to be spatial since he scores well on the PSM as a measure of reasoning. The subject has limitations in visualization but this does not necessarily spill over to spatial reasoning.

The performance of this subject (Figure 7:24) shows increasing latency with increasing pieces rather than the customary sharp change after 4 pieces.

Subject T.B. (Figure 7:25).

This subject achieved the following on the selection tests:

<table>
<thead>
<tr>
<th>Test</th>
<th>Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Progressive Standard Matrices</td>
<td>45/60</td>
</tr>
<tr>
<td>Paper Folding Test (French)</td>
<td>16/20</td>
</tr>
<tr>
<td>Surface Development Test (French)</td>
<td>56/60</td>
</tr>
<tr>
<td>Minnesota Paper Form Board</td>
<td>58/62</td>
</tr>
</tbody>
</table>

He appears to use two strategies which were governed by the demands of the problem and his own assessed skill. The first strategy (shown in red on the flow chart) was followed in any cases where the "proportions" of the shapes allowed a relationship between the pieces
Figure 7:25 Model of performance of Subject TB.
Figure 7:26. Performance of Subject TB showing mean latency and regression for number of pieces and number of different pieces in MPFB problems individually presented.
to be established. Problem 3, for example, has all the pieces the same and in Problem 11 two identical pieces make for symmetry between the four pieces. The subject commented that Problem 15 was the hardest because of the asymmetry of the shapes involved. When such a relationship between the pieces in the array is not apparent the subject is forced to change to a second strategy (shown in blue on the flow chart) which seems to involve looking for a "unique" shape ("as regular as possible so as not to lose its identity") in the answers. "If more than one figure has this shape, choose another and repeat". When only one alternative remains "check all segments with those given". In the simpler problems, defined by the subject in terms of image reproduction and relationship, only one run through the answers is necessary. In the more complicated problems the search for a matching number of pieces proceeds until there is sufficient confidence in one answer and this is then exhaustively checked. The important feature of this approach is that the relationship takes the place of a piece by piece comparison in the first instance and allows for a single "run". However it is not the same as a mismatch "run" but a variation on the processing of the previous subject except that in this case there is a back-up strategy.

This analysis is supported in Figure 7:26 which
shows that the subject has cut down time in the problems with smaller numbers of pieces when compared with the piece by piece processing of Subjects IH and SA who are also slowest in processing five piece problems. Simpler problems are relatively unaffected by number of pieces compared with number of different pieces.

The determining factor appears to be regularity of shape and this in turn affects ability to image relation and transformation. The subject sums up his strategy choice as determined by "how hard it would be for me to reproduce them (i.e. the images) mentally". The heuristic flowchart for this subject involves a single run through the answers based on relationship and a more exhaustive processing based on Strategy 2.

Subject G.K. (Figure 7:27).

Selection test results were:

- Progressive Standard Matrices 52/60
- Paper Folding Test (French) 17/20
- Surface Development Test (French) 58/60
- Minnesota Paper Form Board 62/64

This subject produced one of the most interesting accounts of how he performed the task and the protocol is reproduced here for understanding.

Protocol (used for all problems).

1. Take a good look at the shapes.
2. Define their characteristics.
3. Keep the most outstanding characteristics in mind.
4. Look at each of the following four masses.
5. Eliminate the masses which don’t match.
6. Keep in mind those which you did not eliminate.
7. Do the same procedure as in step 4 and 5 again.
8. Keep following step 5 until you end up with one mass.
9. Keep the remaining mass in mind.
10. Check each of the others all over again to separate those which may match.
11. If any could match check with your original answer and the shapes in mind.
12. Judging by sizes, curves and angles eliminate those again which surely don’t match.
13. When sure of your answer, choose.

Starting with an identified characteristic he appears to cycle a specific mismatch strategy based on the absence of that characteristic. Instead of being satisfied with eliminating a number of answers and then proceeding to a match strategy, he proceeds to adopt a unique strategic component by running another mismatch strategy based on a second characteristic and repeating this procedure until there is only one answer left.

The interpretation that he is simply using a characteristic to eliminate an answer is inappropriate since he states that having identified a possible answer
Figure 7:27 Model of performance of Subject GK.
Figure 7:28. Performance of Subject GK showing mean latency and regression for number of pieces and number of different pieces in MPPB problems individually presented.
this is "kept in mind" while each of the remaining alternatives is checked "all over again to separate those that may match". If there is any other possibility thrown up by this checking then the two possible answers are compared. The comparison is carried out on the basis of the "sizes, curves or angles of the pieces in the possible answers". If one alternative is eliminated by this comparison the other becomes the answer. This process is continued until there is one answer. The subject appears to be aware of the crude nature of the global strategy and takes the precaution of re-processing in case a second possible answer is thrown up. The most likely result of this approach would be to identify the correct alternatives which are the closest contenders and the characteristics of sizes, angles and curves would then be used to identify the correct answer. This is a valuable insight since it prevents proceeding to a piece by piece matching without being certain that at least one alternative will be correct and also takes account of the limitations of the mismatch strategy.

The mean latencies compared with pieces and different pieces are shown in Figure 7:28.
Subject J.B. (Figure 7:29).

Selection test results were:

- **Progressive Standard Matrices**: 54/60
- **Paper Folding test (French)**: 16/20
- **Surface Development Test (French)**: 53/60
- **Minnesota Paper Form Board**: 60/63

Protocol for Problem 15. (Complete protocol in Appendix)

1. Look at particle shapes, picture in mind.
2. Look at the squares.
3. From Step 1 it is possible to eliminate J and F immediately.
4. Look at the proportion of the shapes.
5. H particles appear to suit the shapes given. H is correct.

This subject occupies a position at the global end of the continuum which these protocol analyses have sought to illustrate. Tackling each problem by initially looking at the particular shapes "picturing them in my mind" he appears to develop a structure based on understanding the relationships between the shapes as well as the nature of the shapes themselves (B). He then looks at the alternatives and is able to quickly ("immediately" is the subject's word) eliminate some of them. In the simpler cases all but the answer are eliminated. For the more complex problems a second characteristic is introduced called by the subject "the proportion of the shapes". By this he appears to mean
Figure 7.29 Model of performance of Subject JB.
Figure 7:30. Performance of Subject JB showing mean latency and regression for number of pieces and number of different pieces in MPFB problems individually presented.
the comparison of the sizes of the shapes between array and answer (J). This comparison applied to the alternatives which have not been eliminated produces the answer.

Subject JB reported his processing of the problem without answer as follows: "Look at the particular shapes, picturing them in my mind. From looking at the answers it is obvious that none match the shapes given - no further action". This suggests that the elimination process is fairly accurate and the subject is sufficiently confident to omit a matching process when he is sure that all but the answer have been eliminated. Further support for the view that for this subject rapid elimination works well is the absence of a significant correlation between latency and the number of pieces and the lowest correlation of the 13 subjects between latency and the number of different pieces. See graph of mean latencies. (Figure 7:30). The subject states that a necessary prerequisite for this rapid elimination is the formation of an image.

If there is a disadvantage in this strategy it would seem to lie in the absence of checking when there is only one answer not eliminated. A piece by piece check only occurs when the subject has been unable to eliminate all but one answer.

The purpose in presenting individual accounts of the
13 subjects has been twofold: (1) to show that the data from 13 subjects taken individually can be mapped onto the model which was previously presented. Except in cases where a relation rather than a piece has been referred to in the protocols, this has been possible. In general, however, the relationships appear to be able to be treated as pieces in terms of the model. And (2) to show that within group data there is a wealth of information which allows us to understand more fully the variations in the processes employed by each individual in order to produce what may, on the surface, appear to be the same performance. As Table 7:6 indicates the scores achieved on other tests at the time of selection into the course suggest that the diversity of approach is not related to differences in aptitude since the group is largely homogeneous.

The protocols of the 13 subjects (presented in the discussion above and completely in the Appendix) have been presented in a sequence based on the strategies which they appear to have employed, progressing from a "pure" analytic approach through a more global approach to a synthetic approach combining the advantages of both.

Reference to the results of the experiment aimed at detecting differences in encoding and identifying times (Table 7:7) proved useful in the analysis of individual results. Although the results are uneven when related
to strategy reported, they do indicate that some subjects experience encoding difficulties reflected in length of time and that the careful piece by piece strategies require very accurate encoding to facilitate identification. Those operating an analytic processing, in general, tend to spend more time encoding than identifying while the reverse tends to be true for those operating a mismatch elimination before the final checking by an analytic approach. It would seem that for some subjects skill in encoding or in identifying pieces determines the nature of the strategy to be followed, in other cases, the strategy being employed by the subject governs the demands being placed on the "hardware" and when these cannot be met, the strategy is changed.

Finally it is useful to summarise the indicators for strategy switching and the definition of complexity. The collection of protocols from each of the 13 subjects used in the experiment allowed conclusions to be formed regarding the point at which each might change their processing and the nature of complexity as each perceived it. These are reported in Table 7:8.

CONCLUSION.

The key to the strategy being used seems to be whether the subject is more likely to "take a problem apart", "put the problem together" or engage in some combination of both. Whether this reflects a general
analytic or synthetic cognitive style is a question which lies beyond the scope of the present study.

The major distinction between subjects in their strategy usage appears to centre on their ability to detect a relationship between the various parts of the problem. This is revealed in the ability to put the pieces together, to see the way in which the pieces might relate to each other. Other distinctions involve the ability to remember the nature of the piece being worked with or the new construction which has been generated. There is also the subject defined level of complexity, within which the search for pieces or wholes can be conducted. This, in turn, relates to how well the subject can reproduce a clear representation or image and the time that this can be retained compared with the time needed to complete the processing. There is also the question of whether the subject is aware that in most cases, it is quicker to eliminate some answers and then to match and how flexible the subject is in determining this situation.

At one extreme are subjects who operate the typical Mumaw and Pellegrino analytic model. The main variables are the skill in finding the relevant piece and identifying it, the degree of need to orient the piece into congruence for comparison purposes and the confidence which the subject possesses in his work so that the processing can be terminated before it becomes
exhaustive. At the other extreme are the subjects who fit a more flexible model based on the view that subjects do not solve these problems in the same way and that variations in strategy are an integral part of the problem solving process. It has been argued that a more flexible model can explain both the typical analytic processing provided it is realised that even within such processing there are variations, and the more global approaches which have the advantage of rapidly reducing the working space required. It has been demonstrated that a global strategy on its own presents dangers.

