An Investigation of Cognitive Factors involved in the Development of Problem-solving Strategies by Young Children

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ABSTRACT

There is much current interest in children's problem-solving, both within education, and within psychology.

The present study explores the development of young children's problem-solving abilities, and the cognitive factors which might be related to this. Such development is conceptualised in terms of the emergence of increasingly sophisticated and powerful cognitive strategies.

In a previous study (Whitebread, 1983), which involved 20 children aged 5 and 6 years, a strong interaction was revealed between underlying cognitive factors, strategy use and performance on a reclassification task. The present work is an extension of that study with a more complex task, and with a wider age-range of children. On this occasion, children's performance on an inductive reasoning task (the multidimensional discrimination learning task) was examined. The sample consisted of 72 Leicestershire Primary school children, comprising three equal groups of 24 children aged 6, 8 and 10 years.

The children were tested on a number of cognitive factors theoretically predicted to influence performance on reasoning and problem-solving tasks. These predictors included working memory capacity, metacognitive awareness and control, style of attribution, and two measures of cognitive style (cognitive tempo and field dependence-independence).

Cluster analysis of strategic components revealed a pattern of 7 clusters of increasingly complex strategic behaviours used by the children on the MDL task. These Strategy Clusters appeared to be principally differentiated by an increasing ability to integrate information gained from different trials. Two stylistic variations were also identified which were related to the number of hypotheses verbalised on each trial.

Further investigation involving multiple regression analyses revealed that the major factor which predicted strategic behaviour and performance on the MDL task was metacognitive awareness and control. However, correlational analyses of subgroups revealed interactions between predictors, and between predictors and strategies, in relation to performance. No significant effects were revealed relating to gender, but age effects in relation to predictors, strategies and performance were indicated.

The implications for future research and for the development of children's thinking and problem-solving skills within educational contexts is discussed.

Chapter 1. OVERVIEW

This first chapter provides an overview of the whole thesis, including the educational and psychological rationale behind the empirical study carried out, the design of the study, and the main results and implications. It may be useful to those not wishing to read the whole thesis, or for the reader who is familiar with the field of research and wishes to get an overview of the argument before looking at the details. The detailed argument of the thesis begins at the start of the next chapter, and some readers may wish to start at that point.

Both within education and within developmental psychology there is much current interest in children's developing abilities to think, to reason and to solve problems.

Within education there is a revival underway of interest in a pedagogy of 'active learning'. Curriculum developments enshrined within the new National Curriculum explicitly encourage problem-solving and investigational approaches. There is also what can only be described as a blossoming of interest and enthusiasm in teaching children to think.

All this is probably partly a consequence of, and is certainly informed by, work within developmental psychology over the last 15 years or so concerned with the reasoning and problem-solving abilities of young children. Like much of modern developmental psychology, this work, at least in part, owes its origins to the contribution of Piaget, and to subsequent studies examining Piaget's model of cognitive development, together with his various claims about the thinking and abilities of young children.

The ensuing analysis and exploration of factors involved in the developing cognitive systems of young children has been very productive. It has been largely carried out, however, within the other major paradigm of modern cognitive developmental psychology, the information-processing approach. This was originally developed by such as Klahr & Wallace (1976) and Simon (1978).

Studies of the development of children's problem-solving abilities have been wide-ranging, and have looked at a number of different kinds of problems within different domains. Within the literature, however, the study of problems involving inductive reasoning, with the possible exception of the use of analogy, has been relatively neglected. This is despite the fact that Glaser & Pellegrino (1987), for example, have indicated the centrality of inductive reasoning within human learning. The present study, therefore, attempts to redress this balance somewhat by investigating children's problem-solving behaviour on a task involving inductive reasoning.

The general educational background to the current study, and particularly the resurgence of interest in children's problem solving, is set out in a little more detail within the next chapter. Chapter 3 reviews the psychological research literature in more detail which relates to problem solving and reasoning by young children, the particular inductive reasoning task used within the present study, and the work which has attempted to uncover the cognitive developments underlying children's increasingly sophisticated abilities to think, to reason and to solve problems.

Research arising from Piaget's approach to children's problem solving and reasoning has demonstrated that children are often capable of sophisticated reasoning in a context which makes sense to them, and relates to their experience. A range of studies have indicated that the development of children's performance on problem solving tasks is a consequence of developing features of their underlying cognitive systems, rather than on their abilities to reason. Work within the information processing framework has focussed on children's development of increasingly sophisticated strategies, and the mechanisms by which these are developed and executed.

Within the present study children's performance on a multidimensional discrimination learning task was examined. The sample consisted of 72 Leicestershire Primary school children, comprising three equal groups of 24 children aged 6, 8 and 10 years. The MDL task was chosen as being a useful, and of late a rather neglected, vehicle for examining children's inductive reasoning. It is a task which has a long history within the study of human learning. Both Bruner, Goodnow & Austin (1956), in their classic study of concept attainment, and Gholson (1980) in his and other's studies of hypothesis-testing, have provided analyses of the strategies available to the learner when faced with this task. Within the present study an attempt has been made to use and build upon methodologies developed by this previous research, and to provide a systematic and comprehensive analysis of the development of children's strategies. Previous work with discrimination learning has focussed on young children's developing abilities to deal with negative information and irrelevancy. These two factors are accommodated and investigated within the present design by the presentation of the MDL task in different problem types.

The final part of the literature review examines the range of underlying cognitive factors which have been explored and advanced as significant within the development of children's thinking, reasoning and problem-solving abilities. As Voss (1989) has recently indicated in a useful overall review, analyses of problem-solving have suggested that it involves a wide variety of different cognitive processes.

The manner in which the problem is understood and represented has been found to be crucial to success, as has the construction of sophisticated and highly structured knowledge within the particular domain. These two factors are clearly very strongly interrelated, and the discussion of underlying cognitive factors begins with them. It has long been established that performance on a task is strongly influenced by domain specific knowledge (see, for example, Chi's (1978) classic work on memory for chess positions). Donaldson (1978) and her co-workers have also established that a child's understanding and performance on a task is significantly affected by its relationship to their existing knowledge.

Within the present study, however, no attempt has been made to explore this particular issue further. Rather, the focus of the present study is children's ability to generate strategies on a novel task. As English (1992) has recently reviewed, the relative significance of domain-specific knowledge and domain-general strategies in the development of problem-solving competence is a much debated issue, and it is clear from the literature that the good problem-solver needs both.

Therefore, while the focus of the present study is on the generation of strategies, the significance of children's existing knowledge has very much been taken into account. Thus, the form of the MDL task is based closely on a version designed by Kemler (1978) using a story-and-game context. This is designed so that, in Donaldson's (1978) words, the problem will make "human sense" to young children, and their comprehension of the problem and their ability to develop strategies to solve it will be maximised. Kemler produced results to show that children performed much more effectively on her task than on the standard, abstract MDL task.

The related issue of representation is, however, an important part of the present study. For Siegler (1978), the development of effective problem-solving was seen as mostly dependent upon the manner in which the problem was encoded by the child, and much other research has indicated the significance of the efficiency with which a problem is represented for subsequent performance (See, for example, Johnson-Laird's (1983) work on the construction of 'mental models'). Within the present study the efficacy with which children represented the problem to themselves is construed and examined as an aspect of metacognitive knowledge about the task, which is discussed below.

The development of increasingly sophisticated strategies has been a strong theme within the problem-solving literature. Siegler's (1978) study is also of significance because it is an early example of an attempt to determine the progression of strategies used within a particular context (in his case, the balance beam problem). This is based on a methodology whereby children's strategies are inferred from their pattern of responding. A modified and developed version of this approach is used within the present study, however, which recognises the complexity of the development of strategic behaviour.

Children's responses are analysed in terms of Strategic Components and the patterns in which these components combine together at different stages of strategic development is explored using the statistical technique of Cluster Analysis.

The remainder of the review examines the claims of a number of underlying cognitive factors which have featured prominently in the literature as causal factors in the development of children's problem-solving abilities. The first included is what is sometimes construed as working memory capacity, and elsewhere as speed of processing in short-term memory. The significance of differences in the area of memory was first claimed by neo-Piagetians such as Pascual- Leone (1969,1970) and Case (1974, 1984, 1985). More recently, work by such as Anderson (1992) has suggested that the speed of basic processing is an innate biological factor closely related to the development of intelligence. Here the significance of content knowledge has once again been taken into account, and the FIT measure of general M-space devised by Pascual-Leone (1969) has been used alongside a specially constructed short-term memory test using the materials contained within the MDL task itself.

Over the last 15-20 years perhaps the largest area of growth in the literature of cognitive development has been that related to metacognition, beginning, of course, with the seminal study of Flavell, Beach & Chinsky (1966) (which, interestingly, shared a common concern with 'mediational processes' with studies of discrimination learning at that time). Since the term 'metamemory' was introduced into the literature by Flavell (1971) there has been considerable debate about the significance and definition of metacognitive processes. In a major review of these difficulties Brown (1987), however, asserts her view that

"metacognitive-like concepts lie at the very roots of the learning process" (p.66)

Certainly, Ann Brown and her co-workers have been one of the major research teams to firmly establish metacognition at the heart of the current revival of interest in mechanisms of change and development. There is now hardly an aspect of human functioning or skill which does not have its associated 'meta' component well documented and researched.

Within the present study the distinction first proposed by Flavell (1981) between metacognitive knowledge and metacognitive experience has been followed. As regards metacognitive knowledge, Yussen (1985) and others have reviewed the conflicting evidence about the relationship between metacognitive knowledge and performance. Early studies of this relationship tended to conclude that only a weak relationship existed. Later work, however, has indicated that metacognitive knowledge may be more closely linked to performance where it is directly related to the individual's metacognitive experience of that task. Within the present study, therefore, rather than exploring the children's general metacognitive knowledge about their own cognitive processes, questions have been asked which focussed on the metacognitive knowledge they had derived directly related to the MDL task. These questions focus on the children's experience of the relative ease or difficulty of different versions of the task. As indicated above, this knowledge can also be taken, at least in part, as evidence of the efficacy with which the children internally represented the problem.

Within the area of metacognitive experience the distinction between a monitoring and a control function has been adopted from Brown's (1978) earlier detailed analysis of the necessary components of a metacognitive system. These are referred to by her as Metacomprehension and Insight. The first term is retained within the present study, while the latter control element is characterised as Strategy Flexibility. Tasks have been developed within the present study to measure these aspects of the children's functioning, under the general heading of Metacognitive Awareness & Control.

Finally, various aspects of what might be termed 'learning style' have been included within the analysis. It is a matter of common observation that children's approaches to learning and solving problems vary not only in their effectiveness but also in their style. Within the present study there has been included an element related to the children's style of attribution, and two measures of cognitive style (cognitive tempo and field dependence-independence). The relationships between style of attribution (as originally conceived and developed by Weiner (1972, 1979)), self-concept, and achievement has long been established and explored within educational contexts. Rogers (1982) provides an excellent review of the extensive literature in this area. Weinert (1987) has argued that research related to style of attribution has indicated similarities and significant conceptual links between this as an aspect of motivation and metacognition as an aspect of cognition, and there is interesting work demonstrating links between the two areas. Kurtz & Borkowski (1984), for example, in the context of certain memory tasks, have found significant relationships between aspects of metacognition, attribution and strategic performance. Within the present study the Children's Attribution of Responsibility and Locus of Control Scale (CARALOC) developed by Gammage (1975, 1982) was used. This scale has been specifically designed for use with English Primary school children and has been shown by such as Osborn & Milbank (1987), in a major longitudinal study, to be significantly related to achievement in a number of cognitive areas.

Cognitive style has also been a huge area for research over the last 20 years or so, and has been particularly related to different strategies of approach to solving problems of various kinds. Kogan (1971, 1983) has provided extensive reviews of work in this area, and these two reviews provide a useful insight into the development of research and thinking in the area. The interesting point to note is that while he felt obliged to review at least 9 separate cognitive style dimensions in 1971, by 1983 he felt that only two had proved sufficiently fruitful in the intervening period to be worthy of inclusion. These were Reflectivity-Impulsivity (Cognitive Tempo or R-I) and Field Dependence-Independence (FDI).

Cognitive Tempo was originally conceived and operationalised by Kagan et al (1964), who developed the Matching Familiar Figures Test (MFFT), which is still the most commonly used instrument. Subsequently there have been significant theoretical and methodological advances. At the theoretical level Zelnicker & Jeffrey (1979), for example, have redescribed the dimension in terms of different strategic approaches to processing information. Research has continued to demonstrate the significance of this dimension for cognitive functioning., and explored its relationship to other features. Borkowski et al (1983), for example, demonstrated significant relationships between cognitive tempo, metamemory, strategy use and performance on particular memory tasks.

At the methodological level, the MFFT came in for considerable criticism, leading to the development by Cairns & Cammock (1978) of a longer and more reliable version, which is known as the MFF20. It is this latter instrument which has, therefore, been used within the present study.

Perhaps the single most well-known and certainly the most intensively researched dimension of cognitive style is that of Field Dependence-Independence conceived and developed by Witkin and his associates. The FDI construct was first conceived as an aspect of basic perceptual processes (Witkin et al, 1954) and was then developed into a more general theory of psychological differentiation and cognitive style. It has subsequently been explored in relation to a wide range of cognitive functioning (see, for example, Goodenough's (1976) early review in relation to learning and memory). Interestingly, Pascual-Leone (1969) incorporated FDI into his neo-Piagetian model of cognitive development and successfully used it to explain the phenomenon of low inter-task correlations between Piagetian tasks at the same developmental stage. Witkin et al (1977) developed the case for significant educational implications of FDI. Kogan (1983) reviews work on the relation of FDI to various educational achievements and learning difficulties.

Two key instruments have been devised and used as measures of FDI, the Rod & Frame test (RFT) and the Embedded Figures Test (EFT). Kogan (1983) reviews the evidence that while these two instruments are both tapping the ability to overcome an embedding context, they may be assessing rather different aspects of this. Current methodological advice appears to be to use both instruments and to use both scores, or produce a composite score. Within the present study, therefore, the RFT was used as well as the Children's Embedded Figures Test (CEFT), a version of the EFT devised for use with young children (see Witkin et al (1971)).

In addition to this fairly comprehensive collection of measures of underlying cognitive functioning gender and age were also included in the analysis. This was done partly as a check that the materials and procedures were not gender biased, and that younger children were enabled to display their problem solving abilities. It also had to be considered that gender and age-related differences in certain areas of cognitive functioning, reported in the literature, would appear in relation to performance on the MDL task. As regards age, for example, issues arise in relation to the general pattern of development (eg: linear or U-shaped ?) and recent evidence that the correlations between underlying abilities and performance increase with age (see Schneider & Weinert (1989).

Chapter 4 provides details of the aims and design of the present study. The problem-solving literature, as noted above, has increasingly emphasised the development by children of cognitive strategies. Bjorklund (1990), for example, has recently edited a very comprehensive collection of work carried out in this area. The present study aims, therefore, firstly, to identify the strategies used by children when they are engaged with an inductive reasoning task such as the MDL task, and to map out the way in which these strategies develop. The relationship between strategy use and level of performance on the task is explored. Finally, the study aims to investigate the relationship between a range of underlying cognitive factors, strategy use and performance. In a previous study (Whitebread, 1983), which involved 20 children aged 5 and 6 years, a strong interaction was revealed between underlying cognitive factors, strategy use and performance on a reclassification task. The present work has, therefore, also been conceived as an extension of that study with a more complex task, and with a wider age-range of children.

The outline of the structure of the study begins with details of the procedures for 3 different problem types of the MDL task. As indicated earlier, these different problem types required the children to deal with negative information and irrelevant information, as well as the standard MDL task. The analysis of the children's responses to the MDL task is detailed in terms of 10 Strategy Components and 3 Performance Indicators. Both the Strategy Components and Performance Indicators are derived from previous research, principally that contained in Gholson's (1980) collection of studies of children's hypothesis-testing behaviour on the MDL task. Details of the measures of the various underlying cognitive factors are also provided. These are referred to throughout the rest of the study as the Predictor Measures, although, of course, no causal inference is necessarily implied by this terminology. The interrelationships between these various aspects of cognitive and metacognitive functioning, the development of strategic processing and performance on an inductive reasoning task is a central part of the debate within this thesis.

Chapter 5 contains the report and analysis of the results obtained. Cluster Analysis of the scores for Strategy Components on the 3 different MDL problem types revealed a pattern of 7 clusters of increasingly complex strategic behaviours, within which 5 main clusters appeared in sufficient numbers to be worthy of further analysis. Discriminant Function Analysis of these 5 main strategy 'clusters' revealed that they appear to be clearly distinct groupings (although detailed analysis of individual 'central cases' within clusters reveal some interesting variations within groupings). The different patterns of strategic behaviour revealed by the Strategy Clusters are principally differentiated by an increasing ability to integrate information gained from different trials. Two stylistic variations were also identified which appear to be principally related to the number of hypotheses verbalised on each trial.

Analysis of scores on the Performance Indicators revealed that the children in this sample performed at least as well as those in Kemler's (1978) study, if not better, thus confirming that the form of the MDL task used enabled 6-10 yr. old children to use their problem-solving abilities effectively. A developmental sequence was also revealed between the Performance Indicators representing a developmental sequence in the sophistication of understanding of the task by young children. There are strong relationships between patterns of strategic behaviour revealed by the Strategy Clusters and performance. An attempt was made within the present study to examine learning on the MDL task but this was not particularly successful, although a few interesting pointers emerge.

In the last section of the analysis of results the relationships are examined between the Predictor Measures and strategic behaviour and performance. Correlational analysis revealed that Gender was the only Predictor Measure which was not significantly related to either strategic behaviour or performance. If nothing else this would tend to be reassuring that the materials and/or the methodology used within the study were not gender-biased.

All other Predictor Measures were clearly and positively correlated with performance, although at generally moderate levels, indicating that the relationships might not be simple linear ones and might involve some interactions between predictors as had been found in the author's previous study (Whitebread, 1983). Interestingly, after Gender, the next weakest Predictor Measure in its correlations with Strategy Components and Performance Indicators was the Rod & Frame Test, while the CEFT was amongst the strongest. This indicates support for the view that these two instruments tap into different aspects of FDI, and the MDL task seems to be much more clearly related to the aspects of functioning measured by the CEFT. Along with the CEFT, the other Predictor Measure most strongly associated with strategic behaviour and performance as measured by simple correlations was Metacognition, and within that Metacognitive Awareness and Control rather than Metacognitive Knowledge.

Analysis of the relationships between Predictor Measures and Strategy Clusters revealed clearly distinct patterns of underlying cognitive factors associated with each of the clusters, and, once again, the CEFT and Metacognitive Awareness and Control were the most strongly discriminating between clusters. On this occasion, an intriguing relationship emerged between Metacomprehension and strategic style. Two of the five main Strategy Clusters appeared to share a strategic style involving the production of a high number of hypotheses on each of the trials of the MDL task, a style which in some ways appeared to be interfering with their performance on the task, and yet these clusters both scored strongly on the test of Metacomprehension.

As a further means of disentangling the relationships of the underlying cognitive factors and patterns of strategic behaviour with performance Multiple Regression Analyses were carried out, and they revealed that the major factor which predicted strategic behaviour and performance on the MDL task was Metacognition. Pattern of strategic behaviour was also confirmed as a clear predictor of performance, and even some relation with learning emerged in this analysis. Some support was offered for the view that the Strategy Clusters not only represent different stages in the development of strategic behaviour in relation to the MDL task, but also a development in the ability to learn quickly and apply general strategies in relation to new tasks.

The final part of the analysis of the data from the study consisted of correlational analyses of subgroups within the sample. Evidence from earlier parts of the analysis suggest that there might be significant interactions between underlying cognitive factors, strategic behaviour and performance, and that there might be non-linear developmental relationships present (such as those discussed, for example, in Strauss & Stavy's (1982) review of U-shaped behavioural growth). Within the Multiple Regression Analyses, for example, a considerable amount of the variance was attributed to interactions between Predictor Measures and Strategy Cluster variables. Analyses of subgroups based upon Metacognition and Strategy Clusters confirmed interactions of the kinds predicted, and found earlier in the study of reclassification (Whitebread, 1983). The analysis of age subgroups revealed quite a strong U-shaped developmental pattern of relationships, with a number of Predictor Measures significantly related to performance at ages 6 and 10, but almost completely unrelated amongst the 8 yr. olds.

Following a summary of the main findings of the study in relation to the original aims, a discussion of methodological issues arising from the study is provided in the following chapter, headed Summary & Discussion. Amongst the methodological issues which arise are the successful use of tasks placed in relatively meaningful contexts for young children, and the utility of Cluster Analysis as a way of revealing patterns of behavioural development. The limitations of this kind of cross-sectional study are also discussed, however. While this kind of methodology serves some purposes well, as illustrated in the present study, this may be usefully complemented by studies employing some kind of longitudinal design (the potential of which has been thoroughly argued, for example, by Hoppe-Graff (1989)), and by studies employing the kind of 'microgenetic' approach so well illustrated by Siegler & Jenkins' (1989) recent study of new strategy acquisition. The advantages and disadvantages of using a fairly artificial, 'well-defined' problem such as the MDL task, as opposed to real world problem-solving, are also discussed.