Rejection of the existence of varied strategies means that variations in results can only be explained in terms of efficiency in process working and all individual differences are defined as "hardware" differences. The present model introduces "software" differences which hinge on the skill of the individual in constructing a "whole" image of the total problem and the ability to retain this image as long as the task requires. The most likely cause of error at this point lies in attempting to process too much with the image. There are also the contributions from the degree to which a subject terminates the processing before exhausting all possibilities, and the awareness of individual limitations so that the subject knows when to change the strategy or that the skill required to perform in certain ways is lacking.
Let us assume two ideal strategy types, namely an analytic exhaustive processing and a synthetic, one run identification processing, occupy the ends of a continuum. Between them are located those subjects who are forced by issues of complexity to abandon a construction strategy at an early stage and those who are overambitious in their synthesising skill and so produce a working model which is similar rather than identical to the answer. If used exclusively, this construction strategy results in error because it has been used to match (that is, determine the answer) rather than as a clearing of working space so that approximate answers may be introduced to a "hold" situation.

There are also those whose skill in remembering causes them to work with one answer at a time (Strategy 1), because the ability to form and hold an image is weak and tends to result in a "jigsaw" strategy requiring limited visual transportation because the piece can be held "on top of the alternative" and can then be neglected in favour of working with another piece. Highly developed visual transportation can result in the movement of numbers of pieces "in the mind" while maintaining relationships. Strategy 2 is more likely to be followed where the image can be held so that a number of comparisons can be made or is rapidly refreshed after each comparison.
A clue to the nature of the strategy in use lies in the encoding quality which in some but not all cases is reflected in encoding time. It seems that those performing on a piece by piece strategy take longer to encode than identify while those creating a more related image take longer to identify not just because there is more to be processed but also because the encoding is more general and less finely "grained". This also emerges in the consideration given to the possible answers and the influence which the demands of the problem exert on further evaluation.

In summary, the crucial factors in strategy choice both between subjects and within subjects between differing problems consist of:
(a) how the encoding is developed, as clear and sharp individual images or as an overall picture which is a synthesis of main features;
(b) the ability to form and hold an image for the required working time;
(c) the quality of the image which, if it is a relational encoding, will tend to be most adequate for detecting various levels of difference and, if of individual pieces, allows a careful comparison process;
(d) the ability to replace processes by combinations of others as in the replacement of rotation by an already available relational process;
(e) the ability to control a strategy once it is
operating and to change it in the light of perceived context demands and known skill responses and, (f) the accuracy of the comparison process regardless of strategy usage so that similar and identical are not confused.

It must again be stressed that within a homogeneous group, such as the subjects in the experiments reported in this chapter, the differences in strategy will not be reflected in the scores achieved. The value of knowing the strategy in use and the flexibility of a subject lies in the ability to predict which subjects from those with similar scores will be more likely to succeed in other activities requiring the use of similar strategies.

The following strategy switching signals are apparent in the protocols.
(a) When the ability to identify pieces by characteristics or by labels, an ability which governs the ability to combine those pieces and to fit them together breaks down, there will be change from a global to a more individual strategy. The ability to visualize pieces is not sufficient to develop a structure on which global comparison can effectively mismatch.
(b) The perception of relationships seems to be a necessary condition from which the construction of more inclusive figures proceeds. Where this cannot be achieved strategy will change to a more piece by piece
strategy.
(c) The ability to form pictures "in the mind" and to hold these images once achieved has limits even for the most skillful. Hierarchical development becomes necessary eventually and results in the use of single pieces in large arrays if no relational characteristic is available.
(d) Inability to form a whole, to respond to a formed whole or to verbalise a relationship will force a change to, or the reinforcement of, an analytic strategy.
(e) The elimination of answers by mismatching is a different procedure from establishing a match to determine the correct answer and confusion in knowing which is in operation can create errors.

In general the data from the 13 subjects maps well onto the proposed model. The various strategies can be incorporated subject to the understanding of certain crucial points related to structuring, imaging, and confidence. It is accepted that for some subjects strategic options do not exist. They simply proceed by a route which they find most comfortable. The real test of skill lies in the ability of subjects to realise that a strategic choice exists. The Mumaw and Pellegrino model is disappointing in that it does not allow this option but expects that all subjects will follow the tasks identified as necessary to solution and that individual differences are largely a reflection of skill
variations in the performance of these standard tasks. To this extent it is contended that a model such as that of Mumaw misses the rich diversity of activity on a test such as the MPFB. It is this diversity which makes data other than individual diagnostic administration of the test suspect. Because of this it is not surprising that the predictive ability of the group administered MPFB is very disappointing (Revised Manual ACER 1981).

A number of other subjects not involved in architectural drafting took the tests reported in this chapter and their results and comment are included in the appendices for completeness.
CHAPTER 8: APPLICATION TO TRAINING

To what extent can performance on the MPFB be improved? Our discussion to date has centred around the requirements of the type of problem presented in the MPFB. Taking the task requirements and the range of strategies available, can a training programme be designed which would change the cognitive structure of the individual towards improved performance? What is offered in this chapter is of an exploratory nature aiming to point towards future directions while rounding out the material already presented.

In a recent article Pellegrino (1985) claims that "research has shown that training and practice on the processes of inductive and spatial reasoning can often lead to substantial improvements that are reflected in standardized tests of these abilities". Such a statement offers prospects but how is this to be achieved? To what extent do practice and training operate together? Can they be separated?

Dorner (1978) has tackled this issue by distinguishing three different forms of training methods which have been offered as increasing the efficiency of subjects. The first is what he terms "practice-training" and described in terms of the "shaping of behaviour" model postulated by reinforcement theory. Simply confronting individuals with cognitive problems will result in improved
performance "just as muscle develops as a result of constant exercise".

The second form of training is based on the consideration that problem solving consists of a number of basic processes which, if strengthened individually, should lead to an increase in overall performance. However he concludes that "the trained operations are NECESSARY but in no way SUFFICIENT conditions for complex cognitive abilities ... the decisive factor seems to be strategic: the subjects do not lack the inventory of basic operations, but rather lack possibilities for integrating these basic operations into complex forms of thinking".

Dorner's third type of training consists of teaching the organization of single steps to form a total sequence. So "to these individual abilities must be added the ability to combine individual operations into larger sequences of organizations, the ability to break up these bonds in order to build new sequences, etc.". Strategic training involves teaching an organizational form for single steps "hoping that this has a beneficial effect on the individual's ability to solve corresponding problems".

A very limited experiment was instituted to determine whether the teaching of strategies would have a beneficial result for overall performance on the MPFB. It would be expected that the crucial nature of the
strategy for which we have argued would mean that improvement in the organization of the processes would lead to corresponding improvement in performance.

The experiment was conducted in two parts. Firstly with a group of students and secondly with several individual students. Both sets of results are tentative but offer possibilities for future exploration.

EXPERIMENT 1: GROUP TRAINING.

Subjects: Eleven subjects in a Certificate of Finished Art course volunteered to take part in the experiment. They had all completed Year 11 and were aged between 18 and 23 (Mean age 20.5). They were students who had been in the intake which was tested with the MPFB ten months previously and who had been in the group which supplied the protocols referred to in Chapter 3 (Pilot study 2). Unfortunately some were on work experience during the experiment so the results were limited by subject absence. Also a few of the students in the course had not done the selection tests.

Procedure: Each subject completed the MPFB under normal test conditions. It was argued that those who achieved less than 60 correct out of 64 problems could improve in speed and accuracy and that those who achieved 60 or better would do the alternate form MPFB (DB) with equally satisfactory results.

Two weeks after completing the MPFB under normal
test conditions the subjects were introduced to the various strategies which were possible in order to solve the types of problems on the MPFB. Three possible strategies were explained and examples worked through on the classroom blackboard to illustrate. The three strategies were:

(a) Take one of the pieces from the array with which you feel "comfortable" and go to the answers one at a time. If the piece is present STOP - get another piece. If that piece is also present, get another piece. If it is not present - go to the next answer and repeat. It was explained that this approach could involve some scanning to eliminate obviously impossible answers.

(b) Take one piece from the array and compare this piece with each answer thereby eliminating those without the shape. Take a second piece and apply this to the remaining answers thereby eliminating further answers. Repeat until only one answer left. Check all pieces (optional).

(c) Construct the pieces into a total picture and compare the construction with the answers. It was pointed out that this was the way in which the practice examples work and that it may be most effective with the simpler problems.

The second part of the training consisted of group discussion of how one thought about what one was doing in problem solving and subjects were encouraged to talk
to themselves about their activities and to question what they were doing.

The subjects were then given practice sheets which contained a number of problems set out in the MPFB format but using symbols, words, colours, numbers and letters and the strategies were worked through with these examples. (Figure 8:1).

Finally the subjects did some of the actual problems taken from the alternate form of the MPFB being urged to think about what they were doing and to reflect upon their activity.

After a twenty minute break the subjects repeated the total MPFB test - two subjects did the MPFB (DB) and the other five the MPFB (DA).

RESULTS AND DISCUSSION

In all six subjects took the selection test and the repeat test ten months later. The mean performance in the selection test was 54 correct, 58.8/64 completed. In the re-test the mean correct was 58.2 and the mean completed was 61.8. Table 8:1 shows the individual results.

Five subjects had not done the selection test and so encountered the MPFB for the first time two weeks before strategy instruction. The difference between their performance on the first attempt and the trial following strategy instruction is set out in Table 8:2.
FIGURE 8: Examples of practice material

<table>
<thead>
<tr>
<th>X 0</th>
<th>□ 0</th>
<th>Blue Green Red</th>
<th>Blue Purple Yellow</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>□</td>
<td>Pink Blue Green</td>
<td>Black White Mauve</td>
</tr>
<tr>
<td>X</td>
<td>0</td>
<td>Red Green Blue</td>
<td>Red Yellow Pink</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>2 7</th>
<th>2 8</th>
<th>Hot Picnic Stress</th>
<th>Reason Stress Rush</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>4</td>
<td>Cool Picnic Yellow</td>
<td>Coal Tension Blank</td>
</tr>
<tr>
<td>5</td>
<td>1</td>
<td>Red Stress Rush</td>
<td>Stress Picnic Hot</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>A Z T B D</th>
<th>B T Z R X</th>
</tr>
</thead>
<tbody>
<tr>
<td>G T J R H</td>
<td>Z B L S P</td>
</tr>
<tr>
<td>A R T B D</td>
<td>D B Z T A</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>A T U W</th>
<th>R A T V</th>
</tr>
</thead>
<tbody>
<tr>
<td>X W F D</td>
<td>O U T</td>
</tr>
<tr>
<td>W T U A</td>
<td>Z Q Y W</td>
</tr>
</tbody>
</table>
Table 8:1
Improvement in 6 Ss repeating the MPFB after 10 months.

<table>
<thead>
<tr>
<th>Subject</th>
<th>Change in Number correct</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>55 to 62 +12.7%</td>
</tr>
<tr>
<td>B</td>
<td>60 to 61 +1.6%</td>
</tr>
<tr>
<td>C</td>
<td>57 to 63 +10.5%</td>
</tr>
<tr>
<td>D</td>
<td>55 to 61 +8.7%</td>
</tr>
<tr>
<td>E</td>
<td>50 to 49 -2.0%</td>
</tr>
<tr>
<td>G</td>
<td>47 to 53 +12.7%</td>
</tr>
</tbody>
</table>

Table 8:2
Improvement in 5 Ss when training interposed between first and second attempt at MPFB.

<table>
<thead>
<tr>
<th>Subject</th>
<th>Change in Number correct</th>
</tr>
</thead>
<tbody>
<tr>
<td>F</td>
<td>48 to 55 +14.6%</td>
</tr>
<tr>
<td>H</td>
<td>39 to 47 +20.5%</td>
</tr>
<tr>
<td>I</td>
<td>54 to 61 +12.9%</td>
</tr>
<tr>
<td>J</td>
<td>48 to 50 +4.2%</td>
</tr>
<tr>
<td>K</td>
<td>50 to 49 -2.0%</td>
</tr>
</tbody>
</table>

Subject K was totally disinterested throughout.

This left two subjects who had done the selection test, the next trial ten months later and the final attempt after strategy training. The results are set out in Table 8:3.

Table 8:3
Two Ss took the MPFB as selection test, 10 months later and then after training.

<table>
<thead>
<tr>
<th>Subject</th>
<th>Selection test</th>
<th>Re-test</th>
<th>After training</th>
</tr>
</thead>
<tbody>
<tr>
<td>E</td>
<td>50/53</td>
<td>49/51</td>
<td>57/63</td>
</tr>
<tr>
<td>G</td>
<td>47/64</td>
<td>53/64</td>
<td>56/64</td>
</tr>
</tbody>
</table>

The final numbers were rather disappointing and no firm conclusion could be drawn but it does appear that the results showed improvement after training.

The investigation is reported to give some
indication of how training might be given but caution is sounded in dealing with groups. It was difficult to know what was understood and absorbed in talking about strategies to a group compared with an individual; groups limit the ways in which the various strategies can be practised; there was the problem of subjects not being available for all parts of the experiment.

EXPERIMENT 2: INDIVIDUAL TRAINING.

Part two of the investigation concentrated on four individual subjects who volunteered to take part in the experiment. It was planned to use two as test repeaters and two to be given training but one of the practice subjects asked to be given help in improving performance after it was apparent that he was having difficulties.

Procedure: For the subjects who were to be used as "practice only" the subject was given the MPFB (DA) twice separated by a week and then a further week later given the MPFB (DB).

For the two subjects chosen to be given individual training, the first session consisted of taking the test and then explaining what he thought he was doing. The second session consisted of training as follows:

(a) Emphasis was placed on seeing problem solving as the finding of a pattern or strategy to follow and this was explained in terms of learning tables, algebra transformations and other examples.
(b) The way the subject had explained performance on the first session was discussed.

(c) As both subjects showed weak performance it was decided to concentrate on a piece by piece strategy by showing the subject the stimulus, then each of the answers was presented on a separate card. The subject was then shown one piece of the problem on a card by itself and was asked to use this card to compare with the answers. Those answers which did not contain the piece were removed. The subject was then shown a second piece from the problem and compared this with the answers not removed. When this comparison was completed the answers not containing this piece were removed. Generally this left only one answer but if there were more it was repeated until only one answer remained. This training was repeated several times with different problems. The subject was also shown how two pieces might be put together and used as one unit to look at the answers.

At the end of the training session the subject once again tried the MPFB.

The third session consisted of repeating the training described in the second session and discussing actual examples from the alternative test. Emphasis was placed on choosing which piece to begin with, on watching for clues like identical pieces and the need to consistently follow the strategy so that problems are
RESULTS AND DISCUSSION

The two "practice only" subjects and the training subjects achieved the results as set out in Tables 8:4 and 8:5 to 8:7.

Table 8:4
Practice only given to two subjects.

<table>
<thead>
<tr>
<th>Trial</th>
<th>Subject GP</th>
<th></th>
<th>Subject PC</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>First (DA)</td>
<td>548 secs (27 errors)</td>
<td>904 secs (34)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Second (DA)</td>
<td>455 secs (25)</td>
<td>984 secs (32)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Third (DB)</td>
<td>483 secs (20)</td>
<td>1257 secs (27)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Both subjects were high error subjects but there seems to be little improvement over time. The increase in the DB version for P.C. can be accounted for by the greater concentration of the subject in an attempt to improve on previous efforts — without any great improvement in errors. After the completion of this trial Subject P.C., conscious of his difficulties asked if he could be given some help. It was then that he was added to the training programme and his first trial in the training programme was actually his fourth trial on the MFMB with results consistent with his "practice only" attempts.

Each subject given training is commented on individually.

Subject P.C. In doing the second trial, after training, the subject elected to use a pen to trace what he was
doing and so it was possible to observe his actions. Really concentrating he took a piece, found it or crossed out the answer. On occasions he would bring new pieces to an answer in which he had found the previous piece, at other times he would go right through with the chosen piece to all alternatives and then repeat with the next piece on those he had already crossed out. This made his operating truly exhaustive, and probably accounts for the dramatic increase in time.

Table 8:5
Subject P.C. with training introduced between trials.

<table>
<thead>
<tr>
<th>Trial</th>
<th>Time (secs)</th>
<th>Errors</th>
</tr>
</thead>
<tbody>
<tr>
<td>First</td>
<td>998</td>
<td>29</td>
</tr>
<tr>
<td>Second</td>
<td>2716</td>
<td>20</td>
</tr>
<tr>
<td>Third</td>
<td>1715</td>
<td>11</td>
</tr>
</tbody>
</table>

In his practice trials Subject P.C. had an average time on the errors which was half that of the correct answers but with the introduction of an attempt to use a consistent strategy the position is reversed and time on errors average twice that on correct answers. This may be interpreted as suggesting that instead of just guessing when confronted by a problem he wasn’t able to do the subject now tries to work it out. Where there was a repeat of the first attempt error the time in all cases increased dramatically (from 9.3 secs average to
53.6 seconds). The third trial is still much longer than the last practice trial but the error rate has dropped markedly and by this trial the time for the number of pieces and number of different piece problems is showing the expected increase seen in piece by piece strategies whereas in the practice trials there was little difference in time between three and five piece problems.

Subject J.M. began to lose interest in the experiment and although the overall results don’t show any increase in accuracy the major improvement is in the four and five different piece problems suggesting that despite the errors a more consistent strategy is taking over where previously the subject panicked when confronted with a difficult problem.

Table 8:6
Subject J.M. with training introduced between trials.

<table>
<thead>
<tr>
<th>Trial</th>
<th>Time (in secs)</th>
<th>Errors</th>
</tr>
</thead>
<tbody>
<tr>
<td>First (Problems 1-40)</td>
<td>890</td>
<td>5</td>
</tr>
<tr>
<td>Second (Problems 1-64)</td>
<td>1471</td>
<td>11</td>
</tr>
<tr>
<td>Third (Problems 1-64)</td>
<td>987</td>
<td>14</td>
</tr>
</tbody>
</table>

Subject S.L. was able, with the training, to tackle the harder problems which appear beyond Problem 32 and was showing improving performance as regard to time. This subject brought a seemingly typical Asian desire to please, a determination to learn and an intense
concentration determined to get the right answer. Taking these factors into consideration the results suggest that speed has been increased by the training.

Table 8:7
Subject S.L. with training introduced between trials.

<table>
<thead>
<tr>
<th></th>
<th>First (Problems 1-32)</th>
<th>Second (Problems 1-48)</th>
<th>Third (Problems 1-48)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>979</td>
<td>851</td>
<td>784</td>
</tr>
<tr>
<td></td>
<td>0</td>
<td>3</td>
<td>2</td>
</tr>
</tbody>
</table>

The results are biased in the use of very weak subjects and by the small sample. However there is evidence that a weaker subject is more likely to be amenable to training compared with the more skilled in the group results. The improvements in the weaker performers is an indication that the lack of organization of the approach and the development of a strategy are major factors contributing to error and also to a speedy performance based on guessing. Where a strategy is introduced errors remain fairly constant but the time drops because the subject gains greater confidence in making a choice or the errors drop because the subject becomes more self-conscious of his processing but it takes longer.

It should be stressed that these results are little more than case studies with the aim of indicating what might be expected in further research and the difficulties which may be encountered.
CHAPTER 9: CONCLUSION.

The purpose of this study has been two fold. The first objective has been the investigation of the processes involved in the solution of MPFB problems and their integration into strategies. This has involved an analysis of the way in which individual subjects "see" themselves operating, the way in which subjects tackle a single choice problem based on MPFB type problems and the approaches adopted by a number of subjects to the actual MPFB test. Second, the study has sought to show that without an understanding of the processing strategy being used and the way in which such a strategy may vary with the needs of the problems and the skill of the individual, it is inappropriate to use a test such as the MPFB to evaluate spatial performance. The validity of the test and its predictive powers depend upon the diagnostic possibilities which it provides.

A number of major findings have emerged from these analyses:
(a) The analysis of a fairly homogeneous group of subjects presented in Chapter 7 indicates that the same performance can be produced by different subjects using different strategies and processing routes. The differences between high and low performers may lie in the speed and accuracy of a single strategy but it appears more likely that they reflect the use of
different strategies. Ability to change strategy within test performance is a reflection of skill. The choice of a particular strategy seems to flow from the nature of the encoding, especially if that encoding includes information on the relationships between the particular items from which structuring and construction of the stimulus is possible. The operation of the strategy will be dependent upon the demands of the problem, the knowledge brought to the problem by the subject, the skill of the subject in processing particular information and the interaction of these factors.

(b) A change in strategy can occur between items due to the identification of various cues from within the problem or because of particular skills already held in memory by an individual subject. This skilled performance embraces such abilities as differentiation between similarity and identity, the formation and control of images, verbal labelling based on past experience, the skill in construction or synthesis of a stimulus on the one hand and the analysis of individual items on the other, and the ability to work with a maximum number of stimulus items at the one time. A change of strategy can also occur during performance on one particular item if the subject finds that the strategy in use is not working to a particular confidence level.

(c) To be satisfactory a heuristic model must permit the
consideration of all the processes which might be brought to bear upon a problem and the crucial influence of varying strategy usage. Any model which cannot explain the inclusion or omission of processes and requires that all subjects operate in a fixed method inadequately reflects the diversity of individual performance. While agreeing with some of the conclusions of a recent article by Pellegrino (Pellegrino, 1985) his emphasis on information-processing models providing "the basis for estimating how quickly and how accurately people execute the various spatial processes and for analysing individual differences in spatial-visualization ability" continues to imply that the individuals differ only on the ability to perform certain set processes. Strategy investigations suggest that processes do not necessarily operate sequentially or exhaustively nor according to fixed routes but are "under strategic control". Particular processes may operate in certain combinations thereby rendering unnecessary other expected processes. The recognition of relationship between particular stimuli, for example, renders expected rotation unnecessary.