The final section of this last chapter concludes the thesis by examining the implications of the present study and related work in the area for psychological theory and research, and for educational practice. Amongst the issues raised in relation to psychological research are the value of analysing children's behaviour on tasks in terms of their cognitive strategies, and the need to get away from simple, single factor models of cognitive change and the development of problem-solving skills. Analyses of problem-solving, including that contained within the present study, suggest that it involves a wide variety of different cognitive processes. Current research exists (see, for example, Folds et al (1990), Bjorklund et al (1990) and Howe & O'Sullivan (1990) all contained within Bjorklund's (1990) useful collection of recent work on children's strategies, and English (1992)) which has begun to illuminate the ways in which these different processes and abilities interact and relate to one another, and this work needs to be continued and developed. In particular the central issue of the factors which facilitate transfer of learning and strategies to new domains and new tasks must be an important focus.

Within the educational sphere, a number of issues arise. Teachers need to know which factors are involved in the development of children's abilities to think, to reason and to solve problems. A substantial literature now exists which has established a number of the most significant factors, and it is hoped that the present study makes a contribution to that. As reviewed in the next chapter, there is a strong, emerging interest in active, problem-solving approaches to learning and in teaching children to think. There is still much to be done, however, in raising teachers' understanding of the cognitive skills which enable children to tackle novel tasks and problems, or how they 'learn how to learn'. Models of the 'Good Strategy User' like that suggested by Pressley et al (1987) are valuable in this regard.

Teachers also need to be aware of the issues in relation to teaching children to develop these skills. The debate, for example, about whether general problem-solving strategies can be taught, or whether teaching can only operate within subject domains, is relevant here. So are the emerging Vygotskian models of the teacher as mediator of the child's experience and notions of 'cognitive apprenticeship' (see Collins, Seely-Brown & Newman (1987)). Finally, the evidence of this study and much of the associated literature would suggest that a key element in any programme to help children develop these kinds of abilities must be the development of metacognitive abilities. The work in Britain of such as Nisbet & Shucksmith (1986) and in America of such as Borkowski , Brown and their co-workers (see, for example, Pressley, Borkowski & O'Sullivan (1985) and Campione (1987)) has demonstrated that metacognitive abilities can be developed through teaching, and has begun to indicate the kind of pedagogical principles upon which such teaching must be based.

Chapter 2. BACKGROUND: Problem-solving and Primary Education

There is much current interest in young children's problem-solving. This is true at the level of the Primary school classroom, and within the literature of developmental psychology. Of course, it is often the case that work in these two different spheres is mutually reinforcing and influential. Both are also affected by, and influential upon, current socio-political movements and concerns. So it is the case that there is much talk at the moment within the political sphere of the need for a flexible workforce. Within the educational world there is a recognition that today's children are growing up in a changing world. Providing them with a body of knowledge which seems appropriate at the moment is not adequate to their needs; they need to learn how to learn, to think, to reason and to solve problems for themselves.

Current cognitive developmental models of the child emphasise the active nature of the young learner searching after meaning. Recent work, in particular, has revealed the very early emergence of reasoning and problem-solving capabilities in young children. Yet, it is also clear that there are very considerable individual differences between children in their abilities to think and to learn. The present study is intended as a contribution to our knowledge about the ways in which children's abilities to reason and to solve problems develop, and the factors which might crucially affect individual differences. This is clearly of interest to the developmental psychologist, and also to the teacher of young children.

Before setting out the aims of the present study in detail, however, it will be helpful to review the development of the current interest in children's problem-solving within education and psychology. The next two chapters are devoted to this review. Where issues or research have directly influenced the design and content of the present study this is also indicated (both the review of research and the report of the present study are carried out in the past tense; it is hoped that the explicit indication of the relation between previous work and the present study will be clear enough without resorting to the rather artificial device sometimes used of referring to the present study in the future tense).

An interest in children as problem-solvers within education is not, of course, a new development. The view that young children's learning is best regarded, and best encouraged, as a problem-solving process can be traced back, within modern times, as

Williams (1985) points out, at least as far as Dewey's concern to replace didactic teaching methods with the creation of child-centred learning situations. Bruce (1987), in her review of the ideas of Froebel, Montessori and Steiner, picks out a belief in the value of intrinsic motivation, resulting in child-initiated and self- directed activity, and in allowing the child to interact with their environment, as key principles shared by these pioneers of early childhood education. In the 1960's and 70's Piaget's notion of the child as an active constructor of its own understandings was eagerly embraced by British Primary school teachers, and provided the intellectual underpinnings for a more general adoption of child-centred, activity based learning.

There has been, however, within the British educational system, a notable resurgence of interest in the development and encouragement of children's thinking, reasoning and problem-solving skills over the last decade or so. This new movement, furthermore, has been accompanied by a new and more detailed analysis of the pedagogical and cognitive factors involved in this way of working. This renewed interest is undoubtedly the result of a conjunction of educational, socio-political and psychological factors. We will return to developments within the psychological literature in the next section. It is worth briefly reviewing here, however, the relevant educational and socio-political developments. In general terms these have related to three broad strands: the pedagogy of 'active learning', curriculum developments, and teaching for thinking. We will look at each of these in turn.

Section A) The Pedagogy of 'Active Learning'

In relation to pedagogy, in today's classrooms this broadly 'child-centred' tradition of ideas has translated into a set of principles which Kyriacou, Brown and Constable (1990) have recently described as 'active learning'. This approach, they suggest, embodies five key concepts : the use of concrete materials and direct experience, the use of small group work, pupil ownership of the learning process or task, personal focus and relevance of the learning process or task, and the use of investigational or problem-orientated techniques. This increased interest in 'active learning' has been supported at the level of pedagogical theory by the publication of a wide range of books exploring and advocating the use of active, investigational and child-centred approaches (see, for example, Dennison and Kirk (1990), Hunter and Scheirer (1988) and Rowland (1985)). Such works have explored ideas about ownership, control, negotiation, discovery, meaningfulness, personal relevance, the process-oriented curriculum and so forth which have become the currency of contemporary pedagogical debate.

At the level of classroom practice, Fisher (1987), reviews work carried out across the Primary curriculum and throughout the UK embodying a problem-solving approach. This includes work done in relation to writing from Wiltshire and Croydon, maths problems from Hull and West Sussex, problem-solving with control technology from Richmond, designing and making from the East Midlands and Yorkshire, historical investigations, decision-making in art, moral problems and much more. The bibliographies attached to each of the sections of this book are a testament to the multitude of practical problem-solving and investigational projects, initiatives and publications related to the Primary phase which have been carried out and produced within the UK in recent years.

While it is not of direct concern to the present study, it is worthy of note that, at the level of Secondary education, the picture is very similar. Kyriacou (1992), for example, reviews the extensive changes towards more 'active' styles of learning carried out in Secondary school mathematics over the last decade, while Watts (1991) reviews the field more generally, highlighting the multiplicity of approaches to problem-solving now being adopted across the Secondary school curriculum. This latter author provides several useful case studies, and goes on to discuss issues of planning, classroom management and assessment.

As each of these authors comment, these pedagogical initiatives have very much been encouraged by official curriculum reviews and reports, by Her Majesty's Inspectorate and, latterly, the National Curriculum Council. As long ago as the 1930's the Hadow Report (1931) urged the need for more active and experiential methods of learning. This view was, of course, reiterated strongly by the Plowden Report (1967), although the impact of this report on classroom practice is now recognised to have been much overstated. HMI reports over the last 10-15 years, for example, have continued to bemoan the over-preponderence of didactic teaching and practice, rather than application, of basic skills in Primary classrooms, and the lack of opportunities for problem-solving. Thus, in 'Better Schools' (DES,1985a), they report that:

"In about half of all classes much work in classrooms is so closely directed by the teacher that there is little opportunity either for oral discussion or for posing and solving practical problems." (para. 19)

This concern to develop more investigational and problem-solving approaches within classrooms has, of course, been part of the general move in education over the last twenty to thirty years away from the simple transmission of facts and towards an approach which emphasises much more the processes of learning. This move has been supported by a plethora of research studies aimed at developing teaching programmes and methodologies more securely based in psychological understandings about how children learn.

Amongst the earliest of these attempts to produce a 'cognitive curriculum' were those by Bruner (1966) and a number of preschool teaching programmes based upon Piagetian ideas, mainly developed in the United States, (see, for example, the review by Brainerd (1983a)). The general influence of Piagetian ideas within the British Primary school system is, of course, well documented, although, as with the Plowden Report, probably overstated. That Piagetian ideas have been widely invoked to give an intellectual or academic rationale to the general move towards a more 'active' pedagogy, however, is not in doubt.

Information-processing approaches to thinking and learning subsequently spawned a huge research effort during the 70's and 80's, again principally within the United States, aimed at developing cognitive curricula and instructional programmes. These have been mainly concerned with the development of cognitive skills and strategies, problem-solving abilities and the problems of transfer and learning how to learn. Phye and Andre (1986), for example, provide a good review. Nisbet and Shucksmith's (1986) work in Britain concerned with developing metacognitive learning strategies is very much in this tradition. Most recently, Vygotskian approaches to learning and instruction, emphasising the mediation of knowledge by the teacher, have made a contribution in the ideas of such as Tharp and Gallimore (1988) in the States and Meadows and Cashdan (1988) in Britain. We will return to look at some of these programmes and developments in more detail when we come to consider the educational implications of the present research.

Section B) Curriculum developments

Despite some claims to the contrary, this trend away from 'product' and towards 'process' has been continued and embodied within the National Curriculum. As Fisher (1987) writes:

"This approach moves from simply teaching the children the facts of language, mathematics, history, geography, science and other 'disciplines', towards encouraging children to be scientists, historians, geographers, linguists and mathematicians, through the use of appropriate problem-solving skills and processes." (Introduction)

It is, of course, impossible to separate out the way that children are taught from the content of what they are taught. A new pedagogy inevitably affects both methodology and curriculum. This is most clearly embodied within the National Curriculum. While it is not appropriate here to illustrate this point in detail for all the different subjects, we might take Mathematics as a good example. Within Mathematics, Attainment Target 1 is concerned with 'Using and Applying Mathematics' (DES, 1991a). This new emphasis within Mathematics stems very largely from the influential Cockroft Report (1982), which stated that:

"The ability to solve problems is at the heart of mathematics. Mathematics is only 'useful' to the extent that it can be applied to a particular situation and it is the ability to apply mathematics to a variety of situations to which we give the name 'problem-solving'." (para 249, p.73)

The encouragement in this report (and in the subsequent report by HMI (DES,1985b) 'Mathematics from 5-16') for investigational and problem-solving approaches has been a major factor in the gradual transformation of Primary school mathematics. Numerous publications have embodied this approach, and provided teachers with ideas and support (see, for example, the Association of Teachers of Mathematics' Inset and Resource pack "Towards the Problem Solving School", the magazine "Strategies: Maths & Problem-solving 3-13", Charles (1985) and Whittaker (1986)). A similar picture of increasing concern for processes, to different degrees, could be drawn in relation to each of the other National Curriculum subjects.

Official reports and recommendations regarding teaching methods and the curriculum have, of course, at least in part, arisen as a response to socio-political as well as purely educational issues and developments. This has been nowhere more evident than in the new emphasis within the Primary school curriculum upon Science and Technology. While this development is clearly to a very large extent a consequence of a political imperative to provide a more technologically literate workforce, the move towards a more problem-solving approach is also evident within it.

Thus, Attainment Target 1 within the new Science National Curriculum (DES, 1991b), which counts as 50% of the subject for assessment purposes, is concerned with the skills and processes of 'Scientific Investigation'. This has been, at least in part, the outcome of the considerable amount of research concerned with children's thinking and learning in science, and the implications for teaching, carried out by such as Wynne Harlen (see Harlen & Osborne (1985)), the Children's Learning in Science Project (CLIS) at Leeds University (see Driver (1983)) and others. At the Secondary level, as Adey (1990) points out, the 'Thinking Science' materials produced by the Cognitive Acceleration through Science Education (CASE) project (Adey, Shayer & Yates, 1989), are an attempt to use psychological evidence about how children construct their own understandings of the world to help them develop the cognitive skills of 'formal operational' thinking (we will return to the influence of Piaget later).

But perhaps the single most significant curriculum development within the National Curriculum, and the one which most powerfully embodies the new emphasis on children learning by solving problems, is the Design and Technology Capability element within the Technology curriculum (DES, 1990). It is described thus within the Non-statutory Guidance:

"Design and Technology describes a way of working in which pupils investigate a need or respond to an opportunity to make or modify something. They use their knowledge and understanding to devise a method or solution, realise it practically, and evaluate the end product and decisions taken during the process." (Section A.1.2)

Tickle (1990) has reviewed the manner in which CDT gradually emerged in the 80's as a Secondary school, and then a Primary school, subject. It was first included in an official curriculum document by HMI in 'The Curriculum from 5-16' (DES, 1985c). At the Primary level it was given a boost first by the publication of the seminal work of

Williams and Jinks (1985), and then by the implementation by the Department of Trade and Industry of the curriculum development project 'Problem Solving 5-13' (Sellwood, 1987). HMI produced a report in the 'Curriculum Matters' series (DES, 1987) and the Design Council (1986) declared an early interest, which has continued with numerous support materials and a regular magazine devoted to Primary Design & Technology ('The Big Paper'). Originally included within the remit of the National Curriculum Council working group for Science, Design and Technology (together with Information Technology) was then established as a separate subject in its own right. Over the last 2-3 years there has been an enormous explosion of publications aimed at supporting Primary school work in this area, from the National Curriculum Council, LEA's and commercial publishers.

While there has been controversy over the new balance and relationship between intellectual and practical elements within Design & Technology (the omission of the word 'craft' is significant here), it is clear that the problem-solving approach will remain fundamental to this area. Sellwood (1991) has recently produced a detailed analysis of and rationale for 'The Investigative Learning Process' in the Design and Technology Association's journal, within which he elaborates a 'Practical Problem-solving Model' of teaching and learning which he argues is fundamental to work within Design and Technology, and is applicable across the curriculum. Within this article he makes the following assertion, which states very clearly the new recognition of the significance of problem-solving for the teacher and the now well established position of cognitive developmental psychology:

"While children are exploring, discovering and investigating the world around them, they are inevitably involved in problem-solving of various kinds. The development of skills that can recognise, analyse and then solve problems are fundamental to intellectual development and are, when suitably planned, exercised and monitored, the vital skills of 'learning how to learn'" (p.4)

He goes on to propose a detailed model for teaching the skills of problem-solving, to which we will return in our discussion of educational implications at the end of the present study.

Section C) Teaching Children to Think

The final strand of development which relates to this renewed interest in children as problem-solvers concerns the emergence of 'teaching for thinking' programmes.

As a number of commentators have noted, much of this work initially originated in the U.S.A. where an interest in teaching thinking and problem-solving seems to have developed a little earlier than in Europe and Britain (see, for example, Tuma & Reif (1980), which contains interesting accounts of various programmes for teaching problem-solving skills, mostly to college students, and Baron & Sternberg (1987) for a more recent and excellent review of American work in this area).

Although it is apparent that a considerable amount of work was being carried out in Europe and Britain, until fairly recently, it was all relatively isolated and unreported. Over the last few years, however, partly as a result of the burgeoning interest within the educational and public/political communities noted earlier, there has been a flurry of conferences, publications and other activity. Maclure & Davies (1991), under the title "Learning to Think: Thinking to Learn", edited the proceedings of an OECD Conference organised by the Centre for Educational Research and Innovation (CERI) in July 1989. This was attended by 120 participants, 60 of whom were actively engaged in psychological and educational research related to this area. De Corte et al (1987) and Mandl et al (1989) have edited the proceedings of conferences held by the newly formed European Association for Research on Learning and Instruction (EARLI), much of which have been concerned with learning to learn, metacognition and problem-solving, all issues central to the teaching for thinking literature. Nisbet & McGuinness (1991) produced a detailed review of extensive work in progress on the teaching of thinking skills and strategies across the different regions of Europe and within Britain. Fisher (1990) and Coles & Robinson (1991a) have produced reviews of the rapidly growing work within Britain.

As evidence of the current level of interest in the teaching of thinking within Britain, Coles & Robinson (1991a) cite the 10,000 requests received for the supporting booklet to the BBC's series "The Transformers" (a series of films featuring the work of Lev Vygotsky, Reuven Feuerstein and Matthew Lipman) and the surprising and gratifying rapid sell-out of the first edition of their book published in 1989. This book contains, amongst other things, reviews of the work of Feuerstein ('Instrumental Enrichment') and

Lipman ('Philosophy for Children'), and of the Thinking Skills courses developed in Oxfordshire and Somerset based upon elements of these programmes. The efficacy of these and other courses has been the subject of recent hot debate within the Education Section of the British Psychological Society (see Burden (1993) and replies by Adey (1993) and Blagg (1993)). Nisbet (1991a) even reports that the National Curriculum Council have set up a Task Group to consider learning and thinking skills as a cross-curricular theme, although nothing has been officially heard of their deliberations as yet.

While it would not be appropriate to review all the many different approaches to the teaching of thinking within the present context, a number of general issues of interest arise. First, as a number of commentators point out, there remain basic theoretical differences between psychologists working in this area. Both Maclure (1991) and Nisbet (1991b) characterise one aspect of these differences as being a mostly European attachment to a Piagetian model of developmental stages opposed to the more pragmatic approach of many American researchers, whose main theoretical models, where they have them, tend to be based on information processing approaches. The CASE (Cognitive Acceleration through Science Education) materials of Adey, Shayer and Yates (1989) are a good example of the European, Piagetian influenced approach, while Sternberg's (1986) Intelligence Applied is an example of the American leaning towards an information processing analysis.

The second major debate, so far very much unresolved, is between the 'skills' approach and the 'infusion' approach. On the one hand, Feuerstein et al's (1980) Instrumental Enrichment, Bono's (1976) CoRT material, and much more is predicated on the assertion that there are identifiable thinking skills which can be directly taught. On the other hand, Adey et al's CASE materials, Lipman et al's (1980) Philosophy for Children, and many others are predicated on the assertion that children can only be taught to think via 'infusion' through a process of solving problems in the context of particular subject matter. Both volumes edited by Maclure & Davies (1991) and Coles and Robinson (1991a) have this debate as a central thread of their organisation.

There are, however, a number of common elements running through the vast majority of programmes devised in this area. In the context of the present study it seems appropriate to mention three. First, the crucial role of metacognition in transfer processes is increasingly recognised. In attempting to answer the question "Does 'teaching thinking' work?" Coles and Robinson (1991b) review evaluation studies of various programmes, particularly those of Feuerstein's Instrumental Enrichment and Lipman's Philosophy for Children. They report that both programmes have been shown to work in a number of settings. The test of 'teaching thinking' programmes is usually whether the subjects involved develop generalised improved thinking skills which help them to perform better on novel tasks and problems. To achieve this many programmes place emphasis on the training of metacognitive or 'executive' skills, such as goal-setting, planning and self-monitoring. Coles and Robinson (1991b) refer to Belmont, Butterfield and Ferretti (1982), who reviewed seven studies which provided evidence that transfer of learning skills can be learnt by 'training' metacognitive or 'executive' skills, and concluded that:

"These facts suggest that the deliberate training of superordinate processes will result in important gains in the ability ... to think productively and to solve novel problems. To the extent that productive thinking and novel problem-solving signify intelligence, we may be confident that intelligence can be modified by attending to children's superordinate self-management skills. It is unknown how much improvement can be expected, but we suppose that cognitive researchers have barely scratched the surface." (p.153)

McGuinness (1990) reviews the contents and procedures of a wide range of 'teaching thinking' programmes within the three broad traditions of 'cognitive strategies', 'critical thinking' and 'knowledge restructuring' and concludes that they mostly rely upon enhancing metacognitive skills; furthermore,

"over the years, the role of metacognition has been made more explicit and the variety of metacognitive tools has increased." (p.302)

It is interesting to note, as an example, that Blagg and Ballinger (1991) in their review of their Somerset Thinking Skills course, explicitly discuss the increasing awareness and control by children of their cognitive styles (particularly in relation to Kagan et al's (1964) dimension of cognitive tempo, which is included within the present study).

We will come later to the increasing wealth of psychological research devoted to the exploration of metacognitive processes, and their relation to children's developing abilities to learn and to solve problems. For the moment it is sufficient to note that the significance of 'learning how to learn' is increasingly recognised within the world of education.

The second common feature of many 'teaching thinking' programmes is the recognition of the significance of the quality of the teacher's role in facilitating students' own learning how to learn. This is made most explicit in Feuerstein's model of the teacher as a 'mediator' who selects and organises the world of stimuli for the child. McGuinness (1990), however, demonstrates that such mediation is a recurrent theme, under various other names - teacher modelling, reciprocal teaching, scaffolding, Socratic dialogue and so on - within many successful programmes. As she rightly points out, Vygotsky (1978) is now generally acknowledged as the father of this mediating, social interactionist, view of cognitive development. There is currently a considerable body of research being undertaken to explore the way experts model and scaffold teacher-learner interactions, characterised by Collins, Seely-Brown and Newman (1987) as 'cognitive apprenticeship', and to explore the implications of these processes for the learning of higher order thinking skills (see, for example, Wertsch (1985) and Moll (1990)). While this area of study is not directly relevant to the work carried out here, it has generated considerable interest within the research and educational communities, and it clearly has a direct bearing upon the question of how young children develop metacognitive and problem-solving strategies.

The third common feature of many 'teaching thinking' programmes is an acknowledgement of the importance of the learner's attitudes and motivations and an emphasis upon creating positive learning environments. Nisbet (1991a) reviews a wide range of programmes from both Europe and America which contain this concern as a central element. Most programmes work on the basis that one must not only teach skills, but one must also encourage the disposition to use them. There are numerous findings, to which we shall refer in more detail later (see, for example, Gammage (1982)) which suggest that high self-esteem is a necessary precondition for achievement. There is a general recognition within programmes that positive attitudes to thinking are encouraged in a climate which is tolerant of questioning and exploration, and are discouraged by an emphasis on memorising and an authoritarian regime. Within the present study, the child's attributions in respect of their successes and failures at school are included as a possible factor related to the development of their problem-solving strategies.