The model proposed is based on the possibility of two basic types of strategy: global or wholistic strategies and part strategies. The two strategies may be used in combination with the former preceding the latter. Each of the strategies may operate either
exhaustively or in a self-terminating manner.

(d) The aptitude of a particular subject does not depend solely upon quantitative factors such as the speed and accuracy of using a particular strategy but also upon qualitative skill in changing strategy when it can no longer meet the demands of a problem. Understanding of a particular subject's performance may depend upon realization that a particular strategy option is not available because the conditions for use cannot be met. This may occur, for example, when a subject has difficulty in discriminating between similar and identical items, in synthesising information or cannot control or compare a total figure or individual pieces with confidence.

(e) The variations in the difficulty of identifying "same" and "different" items and in the demands posed by small numbers of stimuli (four or less) compared with larger arrays (five and more) appears to suggest that different processing is involved. With some subjects this may be so, but with others the processing appears to be the same. Ability to use different strategies depending on the demands of the problem seems to be the determinant of individual skill.

(f) Difficulties which subjects encounter leading to errors appear to differ from those difficulties which lead to an increase in reaction time. Accuracy and speed seem to subtend their own particular sets of
processes with accuracy related to the effective use of a strategy and speed related to the capacity of the individual to vary the strategy in certain situations, to terminate processing at a certain level of confidence or to constraints imposed by operating processes.

(g) In protocol analysis the inability to articulate performance appears to be more indicative of a lack of co-ordinated planning than curtailed, chunked or unattended activity. Highly successful performers are able to recall their processing and to provide a logical and consistent path analysis.

(h) Individual processing differences can manifest themselves at various points in the solution process. While the basic processes of encoding, comparison and decision making are necessary their actual performance is controlled by the subject. Because of this proposition, the usual analysis of individual scores in relation to normed data and the correlation of scores on the MPFB with other tests fail to give an adequate explanation of individual differences. The process analysis offered gives insight into the diversity underlying similar scores and offers a rich tapestry of explanation for high and low performance. Any use of the MPFB without this understanding is out of touch with the diagnostic capabilities of the test and is unlikely to aid our appreciation of the psychological concepts involved in performance on the test. Interestingly,
Pellegrino arrives at the same conclusion (Pellegrino, 1985) in writing that "tests based on information-processing theory could be used to diagnose rather than predict performance. They could pinpoint a person's weak areas of cognitive functioning and provide some basis for designing individualized instruction and training to improve cognitive skills". With the proviso that "skills" include processing routes and their variation, Pellegrino's conclusion is acceptable.

(i) For diagnostic and predictive purposes, the MPFB, as it stands, has a number of structural flaws and should be improved by increasing the generality of its training examples, removing bias in answer placement, and "evening up" the number of alternative answers which can be readily eliminated. These changes would enhance its ability to distinguish strategy usage and illuminate overall individual performance.

Each of these conclusions will now be considered in terms of its generalizability and future possibilities.

The basic difficulty in mastering a problem lies in the perception of the initial stimulus, in understanding and organizing it and in becoming oriented to it. Under the same conditions and operating with the same problems, individual subjects acquire different information derived from data believed to be maximally useful for the solution of the problem.

For some subjects this datum consists of isolated
elements, some of which will be essential, some superfluous. Other subjects acquire data in the form of relationships between the various elements rather than the elements themselves. Like a developing photograph, some subjects are able to work with the initial blurred relationships while others prefer to wait for the clarity which an individual piece displays in the fully developed photograph. As Pomerantz (1981) suggests, wholes are perceived by their emergent features which are not the parts themselves but rather stem from the interactions of these parts. He goes on to postulate "the sealed channel hypothesis" in which "the very process of recognizing wholes necessitates discarding (or at least attenuating) information about component parts such as the position, orientation and length of component line segments".

Some subjects tend to work with distinctive structures which encapsulate the entire span of the data and lack analysis of individual characteristics except as these appear in general outline. Others, in contrast, depend on more individual and concrete units. The former have a skeleton, an emerging framework. The latter accept the limits of individual item perceptions and appreciate that to move beyond this opens the risk of losing the perception since it consists of unconnected data in concrete imagery form.

While either form of processing can be quite
effective for the performance of certain problems the generalisation to more demanding situations, such as in mathematics, leads to one approach becoming more effective than the other (Krutetski, 1976). As he notes, capable pupils, when perceiving a problem, "see its 'skeleton' at once, purged of all concrete values and as if visible through the specific data" which he goes on to call "a kind of analytic-synthetic 'vision' of the structure". Such an approach has correspondence with the way in which the proposed model allows for strategies which reduce processing requirements. Krutetski also finds that able mathematics students display a flexibility of mental processing marked by varying methods of operating, reconstructing knowledge, skills and systems to conform to changed conditions and ease of switching from one method of operation to another. Such flexibility characteristics also mark the able subject confronted with spatial-visualization problems.

Krutetski also finds that able students differ from poor students in mathematics in their skill in using search attempts to correct their processing and to stop before a conclusion is reached when on the wrong track. This might explain why more highly skilled performers on the MPFB are slower with positives than negatives (correcting false starts) and poorer performers the reverse.
In the case of spatial problems, and particularly with MPFB problems, processing becomes most effective when there is some form of combination between the two approaches - the identification of individual pieces AND the structural relations which unite them. This enables discrimination not only to distinguish the items but to create the beginning of insight into the method of operation. The way in which this analytic-synthetic vision operates opens the way for a variety of strategy operations which then fall within the repertoire of the individual subject for future performance. The choice of whether or not the entire repertoire is called into operation depends upon the memory structure of the individual and involves both past experience and knowledge.

In such a paradigm the quality of encoding, as the initiator of strategy activity, is dependent upon the efficiency of feature analysis, figure decomposition and synthesis, on verbal labelling and image representation and on the way in which prior knowledge is used to lessen overall processing load. Verbal labelling and image representation may be different factors in encoding with the former using generalized images for comparison and the latter being more amenable to constructed short-term images. Although they may lead to the same performance they tend to place emphasis on prior knowledge or skill respectively.
Lohman and Kyllonen (1983) note the role of encoding in problem solving is to make the "unfamiliar familiar, the meaningless meaningful". The way in which this is done by different individuals may already determine their choice of future modes of operation.

The role of familiarity is explained by Snow and Lohman (1984) when they argue that as experience with a task accumulates "subjects assemble a strategy suited to their particular strengths and weaknesses" but remain limited in this choice by the possibilities which are open to them. This "choice" stems from some form of "controller" which determines whether a particular strategy can be sustained, given the nature of the information available, and regulates performance on the basis of feedback from current performance as the test or task proceeds. The "controller" is also aware of the operating space necessary and available and will seek to maintain a balance by allocating attention, managing memory and controlling assembly functions in the light of task demands. How well this is achieved will determine how effective the performance will be and how flexible the processing needs to be.

Snow and Lohman (1984) see an "inner environment" constantly shifting to meet the demands of the "outer environment" as it is presented by the sequence of items on a test. Their description is of "individual cognitive systems which are very large banks of
cognitive processing skills and chunks of knowledge from which samples are drawn according to the demands of particular cognitive tasks". The way in which these samples are drawn may be dependent on the processes which are going to be used but more likely "because individuals differ in the way they encode and represent visual patterns in memory the selection of strategies may result in part from differences in the nature of the memory representations on which the comparison strategies must operate" (Cooper 1982). In this way an analytic strategy will be based upon a memory representation of sub-units, parts or features while a holistic strategy will be based on a memory representation of all the low level information in the pattern so that information is examined globally. The memory representation required for a combination of these two strategies is therefore necessarily both part and whole with either available as it is required or a sequential switching from the totality to the part and possibly back again for final checking.

In this way both encoding and strategy are item appropriate at any one time as seen by the "controller" which becomes a repository of skill born of past experience and innovative trialling.

Shifts in strategy are prompted by knowledge of past experience and awareness of present task demands within a causation framework including clarity, simplicity,
elegance and, above all, flexibility or innovativeness.

Familiarity allows the omission of certain sequences of operations. Krutetskii (1976) calls this curtailment while Snow and Lohman use the term "skipping of intermediate steps". More importantly, familiarity permits the development of new sequences of operations. Flexibility is, however, always dependent upon two crucial factors if confusion is to be avoided. There must be (1) an underlying logical and well founded reasoning process which can be returned to at any time, and (2) an ability to reconstruct knowledge, skills and systems to enable their application to changed conditions. The "controller" maintains the links "invisibly present" (Krutetski).

Questions which must always be considered in an analysis of this type, if we are to understand variability in processing techniques, include the contents of the strategy repertoire of an individual, how strategies differ qualitatively, what their range and strength possibilities are and what determines their use. Much of this has already been covered but something needs to be said about the generalisability of the two broad areas of strategy which have been postulated.

The argument has been that each individual theoretically has the option of two broad strategies - a global strategy and a part or analytic strategy. These
should be viewed as the ideal types which occupy the end points of a continuum. In practice the activity of any individual can be situated at a point on the continuum. Similar strategy types have been identified by a number of researchers. They are most clearly set out in the work of Cooper and her associates (Cooper, 1980, Cunningham, Cooper and Reaves, 1982) who distinguish Type I and Type II subjects. Type I subjects are described as holistic processors who compare visual memory representations in parallel and whose reaction time is unaffected by the degree of dissimilarity between the items being compared. Type II subjects are analytic processors who use both analytic feature-by-feature comparison and the holistic matching of the first type. For the latter, reaction times decrease as the dissimilarity of a pair of stimuli increases. For Type I subjects "different" responses are made by default while for Type II subjects in their analytic phase the detection of a differing feature means a "different" response.

The difference between these strategies may be either "hardware" based or dependent upon the "software" available to the controller. The difficulties which global strategies can run into if they are used to achieve more than a discrimination has been noted. Global strategies except in a few simple cases, can do no more than sift, eliminate and set up the data. The
point at which a global strategy cuts out as a viable strategy differs between individuals and here it is essential that the controller uses past experience in deciding when to signal the need for a change. The theoretical work of Palmer (1975) gives some explanation why global information when used for more than the assembling of basic hypotheses, i.e. eliminating impossibles, can run into confusion and yet how, when used appropriately, this approach can be a very supportive process to subsequent analytic processing. Palmer argues that strategy follows from what happens first - does the subject interpret the whole or the parts? As he says "global information can be used to generate higher level hypotheses rapidly on the basis of low resolution information" and these hypotheses direct further processing on a bottom-up part to whole basis.