Chapter 3. REVIEW OF LITERATURE

Section A) Problem-solving: the Psychological Research

i) Approaches to Cognitive development: children as problem-solvers

This chapter reviews work which has been done within developmental psychology to explore the means by which children develop their abilities to think, reason and solve problems. This first section examines the emergence of an approach to learning within developmental psychology which implies a model of children as problem-solvers. It also reviews work which has attempted to identify key elements in the structure and development of children's general intellectual processing. The second section focuses down onto research specifically related to problem-solving and reasoning. The third section focuses down even further to look at work within this area which has been concerned with inductive reasoning and its role in learning; within this section the emergence of 'hypothesis theory' as an approach to children's concept learning and rule induction is also reviewed. From the work reviewed in each of these sections a number of significant issues emerge which have influenced the design of the present study.

Within modern cognitive developmental psychology problem-solving has become an increasingly significant area of study. Sternberg (1982) has demonstrated that reasoning and problem-solving abilities have always been integral to notions of intelligence, even within early psychometric conceptions. Over the last 20 years or so, however, that there has been a burgeoning of interest and research into the psychological processes involved. Indeed, some influential modern theorists now regard problem-solving to be the fundamental cognitive activity (see, for example, Anderson (1983)).

Psychological approaches to children's learning, however, have not always fundamentally regarded the child as a problem solver. Modern cognitive developmental psychology owes a huge debt to the work of Jean Piaget, of course, and, as Wood (1988), for example, has argued, it was Piaget's major contribution to place

"'action' and self-directed problem-solving at the heart of learning and development". (p.5)

Wood (1988), in his authoritative recent account of current work concerned with children's thinking and learning, reviews the demise of earlier behaviourist models of children's learning, within which learning was seen as a simple process of building up associations based upon external reinforcement. He reviews, in particular, the volume edited by Hilgard (1964) within which many of the contributors recognised the difficulties of S-R learning theory, and began to recognise the potential contribution of an approach which placed the learner in a more active role.

Interestingly, as Bjorklund (1990) reviews, one of the developments arising out of these difficulties with S-R theory, amongst a group of psychologists referred to as the neobehaviourists, was the proposal that learning could be better explained in terms of intervening 'mediators'. Mediational theorists in the 1960's worked mainly with discrimination learning problems, and we will return to their work at the beginning of the next section when work related to discrimination learning problems will be considered as background to the present study. As we shall see, as Bjorklund (1990) indicates, the verbal mediators postulated by the neobehaviourists are one of the earlier examples of a kind of cognitive strategy.

Piaget's contribution was very considerable indeed. He demonstrated that it was possible to analyse the behaviour of young children in terms of the quality of their reasoning and their cognitive strategies, and, of course, carried out a vast quantity of detailed observations of young children engaged in problem-solving situations (see, for example Inhelder & Piaget (1958, 1964) .

While his general position has been enormously valuable and influential, however, his specific proposals for mechanisms of cognitive change and development have not proved particularly helpful. Meadows (1983, 1993), amongst many others, has reviewed the difficulties with, for example, the notion of 'equilibration' and its two subsidiary processes of 'assimilation' and 'accommodation'. Whilst these processes seem plausible, they remain abstract and hard to tie down to specific predictions about behaviour. Where specific predictions have been possible, furthermore, the empirical data has not been encouraging. The central notion of cognitive conflict or disequilibrium as the engine of learning and development, for example, has been challenged by the work of such as Bryant (1982). This demonstrated that agreement between the information gained from two intellectual strategies may facilitate learning more effectively than conflict.

A more productive analysis of the means by which children become increasingly sophisticated problem-solvers has been that carried out within the information processing framework. Beginning with the early influential work of such as Klahr & Wallace (1976) and Simon (1978), this approach has generated an enormous quantity of detailed research, and an array of different theories. This is not the place to provide a detailed review of this work (see Siegler (1983, 1991) for comprehensive reviews), but a number of key features and themes are germane to the present study.

As Siegler (1991) reviews, the information processing approach to development starts by viewing the child as a processor of information with a strictly limited processing capacity. In order to surmount the difficulties this imposes, children develop ever more sophisticated and more powerful processing strategies. Rather than focus on stages of development, such as those which are such a feature of Piagetian theory, information processing theories focus on the means by which children select and represent information, the processes they use to process and transform it, and the effects of the constraints of their memory and processing systems.

Two further defining features of the approach have been an emphasis on detailed task analysis, and on the precise analysis of change mechanisms. Both are these are also features of the present study. The first follows on very much in the tradition established by Piaget's careful analyses of tasks. However, the analysis of a logician has been replaced by that of a computer programmer. This has materialised in the form of Miller, Galanter & Pribram's (1960) 'TOTE', Klahr & Wallace's (1976) 'production systems' and Simon's (1978) 'problem space'. The argument is that in order to understand the representations and processes engaged in by a child when faced by a particular cognitive task or problem, it is vital to understand the nature of the information which needs to be processed, and the kinds of operations which need to be performed upon it. This kind of approach has been extremely fruitful. Siegler's (1978) analysis of the balance beam problem and Noelting's (1980) work on proportionality are perhaps the two best known examples of structural microanalyses of tasks which have revealed the nature of the development of children's strategic processing.

The issue of "what develops?" and of mechanisms of change has been central to information processing research. Siegler (1983) reviews work which has highlighted basic capacities and processes, strategies, metacognition and the knowledge base as candidates for "what develops?". In his later review (Siegler (1991)) he includes work in a range of areas which has focussed on four change mechanisms: automatisation, encoding, generalisation and strategy construction. These factors seem vital to an effective study of children's problem-solving and, in different ways, many of the processes involved are included within the present study. Rather than intending to focus on the significance of any one factor, however, it is the intention within the present study to examine the relationships between them. A more detailed consideration of these factors is provided in the final section of this chapter.

In a comprehensive consideration of psychological approaches to children's thinking and reasoning, Sternberg & Powell (1983) compare work related to the development of intelligent functioning within the four separate paradigms of Learning Theory, Psychometrics, Piagetian and Information Processing. From this analysis they produce four transparadigmatic principles of intellectual development which emerge across all these different approaches. As such, they have produced an authoritative statement of the current view of the main elements in the development of children as problem solvers.

First, they find evidence from work within each of the four paradigms that

"more sophisticated control strategies (metacomponents) develop with age" (p.400).

Of particular interest in relation to the present study is their argument that within the work of the neobehaviourists, which was mentioned briefly above, metacomponents of a kind are to be found as an explanatory mechanism. White's (1965) theory of the development of the ability to inhibit lower level associative responses so that the higher order conceptual processes will have time to take effect, and the possibility of multiple types of functioning, such as mediated versus unmediated learning (Kendler & Kendler (1975)), are both given as examples where metacomponents involving internal control mechanisms are implied. Within the information processing framework they refer to seminal work such as Flavell's (1981) proposal for a model of cognitive monitoring and Butterfield & Belmont's (1977) demonstration that a key feature of developmentally advanced functioning is the ability to select and apply optimal strategies. Metacognitive aspects of functioning have been a major area of research and theory related to the development of thinking and problem-solving ever since Flavell's studies of 'production deficiency' in the late 1960's, and are a key element within the present study.

Second, Sternberg & Powell (1983) find evidence from all four paradigms that

"information processing becomes more nearly exhaustive with increasing age" (p.402)

As evidence for this they cite, for example, Siegler's (1978) balance beam study, within which he found that a major cause of younger children's failure to solve this problem was their failure to encode all the relevant information. Evidence from a wide range of research has confirmed that the successful problem-solver represents the problem to themselves more accurately, and more thoroughly, than the unsuccessful one. An attempt is made within the present study to explore the effectiveness with which the children represented the MDL problem to themselves. An interesting conjecture here would be the extent to which this relates to Kagan et al's (1964) concept of impulsivity versus reflectivity, and performance on the MFFT test, which is included within the present study.

Sternberg & Powell's (1983) third principle is that

"the ability to comprehend relations of successively higher orders develops with age" (p.403)

Once again they cite evidence from all four paradigms. From the point of view of the present study of particular interest is the evidence they cite from learning theory approaches to concept learning. Odom (1966) and Osler & Kofsky (1966), using versions of the discrimination learning task, both found strategic differences in the way younger and older children responded to the task. They inferred that these differences were the result of differences in the levels of categories which the children were able to use as the basis for their responding. Domain-specific knowledge has repeatedly been shown to enable more structured representations to be made of problem areas. This has implications for the use of more sophisticated strategies, which is a further central feature of the study reported within this thesis, as is the extent to which this use of more sophisticated strategies is enabled by the lower demands made on working memory arising from a more structured knowledge base.

Fourth, Sternberg & Powell (1983) cite evidence that

"flexibility in the use of strategy or information develops with age" (p.405).

Evidence is again cited from the discrimination learning and hypothesis testing literature. Odom & Coon (1966), for example, found that 6 yr. olds were much more likely to stick with a reinforced pattern of responses when it ceased to be reinforced than were 11 year olds. Gholson, Levine & Phillips (1972) found younger children more likely to make fixed responses to multiple discrimination learning tasks, and less likely to respond to feedback than older children. We will return, of course, to this literature in more detail in the next section. That the flexible and appropriate use of strategies is a key factor in the development of intelligent functioning and problem-solving is a central theme of the current study. Of interest also is the extent to which this might be linked to a more field-independent cognitive style, and to the confidence in tackling new problems provided by a more internal locus of control.

Within the problem-solving literature the description Sternberg & Powell (1983) offer has often been characterised as the move from novice to expert. It is the intention within the present study to explore some aspects of the route and mechanisms by which this transformation takes place. More detailed reviews of work related to underlying cognitive factors in development and change mechanisms are provided in the final section of this chapter. Before we come to that, however, we now turn to look in a little more detail at research directly related to problem solving and reasoning, and within that, work related to induction, concept learning and hypothesis testing.

ii) Studies of Problem-solving & Reasoning

Children's problem-solving and reasoning has been studied extensively within modern developmental psychology (see Mayer (1992), for example, for an excellent survey of the field). The vast majority of the work has been carried out within the two main frameworks of Piagetian and information processing theory. Piaget and his co-workers (see, for example. Inhelder & Piaget (1958, 1964)) analysed children's performance on a vast range of reasoning tasks, and interpreted their success or failure in terms of stages in the development of logical structures of thought. The neo-Piagetian and post-Piagetian work stimulated by Piaget's vast achievement has been very productive, and has established a great deal of significance about children's thinking and problem-solving behaviour. Of relevance to the present study is work which has been devoted to exploring and developing Piaget's position in relation to three areas.

First, the work of Donaldson (1978) and many others has established that children are capable of reasoning in a similar manner to adults much earlier than Piaget suggested, providing that they are familiar with the material and that the task makes 'human sense' to them. On the first point, Goswami (1992) has recently demonstrated, for example, that young children are capable of sophisticated analogical reasoning (supposed, according to the Piagetian position, to be dependent upon 'formal operations') with material with which they are familiar. On the second point, there has been some debate about the usefulness of Donaldson's notion of 'human sense'. What is clear, however, as Meadows (1993) has recently reviewed, is that, while both adults and children have difficulties with certain kinds of formal logic, young children are particularly disadvantaged when tasks are presented in an abstract form. Rather more than adults, they are dependent upon a meaningful context to help them to represent to themselves the logical relations between the elements in a task or problem.

Braine & Rumain (1983), summarised a substantial amount of work suggesting a considerable resemblance between the reasoning of children just entering school and that of adults. In the same volume, Brown et al (1983) also reviewed a range of research demonstrating the early emergence of planful, strategic processing in pre-school children (i.e. before the much vaunted 5-7 shift beloved of mediationist (eg: White (1965)) and Piagetian theorists). Work in the last 10 years or so with very young, infant and pre-school children has shown that children's behaviour from a very young age is strategic, although the strategies they construct may not be very effective. Deloache & Brown (1987), for example, have provided evidence of the early emergence of planning skills in children as young as 18 months; Bjorklund (1990) provides a review of other work which supports this view.

Second, a whole range of work has suggested that factors other than logical structure are very often responsible for young children's difficulties with particular tasks and problems. Bryant & Trabasso (1971) demonstrated, for example, that quite young children are perfectly capable of making transitive inferences, and that their difficulties with the Piagetian form of this task were more associated with problems of memory than with logic or reasoning capabilities. Following Pascual-Leone's (1969, 1970) demonstration that the sequence of children's success on Piagetian tasks can be predicted by the working memory load involved, the neo-Piagetians, such as Case (1974, 1984, 1985) have established factors associated with memory and automaticity of basic operations as of major significance in cognitive development. Within neo-Piagetian theory, notions about 'equilibration' have given way, consequently, to much more satisfactory and empirically testable transition mechanisms.

The third area within which Piaget's ideas have been questioned is that relating to the notion of a fixed sequence of 'stages' of development. Brown & Desforges (1979), for example, have reviewed cross-cultural work on Piaget's tasks which has demonstrated that there are clear cultural effects upon the order in which success is achieved on the different tasks. The notion of 'structure d'ensemble', that each stage represents a coherent grouping of logical structures working together under some kind of synergy, and affecting the whole range of a child's cognitive functioning, has also not been well supported by empirical studies (see, for example, the review by Meadows (1983)). Brown & Desforges (1979) report evidence demonstrating very little inter-task correlation between tasks which are supposed to be at the same 'stage'. As we shall review in a little more detail in the final section of this chapter, Pascual-Leone (1969) managed to account for some of these difficulties by incorporating the cognitive style dimension of field-dependence into his model. Taken together all this evidence suggests that there may not be one route through a fixed sequence of stages of development. Within the present study the possibility is explored of different developmental routes based upon different strategic styles of behaviour.

The picture which has thus emerged from a wealth of research is a much more complex one of a range of experiential, contextual and cognitive factors interacting to affect performance. New strategies emerge in a much more piecemeal and domain-specific manner than that suggested by Piagetian theory, as Piaget himself began to concede in later versions of his model, and as the recent review and study of strategy construction by Siegler & Jenkins (1989), for example, confirms.

Work on problem-solving within the information-processing framework has explored behaviour on a wide variety of different kinds of problems, but has begun with an analysis of the characteristics shared by all problems. Following Simon (1978) a problem is said to occur when there is a discrepancy between the present situation ('initial state') and a desired state of affairs ('goal state'), and there is no existing routine that will get from the initial state to the goal state. Solution of the problem involves the execution of 'operators' on the initial state, and there may be 'constraints' on the use of these operators.

Typically, research within this framework has examined behaviour on 'well-defined' problems where the initial and goal states are clearly defined, as are all the possible operators and the constraints upon them. This has enabled cybernetic models to be developed (such as Miller, Galanter & Pribram's (1960) TOTE, Klahr & Wallace's (1976) self-modifying 'production systems' and Simon's (1978) 'problem space') which have enabled the precise formulation of all possible 'moves' and thus the analysis with some precision of the behaviour of children and adults when faced with particular problems. Much of this research has used problems such as the 'Towers of Hanoi' and other such 'transformation' problems. Kahney (1986) has produced a useful review of work of this kind.

The predominant concern of this research has been the demonstration that the development of children's abilities to think, to reason and to solve problems can be described very effectively in terms of the development of increasingly sophisticated strategies, a concern shared with neo-Piagetian theorists and researchers. The study of concept formation, and the identification of strategies such as 'scanning' and 'focussing', by Bruner, Goodnow & Austin (1956) is, of course, seminal in this field. Newell & Simon (1972), in their analysis of such problems as the 'Towers of Hanoi', first identified the planning strategy of 'means-end analysis' (including 'subgoaling') which has subsequently been very thoroughly investigated, and to which we shall return in a moment. Noelting's (1980) study of proportionality with juice mixture problems produced a series of four strategies of increasing sophistication, each involving the consideration of more information than the last. Case (1985) analysed these strategies and demonstrated a progression in the demands on working memory. Siegler (1978) analysed the development of progressively more sophisticated strategies on the balance beam problem in terms of the number of decisions to be made.

A number of theorists have developed models which attempt to explain the development of strategies within an information-processing framework, conceived in terms of conditional procedures very much like a computer programme. Principal amongst these are Klahr & Wallace's (1976) model of self-modifying production systems and Anderson's (1983) Adaptive Control of Thought (ACT*). While these systems have been relatively successful at modelling standard observations regarding skill acquisition (eg: the increasing automaticity of skilled performance), they have difficulty in accounting for the development of new rules or strategies.

An interesting feature of the development of problem-solving strategies, and of skill acquisition generally, is the commonly observed U-shaped developmental pattern of performance. Strauss & Stavy (1982) edited an intriguing collection of studies revealing this kind of pattern of developmental growth within which a number of possible alternative explanations are offered to account for this phenomenon. These include various models involving reorganisation of internal representations, and discontinuities in strategy development. Karmiloff-Smith (1984) proposed an interesting three-phase developmental model which relates problem representation to style of strategic behaviour, and which incorporates data exhibiting U-shaped development from several problem domains including language acquisition and her studies of the block-balancing problem (see Karmiloff-Smith & Inhelder (1974)).

While the investigation of strategy development on 'well-defined' problems has facilitated precision in analysis, researchers have also wanted to investigate problem-solving procedures on 'ill-defined', real world problems. Gilhooly (1988), for example, has reviewed work in the areas of physics, mathematics, computer programming and medical diagnosis, each of which has a significant literature. This work has contributed to a model of the development of problem-solving behaviour in terms of the move from being a novice to being an expert. Green & Gilhooly (1992) have provided a recent review and analysis of work related to expertise.

Essentially, experts have been found to differ in two fundamentals from novices in any particular domain. First, as we have discussed in the previous section, they represent problems differently. Odom (1966) and Osler & Kofsky (1966) have demonstrated the use of higher level categories by older children on a discrimination learning task, and the work by such as Chi, Feltovich & Glaser (1981) on physics problems has confirmed that the more extensive and structured domain knowledge of experts facilitates more effective representation of problems in a number of ways. In particular, experts and novices differed in the features of the problems which they considered relevant to finding a solution. As we shall see when we come to look at research using the multiple discrimination learning task, irrelevant information is a significant source of difficulty for young children in solving problems. This is a factor, therefore, which is included in the present study in the form of a version of the MDL task which contains irrelevant dimensions.

The expert also has access to domain-specific strategies not available to the novice, and shows developments in the sophistication with which general problem-solving strategies are used within their area of expertise. In this regard, Sweller et al (1983), amongst many others, have reported a development from 'working backwards' through a problem using 'means-end' analysis, to a 'working forwards' strategy which has been found in many fields. While the present study is not centrally concerned with the issue of domain-specific knowledge, both these issues of effectiveness of representation and sophistication of strategy use are unavoidable in any consideration of the development of problem-solving abilities, and are, therefore, important elements in the present analysis. Along with other significant underlying cognitive factors, they will be discussed in a little more detail within the final section of this chapter.

An issue of direct educational relevance arises from Sweller et al's (1983) finding that training on tasks with non-specific goals encouraged the development of the more sophisticated and effective 'working forwards' strategy. This would appear to tie in with the suggestion by Vandenberg (1990) that success on real life problems, because of their more 'ill-defined' structure, is more dependent upon representational processes, and may, therefore, necessitate more exploratory activity. We will return to this issue, which relates to the role of play in problem-solving, when we come to discuss the educational implications of the present study.

The other major issue which has arisen from studies of expertise and problem-solving is that of transfer or generalisation of learning. As Siegler & Jenkins (1989) have reviewed, "Those interested in education have long lamented the problem of inert knowledge... where children fail to apply strategies they know to new problems." (p.16)

Expertise appears to be quite domain specific, and individuals who can display considerable expertise in one area can behave like novices in another. Strategies may fail to be applied when they would have been appropriate, or may be applied inappropriately. There are clear links here with the over and under extension of concepts commonly observed in young children. Learning the conditions of applicability of a strategy, Siegler & Jenkins (1989) conclude, may well be at least as difficult as the process of strategy discovery and construction. The evidence would appear to suggest, however, that domain-specific knowledge does not account for all development in problem-solving ability, and that there is a developing ability to transfer and generalise knowledge and general problem-solving strategies. Chi (1978), for example, had to go to considerable lengths to prevent adults from applying general strategies to her face recognition task. Ferrara, Brown & Campione (1986) found clear evidence of a developing ability to transfer inductive reasoning rules amongst 8-11 yr. olds. Work has been done which has successfully demonstrated that it is possible to facilitate transfer in a number of ways, mostly involving some kind of metacognitive training (eg Adams et al (1988), Campione (1987)). This is an important issue to which we will also return in our discussion of educational implications.

Within the literature on problem-solving and reasoning all kinds of problems and reasoning tasks have been investigated and analysed. We have already mentioned the scientific reasoning problems of Inhelder & Piaget (1958, 1964) and the transformation problems examined by such as Newell & Simon (1972), both of which have been major centres of interest and research. To this must be added studies of syllogistic, propositional and deductive reasoning, which have been numerous (see, for example, Braine & Rumain (1983) for a review, and Johnson-Laird (1983) for an account of the mental models approach to representation which has derived from this work). Of interest here is the general finding, supported by Donaldson (1983), that there is a strong resemblance between the reasoning of children entering school and the reasoning of older children and adults. Children and adults make the same kinds of errors, and tend to find the same kinds of problems easy or difficult. This ties in well with the similar finding, reported above, with regard to analogical reasoning, which has also been an area of considerable study (see Goswami (1992)). The roots of development in performance on tasks involving reasoning and problem-solving clearly lie elsewhere than basic reasoning capacities or understandings. It is the search for these other roots of development with which the present study is concerned.

As Voss (1990) and Siegler & Jenkins (1989) have recently argued, however, with the possible exception of analogical reasoning, there has been a relative neglect within modern cognitive developmental psychology of the process which accounts for most human reasoning, and for much of our knowledge acquisition and learning, namely the process of induction. As we noted above, information-processing models of strategy development such as those developed by Klahr & Wallace (1976) and Anderson (1983) have difficulty in explaining the discovery of new rules and strategies. The Framework for Induction proposed by Holland et al (1986), however, is a recent and much more successful attempt to tackle this crucial issue within a production systems type of model. In the next section we will turn to look at this model, together with other work which has explored the relationship between the processes of inductive reasoning, concept formation and hypothesis testing.

iii) Induction, Concept Learning & Hypothesis Testing

The production by Holland et al (1986) of their Framework for Induction marks an important recognition by information-processing theorists that any model of cognitive development must, critically, be able to account for learning, and that the processes of induction are central to this. Principal among the related phenomena involved in human learning to be examined by recent psychological research are concept formation, rule induction and the construction of new cognitive strategies. We will return to the issue of strategy construction in the final section of this chapter. Here, however, it is intended to look briefly at work concerned with concept learning and rule induction, and to how that relates to the work on hypothesis testing by such as Gholson (1980) and Kemler (1978) from which the present study is most directly derived.

The central significance of processes of inductive reasoning within human learning have recently been well argued by such as Holyoak & Nisbett (1988) and Glaser & Pellegrino (1987). Induction is the process by which general rules are derived from particular instances. It is the process referred to by Klahr & Wallace (1976) as 'regularity detection', which is central to their model of the human information-processing system. As is observed by most commentators in this area, the production and use by young children of rules about the structure of language is a common example of this kind of process at work. By contrast, other kinds of reasoning appear to be relatively difficult for the human information-processing system. The work of such as Wason & Johnson-Laird (1972) and Johnson-Laird (1983) on various forms of deductive reasoning, for example, has demonstrated that humans tend not to fully process information, nor to reason by the rules of formal logic, as required by this kind of reasoning. Johnson-Laird's 'mental models' analysis, deriving from work in this area, recognises that human learning is much more a matter of recognising common patterns in experience, and using these patterns to make sense of new situations and problems. This inductive process is sometimes found wanting, but the evidence suggests that it is, nevertheless, the fundamental mechanism of human learning. This is the essential inferential process through which humans go, in Bruner's (1957) words, "Beyond the Information Given".

Holyoak & Nisbet (1988) point out that induction is involved in the modification of two related types of knowledge. Concepts about particular events or instances are developed through the inductive processes of categorisation, and higher-order inferential rules are developed through the inductive analysis of causal relationships. Inferential rules include 'heuristics', or problem-solving strategies. Glaser & Pellegrino (1987) have reviewed the psychological development of measures to test human intellectual aptitude, and have demonstrated that tasks involving 'rule induction' have been central to such measures, and to the models of intellectual processes which have underpinned them.

Research on concept learning has mostly focussed on the two related issues of the development of concepts and categories by young children and the bases upon which concepts or categories are formed. On the first point, once again, the evidence appears to be that, contrary to the earlier suggestions of such eminent theorists as Piaget, Vygotsky and Bruner, young children are capable of forming concepts and categories in exactly the same ways as adults, and do so from a very early age. Based on observations of young children's categorising during play, for example, Inhelder & Piaget (1964) and Bruner, Olver and Greenfield (1966) concluded that pre-school children were incapable of 'taxonomic' or categorical classification, instead producing 'thematic' groupings. Vygotsky (1962) came to a similar conclusion with his block sorting activity, noting the 'chain concepts' produced by children under 6 yrs. old. Smiley & Brown (1979), however, offered an elegant refutation of this view simply by asking preschoolers who sorted objects thematically about the categorical relations among the objects. They found that these young children could explain the categorical relations perfectly. Cole & Scribner (1974) produced some entertaining cross-cultural evidence which throws some light on the situation. Tribespeople in Africa also spontaneously produced thematic groupings, but were quite capable of producing the ostensibly more sophisticated categorical sortings when asked "How would a stupid person do it?" Both the tribespeople and the children clearly possessed the relevant conceptual ability, but chose not to apply it to the particular situation, preferring to respond in a different way which made more sense to them.

Siegler (1991) has reviewed work on the four main possibilities which have been advanced by researchers for the bases upon which concepts may be represented, and the evidence concerning the nature of young children's concept formation. As Holland et al (1986) have argued, the evidence of the work of such as Rosch (1978), however, has led to the current consensus that natural concepts or categories are based on clear 'prototypes' but relatively vague boundary conditions. Smith (1988) has provided a review of the evidence in support of this view, and developed the argument that hierarchical categorisation is an important mechanism of cognitive economy (i.e. lessening the load on working memory). This is an issue to which we shall return in the final section of this chapter, when we come to discuss the role of knowledge and representation in the development of problem-solving abilities.

More recent work on concepts and categorisation has emphasised the instability and flexibility of concepts, and the extent to which local context can affect the way they are represented. Holland et al (1986) have argued that concepts or categories are most accurately described as "clusters of interrelated rules" (p. 179) which are the product of goal-directed inductive mechanisms. Neisser (1987), amongst others, in reviewing developments of Rosch's 'prototype' model, has argued that concepts are best viewed as a kind of 'theory' through which a great deal of an individual's accumulated knowledge is incorporated and used to fit the immediate context. Barsalou (1987) has developed the notion of concepts containing a core of stable, context-independent information, as well as information dependent on the current context, or on recently encountered contexts.

This kind of loosely organised system, with particular pieces of information, or particular criteria, in play or not depending upon the immediate context, ties in very well with current connectionist models of cognition (eg Rummelhart & McClelland (1986)). This relates explicitly to one of the key structural differences from previous information processing, production systems (eg Anderson (1983)) incorporated by Holland et al (1986) in their Framework for Induction. Unlike previous models the Framework for Induction allows more than one rule to 'fire' at a time. They demonstrate how this allowance of a certain degree of parallelism greatly facilitates the generation of new rules in response to new problems and situations, through the processes of induction. It is this crucial role of inductive reasoning in the development of new representations and strategies, in response to new problems, which has guided the choice of type of problem to be investigated within the present study.

Various further kinds of evidence have been instrumental in substantiating the current view that children's early reasoning is 'theory' driven. The first comes from work examining the claim of such as Piaget that much of children's early reasoning is perceptually dominated. Carey (1985a), Gelman & Markman (1986) and others have done fascinating and important work in this area, and have demonstrated, for example, that children as young as 4 yrs. old rely heavily on categories to direct their inferences, even when category membership is pitted against perceptual similarity.

Another source of evidence in this area relates to the way children make sense of commonly occurring sequences of events in their lives. The work of such as Schank & Abelson (1977) on 'scripts' and Nelson (1986) and her colleagues on 'General Event Representation' has emphasised, for example, the significance of inductive processes to generate theories about common patterns of events in their world which guide children's future representations and actions.

A third kind of evidence comes from a range of experimental work carried out with a number of different inductive reasoning tasks. This work has been reviewed by such as Glaser & Pellegrino (1987) and Gilhooly (1988), the latter under the heading of "Generating and Testing Hypotheses". The tasks studied include analogy problems, concept identification problems (of which the MDL problem in the present study is an example), series completion problems and problems involving simulated and real research environments.

An interesting and significant finding of work related to series completion problems and problems involving simulated and real research environments is the consistent prevalence of a 'verifying' or confirmatory strategy. Wason (1960), for example, in a version of the series completion task which required subjects to generate other series which conformed to the rule, found an overwhelming tendency for subjects to generate series consistent with their hypothesis and to keep on doing so until they felt confident enough to announce their hypothesis as correct. Few subjects either tried out series which would falsify their hypothesis, or spontaneously varied their hypotheses. In studies of simulated research environments Mynatt et al (1978) similarly found that deliberate attempts to falsify hypotheses almost never occurred. Klayman & Ha (1987, 1989), in a series of studies based on Wason's (1960) number series production task, also found that successful and unsuccessful subjects showed the same predominant 'positive test' strategy; they did find, however, that successful problem solvers were much more likely to positively test alternative hypotheses.

Mynatt et al (1978) found also that, although subjects were mostly able to respond appropriately to the occurrence of disconfirming evidence, there was a tendency to disregard it about a third of the time. The evidence from this kind of study tends to confirm the view that human reasoning does not typically follow the classic 'scientific method' . Rather, it is dominated by an inductive mode of functioning which is simply set up to recognise common patterns and to act on them. Until information is presented by experience which does not fit the existing pattern, that pattern is the one that holds; and, indeed, it might even hold in the face of disconfirming evidence, up to a point. Karmiloff-Smith & Inhelder (1974), for example, argued that children do not recognise the significance of disconfirming evidence until a hypothesis is well established. It is only then that children begin to recognise the significance of counter-examples. At the end of a recent, thorough review of the evidence in relation to this issue, Small (1990) has suggested that failure to modify a hypothesis after disconfirming evidence may have beneficial consequences for young children. In the real world rules are not as tidy as in the laboratory, and often have exceptions. Young children often have to formulate rules which handle the majority of cases. In these circumstances, Small (1990) argues, it would be maladaptive to give too much weight to disconfirming evidence. Klayman & Ha (1987, 1989) have also argued that their 'positive test strategy' can be a very good heuristic for determining the truth or falsity of a hypothesis under realistic conditions. They go on to argue that human hypothesis-testing strategies must be understood in terms of the interaction between the strategy and the task at hand. This is an important research issue to which we will return at the end of the thesis.

In the context of the present study this mode of functioning might be characterised as a 'Win/Stay' strategy. As we shall see, it is the establishment of this kind of strategy which proves to be crucial in a concept identification task, of which the problem in the present study is an example. Another important piece of evidence which has established the view that children's reasoning is based on a process of generating 'theories' or 'hypotheses' about regularities in the variety of their experience, is that from the neo-behaviourist, mediationist studies of discrimination learning conducted by such as the Kendlers (see Kendler & Kendler (1975) for a review).

The Kendlers, and others, investigated two alternative theories of concept learning, which have been characterised as the 'continuity theory' and the non-continuity theory'. The 'continuity theory' is that advanced by the behaviourist learning theorists such as Hull (1920) and involves the establishment and strengthening of single S-R associations between consistently present aspects of the stimulus and the particular response. Hull (1920), for example, demonstrated this process by which subjects learnt to respond appropriately to the ever-present 'radicals' in different sets of Chinese characters. The 'non-continuity theory' suggests that individuals actively construct and test hypotheses until one works on a 'Win/Stay, Lose/Shift' basis (i.e. by induction). This theoretical approach was first advanced by Bruner, Goodnow & Austin (1956), and developed by such as Levine (1975) and Gholson (1980).

Kendler & Kendler (1975) review their investigation of these two theoretical positions by means of a series of experiments involving shifts in the rules. These involved 2-dimensional discrimination learning tasks, where an original rule is learnt (i.e. that one of the two values of one of the dimensions is the correct solution), and then the rule is changed in one of two ways. Either, the other value of the same dimension becomes the correct solution (a 'reversal shift') or one of the values of the other dimension becomes the answer (a 'nonreversal shift'). Kendler & Kendler (1975) argued that the continuity theory, that concept learning involves strengthening single S-R associations, would predict that the 'reversal shift' would be the more difficult to learn because this involves unlearning an already established association as well as learning a new one; by contrast the 'non-continuity' theory, that concept learning involves forming a rule that 'mediates' between the stimulus and the response, would predict that the 'reversal shift' would be easier because the same rule still mediates, but just the values have changed. Their results supported the 'non-continuity' theory for college students and verbal children, but the 'continuity' theory for preverbal children and laboratory animals.

These results were supported by further experiments involving an ambiguous shift of the rule, where subjects were given positive feedback about items containing both the opposite value of the original dimension, and one of the values of the other dimension. Subjects responses were classified in terms of the kind of shift they adopted. 'Reversal' shifts (i.e. adopting the opposite value of the original dimension) were preferred by 37% of 3 yr. olds, 50% of 5 yr. olds and 62% of 10 yr. olds. Kendler & Kendler (1975) concluded that as age increases thinking in the concept learning situation is more likely to be mediated by a general rule rather than by individual associations.

Subsequent work in the area, and the results of the present study, however, would suggest that the interpretation by the Kendler's of the behaviour of preverbal, very young children, may be misguided. While it may be the case that laboratory animals form simple associations, the evidence about young children in relation to concept learning and other reasoning and problem-solving situations, some of which we have reviewed in the previous section, suggests that they are forming theories and devising strategies from a very early age, although these theories and strategies may be rather inadequate. As noted above, we will return to the issue of children's strategies in the next section.

The important general finding of support for the 'non-continuity', rule induction model of concept identification was further supported by Trabasso & Bower's (1968) study of college student's pattern of performance on a 6-dimensional task. Their pattern of choices remained at chance level for a long time, and then suddenly jumped to 100% correct. Furthermore, performance was not unduly disrupted by a rule switch half way through, while they were still responding at chance levels. This pattern does not accord with a model of gradually strengthening single S-R associations. It does accord with a model of trying out various rules or 'hypotheses' until one is found that fits, and then staying with that i.e. the hypothesis testing strategy of 'Win/Stay, Lose Shift' identified above.

As Gholson (1980) has reviewed, this kind of evidence was crucial in the establishment of 'hypothesis theory' within the study of children's learning. The term 'hypothesis' had originally been used by Krechevsky (1932), a graduate student working with Tolman, to describe systematic response patterns exhibited by rats prior to solution in various discrimination tasks. The term, and the essential idea behind it, was not picked up again, however, until Levine (1959), a graduate student of Harlow's, systematised the 'error-factors' (systematic response sequences prior to the achievement of learning set) Harlow (1950) had identified from his work with monkeys' discrimination learning.

Rather than viewing these response patterns as errors interfering with learning, Levine reconceptualised them as part of a larger set of possible response patterns, some of which led to acquisition of the learning set. He characterised these response patterns partly in terms of the outcome of the Trial 1 response ('Win' or 'Lose') and whether or not the response to Trial 2 was the same as to Trial 1 ('Stay' of 'Shift'). Thus Harlow's 'stimulus-preference' error factor became 'Win-Stay, Lose-Stay', and a response sequence which led to acquisition of the learning set was characterised as 'Win-Stay, Lose-Shift'. As the label 'error factor' was no longer appropriate, Levine (1959) substituted Krechevsky's term 'hypothesis'.

Gholson (1980) goes on to review how the emergence of mathematical learning theory, and the work of such as Restle (1962) and Trabasso & Bower (1968), established 'hypothesis theory' in the 1960's as the dominant model for the analysis of children's learning. This kind of work, together with the seminal study of Bruner, Goodnow & Austin (1956) firmly established the multidimensional discrimination learning (MDL) task as a fruitful tool for the investigation of children's conceptual learning, and 'hypothesis theory' as the most constructive model of the kind of learning involved. A number of researchers (see, for example, Sperr (1973) and Fuchs & Turner (1981)) subsequently explored and established links between the ability to generate and test hypotheses on MDL tasks and other well established skills of classification. As we have reviewed in this section, this lies very well with more recent models of children's conceptual learning as an inductive process of constructing 'clusters of interrelated rules', as identified by such as Holland et al (1986).

The present study is an attempt to develop the work of such as Levine (1975), Kemler (1978), Gholson (1980) and others with the MDL task, and to continue and extend the exploration they began of the factors which influence children's performance on this kind of task, and the way in which children's strategies for generating and testing hypotheses develop. In order to explain the rationale behind the design of the present study it is necessary to review the work they carried out, and the methodological and psychological issues they developed. This review is carried out in the next section.

Section B) Multidimensional Discrimination Learning Problems & Hypothesis Testing

i) Methodological developments

Following on from the pioneering work of Bruner, Goodnow & Austin (1956) there was a massive amount of experimentation, particularly over the next 25 years or so, using every possible variation of the multidimensional discrimination learning task with adults and with children of varying ages. This section attempts to review the major findings of this work, particularly as they relate to the present study. Research has focussed on the factors which make concept identification easier or more difficult, the kinds of strategies which are adopted by children and adults, and the development of performance on this kind of task by children. These issues are addressed in the later parts of this section concerned with the MDL task. In the first part, however, certain key methodological developments are reviewed which have influenced the design of the present study.

As will emerge during this review, just as with research related to children's problem-solving strategies across a range of different kinds of problem, strategies and performance on the MDL task are very dependent upon the exact nature of the task. This is an issue to which we will return in chapter 6 when we come to consider implications for future research and theory. Within the present study, however, an attempt has been made to produce a form of the MDL task which would enable young children to demonstrate their inductive reasoning abilities, while at the same time allow the identification of developmentally different strategic and performance levels.

a) Identification of Strategies: Blank Trials and Introtacts

The first major theoretical debate in the early days of hypothesis theory concerned the processes by which hypotheses are selected, and it was this debate which led to key methodological developments concerning the identification of subjects' hypotheses and their strategies for selecting them.

Restle (1962) and Trabasso & Bower (1968) developed a mathematical model of hypothesis selection which they demonstrated was generally able to account for the choice responses of adult humans on discrimination learning tasks. This model made three assumptions. First, when subjects are told "right" after a particular choice, they retain the same hypothesis and choose accordingly on the next trial (characterised elsewhere as 'Win/Stay'). Second, when subjects are told "wrong" , they reject their hypothesis and select a new one ('Lose/ Shift'). Third, and this is the area of contention, that subjects select a new hypothesis by returning the just-disconfirmed one to the pool of all possible hypotheses, and then randomly selecting a new hypothesis from the pool. Thus the just-disconfirmed hypothesis had the same chance of being selected as any other hypothesis. This was tantamount to assuming that subjects immediately forgot the just-disconfirmed hypothesis and was referred to as the 'zero-memory' assumption.

While this set of assumptions led to mathematical calculations of patterns of choices which fairly accurately matched observed behaviour, the suggestion implied in the 'zero-memory' assumption about adult memory was clearly contentious. Levine (1966), therefore, argued that, rather than making these kinds of a priori assumptions about hypothesis choice behaviour, it would be much better to probe directly the nature of subjects' hypotheses at each trial. It would then be possible to determine empirically whether subjects retained the same hypothesis after a "right", changed their hypotheses after a "wrong", and on what basis new hypotheses were selected.

Levine (Levine (1966), Karpf & Levine (1971)) devised and investigated two techniques or 'probes' to identify hypotheses which have subsequently formed the methodological basis of work aimed at identifying patterns of hypothesis selection (or 'strategies') in human discrimination learning. These two techniques involve the use of 'blank trials' and 'verbal introtacts'.

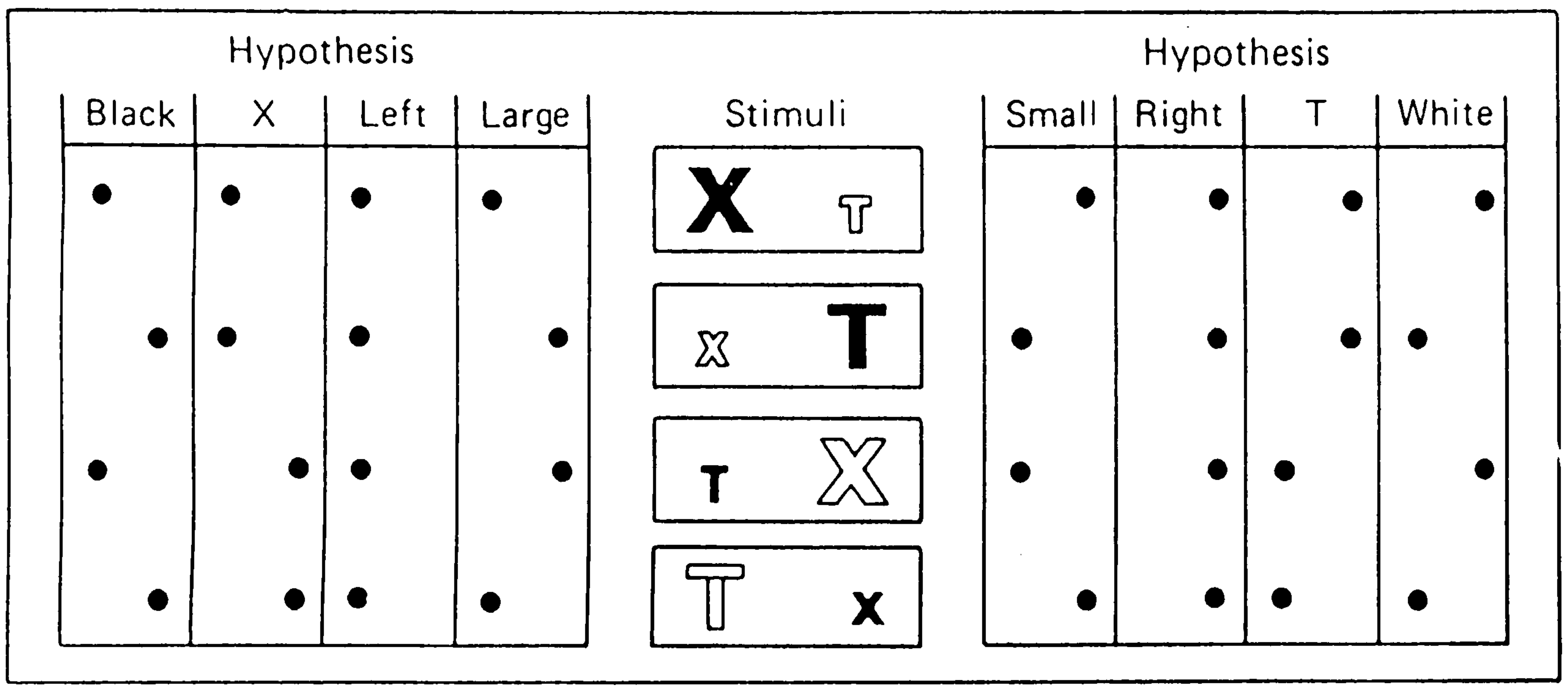
The 'verbal introtacts' technique simply consists of asking subjects to state their current hypothesis after each trial ('tact' is a Skinnerian term for a verbal statement contingent upon a particular stimulus situation; 'introtact' is thus a verbal statement contingent upon an internal stimulus - in this case, a 'hypothesis'). To begin with Levine (1966) was unhappy about this as a way of proceeding, on a number of grounds. There is, to begin with, of course, the general issue of the validity of subjects' verbal reports of their own internal processing. In relation to discrimination learning, Verplanck (1962), for example, a prominent conditioning theorist of the time, had suggested that there was no strongly systematic relation between verbalised hypotheses and overt choice responses. Second, there was the concern that requiring subjects to verbalise their hypotheses might induce them to employ hypotheses when this might not be the way they would have proceeded with the task otherwise. Finally, Levine wanted to devise a technique with general applicability to children and animals as well as adult humans.