The only situation in which a global strategy can carry processing to a conclusion occurs when subjects refer to the answer "jumping out". In this case the subject has such confidence in the chosen answer that no further hypothesis testing is necessary. This characteristic of subjects may be due simply to a very rapid processing whereby the "curtailment" of processes is so radical that the answer appears to be available "on the spot". Krutetskii (1976) found this in very capable mathematics students. On the other hand a number of writers have described it in alternative ways,
as "controlled hallucination" arising from a deliberate inactivity of the comparator stage (Allport, 1977), an early perceptual organization which so protects the target from interference that it "jumps out" in visual search (Banks and Prinzmetal, 1976), where the background elements are homogeneous "reaction time is often independent of the number of background elements suggesting that the target pops out as a figure on ground" (Pomerantz, 1981), or that the subject in some way does not "see" non-critical items, "sees only a blur until the target jumps out" (Neisser, 1963).

The drawbacks to the global strategy are primarily in the quality of the construction and the difficulty of "holding" this construction for any length of time before it begins to blur comparisons between similar and identical items thus increasing errors on false-positives. The factors which are integral to both construction and holding are individual skill in generalization whereby the essence of a problem is identified and the general features of the structure are grasped; the skill in abbreviating processes to the point where they are no longer conscious; flexibility including the skill in varying operations where expedient, reconstructing knowledge and systems to conform with changed conditions and ease of switching; reversibility of the direction of reconstruction and, finally, the ability to vary the approach even while the
trial is continuing so that it is not processed to its end before a change is made. When these factors are present within the processing repertoire of an individual then the global strategy is a great aid to efficient and speedy operation. If they are missing, the global approach is headed for difficulty.

Santa (1977) also proposes a two stage model in which the holistic response is viewed "as a set of criteria on a familiarity count. As features are matched they increment a counter. Identity comparison is based on the counter quickly reaching the criterion for holistic same response". On the other hand if the familiarity count remains below the criterion then a fast 'different' response ensues. In the middle range stimuli are subjected to a thorough element by element comparison. While accepting this model in principle it is argued that in a test such as the MPFB only on a few occasions will the familiarity counter exceed the level required for identity but it will be a valuable tool for the elimination of items which obviously are not reaching that level.

The global approach is dependent upon the skill of the subject in reducing the noise elements in the array. It seems that some subjects can operate on numbers of items without undue hardship, while others are immediately hampered when they progress beyond the simplest item. Hoffman (1975) argues for a two stage
process also but generally accepts Neisser's model (1967) of a parallel comparison which generates a similarity measure for each comparison item. Items are then transferred serially, by a process of selective attention, in order of decreasing similarity, to a serial exhaustive process. The results and model reported suggest that this is too cumbersome and that the initial similarity measure aids a terminating search.

The generality of this process or strategy in human processing suggests that it is available to many subjects but its contribution and limitations are not wholly understood so that some subjects use it without care while others have rejected global operating as an option.

The question of strategy is related to the issue of sex-related differences which is not touched on in this study but has stimulated much discussion. The material has been reviewed by Fairweather (1976) and Newcombe (1983). Caplan, MacPherson and Tobin (1985) point to the serious problems which exist in the area especially the lack of consistency in definition of "spatial abilities" and questions of methodology and conclude that the hypothesis that males are superior is unwarranted.

If the brain-lateralization and genetic theories are correct then the corollary must be that spatial tasks
reflect predetermined patterns of processing. Both the results suggested in Chapter 8 and studies from Barratt (1953) to Pellegrino (1985) suggest a malleability in spatial abilities. Such malleability is best accounted for in terms of variation in strategy or by the ability of subjects to quickly learn strategy usage. Caplan et al. (1985) conclude that "if an individual chooses to hold a mental picture of a design, perhaps that activates the right hemisphere, whereas if the individual tells herself or himself that an item looks like a house, perhaps that activates the left hemisphere. If this is true, then researchers who are attempting to measure degree of brain laterization have confounded results because of strategy choice".

Another issue to which strategy is relevant is that of learning disabled children who are characterized as strategy deficient. Bauer (1982) asserts that the assessment of strategy use may aid in the identification of learning disabled children. If this is so then the work reported here may also be seen as generalizable to the identification and remediation of learning disabled. As Shepherd, Gelzheiser and Solar (1985) assert "one way to substantiate the educational importance of a production deficiency in learning disabled students would be to use school tasks to assess spontaneous strategy use and the effect of strategy instruction ... evidence does suggest that decisions about strategy
instruction should be made for individual children in relation to specific tasks". The work of Reuven Feuerstein and his colleagues in Jerusalem on Instrumental Enrichment as a form of strategy instruction may be seen as the prototype of this type of work. (Feuerstein & Rand 1979, Rand, Tannenbaum and Feuerstein 1979, and Feuerstein et al. 1979).

These two issues have been mentioned because it may be that strategy investigation will shed light on the difficulties involved and offer possibilities for further research and remediation.

Conclusion (e) referred to the issue of "same-different" processing which has been discussed by psychologists over the past two decades. Are the same processes used in each case or has the processing of items resulting in differing conclusions to be explained in different ways? The experiments reported here help to shed some light on this question.

The difference between reaction times for "same" and "different" responses is a concern because it has been experiments in this form which have been used in identifying processes within tasks. Bamber (1969) suggested that we have two different procedures operating in the comparison of stimuli - a serial self-terminating processor which initiates a "different" response as soon as a difference is detected and an identity reporter which is relatively fast and initiates
a "same" response when the stimuli are identical. The defining of "relatively fast" leaves the model able to predict just about any type of relationship. In a later article Bamber (1975) defines the identity reporter as "always faster than the serial processor".

Reed (1973) proposes that subjects always first attempt an identity match based on a parallel comparison of features. If the decision is uncertain "they test each feature sequentially and respond 'different' as soon as a difference is detected and 'same' if no differences are detected". As Reed suggests such a model would predict that sequential testing usually follows whenever two patterns are different and does not follow whenever the two patterns are identical. In conditions of simultaneous presentation Reed reports that the "superiority of the identity match depended upon the use of familiar stimuli, whereas the detection of differences was independent of familiarity".

The results reported in Chapters 4 and 5 suggest a complicated situation. Looking at the group data for the Wholistic condition shows that the comparison of stimulus figure and a dissimilar figure (N2) is faster for 'same' in five problems out of twelve and with the comparison of stimulus and a similar figure (N3) only three problems are faster for "same" and these are at the complex end of the problem scale. In all other cases it is quicker to respond 'different'. In those
conditions where the comparison requires some transformation the 'same' response is always slower. When individual performance is considered, high ability subjects are faster at responding 'different' than 'same' while the reverse is true for low ability subjects in the wholistic comparison. This was explained at the time as a difference in mismatch detection where low ability subjects were prone to recycle processes to reach a confidence level and also lacked the processing speed of high ability subjects.

Similarly in the error structure those who make the majority of their errors in identifying 'same' took longer to process 'same' items, while those failing to pick 'different' in similar but non-identical stimuli took longer in the negative processing condition. It was concluded that this reflected an individual difference in that some subjects are quicker and more accurate at rejecting a mismatch but have difficulty with identifying 'same' while others are more accurate and faster at identifying 'same' than 'different'. It was further contended that the same-different problem arises from individual differences rather than from some general processing feature. Individual difference, also, may flow from the nature of the selective attention which the individual places on the specific details required at times to the detriment of what is defined as unimportant. This definition of what is
attended to may reflect the degree of familiarity of the item for the subject.

This result may be further explained in the light of a suggestion by Printz (Printz and Ataian, 1973, and Printz, 1975) that the search process is in fact two processes - a target controlled search and a context controlled search. In context controlled search, the search is under the control of recognizers sensitive to large portions of the display. If the target is present it is "detected in the same way one detects a flash of light, as an event which does not fit into the subject's model of his present environment". If the search finds context only then that item can be eliminated. If there is doubt then it is held for target controlled search. Target controlled search provides identification of what has just been detected as "a hurdle in progress". Target controlled search as a check either identifies the target or can discard the item as close but not identical. While the context controlled search may be pre-attentive the target controlled search requires focal attention.

Applying this model to our data suggests that some subjects are able to combine target and context controlled search in a scan (eliminate) and check (establish target) program. Others are able to eliminate under context control but either neglect or are careless with a subsequent target controlled search.
A third group of subjects appear to operate entirely on a target controlled search basis sometimes being faster when they come across the target ('same') and sometimes slower if they fail to find the target ('different'). Such an explanation fits well with our own model. Which control strategy is introduced is contingent on the task demands, the degree of familiarity and the degree of complexity. It would be expected that many for whom the MPFB type problem is unfamiliar will operate target controlled search since context controlled search is likely to produce error and/or confusion. Familiarity will lead to increased speed by adding context controlled search thereby reducing the effect of target set size.

This explanation allows us to identify the psychological factors operating in the model. Scan takes place under context control as a 'once-off' run and what is not eliminated is actually detected as a critical location and then subjected to target controlled search. The scan elicits attention which then draws in focal attention to make identification possible.

A final point is raised by an interesting article by Vurpillot (1968) which needs development. She sees the 'same-different' issue as a developmental one believing that scanning is an adult ability which arises from the development of a spatial frame of reference and thereby
allows the scanning to be systematic across the whole stimulus and not limited to the same field as target identification encompasses. This raises the possibility that many of our weaker subjects on the MPFB are suffering from processing defects which are developmental or learned.

In summary it is contended that effective solution of 'same-different' tasks demands developed scanning under context control to detect 'different' and target controlled checking of identified locations to determine 'same'. Attention requirements are different.

It was also shown in Chapter 5 that there seems to be a significant variation in reaction time taking place around four to five pieces in the stimulus array. In the process analysis experiments a sharp increase from four to five pieces was found after moderate increases between two and four pieces. The same pattern is apparent in the relationship between mean performance time and number of pieces on the total MPFB test. The actual nature of this change is unclear but it is hypothesised that it is related to the ability of the subject to control an image representation and to perform various processes while it is controlled. It is a hundred years since Galton wrote about what happens when individuals lose control of memory imagery: "they find a difficulty in shifting their mental view of an object and examining it at pleasure in different
positions... If they see an object equally often in many positions the memories combine and confuse one another, forming a 'composite' blur which they cannot dissect into its components. (Galton, 1883 quoted in Richardson, 1972). When this loss of clarity takes place a new approach is introduced which works with subitized elements or chunking of the elements into manageable units or an approach based more on reasoning. Such spatial reasoning is totally analytic and of necessity target controlled. It is this change which makes the MPFB five piece problems more closely related to general intelligence while the earlier and simpler problems are concerned with spatial relations especially where there are no transformations required. Problems in between are probably purer measures of spatial visualization.