As an alternative, non-verbal technique Levine (1966) devised the method of 'blank trials'. This method assumes that if a subject is given no feedback after a trial they will retain the same hypothesis for the next trial. If a series of 'blank trials' is given, therefore, assuming the subject's hypothesis remains the same, it should be possible to identify their hypothesis from their pattern of choices. He devised series of these 'blank trials' to insert in MDL problems as a hypothesis probe. An example of such a series of trials for a 4-dimensional MDL problem is shown in Figure 3.1. As can be seen, the stimuli for these trials are constructed in such as way that the pattern of choice responses for each of the possible hypotheses is unique.

The initial results with this technique were very positive. Levine (1966) gave a sample of college students a series of 16-trial 4-dimensional problems. Feedback was provided on Trials 1, 6, 11 & 16. Sets of 4 blank trials were interposed between the feedback trials. Analysis of choice-response patterns on blank trials showed that simple hypothesis patterns of the kind illustrated in Figure 3.1 occurred 92.4% of the time. Levine (1966) therefore claimed that it was clear adults do employ hypotheses in the MDL problem and that blank trials provide a successful probe for these hypotheses. He also found that the 'Win/Stay' strategy was employed 95% of the time (i.e. subjects retained their original hypothesis after positive feedback) and that 'Lose/Shift' was used 98% of the time (i.e. subjects changed their hypothesis after negative feedback). This latter finding was clear evidence against Restle's (1962) 'zero-memory' assumption, which would predict on this kind of problem that the just-disconfirmed hypothesis would be retained an eighth of the time (i.e. the figure for changing hypothesis should only be 87.5%).

When it came to analysing the behaviour of children on the MDL task, however, as Phillips & Levine (1975) review, the blank trials technique was found to be rather less helpful. To begin with, use of the blank trial probe with children (7-13 yr. olds) by such as Eimas (1969) had shown that children were sometimes unresponsive to feedback (for, example, retaining the same hypothesis after negative feedback as much as 10% of the time). During early explorations with systematic patterns of responses

Figure 3.1
Blank Trial probe: 8 patterns of responses corresponding to each of the possible hypotheses on a 4-dimensional MDL problem (from Levine (1966))



Levine (1963) had noted that there could be two sources of systematic patterns: hypotheses, which were responsive to feedback, and what he termed 'response-sets', which were not. Examples of the latter, observed in children's patterns of responses, included 'position-preference', when the child always chose the item on the left or right, irrespective of feedback, 'position-alternation' (a left, right, left, right pattern) and 'object-preference', which is a preference for choosing a particular value of one of the dimensions, just the same as a genuine hypothesis, except that the child stays with it whatever, adopting what might be characterised as a 'Win/Stay, Lose/Stay' strategy. In Levine's (1966) original blank trials some hypotheses and response-sets were confounded in the same pattern of choice responses. This problem obliged Phillips & Levine (1975) to construct new blank trial probes which would discriminate between hypotheses and response-sets.

Another more intractable difficulty, however, resulted in the abandonment of the use of blank trial probes with children. The problems constructed by Levine (1966) were quite short, with only 4 feedback trials. Gholson, Levine & Phillips (1972) recognised that children, as less efficient problem-solvers than adults, would need longer problems if they were to experience the success of solving them. They, therefore, used problems with 76 trials (16 feedback trials and 15 sets of 4 blank trials). This, of course, made the procedure extremely cumbersome, if the children were to tackle a number of different problems. The extent to which young children would be able to maintain concentration over this kind of length of procedure must be somewhat in doubt. Gholson, Levine & Phillips (1972) certainly found a high proportion of blank trial probes 'unclassifiable', which they presumed to be a consequence of children making accidental mistakes in their patterns of choices. As they were attempting to identify the 'systems' or strategies being used by the children in responding to feedback, this required that each child responded accurately to three feedback trials in a row (or a run of 15 actual trials) for their 'system' to be identified. An unacceptably large proportion of problems, in consequence, produced no usable data.

At the same time as these difficulties were emerging, the validity of 'verbal introtacts' as a technique for identifying hypotheses and strategies was supported by new evidence. Karpf & Levine (1971) presented college students with sets of 4-dimensional problems, some of which involved blank trials and others required the students to give verbal introtacts. They found virtually no differences in the results obtained with the two methods; both techniques yielded the same description of underlying hypothesis-testing processes. If anything, in fact, they found the introtact data to contain slightly better consistency and attributed this to the greater possibility of errors with the blank trial technique as discussed above. They also investigated the possibility that inserting verbal introtacts in a problem might have an effect on problem solution. In fact, they found that the percentage of problems solved was virtually identical irrespective of the probe used, and concluded that blank trial and introtact probes were interchangeable with adults.

Following on from this Phillips (1974) compared the performance of 7 and 11 yr. old children in blank trial and introtact conditions with 4-dimensional problems. With the 11 yr. olds the results were very similar to those of Karpf & Levine (1971). With the 7 yr. olds, however, significantly more problems were solved in the introtacts condition than when blank trials were used. In the blank trials condition, furthermore, more 7 yr. olds were found to be relying on response-sets (or 'stereotypes' as Phillips refers to them) rather than responding to feedback in making their choices. Phillips & Levine (1975) suggest a number of reasons why this might be the case. First, they present evidence that the 4-dimensional problem presents heavy cognitive demands for 7 yr. olds, and that in these conditions the blank trial probe procedure, which in itself places extra demands on memory, makes the task unmanageable for some 7 yr. olds. The results of a study by Fingerman (1974) replicating the Karpf & Levine (1971) study, but adding an 8-dimensional version, would seem to support this view. In this more demanding version of the task college students were also more successful in an introtact condition than when blank trials were introduced. Second, Phillips & Levine (1975) suggest that the insertion of introtacts might lead to an increase in memory/rehearsal strategies amongst 7 yr. olds. Finally, they suggest that having to state their hypothesis and receiving feedback on every trial may 'clarify' the task for younger children.

The overall picture, therefore, is that the use of blank trials would appear to lead to an underestimation of the problem-solving abilities of young children on the MDL task. For this reason Kemler (1978) uses verbal introtacts, and presents evidence to show that this technique did not disrupt the children's performance, and that the verbalisations produced were valid indices of their actual working hypotheses.

On this last point, Phillips (1974) and Spiker & Cantor (1977) had expressed some reservations, finding that some kindergarten (5 yr. old) children produced hypotheses apparently unrelated to their actual working hypotheses, and to their subsequent choice behaviour on the next trial. Phillips (1974) referred to these children as 'stimulus describers', and interpreted their behaviour as a consequence of a misunderstanding of the task instructions in relation to verbalisation of their 'hypotheses'. This interpretation was based on the fact that, when asked for the solution after successful completion of MDL tasks, these children were usually able to correctly identify it, despite not having mentioned it at all during the actual solution process.

Cantor & Spiker (1978), however, found that by adjusting their version of the MDL task so that the requirement for verbal introtacts did not interfere with the processing of young children, and by providing pretraining in hypothesis-testing strategies, it was possible to more or less eradicate instances of 'stimulus describing'. On this basis they concluded that introtact probes were a suitable instrument for monitoring the problem-solving strategies of kindergarten children. Kemler (1978), similarly, found virtually no evidence of stimulus describing in her data, and suggests that this (and some other related difficulties young children were found to have in early research with the MDL task) may well be accounted for by the abstract nature of the task and young children's consequent misinterpretations about what it required them to do.

On the basis of this kind of evidence the technique of verbal introtacts is used within the present study. An interesting index of the validity of the children's verbalised hypotheses will be the extent to which they are locally consistent (i.e. relate to feedback on the current trial) and consistent with the choice behaviour on the next trial. We will return to this point when we come to analyse the strategies used by the young children within the present study. The issue of abstract and meaningful contexts is an important one to which we will return in part c) below of this methodological discussion.

While Levine's (1966) blank trial probe is not used within the present study, however, as a way of revealing subjects' hypotheses, what has been preserved is the 'internally orthogonal' structure of the sets of stimulus pairs contained within such probes. Within the present study this way of structuring the stimulus materials is used for the slightly different purpose of ensuring that all problems presented a standardised opportunity for the children to sample the available information. This way of structuring the stimulus materials in a problem, represented in the example in Figure 3.1, ensures that, within a 4-dimensional problem, over a run of 4 trials each of the 8 separate values (possible 'solutions') receives a unique pattern of feedback (corresponding to the hypothesis patterns illustrated). This helps to ensure that the problem is equivalent in terms of the pattern of presentation of information whichever value is taken as the 'solution'. This matter of the frequency and patterning of information presentation is an important one in concept identification, as originally highlighted by Bruner, Goodnow & Austin (1956). This issue is not a focus of the present study, but its effects need to be controlled for if it is not to confound our results. It is also important, as we noted Phillips & Levine (1975) discovered, to be able to distinguish between response preferences for particular items or positions, and between other more sophisticated strategies. A detailed description of the ways in which the MDL problems were structured within the present study to control for various possible confounding effects is provided in the next chapter.

The pattern of choices made by subjects, allied to their stated hypotheses, was first used by Gholson, Levine & Phillips (1972) to analyse what they describe as the subjects' 'system'; this was developed further by Kemler (1978) and is developed again within the present study. We shall return to this aspect of the identification of strategies when we come to consider work on children's strategies on the MDL task at the end of this section.

b) Performance Indicators

Research attempting to investigate the hypothesis testing behaviour of children with the MDL task has used a progression of different measures of their performance. These different measures have reflected the questions under investigation at different stages in the development of this area of research.

The first research in this area with children was merely aimed at establishing whether children's behaviour on the MDL task could be described in terms of hypothesis testing. Thus Eimas (1969) replicated Levine's (1966) experiment using blank trial probes with children aged 7, 9, 11 and 13 years old., and reported that the mean percentages of blank trial probes conforming to simple hypotheses were 71, 73, 77 and 79 respectively.

Gholson, Levine & Phillips (1972) took this a stage further and analysed the 'hypothesis-sampling systems' of kindergarten children (5 yr. olds) as well as the ages sampled by Eimas. The issue here was the ways in which young children responded to feedback and co-ordinated information from the feedback on successive trials. As we shall see when we come to discuss research related to the development of children's strategies, they made a distinction between 'stereotypes' and 'strategies'. They concluded that 5 yr. olds showed no evidence of the use of hypothesis-testing strategies. Subsequent research, such as that of Kemler (1978) and Schuepfer & Gholson (1980), attempted to explore and refine their model of the development of hypothesis-testing strategies, and, as we shall see, the identification of strategies of concept identification, and the mapping out of the ways they develop, has been a major focus of research. The pattern of children's choices, and the relationship of these to their stated hypotheses, have been major focuses of this kind of analysis. This kind of analysis is a central aspect of the current study.

Research concerned with other questions, however, has used other measures of performance. The general performance level of children at different ages, and of different abilities, and the effects of different aspects of the MDL task, and the 'cognitive subprocesses' involved, have been generally assessed by reference to the number of problems solved (see, for example, Tumblin & Gholson (1980)). A more sophisticated measure, which is widely used within the literature, is the Trial of Last Error (see, for example, Kemler (1978), Phillips & Gholson (1980) and Cantor & Spiker (1984)). This is the measure of successful problem solution adopted within the present study. It simply involves establishing a criterion for successful solution, and recording the number of trials before that criterion is reached. Within the literature the criterion generally adopted has been five successive correct choices first established by Gholson, Levine & Phillips (1972), and this is the criterion used within the present study.

Kemler (1978) and Cantor & Spiker (1984) both used verbal introtacts as probes of the children's hypotheses and additionally required for the children to reach criterion that they should verbalise the correct hypothesis on each criterion trial. Within the present study this additional criterion was not adopted because it was felt that this potentially confounded two rather different aspects of performance, namely the ability to solve an MDL problem and the ability to verbalise accurately about the hypotheses used to do so.

The apparent inability by young children at certain stages to monitor and report upon the mental processes which have guided their behaviour and decision-making is a commonly observed phenomenon, and has been a central focus of work on metacognition, which we shall briefly review in the next section. This phenomenon has been recorded by Lunzer (1968) and Piaget (1977), for example, in relation to the oddity problem, where children can solve such problems but, when asked how they did it, are unable to produce the correct distinguishing feature. Lunzer (1968) found only one 4 yr. old who could not learn to solve oddity problems, but it was not until the age of 8 that children could generally give a satisfactory explanation or pose similar problems themselves. Phillips (1974), as we have discussed above, found a very similar phenomenon with the MDL task amongst children as old as 7. She found a number of children who reached the criterion of 5 successive correct choices without ever verbalising the correct hypothesis. She refers to these children as 'stimulus describers'. When asked for their hypotheses they apparently picked at random any feature of the 'correct' stimulus.

Although Phillips (1974) did find many of these children able to state the correct hypothesis subsequently at the end of the problem, and while some of this 'stimulus describing' may be attributable to young children's misunderstandings about an abstract task, there remains the possibility that the ability to verbalise the hypothesis or hypotheses currently under active consideration is a distinct aspect of performance on the MDL task. As such this may indicate significant aspects of representational processes in relation to the development of problem-solving and concept learning strategies. The relationship between this aspect of performance and the children's abilities to represent the MDL task (as measured by the questions relating to metacognitive knowledge) will be an interesting aspect of the investigations within the present study.

A final further aspect of performance investigated within the present study relates to the number of hypotheses verbalised on each trial of a problem. Early work using the MDL task was very much influenced by Levine's (1963, 1966) assumption that, even in a 4-dimensional problem, subjects proceed by identifying and testing one hypothesis at a time. In later work, however, Levine (1970) found that college students routinely monitor several hypotheses both before the trial of last error (when they have presumably solved the problem) and after it. Young children were presumed, however, to operate with only one hypothesis at a time, and this was supported by the early findings of such as Eimas (1969). Furthermore, in support of this general view, Ingalls & Dickerson (1969) found that most children completely ignored 1 or 2 dimensions from consideration at all during standard 4-dimensional MDL problems containing blank trial probes.

However, when Phillips & Gholson (1980) gave them the opportunity to verbalise more than one hypothesis on each trial, and facilitated this by the use of a memory aid displaying all 8 possible hypotheses, different children displayed different patterns of performance. Rather than being asked to verbalised an hypothesis on each trial, the children were asked to indicate "which things could still be correct". Some indicated only 1 hypothesis on each trial while others indicated 3 or 4 . Some, furthermore, were able to indicate with increasing accuracy the number of hypotheses which were actually still possible solutions after different numbers of trials (i.e. 4 on Trial 1, 2 on Trial 2, and 1 on Trial 3). This would appear to be an important, and probably the most sophisticated, aspect of performance on the MDL task (which, for example, clearly involves the use of the most sophisticated strategy of 'Focussing' originally identified by Gholson, Levine & Phillips (1972)).

Within the present study, therefore, the children were also given the opportunity to verbalise as many hypotheses as they wished after each trial. It is hoped in this way to more accurately represent the actual structure of their strategic processing of the task. As we shall see, the number of hypotheses verbalised per trial emerges as an important component of different strategic styles in relation to the MDL task. The number of hypotheses verbalised on Trials 1, 2 & 3 was also used as a Performance Indicator. It will be interesting to compare the performance of the children on the MDL task in the present study with those in Phillips & Gholson's (1980). No memory aid was provided in the present study, but the task was presented in a more meaningful context (an issue to which we will turn in a moment).

The possibility of a developmental sequence of performance on the MDL task is investigated within the present study. It seems probable that the ability to produce the ideal performance of verbalising the correct 'live' number of hypotheses on the first 3 trials will develop later than the ability to solve the MDL problem and verbalise the correct solution. These different aspects of performance may be indicative of developments in the ability to represent the problem and to process the information involved. This will be an important area for discussion later in the analysis of the results of the present study.

Details of the precise manner in which these three Performance Indicators were measured and scored are recorded in the next chapter and in Appendix A.7.

c) Abstract and Meaningful Contexts

Kemler (1978) introduced the major methodological innovation of presenting the MDL task to young children within a story-and game context, and argued that many of the previously perceived difficulties which young children had with the MDL task were a function of its abstractness. In her version, which has been very largely adopted within the present study, the children had to identify an item of clothing always worn by one of two identical twins. In previous studies with young children the task was always presented in the abstract form represented in Figure 3.1, as conceived by Levine (1963, 1966) and others.

As we shall review later when we come to look at evidence about children's performance on the MDL task, Kemler found children's abilities to act strategically and to solve problems when the task was presented in this more meaningful way to be considerably enhanced. Cantor & Spiker (1984) supported this finding in a study where the conventional multidimensional stimuli were replaced by toy animals, and found children as young as 5 yrs. old capable of the kinds of long-term strategies which even Kemler (1978) had not found. While this latter result appears to be partly the result of lightening the memory load of the task, the beneficial consequences of presenting the task in a context which enables young children to see its purpose is clearly confirmed. The parallels with the work of Donaldson (1978) and many others in relation to abstract Piagetian tasks is compelling. Just as the abilities and understandings of young children were underestimated by the misleading nature of many Piagetian tasks, so it would seem have the problem-solving abilities of young children in relation to concept identification on such as the MDL task. It will be interesting to compare the levels of performance of the children on a meaningful task within the present study with that achieved by children in previous work.

Researchers using the conventional abstract form of the task noted a number of apparent difficulties young children had with it. We have previously noted, for example, the difficulties identified by Phillips (1974) in relation to children 'stimulus describing'. In this case, when children were asked for a verbal introtact they read off, apparently at random, any of the characteristics of the positively reinforced stimulus, apparently to 'describe' which of the stimuli was the positive instance on that trial. They did not necessarily indicate their working hypothesis. Kemler (1978) found very little evidence of this kind of 'stimulus describing' behaviour on her task.

A further difficulty experienced by young children and identified by such as Eimas (1970) and Phillips & Levine (1975) occurred when they received negative feedback relating to their choice of stimulus on any particular trial. Tumblin & Gholson (1980) reviewed the evidence and carried out a study which appeared to show that young children benefited from being directed to switch their attention from the negative instance chosen to the complementary positive instance also on display in the standard MDL task. Some children in this study were taught the rule "wrong means look at the other picture", and their use of strategies and ability to solve the MDL problems was significantly improved as a result.

While this has been presented within the literature as an aspect of young children's lack of control of their attention, it seems much more likely to be a problem arising from children's failure to understand the logical structure of the task. In a slight variation in the administration of the task devised by Kemler (1978), within the present study the children were provided with no directional cue as to the positive instance in any particular trial. It is suggested that the more meaningful task will facilitate young children's understanding of the logic of the situation, and such an attentional aid will be unnecessary. The 'local consistency' of the hypotheses produced by the children will be a useful indication of the validity of this analysis.

The decision not to include a directional cue within the present study follows a fundamental principle of design adopted in relation to the MDL task. This is that the task of concept identification from multidimensional stimuli should be presented to the children in a way which, as far as possible, simulates real life learning. This involves it being presented in a way which is meaningful to them and makes sense, but also in a form uncluttered by artificial aids. This flows from the intention stated earlier to produce a form of the MDL task which would enable young children to fully demonstrate their inductive reasoning abilities, while at the same time allow the identification of developmentally different strategic and performance levels. In the next part of this discussion of work with the MDL task we consider a number of factors which have been found to affect children's performance, and explain the rationale arising from this work for the form of the task adopted in the present study.

ii) Factors Affecting Children's Performance

a) Memory

In relation to this concern to keep the task uncluttered by artificial aids, the results of using a memory aid reported by Eimas (1970), Phillips & Gholson (1980) and Kemler (1978) are of interest. As we shall see when we come to discuss research on the development of children's strategies on the MDL task, an early concern was the apparent inability of young children to use feedback information from previous trials to help them find the correct hypothesis. In an attempt to discover to what extent this was simply a memory problem (rather than one of understanding or strategy) a number of researchers devised memory aids to use with the task. Using a memory aid with an abstract form of the MDL task was found to be beneficial to 8 yr. olds by Eimas (1970) and 8 and 11 yr. olds by Phillips & Gholson (1980).