A number of questions have been raised in this study regarding the validity of the MPFB in its current form. The Manual (Revised 1981) makes two assertions: the test is a valid measure of spatial visualization ability and to a smaller extent of general intellectual ability. The previous Manual (ACER, 1963) argued that in samples representing a wide range of ability, about fifty percent of the variance in test scores can be attributed to a general ability factor. Spatial visualization, general intellectual ability and general ability are not defined in psychological terms. The revised Manual admits that among restricted samples the MPFB shows only
moderate correlations with scores on intelligence tests.

That the authors of the Manuals have avoided defining spatial ability is not surprising considering the difficulty which psychologists have experienced especially in their factor analytic studies. Lips, Myers & Colwill (1978) offer the following definition. "Spatial abilities are those that enable a person to locate an object in space, mentally rearrange objects, recognize shapes, AND SO ON". (my italics). The phrase "and so on" adds nothing in the way of clarification but points to the difficulty experienced in defining the concept. Maccoby and Jacklin (1974) report that "Spatial ability, even more than verbal or quantitative ability, is difficult to define". MacFarlane-Smith (1964) wrote that there is no psychometric definition of "spatial visualization" that is generally accepted. Such apparent certainty on the part of the test distributors and uncertainty from the researchers creates apprehension in the user. How then is the test to be considered in the light of this investigation and in what ways might it be improved?

(a) The Structure of the Test.

An analysis of the test points to a number of structural problems. Firstly, the Practice Examples do not prepare the subject for the broad range of problems to be encountered and may bias subject expectations and pre-condition the method of operation.
There is, also, the issue of bias in the placement of the correct answer in the five alternatives which are offered. In the 64 problems the correct answer occupies the first position 13 times, the second 14, the third 11, the fourth 12 and the fifth 14. It has been established that the highest percentage of subjects to complete the test is about 30 and in some groups is as low as 9. In the case of low performers (i.e. those completing about half the test) it is found that the correct answer occurs in the first 32 problems 12, 6, 5, 5, 4 times in the first to fifth positions. If the subject is biased to the first answer initially this may cause a bias towards Strategy 1.

A third cause of concern is the number of nearly correct answers given among the five alternative solutions. Some problems have only two possible solutions while others have all five solutions at least near enough to be given serious consideration.

(b) The Psychological Concepts

This test is advertised in the ACER Catalogue (1985) under the heading "Manual-Mechanical-Spatial". The implication is that the MPFB is a valid, evaluation instrument for these concepts. The concepts themselves are not defined and it is not explained how the test is suitable for "selection of applicants for training in certain skilled trades, and as an aid in the vocational counselling of clients who may be contemplating such
training" (Revised Manual, 1981). The question of what this test measures is unanswered and unless the results of the type of investigation offered here are taken into consideration there can be little understanding of the influence of psychological concepts and strategies.

(c) Method of processing in test achievement.

Unless it is implicit that the same score can be achieved by following different routes and strategies, it must be assumed that the test designers believed that the test could only be solved by one processing method. Since it has been shown that this is not so suggests that the test taps a malleable processing aspect dependent upon individual reaction to test demands rather than a firm and immutable characteristic of human performance. Only if the latter is true can scores be validly compared and claims concerning relative ability be made.

(d) Predictive ability

Correlations with other tests and with academic results are disappointing and neither serve to distinguish the characteristic being measured by the test from other test aptitudes nor to predict future performance in areas assumed to require certain skills. The limitations of correlation analysis are evident in the analysis which shows that subjects achieving similar scores on the MPFB and also on other tests can be operating in quite distinct ways.
(e) Speed-accuracy trade-off.

As already noted the numbers completing the test in the specified time can vary between groups and certainly between individuals. Despite this, the test is claimed to be a test of power (Pellegrino and Kail, 1981) rather than speed. It seems hard to evaluate a test which can vary between one in three and one in ten completing the test. In individual administration it was found that some subjects required 35 minutes to complete the test while others completed within 10 minutes. That scores are usually reported as a single figure without the benefit of knowing the number completed makes it difficult to distinguish the fast and accurate, the fast and inaccurate and the slow and accurate. It would seem valid to believe that a subject doing 64 problems in 20 minutes and getting 40 correct is operating differently from the subject who completes 40 problems and gets them all correct. If visualization is defined as a power factor and then the subject is not given time to complete the test then the test is forced into the same category as the "speeded" spatial relations factor.

It is contended that the continued use of the MPFB in its present form does not contribute to our understanding of human spatial performance. On the other hand should the criticisms raised above be accepted and the test used as a diagnostic instrument with all subjects taking all problems then it will be
possible to affirm the following:
(a) Noting the accuracy and speed with which the range of problems can be completed by a subject will give insight into the skill of processing and the nature of processing.
(b) The solution of different problems in different ways will show the flexibility of the subject.
(c) The method of operation will form a more reliable predictor of performance on other tasks than the usual correlation methods.

Using an approach similar to that outlined in this paper it is possible to explore questions of learning, the teaching approach needed to increase subject performance and the processing deficiencies which underlie previous failure and the techniques of deficiency correction.

The diagnostic use of the MPFB as outlined offers a tool for exploring the aptitude of each individual in spatial activities insofar as such ability is an amalgam of background knowledge, a reference system, a method of operation, a definition of complexity and a level of operating abstraction. The present study has been a first attempt at such use offering psychological definition of performance and aptitude.
APPENDICES

Appendix A. Examples of the French et al. (1963) Paper Folding Test (VZ2) and Surface Development Test (VZ3) referred to in Chapter 7.

Appendix B. The results of additional subjects tested with Experiment 7:1 material.

Appendix C. The written protocols of subjects in Experiment 7:1 reporting on "four-in-a-row" problems.

Appendix D. Mean latencies and regressions as a function of trial type, item type and number of stimulus elements for each individual subject in Experiment 5:1.
APPENDICES

Appendix A. Examples of the French et al. (1963) Paper Folding Test (VZ2) and Surface Development Test (VZ3) referred to in Chapter 7.

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PAPER FOLDING TEST — VZ-2

In this test you are to imagine the folding and unfolding of pieces of paper. In each problem in the test there are some figures drawn at the left of a vertical line and there are others drawn at the right of the line. The figures at the left represent a square piece of paper being folded, and the last of these figures has one or two small circles drawn on it to show where the paper has been punched. Each hole is punched through all the thicknesses of paper at that point. One of the five figures at the right of the vertical line shows where the holes will be when the paper is completely unfolded. You are to decide which one of these figures is correct and draw an X through that figure.

Now try the sample problem below. (In this problem only one hole was punched in the folded paper.)

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A   B   C   D   E

[Diagrams of folded paper with holes at different positions]
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SURFACE DEVELOPMENT TEST — VZ-3

In this test you are to try to imagine or visualize how a piece of paper can be folded to form some kind of object. Look at the two drawings below. The drawing on the left is of a piece of paper which can be folded on the dotted lines to form the object drawn at the right. You are to imagine the folding and are to figure out which of the lettered edges on the object are the same as the numbered edges on the piece of paper at the left. Write the letters of the answers in the numbered spaces at the far right.

Now try the practice problem below. Numbers 1 and 4 are already correctly marked for you.

NOTE: The side of the flat piece marked with the X will always be the same as the side of the object marked with the X. Therefore, the paper must always be folded so that the X will be on the outside of the object.
Appendix B: Further material from Experiment 7:1.

A number of other subjects did the tests in the format described in Chapter 7. The analysis of these subjects together with flow charts are added for the sake of completeness.

Subject S.C. (Figure B:1)

This subject is a 21 year old of Chinese background doing year 12 applied science. He is very competent in mathematics and computer science having already reached tertiary level in China.

His approach to the problem depends upon the answer to the question "Are any particular relationships apparent on looking at the problem?" The flow chart shows the emergence of two strategies directly dependent upon the answer to this question: a piece by piece check or a total comparison which, if positive, is followed by a piece comparison "as soon as possible" so to this extent the answer is fully processed while the subject has it under control. This variation may be necessary because he experienced difficulty in identifying pieces after encoding in the search experiment or because he runs the mismatch and then the match strategies very quickly and as a whole.

Subject S.W. (Figure B:2)
Figure B:1 Subject SC modelled on heuristic flow chart.
This subject is a 19 year old doing Year 12 Applied Science. Like subject S.C. this subject bases his approach on a question: "Does the problem have a particular characteristic?" From answering this question the subject forms a total image with which he proceeds to a very rapid identification of an answer. This rapid identification appears to break down in the middle range of problems suggesting that the subject fails to see when to change strategy.

Although the protocol does not clearly indicate a more piece by piece comparison there is some suggestion that a strategy of this type may operate in the more complex problems. The clue comes from the encode and identify part of the experiment. Those problems solved by rapid identification also match with problems where the identifying time is quicker than the encoding time but the reverse is true where the strategy is reversed and the problems are more complex. The signal for this subject to change strategies is difficulty in identifying the relationship or the particular characteristic with which the strategy started. The strategy change in this case is not so much a change in strategy but a change in the size of the item being used for comparison. Just because a protocol speaks of working with a related structure or a combined figure does not necessarily identify a global strategy.
Figure B:2 Subject SW modelled on heuristic flow chart.
Subject M. (Figure B:3)

This subject also follows the rapid match then slower piece match which we have just seen. She is a Year 12 student doing General Studies aged 18.

Subject M begins by looking at the shapes and seeing if there is anything "special about them (e.g. all the same, all triangular)." This special characteristic allows easy matching according to the subject and is pursued as a first step. (Shown in pink on flowchart). If matching on this basis is not possible, she proceeds to choose one shape and match it to an answer. If successful she chooses another shape and matches it to the same answer. If still successful she checks if the total shape is "OK" then chooses it. The process is repeated on the next answer if a match is unsuccessful at any point.

The subject changes strategy or fails to detect a special relation when the figures are not easily related and controlled. These three subjects are included because they are examples of articulate students who explain their activity in terms which can be incorporated into the proposed model although it is apparent that when the rapid strategy is used to match rather than mismatch there are difficulties unless a check is built into the processing. The model suggests that the use of this strategy using a whole figure to match will experience difficulty because the image
Figure B:3 Subject M modelled on heuristic flow chart.
constructed is not precise enough to allow accurate matching. The use of this constructed image is to eliminate those alternatives which are clearly wrong.

Subject Anna. (Figure B:4)

Just to show that not all subjects can explain what they are doing, our final example is of a Year 12 General Studies subject aged 18 who drew the attached flow chart herself. This subject makes the most errors (10 out of 16) while still taking above average time on the individually administered problems. The number of pieces, number of different pieces, and complexity seem to have no influence on solution time. What is happening?