However, when Kemler (1978) used a similar device with her more meaningful task, if anything, it appears to have interfered with young children's processing. In a review of this issue and others, Linder & Siegel (1983) argue that this difference in effect is attributable to the abstract - meaningful distinction between the two varieties of MDL task which we have just discussed . Certainly, it would seem likely that where a meaningful task is presented, any artificial additions or complications may confuse rather than help children to tackle it with their full potential. It is not, in fact, clear that the devices used by such as Eimas (1970) and Phillips & Gholson (1980) improved children's performance because they acted as a memory aid; they might, more plausibly, have helped because they made the logic of an abstract form of the MDL task clearer to young children. Memory aids are not generally available or used by children during real life conceptual learning or problem-solving. A memory aid was not, therefore, included in the present study. It will be interesting to compare the performance of children on the present task with those of Phillips & Gholson (1980), for example, to see what differences arise from these different forms of the task.

Beyond this particular issue, however, it is clear that memory is a significant factor in any problem-solving behaviour, and will have significant effects upon performance on the MDL task. In the following section examining factors related to children's cognitive development, the important work by such as the neo-Piagetians (eg: Pascual-Leone (1969, 1970) and Case (1974, 1984, 1985)) and others on working memory as a key constraint affecting children's problem-solving will be briefly reviewed.

An overwhelmingly important point to recognise from this research of relevance to the present study is that the strategies adopted by children in relation to any task are significantly affected by the working memory demands imposed (see, for example, Scardamalia (1977)). We have already seen this in relation to the MDL task in the case of Cantor & Spiker 's (1984) simplification (removing the dimensionality element of the task), and Phillips & Levine's argument that blank trial probes affected young children's performance because of the extra memory load imposed. This latter point was supported by reference to Fingerman's (1974) study demonstrating the same effect for college students when they were presented with an 8-dimensional problem.

The main way that the memory demands of the MDL task can be varied is by altering the number of dimensions involved. Levine's (1963, 1966) original studies of hypothesis testing involved 4-dimensional problems, but other investigators have used tasks involving anything from 2 to 8 dimensions. Davis (1985) provides a comprehensive review of children's performance on studies varying in the number of dimensions involved. What was important within the present study, however, was to use a task of a sufficient level of demand so that children aged 6, 8 & 10 would display a range of strategic behaviour. Based upon Kemler's (1978) study, within which she used 3, 4, 5 and 8-dimensional problems very similar to the problem used here, it was decided within the present study that 4-dimensional problems of this kind would serve the purpose, and the resulting analysis of children's strategic behaviour and performance on the task will be seen to largely validate this judgement. In any case, as is indicated in the next part of this review, a version of the task requiring children to use negative information was included in the study which would place extra load on working memory. It seemed unnecessary, therefore, to vary the number of relevant dimensions as well.

b) Negative and Redundant Information

It has been established for some time that young children have more difficulty dealing with negative than with positive information. Luria (1961) demonstrated this in several experiments. Before age 4-5, for example, he found that children were able to respond to the command "press", but unable to restrain pressing for the command "don't press".

In information processing terms this may be accounted for by the extra demands negative information makes upon working memory. Chomskian analysis (see Chomsky (1957)) of the structure of language, for example, suggested that negatives take longer to process because they impose an extra transformation. A negative piece of information, according to this view, is stored as a positive representation, plus a negative qualifier, and is thus two 'bits' of information instead of one. The greater likelihood of success from feedback of what is correct has also been highlighted by such as Bryant (1982) in his important study of agreement and conflict between children's strategies in relation to a measurement task.

The difficulties children have with negative feedback within the MDL task has been a constant theme within the literature. We have already discussed the difficulties identified by such as Eimas (1970), Phillips & Levine (1975) and Tumblin & Gholson (1980) when children received negative feedback relating to their choice of stimulus on any particular trial. As we have argued, this particular difficulty may have been a consequence of the abstract version of the MDL task used in these studies, and may have been a problem of understanding the task rather than of memory load.

A number of other studies, however, have highlighted a difficulty related to dealing with negative feedback which may have more substance. This is the commonly observed difficulty of children rejecting irrelevant and disconfirmed hypotheses and dimensions. In their original analysis of hypothesis testing systems, Levine, Phillips & Gholson (1972) identified 'perseveration' (staying with the same object or position) and 'alternation' (alternating between positions or values of one dimension) as typical early patterns of responding which did not seem to be responsive to negative feedback. Davis (1985) reviews a range of early studies demonstrating that children's typical strategy on discrimination problems under the age of 4 is likely to be perseveration, and then alternation. Even Kemler (1978), with her more meaningful task, found kindergartners (5 yr. olds) with a strong tendency to resample previously rejected hypotheses.

Explanations for these difficulties with negative information vary. Toppino (1980), for example, explored this phenomenon in a series of three experiments and concluded that children have a general inferential deficit for making use of negative and irrelevant information. Davis (1985) argues from this that perseveration and alternation reflect the young child's inability to differentiate between relevant and irrelevant information. He cites findings from physiological studies which relate inability to use cues from error to the absence of internal inhibitory function.

This relates to ideas about the development by children of the voluntary or selective control of their attention. This is an important aspect of the development of metacognitive control, and is a feature of children's developmental cognitive processing, of course, with a long research history. Lane & Pearson (1982), for example, have provided a review of the extensive literature in this area. Young children have consistently been found to be influenced in their problem-solving by the perceptual salience of particular aspects of the stimulus (eg: Odom (1978)) and to fail to selectively attend to the relevant aspects of a situation (eg : Hagen & Hale (1973)).

Problems of this kind in relation to the MDL task have been identified and investigated by Kemler, Shepp & Foote (1976), Barringer & Gholson (1980) and others. Indeed, Zeaman & House (1963) attempted an early application of theories of selective attention to children's discrimination learning. Kemler (1978), however, refutes their view that the tendency to resample recently rejected attributes is a result of an attentional bias for a perceptually dominant stimulus dimension. She found that the kindergartners in her study perseverated on a variety of different dimensions. Kemler, Shepp & Foote (1976) did find evidence, however, of 5 and 7 yr. olds attending to incidental information about attributes in a way that 10 yr. olds did not. Barringer & Gholson (1980) investigated performance by normal and underachieving readers (aged 9 and 10) on a standard 4-dimensional task and an 8-dimensional task where 4 dimensions were relevant, and 4 irrelevant to solution. They found that the underachieving readers were twice as likely as the normal readers to exhibit irrelevant hypotheses.

Despite her earlier finding of some problems with attention, however, Kemler (1978) sees the problem as more probably a combination of a memory deficit, with kindergartners relying solely on the information from the current trial, and a deficiency in young children's logical understanding of the MDL task which results in them staying with one attribute or dimension, and simply alternating between the values of that dimension depending on local feedback on each trial. She refers to this commonly observed pattern as 'attribute perseveration'. This is reminiscent of the work, to which we have referred earlier, stimulated by such as Wason (1960), which has demonstrated and explored the 'confirmatory bias' of human inferential reasoning. As we reviewed, a range of evidence has found adults reluctant to try out alternative hypotheses in certain 'scientific reasoning' tasks, and it may be that young children are merely showing the same bias on a task which is relatively more challenging for them. This is an issue which has continued to stimulate research and to which we will return in our conclusion.

Whatever the causes of these difficulties with negative feedback and redundant information, it seems important to try to distinguish between them. For this reason within the present study two alternative versions of the MDL task were used, in addition to the standard 4-dimensional version. In order to ensure that the children really did have to deal with negative information a 'one-card' version of the task was devised, whereby only one half of the normal stimulus array of two complementary stimulus cards was shown. Instead of making the usual choice of the correct stimulus, the children had to say whether this was a positive or negative instance (in the context of the task devised by Kemler (1978) this amounted to saying which of the two twins they thought was displayed on the card in view). Following a negative instance, the children thus had to infer positive items, rather than being able to just simply look across at the complimentary positive instance revealed on the other card. The children's ability to deal with irrelevant information was dealt with by using an 8-dimensional version of the task, similar to Barringer & Gholson's (1980), where 4 dimensions were relevant, and 4 irrelevant, in any problem.

c) Feedback

Arising from their early seminal study of concept identification behaviour on an MDL type of task, Bruner, Goodnow & Austin (1956) highlighted as one of the key issues in concept learning the nature and patterning of feedback. As Tumblin & Gholson (1981) review, this was also a key issue in much of the early study of discrimination learning carried out within the framework of behaviourist learning and conditioning theory.

Issues to be investigated included the effects of varying the amounts of feedback (eg: partially reinforcing a particular stimulus (Weir (1964)), varying the type of feedback, including material, verbal and directional aspects (Daniel, Tumblin & Gholson (1980)) and the differential effects of positive and negative feedback (Gholson, Levine & Phillips (1972)). This is not an issue which is pursued within the present study, but it is important to control for its effects. Within the present MDL task feedback was provided on every trial, and it was purely verbal in nature. We have reviewed above the rationale for concluding that the efficacy of directional feedback demonstrated by such as Daniel, Tumblin & Gholson (1980) may well be an artefact of the abstract version of the MDL task used.

Tumblin & Gholson (1981) review evidence to show that children become progressively more efficient at dealing with positive and negative feedback. Since there is good reason to believe, however, as we have reviewed above, that negative feedback is more difficult to deal with than positive, the relative proportions of the two kinds of feedback received may well have significant effects upon the ease with which a new concept is learnt. As we have also indicated above, there is clear evidence to suggest that the strategies adopted by children in relation to any task are significantly affected by the working memory demands imposed (Scardamalia (1977)), and it may well be the case that negative feedback imposes extra demands on memory.

In an important investigation of this issue in relation to the MDL task, and its relation to other classification skills, Fuchs & Turner (1981) explored the effects of different feedback patterns. They used Levine's (1966) standard 4-dimensional task with 7 and 8 yr. old children and preprogrammed the feedback sequence for the first three trials. Given the orthogonal structure of the stimuli presented, as we have outlined earlier, this feedback sequence then logically defined the correct solution to each problem, and the feedback on subsequent trials was then determined by that. The feedback sequences used were:

++- (right, right, wrong)
--- (wrong, wrong, wrong)
-+- (wrong, right, wrong)
+-- (right, wrong, wrong).

In line with the processing model suggested above, they found both that these feedback sequences were related to the probability of a problem being solved, and that the feedback involving least memory demand (++-) evoked the most sophisticated strategy.

As a consequence, within the present study, Fuchs & Turner's (1981) method of defining the solution to any problem by a preprogrammed feedback sequence was adopted, but in this case with the purpose of ensuring that each subject received the same selection of feedback sequences across the problems tackled. The details of these arrangements are provided in the next chapter.

iii) Children's Strategies and Performance

A major concern of research concerned with hypothesis-testing behaviour in relation to the MDL task has been to explore the development of children's and adults' use of strategies, and consequent improvements in performance. An attempt has been made within the present study to build on this previous work, and to examine systematically the components which have been identified which together comprise the various strategic approaches to this kind of task.

Bruner, Goodnow & Austin (1956) used a version of the MDL task in their seminal study of concept learning, and identified two distinct patterns of strategic behaviour. Their 'wholist' strategy involved subjects in remembering all the attributes common to those instances where the response was "correct", thus eliminating attributes that were not part of a positive instance. In relation to a slightly different version of the task, where subjects decided for themselves which instances they would sample, the equivalent types of strategy were referred to as 'focussing'. Other subjects adopted 'partist' or 'successive scanning' strategies which involved them in identifying just one hypothesis at a time, keeping it while it continued to predict "correct" responses, but replacing it with a new hypothesis, based on all past experience, when it did not. In general, 'focussing' strategies were found to be more efficient because they placed less load on memory.

While Bruner, Goodnow & Austin's (1956) subjects were college students, Mosher & Hornsby (1966) provided early evidence of children's developing abilities to use strategies in a study using a version of Twenty Questions with 6, 8 and 11 yr. olds. Once again they found two general kinds of strategies, which relate well to those identified by Bruner and his colleagues. 'Constraint-seeking' strategies attempted to constrain the number of alternatives by asking questions which eliminated large numbers of the possible solutions. This is clearly related to 'focussing'. 'Hypothesis-scanning' strategies tested a single possibility with each question, clearly equivalent to 'successive scanning'. Mosher & Hornsby (1966) found that children over the age range studied showed a developmental pattern of increasing reliance on the more effective 'constraint-seeking' strategy.

As we shall see, these early studies identified an important element in different patterns of strategic behaviour which was confirmed by later studies of hypothesis-testing on the

MDL task, and which is a significant finding of the current study. The distinctions identified would seem to relate closely to a range of findings from other studies of problem-solving strategies. The 'holist' and 'serialist' strategic styles identified by Pask & Scott (1972), for example, would appear to be closely related.

The crucial issues, from a strategic point of view, which were identified early on in the hypothesis-testing research, are the extent to which an individual is responsive to feedback, and the basis upon which possible hypotheses are sampled. We have reviewed earlier the 'zero-memory' model proposed by Restle (1962), which assumes perfect responsiveness to feedback but no memory for previously rejected hypotheses. Levine and his colleagues (Levine (1966), Gholson, Levine & Phillips (1972)), however, demonstrated that neither elements of this model appeared to be correct, and produced the first systematic attempt to map out the development of strategies of hypothesis sampling and testing.

Gholson, Levine & Phillips (1972) used the blank trial methodology and carried out studies with 7, 9 and 11 year old children, and with kindergartners (5 yrs. old). In the first experiment with the older children, they identified 4 hypothesis sampling 'Systems', 3 of which they described as 'Strategies', and 1 as a 'Stereotype'. These were identified by examining the choice and hypothesis protocols of subjects and analysing them in various ways. Thus, they found that the children maintained their hypotheses when told "correct" as often as adults ('Win/Stay'), but had an increased tendency to maintain disconfirmed hypotheses. Rather than being as a result of a 'zero-memory', random sampling of all possible hypotheses after negative feedback, however, this appeared to be the result of a small proportion of the children exhibiting a 'Stimulus Preference' response-set whereby their chosen hypothesis was maintained irrespective of feedback ('Win/Stay, Lose/Stay'). This they described as a 'Stereotype'.

The remainder of the children (about 90%) were 'locally consistent' following negative feedback, and produced new hypotheses which had not just been disconfirmed. While all these children were locally consistent, however, the extent to which they used information from previous trials varied. Where all previous information was co-ordinated they referred to the strategy adopted as 'Focusing'. With the orthogonally constructed stimulus materials used, this would mean that after Trial 1, the hypothesis would be one of the 4 positively confirmed, after Trial 2 it would be selected from the 2 remaining hypotheses consistent with the feedback on both trials, and after Trial 3 it would be the solution. Two further less efficient ways of proceeding were also identified. First, 'Dimension Checking' consisted of a strategy whereby a dimension is eliminated and not repeated following each "wrong" response. This implies co-ordinating the information from two successive trials, since, if a hypothesis is correct on one trial and wrong on the next, the complementary value of that dimension must also be wrong. Even less efficient was the strategy of 'Hypothesis Checking' which consisted of eliminating and not repeating each separate hypothesis after it has been disconfirmed.

In their experiment with kindergartners, however, Gholson, Levine & Phillips (1972) found much more evidence of stereotypic response sets. The 5 yr. olds maintained their hypothesis after positive feedback 79% of the time (as compared to 93% for 7 yr. olds, 94% for 9 yr. olds and 97% for 11 yr. olds), but they also maintained it 46% of the time after negative feedback. Examination of the protocols led to the identification of two further Stereotypes, 'Position Preference' and 'Position Alternation'. While Hypothesis and Dimension Checking were the dominant patterns found for 7 yr. olds, the 5 yr. olds appeared to be predominantly adopting response sets unresponsive to feedback.

As we have discussed in the earlier part of this section looking at methodological developments, however, Phillips & Levine (1975) and Kemler (1978) have argued that the blank trial technique interferes with the performance of young children, and Kemler (1978) also argued that the abstract nature of the MDL task itself would have a similar effect. In her study she also developed the 'Stereotypes' and 'Strategies' approach, arguing that this analysis omitted an intermediate problem-solving mode. Thus, while the Strategies of Hypothesis and Dimension Checking, and Focusing, involved long-term co-ordination of information from successive trials, and the Stereotypes involved no co-ordination of information at all, Kemler (1978) suggested that hypothesis testing strategies could be identified which involved short-term efficiency without any long-term planfulness.

An example of this is kind of short-term strategy is 'random sampling with local consistency'. Kemler (1978) demonstrated that many of the protocols in Gholson, Levine & Phillips' (1972) study could have been produced by this kind of strategy, and may well have been mis-classified as Hypothesis or Dimension Checking. She calculated that 50% of the protocols produced by random sampling with local consistency would be misclassified as Dimension Checking and 30% as Hypothesis

Checking. On this basis she replaced the kind of protocol analysis carried out by Gholson, Levine & Phillips (1972) with a series of statistical tests devised to detect short-term and long-term efficiency.

Thus, for short-term efficiency she found that, on standard 3, 4 and 5-dimensional versions of the MDL task, 7 and 11 yr. old children maintained hypotheses which were consistent with positive feedback on a trial ('Win/ Stay') an average of 91% and 98% of the time. Following negative feedback, every child except one 7 yr. old (who only failed to do so on one occasion) immediately rejected disconfirmed hypotheses ('Lose/Shift'), and new hypotheses were consistent with local feedback 100% of the time for 27 out of 32 7 yr. olds and 31 out of 32 11 yr.olds. Choices on each trial were consistent with the hypothesis stated at the end of the previous trial 79% of the time for 7 yr. olds and 84% of the time for 11 yr. olds.

As regards long-term efficiency she first of all examined the extent to which children avoided repeats of rejected dimensions ('Dimension Checking') and found that for the 7 yr. olds, out of 64 problems, 48 3-dimension and 32 5-dimension problems were solved without repeats; for the 11 yr. olds the figures were 59 and 49 out of 64. In a further analysis she demonstrated a statistically significant development in this kind of long-term strategic processing between the two age groups.

Intriguingly, further analysis of the hypotheses generated by the children who were not Dimension Checking revealed that some of these children were carrying out a strategy which Kemler (1978) referred to as 'attribute perseveration'. This involved a hypothesis pattern which alternated between the values on the same attribute or dimension depending upon feedback. Some children were more inclined to this pattern than others; other children were presumably engaged in differing degrees of Hypothesis Checking, although not a single instance of this as a pure strategy emerged from Kemler's (1978) data.

In further experiments, Kemler (1978) explored the upper and lower limits of young children's capabilities. At the upper limit, she found no evidence of children using 'stimulus memory' as well as 'hypothesis memory'. Thus, while the 7 and 11 yr.olds in her study often avoided resampling hypotheses they had previously selected and had rejected, they did sample hypotheses which had occurred in previously disconfirmed stimuli.

At the lower end, however, she found evidence to contradict Gholson, Levine & Phillips' (1972) claim that only 6% of kindergartners used strategies. Thus, while 5 yr. olds solved problems more slowly than older children, they did solve 73% of their problems in under 20 trials, which they could not do without some kind of strategy. On measures of short-term efficiency there was little sign that 5 yr. olds were qualitatively inferior to older children. On standard 4 -dimensional versions of the MDL task, they maintained hypotheses which were consistent with positive feedback on a trial ('Win/ Stay') an average of 90% of the time. Following negative feedback, they immediately rejected disconfirmed hypotheses ('Lose/Shift') 99 % of the time, and new hypotheses were consistent with local feedback 99% of the time. Choices on each trial were consistent with the hypothesis stated at the end of the previous trial 76% of the time.

As regards long-term efficiency for her group of 5 yr. old children, however, she once again found an overwhelming tendency to repeat hypotheses which had previously been rejected. The pattern identified with some 7 yr. olds as 'attribute perseveration' was much more common. Of her 36 subjects 28 manifested this kind of pattern at some stage. These children were far more strategic than had previously been suggested, however, using a number of elements of short-term strategies which clearly, eventually, allowed them to achieve a solution.

Schuepfer & Gholson (1980) subsequently carried out a detailed analysis of the beginnings of strategic behaviour with 3/4 and 7/8 yr. old groups of children. They used 2 and 4-dimensional problems of the standard abstract variety, and explored in detail the means by which children made progress from the various response-sets of position and object preferences to being capable of the kind of short-term strategic processing identified by Kemler (1978)

At the earliest stages, amongst the 3 and 4 yr. olds, they found position hypotheses, which gradually gave way to object preferences. Interestingly, while Lose/Shift object was a strong component of object responding from the outset, Win/Stay object only gradually emerged. This finding of the earlier appearance of Lose/Shift than of Win/Stay is interesting, and will be seen to be borne out by the results of the present study. Amongst the 7 and 8 yr. olds they found evidence of a further stage, whereby irrelevant, disconfirmed hypotheses (eg: position, object -alternation) were more systematically rejected. This parallels the transition Kemler (1978) identified between short-term and long-term processing.

Within the present study, an attempt has been made to build on this research and develop a systematic analysis of the whole range of strategic processing on the MDL task. This has been done by analysing the hypothesis and choice protocols of the children according to each of the significant elements of strategy development identified by this earlier research. These elements have thus become the 10 Strategy Components within the present study. A central part of the work of the present study is to try to identify in more detail how these various elements or components are combined together at different stages in the development by children of strategic approaches to the MDL task. Details of the Strategy Components, and their scoring, are provided in the next chapter.