Her description of what she is doing goes "shapes varied, looked at the picture, looked back at the shapes, looked to see where they belonged". From the flow chart the impression is of a uniting of the pieces and immediate comparison, thereby working a wholistic approach uninfluenced by the context and yet she takes a comparatively long time. Her description of tackling a five piece problem was "looked at the mixed up shapes, didn’t know where I was going, chose any one". If she is operating some type of whole approach she is completely "thrown" by the problem which has no answer "shapes, very different - looked confusedly, looked at shapes, looked at picture, still very confused, chose
Figure B:4 Flow chart of processing drawn by Anna.

START

LOOK AT PIECES

ARE THEY ALL DIFFERENT

YES

TRY AND MATCH

STOP

NO

PICK ANOTHER ANSWER

LOOK AT THE SHAPE CAREFULLY

DO SHAPES MAKE SENSE

NO

PIECE THEM TOGETHER

GIVE ANSWER
any of the alternatives". It is almost as if the subject is lost when there is no answer to "see". This is one of the dangers of entirely wholistic approaches. The subject must possess the ability to "see" what does and doesn't look right and there must be an answer which may trigger a response.

One of the points made previously related to the emergence of a "jump out" strategy and this section seeks to explore this more carefully by taking the protocols of two women in their early 40s who completed the test and spoke of this "jump out" or "instinctive" method. Both were taken through a number of problems and their descriptions were taped. The major points made were the following.

Subject O.M. (Figure B:5)

"I began by looking at all the shapes and tried to put them together in my mind. I then looked at the answers as a whole until MY EYES PICKED UP AN ANSWER (my emphasis)" The subject went on to describe arriving at
Figure B:5 Subject OM modelled on heuristic model.
an answer "without seeing the others (answers) they are rejected".

When explaining activity on Problem 19 (Figure B:6) "while looking it was immediately jumping out that L is the right one". To explain this she had to resort to a sequential explanation. After some thought "take the problem images, look at answers - when I see images that match up in my mind I cotton on to that particular whole. If I make a combined image and that one (answer) isn't the one expected, then it isn't recognized."

Commenting on Problem 26 (Figure B:6) "talking (about what I'm doing) hinders - burn the shapes into my mind and then look for a whole. Verbalising cuts across my visual image. In this problem it is difficult because all pieces are different - lose spontaneity - have to work it out with individual pieces. If I lose my image I am confused". In problem 40 "no immediate picture, M looks as if it is right. M put together looks like all those pieces (in the problem). Would need to check - others obviously wrong".

The accompanying flow chart (Figure B:5) suggests how this approach can be fitted into the proposed model. It assumes that either there is not only very fast elimination but the image holds long enough to allow a matching process or that these two processes act in parallel. The combination of both processes may create the "jump out" phenomenon. It is also interesting to
find here support for a "holding basket". Either there are different levels of confidence in the elimination or

![Diagram of shapes]

Figure B:6

the difficulty of being certain of a match may result in a single answer being held for exploration by the piece-match approach just as when two answers are held. The difficulties for this subject came in those problems "where there was nothing to focus on" and complexity was seen in many-sided irregular shapes, "shapes which did not fit in with a concept I already had" or "those which could easily be confused with a similar shape".

Subject M.L. (Figure B:7).

This subject is an instructor in architectural drafting and offered to participate because it was her students who were involved in the experiment reported in Chapter 7.

While doing the MPFB the subject verbally describes the pieces to herself and then looks at the answers "to
Figure B:7 Subject ML modelled on heuristic model.
see if a solution comes. When this happens she refers to it as her "instinctive method". Difficulties arise when she can't deal with the problem pieces in verbally descriptive terms. Her strategy is to eliminate as is seen by the following comments taken from her taped protocol:

In Problem 48 (Figure B:8): "The answer must be E because the others are disqualified". This follows a comment about the "instinctive method whereby I look at the whole lot (of the answers) and the answer will jump out".

The strategy appears to break down in problems such as Problem 40 (Figure B:8) where the protocol goes "five oddies. I have to look for specific shapes. I chose the large bottom left shape and try to place it (silence) .. no .. the proportions look all wrong to me .. we have two (counting) .. hell, I hate this one (silence) .. it's not N, not O, not P, I reckon it's M".

Later the subject was asked what went wrong in Problem 40 to which she replied: "the shapes are all similar and I couldn't describe them (no known technical terms) and although I would narrow the answers to two or three I then had to look for a distinctive shape".

Unlike Subject O.M., this subject found it easy to talk while working and while working she is continually talking to herself and moving her fingers around.
Subject ML is engaged in a rapid process of elimination and if this doesn't give the answer immediately then the remainder have to be checked systematically. Although both subjects fit the proposed model they work in different ways. For Subject OM it is a visual strategy dependent upon a clear and long lasting image creation, for Subject ML the pieces are all given names and the problems are solved (i.e. eliminated and matched) by logic based on proportions and structures. This is seen in the following two comments:

Commenting on Problem 19 (Figure B:6): "I eliminate the ones which it definitely is not - not M, not N. I like the proportions of L - that looks kind of right - I'll make a guess on it". Later she commented "that was a swine, I couldn't get a distinctive shape" and again on Problem 37 (Figure B:8) she said: "one rectangle, one trapezium, triangle - not V because it is a rectangle and two triangles, W could be but I'm not satisfied with the proportions of the triangle - X looks about right -
I'll check the other two - if I was in a hurry I wouldn't bother to check and I'd then be wrong - in fact it's definitely not Y - it must be Z.

Where names or labels cannot be given to the pieces or the problem is what ML calls "optically deceiving", the subject resorts to piece matching. She also suggests a reason why individually administered single problems can be done more quickly than in the normal administration by saying "to see a whole page of problems can be very confusing and it takes time to get oriented".
Appendix C. Complete Protocols of Subjects taking part in Experiment 7:1.

The subjects reported on a number of the problems in the "four-in-a-row" format but they can be generalized to reports on Problems 3 and 15, the former consisting of three equal pieces which need only be put together and the latter consisting of four unequal and dissimilar pieces.

SUBJECT M.S.
Problem 3. 1. Look at shapes.
   2. Look at alternate finished shapes.
   3. Look back at the sizes of each shape.
   4. Determine the larger sizes.
   5. Rotate the shapes to a shape similar to the four alternatives.
   6. Elect your answer.

Problem 15. 1. Look at shapes.
   2. Pick out largest shape.
   3. Choose, out of the four alternative answers possible, answers with the largest shape.
   4. Look at smaller shapes.
   5. See which of the chosen in Step 3 have similar smaller shapes.
   6. Elect your answer.

All other four and five piece problems included an additional step to the process outlined for Problem 15. This step was inserted following step 2. Step 3: Rotate and join the largest shape to similar shapes in the four alternatives.

SUBJECT W.M.
Problem 3. 1. Look at the jumbled sections.
   2. Go through the assembled shapes.
   3. Pick one of the jumbled sections and try and match it to the choice of the assembled shapes.
   4. Do the same with each of the separate jumbled sections.
   5. Pick that answer has all the sections in it.
   6. Match the assembled shape with each section as a check.
   Same method used each time.

Problem 16 was the most difficult for me because the shapes were a lot alike and in trying to match the individual sections they looked the same and were harder to match.

SUBJECT S.A.
Problem 3. 1. Look at the problem.
   2. Look at the answers.
   3. Shuffle the pieces around in your mind to suit
each answer.

4. Then check to see if each piece in the answer is the same size and shape as in the question.

5. Do this to each answer until you find the one that fits.

Problem 20
(Verbal)

1. Look at question.
2. Look at A (first answer).
3. Take biggest piece. Find in A. Not in A.
4. Take biggest piece. Look in C. Fits.
5. Take triangle (top right). Fits in C.
6. Take triangle (bottom left). Fits in C.
7. Take rectangle (Bottom right). Fit C. No.
8. Go back to biggest piece. Doesn’t fit D.

Doesn’t fit B.
9. Checked all pieces into C. Out.
10. Must be A.

SUBJECT G.H.

Problem 3.

1. Look at problem.
2. Count the number of shapes in the first diagram on the LHS of the page.
3. Study these shapes, their size and shape.
4. Look at the shapes to the right of this first diagram labelled D, B, A, E respectively.
5. Go back to the first diagram.
6. Ask yourself questions. For example: are these shapes the same size? Are they the same shape?
7. If these shapes are the same size, look at the shapes to the right of the first diagram and pick out the one made up of shapes all the same size. Answer D.
8. To check your answer, study the other shapes, that is B, A, and E and look for similar qualities. This will certify your decision.

Problem 15.

1. Look at the problem.
2. Study the shapes in the square on the LHS.
3. Rearrange these shapes in your mind while looking at the squares J, G, F, and H, still referring back to the first diagram.
4. Look at the size and shape of the pieces.
5. Look for these shapes in each of the squares.
6. The square with all of these shapes in it is correct.

SUBJECT I.H.

Problem 3.

1. Look at the shapes
2. Does D fit?
3. Does B fit? No. Shapes aren’t the same.
4. Does A fit? No. Not all shapes are same.
5. Does E fit? No. All three shapes are different.
6. D must fit. All shapes in problem are same.

All three shapes in D are the same.
Problem 15.  1. Look at the shapes.
    2. How many triangles? One. Can’t be F.
    3. How many identical shapes? None. Can’t be F or G.
    4. Check sizes of various pieces. Are they the same dimensions? No. One piece of J doesn’t match that of problem.
    5. H must be right because F, G, J don’t fit.

Problem 12.  1. Look at shapes.
    2. Compare one piece with the same corresponding shape in all the boxes.
    3. Box U has small triangle, one side curved, two sides equal. Should be one side curved, two sides not equal. Box R too big. Box Q not curved enough. T must be right.

SUBJECT J.A.
Problem 3  1. I looked at the shapes.
    2. The I quickly look at the shapes with the letters beside them (the answers).
    3. I looked at the first shapes again.
    4. I looked at each answer in turn.
    5. I looked then at the first shape and tried putting it together to make one of the shapes.
    6. D looked like the shapes put together.

Problem 15.  1. Looked at the shapes.
    2. I looked for a shape - the biggest.
    3. I tried to see if that shape was on one of the other shapes (the answers).
    4. When I found one I checked if the other shapes were the same.
    5. If they are not the same I check another lettered shape until I find one that matched all the shapes.

Problem 12.  1. Looked at the shapes.
    2. I tried to put the circle onto the other shape (in the problem).
    3. Then I looked at the lettered shapes.
    4. I picked the shape (answer) that looked like the shape I had put together.
    5. When I found one I then looked at the first shape (problem) and then tried to fit the small shapes in.
    6. If they fitted that was answer, if they didn’t fit I went on to another shape (answer) until they did.