Before we come to that, however, we must look first briefly again at the issue of what underlying cognitive factors develop in order to facilitate this development of strategic processing and behaviour.

Section C) Children's Thinking: what develops?

Gholson (1980) and his co-workers began the attempt to explore what they termed the 'cognitive subprocesses' involved in children's development of hypothesis-testing strategies on the MDL task. However, this was confined to initial investigations of the role of attention (Tumblin & Gholson (1980) and Barringer & Gholson (1980)), the effects of different kinds of feedback (Daniel, Tumblin & Gholson (1980)) and the effects of explicit memory aids (Phillips & Gholson (1980)). While, as we have reviewed, these studies contained a number of useful methodological developments, and raised some issues worth pursuing, within the present study a much more thorough attempt has been made to investigate the relationship between significant aspects of children's cognitive development and strategic behaviour and performance on the MDL task.

As Voss (1989) has recently indicated in a useful overall review, analyses of problem-solving have suggested that it involves a wide variety of different cognitive processes. Many of these processes have emerged above in our literature review. As Pressley, Borkowski & Schneider (1987) have argued, it has become well established that what they refer to as 'The Good Strategy User' needs knowledge, access to a wide range of cognitive strategies, the cognitive and metacognitive abilities to use strategies effectively, and an affective disposition to make the necessary effort. This section is intended to briefly pull together the major research issues in relation to each of these areas, and to indicate how they have been dealt with within the present study.

i) Domain Knowledge and Representation

The manner in which a problem is understood and represented has been found to be crucial to success, as has the construction of sophisticated and highly structured knowledge within the particular domain. These two factors are clearly very strongly interrelated.

It has long been established that performance on a task is strongly influenced by domain specific knowledge (see, for example, Chi's (1978) classic work on memory for chess positions). Donaldson (1978) and her co-workers have also established that a child's understanding and performance on a task is significantly affected by its relationship to their existing knowledge. As we have reviewed, research on expertise in a number of domains has repeatedly revealed the key role of highly abstract knowledge structures which powerfully organise expert's declarative knowledge and their handling of problem-solving strategies.

Attempting to solve a problem in an area in which a person has some knowledge is facilitated in a number of ways. Sternberg & Powell's (1983) third principle of the development of intelligent functioning, the 'ability to comprehend relations of successively higher orders' is clearly related to the development of a more highly structured knowledge base. Pressley, Borkowski & Schneider (1987) have also reviewed an extensive range of work demonstrating that knowledge facilitates more efficient and more extensive use of strategies. Processes of 'chunking' (Miller (1956)) and of automatisation of basic operations (Case (1974, 1984, 1985)) have been identified as ways in which knowledge reduces load on working memory.

This kind of evidence has led some researchers to claim that the development of the knowledge base is the crucial, and perhaps only, difference between young children and adults. Carey (1985b), for example, has written that:

"the acquisition and reorganisation of strictly domain-specific knowledge . . . probably accounts for most of the cognitive differences between 3-year-olds and adults" (p.512)

As we shall see, however, this is a claim which has been made for other aspects of the cognitive system with equal force and certainty. As English (1992) has recently reviewed, for example, the relative significance of domain-specific knowledge and domain-general strategies in the development of problem-solving competence is a much debated issue, with researchers on either side claiming the major significance for one aspect or the other. It is English's (1992) view, and that of the present author, however, that the evidence suggests the good problem-solver needs both.

Within the present study, however, no attempt has been made to explore the issue of domain-specific knowledge further. Rather, the focus of the present study is children's abilities to generate and use strategies on a novel task. However, the significance of children's existing knowledge has very much been taken into account. Thus, the form of the MDL task is based closely on the version designed by Kemler (1978) using a story-and-game context. This is designed so that, in Donaldson's (1978) words, the problem will make "human sense" to young children, and their comprehension of the problem and their ability to develop strategies to solve it will be maximised. Kemler produced results, as we have indicated earlier, to show that children performed much more effectively on her task than on the standard, abstract MDL task.

The related issue of representation is, however, an important part of the present study. For Siegler (1978), the development of effective problem-solving was seen as mostly dependent upon the manner in which the problem was encoded by the child, and much other research, as we have seen, has indicated the significance of the efficiency with which a problem is represented for subsequent performance (See, for example, Johnson-Laird's (1983) work on the construction of 'mental models'). Within the present study the efficacy with which children represented the problem to themselves is construed and examined as an aspect of metacognitive knowledge about the task, which is discussed below.

ii) Cognitive Strategies

As we have seen, the development of increasingly sophisticated strategies has been a strong theme within modern cognitive developmental research. Bjorklund (1990), for example, has recently edited a very comprehensive collection of work carried out in relation to the development of children's strategies across a wide range of intellectual functioning. This includes mathematics, reading, the processes of attention and a variety of different kinds of problem-solving. As we have reviewed, this concern has its origins in such seminal work as Bruner, Goodnow & Austin's (1956) analysis of concept learning strategies, Miller, Galanter & Pribram's (1960) work on cognitive plans and Newell & Simon's (1972) identification of such general strategies as 'means-end analysis'. We have also reviewed the manner in which this early work influenced the development of research into children's hypothesis testing upon which the present study is founded.

An important distinction has arisen in the literature between domain-specific and domain-general problem-solving strategies. As English (1992) has recently reviewed, some researchers have claimed that problem-solving skills are inherently domain-specific and best explained as a consequence of expertise within a knowledge domain. As she demonstrates, however, the generation of domain-specific strategies in relation to a novel problem is best explained in terms of the interaction between domain-specific knowledge and domain-general strategies. Brown et al (1983) reviewed the relevant literature very comprehensively, and concluded that domain-specific knowledge was a necessary but not sufficient condition for effective learning and problem-solving. The effective use of general learning strategies was also crucially necessary. Pressley, Borkowski & Schneider (1987) reviewed a wide range of research evidence demonstrating the significance of both specific and general strategies for effective problem-solving.

Within the present study (as with English (1992)) the focus is upon the generation of goal-specific strategies related to a novel problem which is nevertheless placed within a meaningful context. The emphasis here, therefore, is upon the role of general strategies in generating goal-specific strategies. As both English (1992) and Pressley, Borkowski & Schneider (1987) review, the general problem-solving strategies which have been most commonly identified within the literature relate to the metacognitive processes of monitoring (or self-awareness) and control (or self-regulation). These processes are included within the present study and will be discussed below under the heading of 'Metacognitive Awareness and Control'.

The analysis of specific strategies within the present study is based on the methodology commonly adopted within the hypothesis testing literature, whereby children's strategies are inferred from their pattern of responding. A modified and developed version of this approach is used within the present study, however, which recognises the complexity of the development of strategic behaviour identified by more recent research, such as that of Siegler & Jenkins (1989). They contrast their model of strategy construction with the model implied in, for example, Siegler's (1978) earlier work on strategy development. In the earlier studies the assumption was that a problem could be solved using a series of discrete strategies, and children would respond to the problem by consistently using one of these strategies. Development consisted of moving from using one discrete strategy to the next. As we have seen, this was similarly the model assumed by early work on hypothesis testing. Siegler & Jenkins' (1989) provide more recent evidence, however, which suggests that the processes of strategy use and development are very much more complicated. In response to any problem children use a mix of strategies, the frequency distribution between which will vary over time, and be influenced by a range of circumstances. New strategies emerge through a process of strategy construction involving combining parts of existing strategies in novel ways, or grafting on new segments to existing procedures.

The methodology of strategy identification embodied in the present study recognises these kinds of complexities. Rather than predetermining a set of discrete strategies which can be used on the MDL task by some kind of logical analysis, a procedure has been adopted which attempts to discover the kind of strategy mix actually employed by children. The children's responses were, therefore, analysed in terms of Strategic Components derived from previous work on the MDL task, and the patterns in which these components combine together at different stages of strategic development was explored using the statistical technique of Cluster Analysis. The details of these Strategy Components are provided in the next chapter, and the report of the results of the present study in Chapter 5 begins with the analysis of the Strategy Clusters which emerged.

iii) Working memory

As we have seen, one of the central insights of the information-processing approach to human cognitive functioning has been the constraint of limited short-term memory capacity (most notably highlighted by Miller's (1956) classic paper on the 'magic number 7'), and its implications. We have also reviewed earlier studies which have demonstrated significant effects of memory on performance on the MDL task. This is clearly an aspect of underlying cognitive functioning which had to be included in the present study.

The most influential early model of the structure of the memory system was the multi-store model developed by Atkinson & Shiffrin (1968) within which they proposed that controlled processes such as rehearsal and organisation were applied in the short-term store to maintain information, transfer information to and from the long-term store, and solve problems. Shiffrin & Schneider (1977), amongst others, went on to analyse these controlled processes, or strategies, in terms of the amount of the limited short-term memory capacity required for an operation's execution. Subsequently, the investigation of 'working memory systems', first suggested by such as Baddeley and Hitch (1974), has proved to be a very fruitful area.

This work has been paralleled and reinforced by the work of the neo-Piagetians we reviewed earlier which re-analysed Piaget's problem-solving tasks in terms of their demands on children's memory capacities. The work of Pascual-Leone (1969, 1970) was seminal in this area. In an extensive range of studies he demonstrated that the sequence of children's success on Piagetian problem-solving tasks could be predicted by the load on working memory involved in each of these tasks. This led him to develop a theory of M-space (a measure of working memory capacity), which he claimed the evidence suggested grew maturationally.

In developing these ideas, however, Case (1974, 1975, 1985) has presented evidence that the apparent growth in the size of working memory capacity is, in fact, a product of increasing automaticity of basic operations. The key studies here were those reported by Case, Kurland & Goldberg (1982), within which they demonstrated a strong relationship between word memory span and speed of word repetition (a measure of automaticity of basic operations) for children and adults. Both measures were demonstrated to show improvement with age, and the role of experience and familiarity was highlighted by the finding that adult's performance with nonsense words matched that of 5-6 yr. old children on real words on both measures.

Here, once again, some researchers have been attracted to the view that developments in the memory system are the fundamental cognitive development which facilitate everything else. Brainerd (1983), for example, prefaced a comprehensive review of work on 'working memory systems' by the claim that

" cognitive development can, in fact, be reduced to memory development." (p. 168)

More recently, work by such as Anderson (1992) has suggested that the speed of basic processing is an innate biological factor closely related to the development of intelligence. Within the present study, however, the view is taken that while developments in working memory capacity are clearly an important element in the development of cognitive functioning, they are one element in a complex set of inter-relationships with other factors. In particular, there is clear evidence of inter-relationships with both domain-specific knowledge and familiarity, as illustrated by much of the work reviewed above, and with the use of strategies. On the latter point, for example, the elegant studies reported by Scardamalia (1977) have demonstrated that the strategies adopted in relation to a task will vary according to the memory load imposed.

The inter-relationship between working memory capacity and familiarity with the material to be remembered, as we have reviewed, has been suggested by Linder & Siegel (1983) to account for the discrepant findings of Eimas (1970), Phillips & Gholson (1980) and Kemler (1978) in relation to the utility of memory aids with the MDL task. Kemler (1978) found that a memory aid did not help children with her more meaningful task containing material which would be more familiar to them than the abstract material used in the other studies. Within the present study, the same more familiar materials were used, in order that the working memory load of the task would be manageable for young children. Even in this case, however, it is clear that the effective working memory capacity for the materials used in the MDL task would vary between children, and this might be a significant factor in their problem solving behaviour.

The recognition of the complex inter-relationships between working memory and other aspects of cognitive functioning has led to the use within the present study of two complementary measures of working memory capacity. The significance of domain-specific knowledge or familiarity has once again been taken into account, and a specially constructed short-term memory test using the materials contained within the MDL task itself was therefore used as one measure (as opposed, for example, to a digit or word-span test which would be dependent upon experience in another domain). It was clear, however, that this kind of short-term memory test is itself subject to the use of strategies. Children who were able to generate and use effective strategies on the MDL task might well also be able to do so for this short-term memory test. It was, therefore complemented by the use of the FIT measure of general M-space devised by Pascual Leone (1969), upon which it is much more difficult to behave strategically, but which is, of course, unrelated to the MDL task in terms of domain-specific knowledge.

iv) Metacognition

As was noted in the earlier discussion of educational programmes designed to teach children to think, a strong and consistent element within such programmes has been an emphasis on the processes of metacognition. Similarly, over the last 15-20 years perhaps the largest area of growth in the literature of cognitive development has been that related to metacognition. This has its origins, of course, in the seminal study of Flavell, Beach & Chinsky (1966) (which, interestingly, shared a common concern with 'mediational processes' with studies of discrimination learning at that time). Young children were found to be capable of carrying out a memory strategy, but incapable of producing that strategy for use spontaneously. This finding led to the notion of 'production deficiency' and a blossoming of research concerned with children's knowledge about and control of their own cognitive functioning. While the development of working memory might be necessary to enable children to carry out more and more complex strategies, it was clearly insufficient to explain the origins of new strategies in children's repertoires. For this, researchers have increasingly looked to the development of metacognition. There is now hardly an aspect of human functioning or skill which does not have its associated 'meta' component well documented and researched.

Since the term 'metamemory' was introduced into the literature by Flavell (1971), however, there has been considerable debate about the significance and definition of metacognitive processes. As we shall see, some of the key developments arising from the research associated with this debate are reflected in the measurement of metacognitive processes within the present study. In a major review of these difficulties Brown (1987), however, in a conclusion which echoes the claims for other aspects of cognitive functioning reviewed above, asserts her view that

"metacognitive-like concepts lie at the very roots of the learning process" (p.66)

Certainly, Ann Brown and her co-workers have been one of the major research teams to firmly establish metacognition at the heart of the current revival of interest in mechanisms of change and development. It will be recalled that Sternberg & Powell's (1983) first principle of intellectual functioning is, significantly, that 'more sophisticated control strategies (metacomponents) develop with age'.

Of interest in relation to the present study are the models provided by Brown & DeLoache (1978) and Shatz (1978) to account for production deficiencies, and to suggest a way in which metacognitive processes might interact with working memory capacity. It will be recalled that in a previous study (Whitebread (1983)) such an interaction was found. Shatz (1978) pointed out that the metacognitive processes of conscious monitoring themselves require some working memory space. They will only occur, therefore, when all the individual's working memory capacity is not taken up by carrying out the actual task. Brown & DeLoache (1978) developed this into a general model of learning both developmentally and within any task. They suggested that the novice on any task will initially show little or no 'intelligent self-regulation'. Then, as the task and its sub-processes become more familiar (and, thus, according to Case's (1974, 1984, 1985) model take up less working memory capacity) there will be an increasingly active period of deliberate monitoring and self-regulation. Finally, as the necessary subprocesses and their coordination become overlearned, expertise is achieved and performance on the task becomes relatively automatic. It is one of the major aims of the present study to explore whether this kind of interaction between metacognition, working memory capacity and performance appears in relation to the MDL task.

Within the present study, in our consideration and measurement of metacognition, the distinction first proposed by Flavell (1981) between metacognitive knowledge and metacognitive experience has been followed.

a) Metacognitive Knowledge

As regards metacognitive knowledge, Yussen (1985) and others have reviewed the conflicting evidence about the relationship between metacognitive knowledge and performance. Some early reviews, such as that by Cavanaugh & Perlmutter (1982), tended to conclude that only a weak relationship existed, while other work, such as that reviewed by Wellman (1983), found evidence of stronger links.

Schneider (1985), however, in an integrative review of research attempting to find links between metamemory and memory performance, concluded that the strength of the relationship found depended upon the aspect of metamemory upon which the study focussed, and the methodology used to assess it. The early work reviewed by Cavanaugh & Perlmutter (1982) tended to rely on single measures, often derived from questionnaires or verbal questions relating to subjects' general knowledge about different memory tasks. Later work, however, as Wellman (1983) and Schneider (1985) discovered, indicated that metacognitive knowledge may be more closely linked to performance where it was directly related to the individual's own metacognitive experience of the task in question.

Within the present study, therefore, rather than exploring the children's general metacognitive knowledge about their own cognitive processes, questions have been asked which focus on the metacognitive knowledge they had derived directly related to the MDL task. These questions focus on the children's experience of the relative ease or difficulty of different versions of the task. As indicated above, this knowledge can also be taken, at least in part, as evidence of the efficacy with which the children internally represented the problem.

Schneider & Weinert (1989) have reviewed more recent studies of metamemory-memory links which indicate that the intercorrelations among metamemory, strategic memory behaviour and performance increase with age. Schneider (1986), for example, found low correlations between metamemory and strategic memory behaviour amongst 6/7 yr. olds, but significant correlations for 8/9 yr. olds. Schneider & Weinert (1989) have suggested that this pattern may be accounted for by the developing interactions between strategy use and strategy knowledge suggested by Flavell's (1978) bi-directionality hypothesis and the principle of reciprocal mediation developed by Pressley, Borkowski & O'Sullivan (1985) as part of their model of knowledge about strategies. According to these models, initial strategy use leads to some vague recognition of the strategy's usefulness, which in turn leads to greater strategy use, which then leads to more developed knowledge of the strategy's utility, and so on. By this kind of process, knowledge and strategic behaviour become increasingly closely related. Within the present study, as will reported in the Results chapter, the pattern of development of these kinds of relationships was examined by looking at relationships within age subgroups.

b) Metacognitive Awareness and Control

Wellman (1983) and Schneider (1985) also produced evidence to suggest that measures of subjects' on-line monitoring and control of their own understanding and performance might tend to be more directly related to performance. This relates to the aspect of metacognitve activity referred to by Flavell (1981) as metacognitive experience. Within this area the distinction between a monitoring and a control function has been adopted from Brown's (1978) earlier detailed analysis of the necessary components of a metacognitive system. These are referred to by her as Metacomprehension and Insight. The first term is retained within the present study, while the latter control element is characterised as Strategy Flexibility.

Both Brown (1978) and Robinson (1983) have provided reviews of work related to Metacomprehension, and demonstrate the complexities of the cognitive processes involved. As they both argue, being aware of one's own level of understanding in relation to any problem or task is fundamental to putting together an effective pattern of strategic behaviour in response to it. The problems of Metacomprehension, as they both make clear, however, can range from simply being aware that you do not know something to the very complex business of ascertaining that you have the optimal information for tackling a particular task, or identifying the exact source of one's difficulty. The simple recognition that you do not know something may be a necessary precursor to strategic development, but, some evidence would suggest, may also not be sufficient.

Robinson (1983), for example, reviewed her own work and that of Markman (1981) relating to young children's difficulties with monitoring their own understanding of verbal messages. Sometimes the children were unaware of any problem of understanding, but even when they were aware that they had a problem they often could not analyse its source. Nisbet & Shucksmith (1986), reviewed the evidence on this point, and concluded that if children are simply aware that they do not understand this can lead to a kind of 'destructive bewilderment', rather than the kind of constructive cognitive conflict suggested by Piaget. As we will see, the present study offered some support for the position that metacomprehension, at an elementary level, may be a necessary but not sufficient cause of strategy development.

Measuring the extent to which young children are aware of their own level of understanding is clearly not a straightforward matter. Brown (1978), however, presented evidence that requiring children to rate the confidence they had in their responses to a problem seemed to be a useful technique, and one which Berch & Evans (1973), for example, had successfully used with children as young as 6 yrs. old. This task was, therefore, adapted as a measure of Metacomprehension within the present study.

As Brown (1978) goes on to argue, a central feature of the successful problem-solver is that they use their on-line monitoring of their own understanding and success at tackling the problem to guide their choice and execution of cognitive strategies. Sternberg & Powell's (1983) fourth principle of intellectual functioning, it will be recalled, was that 'flexibility in the use of strategy or information develops with age'. Brown (1978) reviews the work of Butterfield & Belmont (1977), for example, who examined changes in the employment of a particular strategy as a function of task difficulty. They found that young children took longer to select a strategy initially, abandon it when it was no longer necessary, and reinstate it when its use was again required. Small (1990) has reviewed a range of more recent studies which have confirmed that Strategy Flexibility and self-regulation increase with age and are related to successful problem-solving. Within the present study a measure of Strategy Flexibility was devised, based upon the approach of Butterfield & Belmont (1977), but related to the MDL task. This involved a measure of how quickly the children abandoned a taught strategy when it was no longer appropriate.

v) Attributional style: Locus of Control

A further common feature of educational programmes designed to teach children to think, as we noted earlier, has been a recognition of the importance of the learner's attitudes and motivations. The relationships between style of attribution (as originally conceived and developed by Weiner (1972, 1979)), self-concept, and achievement has long been established and explored within educational contexts. Rogers (1982) provides an excellent review of the extensive literature in this area.

Weinert (1987) has argued that research related to style of attribution has indicated similarities and significant conceptual links between this as an aspect of motivation and metacognition as an aspect of cognition, and there is interesting work demonstrating links between the two areas. Borkowski, Milstead & Hale (!988), for example, in a major analysis of the components of children's metamemory, present a range of evidence to support the view that attributional beliefs are closely related to the effective use of cognitive strategies. Thus, Kurtz & Borkowski (1984), in the context of certain memory tasks, found that children who attributed their successes to effort (i.e. an 'internal' locus of control) were more strategic and higher in metamemorial knowledge than children who attributed learning outcomes to non-controllable factors such as ability or task characteristics (i.e. an 'external' locus of control).