The simplest shapes were "the shapes that I knew were most common or easy to remember".

SUBJECT T.P.
Problem 3. 1. Look at shapes.
   2. Are they the same size? Are they all the same? How do they fit together? Do they form a circle etc?
   3. They form a circle, etc. If they are the same size then the answer must be a circle divided into so many equal parts.
   4. The answer is D.

Problem 15. 1. Look at shapes.
   2. Look at choices for answers.
   3. Take apart each answer in your head and look to see which parts are the same as the question.
   4. Are they all the same? No: go to next answer.
   5. Yes: accept that answer.

Simplicity equals "basic line work, common shapes which are dealt with daily". Complexity consists of "irregular shape and trouble fitting together".

SUBJECT A.R.
Problem 3. 1. Investigate the left hand column and shapes.
   2. Investigate each diagram in right hand column.
   3. Then I made up the shapes in the left hand column and decided they were corresponding with a picture on the right hand column.

Problem 15. 1. Investigate the shapes in the left hand column.
   2. Decided what shapes they were.
   3. Then I glanced across the four diagrams on the right hand side and broke up each one into the separate shapes.
   4. Then I went back to the left hand column and, keeping in mind the four diagrams on the right, tried to put the separate pieces together.
   5. Then I glanced back at the four pictures and decided which picture it corresponded to.

Problems 9, 11 and 12 were done like 3, the others like 15.

The most difficult problem was "number 16 because it failed to provide any regular, common shape which I tended to look for in all the others".

SUBJECT P.B.
Problem 3. 1. I looked at the shapes given on the left.
   2. I noticed that the shapes given were all one third of a circle.
   3. I then looked at the made up shapes on the right hand side.
   4. I looked for a circle that was evenly divided into three.
Problem 15 1. I looked at the shapes given on the left.
   2. I fitted the shapes together to form a picture in my mind.
   3. I looked to the right hand side and glanced at the four given made up shapes.
   4. I then eliminated the given shapes J, G, and F because the shapes given to make up these three shapes were different from those given on the left hand side.
   5. I checked out shape H and chose.

Problem 20. 1. I looked at the shapes given on the left.
   2. I looked at the four solutions.
   3. After closely looking at the four shapes I realised there was no correct answer.

Question 16 "I found it to be the most complex because the shapes were all alike and roughly the same size, and the four solutions were all alike. Question 16 took a little longer than the rest to complete".

SUBJECT C.P.
Problem 3. 1. Look at the shapes in the left hand column.
   2. Decide when the shapes are put together which one it is.
   3. Imagine the overall shape.
   4. Decide which answer matched the imagined shape.
      Check through others to confirm your answer.

Problem 15. 1. Look at the shapes in the left hand column.
   2. Compare sizes of shapes in left hand column to right hand column.
   3. Decide nature of problem if put together.
   4. Imagine the overall shape.
   5. Decide which answer matched the imagined shape.
   6. Check to make sure you're right.

Problem 16. 1. Look at the shapes in the left hand column.
   2. Compare sizes of shapes problem and answers.
   3. Put the shapes together.
   4. Go through all the shapes individually.
   5. Decide which answer matched.
   6. Check through to confirm your answer.
   7. Think about your answer.

The hardest problem "was number 15 because the shapes were all different sizes and different shapes".

SUBJECT T.B.
Problem 3. 1. Determine the proportions of the shapes given.
   2. Realization of equality!
3. Look for circle with equal segments.
4. D is only correct answer.

Problem 15. 1. Look for unique shape amongst those given.
2. Scan from left to right finding figure with unique shape.
3. If more than one figure has shape, choose another (piece).
4. When you think you have found figure check all segments with those given.
Problem 16 was done the same as 15 except that in step 2 "try to choose regular shape so as not to lose its identity".
Problem 15 was the hardest "because of the asymmetric nature of the shapes involved".

SUBJECT G.K.
The same process is followed for all problems as follows:
1. Take a good look at the shapes.
2. Define the characteristics.
3. Keep the most outstanding characteristics in mind.
4. Look at each of the following four masses.
5. Eliminate the masses which don’t match.
6. Keep in mind those which you did not eliminate.
7. Do the same procedure as in step 5 again.
8. Keep following step five until you end up with one mass.
9. Keep the remaining mass in mind.
10. Check each of the others all over again to separate those which may match.
11. If any could match check with your original answer and the shapes in mind.
12. Judging by sizes, curves or angles eliminate those again which surely don’t match.
13. When sure of your answer, choose.

In relation to Problem 20, go through steps 1 to 9. If you then find that it doesn’t match go through steps 1 to 9 again. If it still doesn’t match write "none".

SUBJECT J.B.
Problem 3. 1. Look at particle shapes, picture in your mind.
2. Then look at the circles.
3. From looking at them they appear evenly sized.
4. D is the only one with equally sized parts.

Problem 15. 1. Look at particle shapes, picture in your mind.
2. Look at the squares
3. From step 1 it is possible to eliminate J and F immediately.
4. Look at the proportion of the shapes.
5. H particles appear to suit the shapes given. H is correct.

Problem 16. 1. Look at particles, picture in your mind.
2. Look at octagons
3. Look at proportion of shapes.
4. Eliminate O and N.
5. Conclude L is correct.

Problem 20. From looking at the triangular shapes it is obvious that none match the shapes given. The most difficult shapes are usually the smallest with the most sides (Problem 16). The simplest are large with very few irregularities.
Appendix D. Mean latencies and regressions as a function of trial type, item type and number of stimulus elements for each individual subject in Experiment 5:1.

Trial type consists of positives (array and answer identical), Negative 2 (array and answer significantly different), and Negative 3 (array and answer similar but not identical).

Item type consists of Wholistic (W), Separated (S), Displaced (D), Rotated (R), Rotated and Displaced (RD), and the original MPFB problem (FB). (For examples see Figure 5:2).

Number of Stimulus Elements equals the number of pieces in the array.
Subject JS. Mean latency as a function of trial type, item type and number of stimulus elements.
Subject JS. Regression latency as a function of trial type, item type, and number of stimulus elements.

**POSITIVES**

- W1
- S1
- D1
- R1
- R1
- FB1

**NEGATIVES**

- W2
- S2
- D2
- R2
- R2
- FB2

**NEGATIVES 2**

- W3
- S3
- D3
- R3
- R3
- FB3
Subject AR. Mean latency as a function of trial type, item type and number of stimulus elements.
Subject AR. Regression latency as a function of trial type, item type and number of stimulus elements.

### POSITIVES

- **No of Pieces**
- **Time Sec.**

### NEGATIVES

- **No of Pieces**
- **Time Sec.**

### NEGATIVES 2

- **No of Pieces**
- **Time Sec.**

### NEGATIVES 3

- **No of Pieces**
- **Time Sec.**
Subject W.Mc. Mean latency as a function of trial type, item type and number of stimulus elements.

**POSITIVES**

- Time Sec.
- No of Pieces

**NEGATIVES 2**

- Time Sec.
- No of Pieces

**NEGATIVES 3**

- Time Sec.
- No of Pieces
Subject WM. Regression latency as a function of trial type, item type and number of stimulus elements.
Subject DK. Mean latency as a function of trial type, item type and number of stimulus elements.
Subject DK. Regression latency as a function of trial type, item type, and number of stimulus elements.
Subject RM. Mean latency as a function of trial type, item type and number of stimulus elements.
Subject RM. Regression latency as a function of trial type, item type, and number of stimulus elements.
Subject TT. Mean latency as a function of trial type, item type and number of stimulus elements.
Subject TT. Regression latency as a function of trial type, item type, and number of stimulus elements.
Subject HS. Mean latency as a function of trial type, item type and number of stimulus elements.
Subject HS. Regression latency as a function of trial type, item type, and number of stimulus elements.

![Graphs showing latency as a function of number of pieces for different trials and item types.](image-url)
Subject JM. Mean latency as a function of trial type, item type and number of stimulus elements.

**POSITIVES**

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<thead>
<tr>
<th>Time Sec.</th>
<th>No of Pieces</th>
</tr>
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<tbody>
<tr>
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<tr>
<td>10</td>
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**NEGATIVES 2**

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<tr>
<td>10</td>
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<td>20</td>
<td>4</td>
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<td>30</td>
<td>5</td>
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</tbody>
</table>

**NEGATIVES 3**

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<tbody>
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<tr>
<td>20</td>
<td>4</td>
</tr>
<tr>
<td>30</td>
<td>5</td>
</tr>
</tbody>
</table>
Subject JM. Regression latency as a function of trial type, item type, and number of stimulus elements.
Subject MS. Mean latency as a function of trial type, item type, and number of stimulus elements.
Subject MS. Regression latency as a function of trial type, item type, and number of stimulus elements.
Subject BA. Mean latency as a function of trial type, item type, and number of stimulus elements.
Subject BA. Regression latency as a function of trial type, item type and number of stimulus elements.
Subject MCa. Mean latency as a function of trial type, item type, and number of stimulus elements.
Subject MCa. Regression latency as a function of trial type, item type, and number of stimulus elements.
Subject HR. Mean latency as a function of trial type, item type, and number of stimulus elements.
Subject HR. Regression latency as a function of trial type, item type and number of stimulus elements.
Subject AS. Mean latency as a function of trial type, item type, and number of stimulus elements.

As this subject made 32 errors in Negative 3 problems (out of a possible 72) the results were not plotted as means.
Subject AS. Regression latency as a function of trial type, item type, and number of stimulus elements.
Subject WH. Mean latency as a function of trial type, item type, and number of stimulus elements.
Subject WH. Regression latency as a function of trial type, item type, and number of stimulus elements.
Subject GM. Mean latency as a function of trial type, item type, and number of stimulus elements.
Subject GM. Regression latency as a function of trial type, item type, and number of stimulus elements.
Subject LG. Mean latency as a function of trial type, item type, and number of stimulus elements.
Subject LG. Regression latency as a function of trial type, item type, and number of stimulus elements.
Subject MCo. Mean latency as a function of trial type, item type, and number of stimulus elements.
Subject MCo. Regression latency as a function of trial type, item type, and number of stimulus elements.
Subject MCg. Mean latency as a function of trial type, item type, and number of stimulus elements.
Subject MCg. Regression latency as a function of trial type, item type, and number of stimulus elements.
Subject LB. Mean latency as a function of trial type, item type and number of stimulus elements.
Subject LB. Regression latency as a function of trial type, item type, and number of stimulus elements.
Subject CP. Mean latency as a function of trial type, item type, and number of stimulus elements.
Subject CP. Regression latency as a function of trial type, item type, and number of stimulus elements.
REFERENCES