Within the present study Locus of Control was measured by means of the Children's Attribution of Responsibility and Locus of Control Scale (CARALOC) developed by Gammage (1975, 1982). There are many scales in this field of attribution and self-esteem (see Phares (1976) and Lefcourt (1976) for comprehensive reviews), but the CARALOC scale is one of the few developed and refined for use with English Primary school children. It attempts to measure the extent to which a child's Locus of Control is internal, as opposed to external. It has been shown by such as Osborn & Milbank (1987), in a major longitudinal study, to be significantly related to achievement in a number of cognitive areas.

vi) Cognitive Style:

The final aspect of cognitive functioning which has been widely suggested to have important implications for problem-solving behaviour is that of 'cognitive style'. Analysis of the different strategies used in relation to particular tasks has led some researchers to suggest that individuals might vary in their strategic preferences. We have mentioned in our earlier discussion of children's strategies in relation to the MDL task, for example, the 'holist' and 'serialist' styles identified amongst adults by Pask & Scott (1972). Cognitive style has been a huge area for research over the last 20 years or so, but there remains much debate about the validity of many of the models developed.

Kogan (1971, 1983) provided extensive reviews of work in this area, and his two reviews offer an insight into the development of research and thinking in the area. The interesting point to note is that while he felt obliged to review at least 9 separate cognitive style dimensions in 1971, by 1983 he felt that only two had proved sufficiently fruitful in the intervening period to be worthy of inclusion. These were Reflectivity-Impulsivity (Cognitive Tempo or R-I) and Field Dependence-Independence (FDI). Schmeck (1988) has argued in an even more recent review that a range of conceptualisations or styles can all be encompassed by one broad inclusive dimension of individual difference, which he labels 'global versus analytic'; this looks similar to Pask & Scott's (1972) 'holist' and 'serialist' dimension, but is in fact a much broader conception embracing elements of cognitive and attributional functioning. Nevertheless, within it R-I and FDI are recognised as significant elements, with the 'global' style implying Impulsivity and Field-Dependence and the 'analytic' style involving more Reflectivity and Field-Independence. It is these two dimensions of cognitive style, therefore, which are included in the present study.

a) Cognitive Tempo: Reflectivity- Impulsivity

Cognitive Tempo was originally conceived and operationalised by Kagan et al (1964), as a dimension involving the extent to which an individual can delay a response when searching for a correct answer, where what response to make is initially uncertain. Subsequently there have been significant theoretical advances. Zelnicker & Jeffrey (1979), for example, redescribed the dimension in terms of different strategic approaches to processing information which relate closely to Pask & Scott's (1972) 'holist' and 'serialist' dimension, as well as to Schmeck's (1988) reconceptualisation described above.

What is clearly involved in the Matching Familiar Figures Task (MFFT) devised by Kagan et al (1964), which is by far the most commonly used instrument, is the thoroughness with which information is encoded and processed before a response is made. The Reflectivity end of the dimension involves delaying a response until the relevant information has been thoroughly encoded and processed, while the Impulsivity end involves responding more quickly, and before all the relevant information has been thoroughly considered. Kagan et al (1964) and others have presented evidence which shows that children move more towards the Reflectivity end of the dimension with age. Subsequent research has demonstrated the significance of this dimension for cognitive functioning, and explored its relationship to other features. Borkowski et al (1983), for example, demonstrated significant relationships between cognitive tempo, metamemory, strategy use and performance on particular memory tasks. This is clearly related to the well researched finding that gifted children and adults spend longer encoding a problem before responding than do average children (see, for example, Sternberg & Rifkin's (1979) study of analogical reasoning). Sternberg & Powell's (1983) second principle of intellectual functioning, it will be recalled, was that 'information processing becomes more nearly exhaustive with increasing age'.

Of particular interest in relation to the present study is the review by Davis (1985) of research demonstrating a link between Cognitive Tempo and performance on concept learning and discrimination tasks. Nuessle (1972), for example, used Levine's (1966) version of the MDL task with 10 and 14 yr. olds and found that Reflectivity was associated with more proficient use of the Focussing strategy. He suggested that a reflective cognitive style facilitates focussing because it allows for the more effective retrieval and recoding of information.

At the methodological level, there have also been significant developments. Kagan et al's (1964) MFFT came in for considerable criticism, leading to the development by Cairns & Cammock (1978) of a longer and more reliable version, which is known as the MFF20. It is this latter instrument which has, therefore, been used within the present study.

b) Field Dependence-Independence

Perhaps the single most well-known and certainly the most intensively researched dimension of cognitive style is that of Field Dependence-Independence conceived and developed by Witkin and his associates. The FDI construct was first conceived as an aspect of basic perceptual processes (Witkin et al, 1954) and was then developed by Witkin et al (1962) into a more general theory of psychological differentiation and cognitive style. It has subsequently been explored in relation to a wide range of cognitive functioning (see, for example, Goodenough's (1976) early review in relation to learning and memory).

Interestingly, Pascual-Leone (1969) incorporated FDI into his neo-Piagetian model of cognitive development and successfully used it to explain the phenomenon of low inter-task correlations between Piagetian tasks at the same developmental stage. He did this by demonstrating that the difficulties children had with Piagetian tasks were of two distinct origins. Some tasks were difficult because of the load they placed on memory, but others were difficult because of their misleading structure. The latter kinds of task were more easily solved by Field-Independent subjects.

Kogan (1983) reviews work on the relation of FDI to various educational achievements and learning difficulties. Early versions of the theory saw Field-Independence as superior because this involved a more impersonal, analytic and task-orientated approach. More recently, the two ends of the dimension have been seen as more equally valuable, with Field Dependent individuals better at interpersonal and holistic tasks (it may be that some of Piaget's tasks were more difficult for such children because they paid too much attention to misleading social cues).

Witkin et al (1977) argued that FDI has major educational implications and reviewed a range of studies providing evidence that Field Dependent children learnt more neffectively when the material had a social content, where there was external reinforcement, where the material was relatively structured, and where the relevant information was more perceptually salient. Field-Independent children, on the other hand, learnt more effectively when material was presented as an intentional learning task, where learning depended upon intrinsic motivation and the material was relatively unstructured; they were also relatively unaffected by the perceptual salience of relevant information. Of particular interest in relation to the present study is evidence Witkin et al (1977) presented of the relative difficulty Field-Dependent children might have with concept-learning tasks which require them to adopt an analytic, hypothesis testing approach. This would lead to the prediction that such children would have relative difficulty with the MDL task.

Two key instruments have been devised and used as measures of FDI, the Rod & Frame test (RFT) and the Embedded Figures Test (EFT). Kogan (1983) reviews the evidence that while these two instruments are both tapping the ability to overcome an embedding context, they may be assessing rather different aspects of this. Current methodological advice appears to be to use both instruments and to use both scores, or produce a composite score. Within the present study, therefore, the RFT was used as well as the Children's Embedded Figures Test (CEFT), a version of the EFT devised for use with young children (see Witkin et al (1971)). Details of this and all the other measures used within the present study are provided in the next chapter.

Section D) The Contribution of the Present Study

The present study thus arises in response to the current interest within both education and psychology related to the developing thinking, reasoning and problem-solving abilities of young children.

A range of studies have indicated that the development of children's performance on problem-solving tasks is a consequence of developing features of their underlying cognitive systems, rather than on their abilities to reason. Work within the information processing framework has focussed on children's development of increasingly sophisticated strategies, and the mechanisms by which these are developed and executed.

Studies of the development of children's problem-solving abilities have been wide-ranging, but the study of problems involving inductive reasoning (with the possible exception of the use of analogy), a process central to much of human learning, has been relatively neglected. The present study, therefore, attempts to help redress this balance by investigating children's problem-solving behaviour on a task involving inductive reasoning. The study aims to identify the developmental sequence of strategies developed by children on an inductive reasoning task, and the underlying cognitive factors which might be related to this development.

The task chosen for investigation was the multidimensional discrimination learning task. This task has a long history within the study of human learning, but analysis of the development of strategies in relation to it by young children has been rather piecemeal. Within the present study an attempt has been made to use and build upon analyses and methodologies developed by previous research, most notably that concerned with the hypothesis-testing approach, and to provide a more systematic and comprehensive analysis of the development of children's strategies.

The methodology used within the present study recognises the complexity of the development of strategic behaviour identified by more recent research. In earlier studies the assumption was that a problem could be solved using a series of discrete strategies, and children would respond to the problem by consistently using one of these strategies. Development consisted of moving from using one discrete strategy to the next. More recent evidence, however, has suggested that, in response to any problem, children use a mix of strategies, the frequency distribution between which will vary over time, and be influenced by a range of circumstances. New strategies emerge through a process of strategy construction involving combining parts of existing strategies in novel ways, or grafting on new segments to existing procedures.

The methodology of strategy identification embodied in the present study recognises these kinds of complexities. Rather than predetermining a set of discrete strategies which can be used on the MDL task by some kind of logical analysis, a procedure has been adopted, involving analysis based upon Strategy Components, which attempts to discover the kind of strategy mix actually employed by children.

A further reason for the choice of task related to the fact that it would be a 'novel' task for the children, and one which is not clearly dependent upon any particular knowledge base. Much of the recent literature on the development of problem-solving strategies has been concerned with the development of expertise within particular domains. The relative significance of domain-specific knowledge and domain-general strategies in the development of problem-solving competence is a much debated issue, but it is clear from the literature that the good problem-solver needs both. If we are to understand how the good problem-solver uses general strategies to develop task specific strategies, we must study performance on novel tasks. The second important focus of the present study is, therefore, on the contribution of different aspects of the cognitive system to the generation of goal-specific strategies.

Attempts to relate the development of strategies and performance on the MDL task to underlying cognitive factors have been extremely limited. The present study therefore attempted to examine the relationship of the development of strategies and performance on the MDL task to a range of underlying cognitive factors which have been advanced as significant within the development of children's thinking, reasoning and problem-solving abilities. These factors related to metacognitive knowledge (which relates to representation of the problem), metacognitive awareness and control, working memory, attributional style (locus of control), and cognitive style (reflectivity-impulsivity and field dependence-independence).

Much of the literature is devoted to advancing the cause of one particular feature of the cognitive system as the fundamental determinant of cognitive change and development.

The present study, however, emphasises the need to get away from simple, single factor models of cognitive change and development, and instead emphasises the need to investigate the significant interactions between underlying cognitive factors, strategy use and performance. In a previous study (Whitebread, 1983) with 5 and 6 yr. olds a strong interaction was revealed between age, working memory, metacognitive awareness, strategy use and performance on a reclassification task. The present study attempted to examine these kinds of interactions on a more complex task and over a wider age group. As regards age, for example, issues arise in relation to the general pattern of development (eg: linear or U-shaped ?) and recent evidence that the correlations between underlying abilities and performance increase as children develop through the Primary years.

In order to investigate these various issues, the study was structured in relation to 4 areas of investigation, or aims. These involved the analysis of the sample of children's responses to the MDL task in terms of the development of problem-solving strategies, the relation between strategies and performance, the relationships between the various cognitve factors and the development of problem-solving abilities, and interactions between cognitive factors (or 'predictors'), strategies and performance. In the following chapter, details are provided of the ways in which the study was structured, and the investigations and analyses which were carried out, in order to address these 4 central aims.

Chapter 4: DESIGN OF THE STUDY

Section A) Introduction: Aims and Structure of the Study

The forgoing review of the literature relating to the development of children's problem-solving abilities and related cognitive factors sets out the background of research and ideas upon which the present study was conceived. This chapter is intended to explain the aims of the present study and the details of the design and execution of the empirical work carried out.

The 4 broad aims of the study were to identify the development of children's strategies on the MDL task, to examine the relationship between these patterns of strategic behaviour and performance, to examine the relationship between various underlying cognitive factors and problem-solving ability, and to investigate any interactions between these predictors, strategies and performance. The remainder of this section sets out these aims in detail, indicating the main ways in which they arise from previous work discussed earlier, and the broad structure of the methodology developed to carry them out.

i) The Development of Problem-solving Strategies

The first main aim of the study was to investigate the pattern of development of strategic behaviour amongst Primary school aged children on an inductive reasoning task. For the purposes of the present study this was investigated using the Multidimensional Discrimination Learning (MDL) Task. As reviewed above, this task is one which has been widely employed within the problem-solving literature, and one which simulates in a controlled manner learning through the processes of rule induction. Gholson (1980) and his associates, Kemler (1978) and others have developed techniques related to this task which allow close analysis of the strategies adopted by subjects. Kemler (1978) has also devised an ingenious story-and-game format which makes the task usable with young children. These investigators and others have also carried out detailed analyses of features of the MDL task which appear to provide difficulties for young children, and of the developmental range of strategies adopted by children in their attempts to solve the problem.

Working from this basis, within the present study an adapted version of Kemler's MDL task was used, with the children being required to verbalise hypotheses (or 'introtacts') on every trial. The advantages of providing a meaningful context for the task, and of the verbal introtact requirement, have been discussed in our earlier review of methodological developments.

The children's responses were analysed according to 10 Strategy Components, again based very largely on the work of Gholson (1980), Kemler (1978) and their associates. This approach was adopted, as indicated in the last section of the previous chapter, in recognition of the complexity of the development of problem-solving strategies. Research outlined earlier suggests that children's responses to a problem-solving task can best be described in terms of increasingly sophisticated and complex patterns of strategic behaviour, involving successive recombinations of different strategic elements. The 10 Strategy Components devised seek to offer a comprehensive description of the elements which might make up these developing strategic patterns. Cluster Analysis was used as a means of identifying these patterns, and Discriminant Function Analysis to determine the nature of relationships between different Strategy Clusters.

ii) Strategies and Performance

The second main aim of the study was to examine the relationship with performance of the revealed patterns of strategic behaviour. As we have discussed in the previous chapter, much of the problem-solving literature has suggested that children's performance is strongly linked to their strategic behaviour. It was therefore important to establish whether this was the case with the MDL task as used within the present study.

Again derived from the work of Gholson (1980) and others reviewed above, 3 different measures of performance were devised within the present study, and are referred to within the report of the study as the Performance Indicators. These Performance Indicators consisted of a measure of how quickly each problem is solved (Trial of Last Error), whether the solution to each problem is correctly verbalised once it has been discovered (Verbalisation of Correct Hypothesis during Criterion) , and to what extent 'perfect processing' is produced in the pattern of verbalised hypotheses on the first 3 trials of each problem (Hypotheses on Trials 1,2 & 3). A subsidiary aim of the study was to investigate the possibility that improvement on these Performance Indicators will not occur simultaneously, but will follow a developmental sequence representing a deeper understanding of the task.

iii) Predictors of the Development of Problem-solving Abilities

As reviewed above, a wide range of cognitive factors have been identified in the literature as being significant for general cognitive development and, specifically, the development of problem-solving abilities. It was the third main aim of the study to establish to what extent the patterns of strategic behaviour and performance on an inductive reasoning task such as the MDL task appeared to be related to such cognitive factors.

The influence of these factors were explored in two different ways within the present study. First, within the MDL task itself it was attempted to examine the influence of certain factors by varying the form of the problem. Thus, as well as the standard 4-dimensional problem, subjects were asked to tackle problems which obliged them to deal with negative information and with redundant information or 'noise'. We have discussed earlier work which has attempted to look at children's difficulties in dealing with negative and irrelevant information on the MDL task, and suggestions that these forms of problem place additional loads upon working memory and upon selective attention. Different versions of the problem were devised within the present study which, it was hoped, would clearly distinguish between these two different aspects of cognitive functioning.

Second, separately from the MDL task, subjects were assessed on Predictor Measures related to Working Memory capacity, Metacognitive Knowledge and Awareness and Control, Attributional style (Locus of Control), Cognitive Tempo (Reflectivity-Impulsivity) and Field Dependence-Independence. Some of these measures have been developed and published within the relevant literature, and some were specifically devised for the present study. We have reviewed in the last chapter the ways in which these aspects of cognitive functioning have been shown to relate to the development of problem-solving strategies and performance.

It is, of course, possible that other factors than those included in the present study might be involved in determining the children's responses to the MDL task. In order to at least partly cover this possibility the children's Gender and Age was also included in the analysis. Any large effects associated with these factors, and not associated with any of the cognitive factors included in the study, could be taken as evidence of the influence of contextual, maturational or other cognitive factors not included in the present study.

As these Predictor Measures were likely to intercorrelate (which turned out to be the case, as will be reported in the next chapter), it was planned to use Multiple Regression Analysis to separate out their individual effects in relation to performance.

iv) Interactions between Predictors, Strategy and Performance

As we have indicated earlier, a previous study (Whitebread (1983)) had revealed significant interactions between underlying cognitive factors, patterns of strategic behaviour and performance on a reclassification task. In particular, an interaction was found between metacognition and working memory in relation to performance. As we have reviewed in the previous chapter, there is research evidence to suggest, for example, that significant interactions might be expected between metacognition and working memory. The fourth main aim of the present study was, therefore, to examine the possibility that the relationships between different elements of problem-solving behaviour are complex and non-linear. This was done, as before, by examining correlations between Predictor Measures and Performance Indicators within sub-groups of the sample. It was planned to look at sub-groups defined by Metacognition (as was the case in the earlier study), by Strategy Cluster, and by Age. It seems likely that aspects of metacognitive processing and pattern of strategic behaviour should mediate the relationship between other cognitive abilities and performance. The analysis by age was intended to reveal any tendency towards U-shaped development, and to investigate the possibility that underlying cognitive functions might be increasingly related to performance as children grow older.

Section B) Procedures

i) Structural Arrangements

a) Sample of Children

The study was carried out with a sample of 72 Leicestershire Primary school children, comprising three equal groups of 24 children aged 6,8 and 10 years. The children were drawn equally from 2 large village schools which together drew their children from across the social spectrum. Within each age subgroup half were drawn from each school, and within each of these age/school subgroups of 12 children, half were girls and half boys. Based on work reviewed earlier with the MDL type of problem, it was felt that this sample would provide the full range of performance and strategic behaviour which we wished to investigate, while all the children should be mature enough to understand what was required in each of the various problems and tasks.

b) Timetable of Tasks and Tests

The various tasks and tests administered within the study were carried out with each of the children on 7 separate days according to the following schedule:

Day 1 Working Memory test with MDL materials

Day 2 Multidimensional Discrimination Learning (MDL) task
Metacognitive Knowledge questions
Metacomprehension test
Strategy Flexibility test

Day 3 Matching Familiar Figures test (MFF20) (Cognitive Tempo)

Day 4 Rod & Frame Test (RFT) (Field Dependence-Independence)

Day 5 Children's Embedded Figures Test (CEFT) (Field Dependence-Independence)

Day 6 Figural Intersections Test (FIT) (Working Memory)

Day 7 Children's Attribution of Responsibility and Locus of Control (CARALOC) Scale (Locus of Control)

Day 2 was always the very next day after Day 1. The WM test with MDL materials was administered first to familiarise the children with the MDL materials, and it was important that the children came to the MDL task with this fresh in their minds. The various tests related to Metacognition were all carried out on the same day as the MDL task itself, so that the metacognitive experiences and learning which had occurred during the MDL task should also still be readily available to recall.

Each of the other 5 tests was administered on a separate day, over the course of the next week or so. The group tests (FIT and CARALOC) were left to the end, so that the children would be very familiiar with the experimenter by that stage, and thus more likely to be relaxed with him when they were in a small group.

ii) The Multidimensional Discrimination Learning Task

a) Methodology and Design of the Problem

The MDL task used in the study was very strongly based upon that developed by Kemler (1978). As we have discussed earlier, the principal components of this method which make it particularly helpful when investigating the problem-solving behaviour of children, are the use of verbal 'introtacts' and the setting of the problem in a story-and-game context. Each child was asked to solve three different forms of the MDL problem, or three problem 'types':

- the standard problem (problem type a)

- the problem involving the use of negative information (problem type b)

- the problem with 'noise' or redundant information (problem type c)

1. Materials

Each one of the stimuli consisted of a $5^1/_2$ x 8 in. line drawing of a young girl portrayed from the knees to the top of the head. The differences between stimuli were introduced by elaborating the basic form with variable kinds of clothing. These clothing items consisted of 2 variations for each of 8 clothing attributes or 'dimensions', as follows:

Hair	ribbons/bobbles
Hat	crown/pointed
Glasses	clear/dark
Necklace	beads/pendant
Badge	teddy bear/butterfly
Hand	ring/bangle
Belt	buckle/bow
Balloon	sausage/round

For the pre-training procedure to familiarise the children with the materials and the accompanying story, the materials consisted of 2 basic cards with no extra clothing items, labelled "A" (for "Anna") and "S" (for "Sally"), and 2 sets of cut-out versions of the extra clothing items (see Appendix A.1).

For the standard problems the materials consisted of 2 sets of 16 complementary pairs of cards (each pair representing Anna and Sally at a particular moment in time) with each girl shown wearing all possible combinations of clothing items from 4 dimensions (see Appendix A.2).

For the problems involving the use of negative information, where only one card is shown on each trial (representing either Anna or Sally), the materials consisted of 2 further sets of 16 cards showing all possible combinations of clothing items from 4 dimensions.

For the problems involving 'noise' or redundant information, the materials consisted of 2 sets of 16 pairs of cards, structured as for the standard problems with each girl shown wearing all possible combinations of clothing items from 4 dimensions, but with the girls on each occasion or trial also wearing 4 identical clothing items from the remaining 4 dimensions not involved in that particular problem (see Appendix A.3).

2. Procedure

Pre-training

Each subject was presented with the MDL problems individually. They were introduced to the problems by the experimenter recounting to the child the story of two identical twins (examples of which were to be found in each of the two schools, and were referred to). These twins were called Anna and Sally and they always dressed alike, with the result that their identities were always being confused by their school friends and by their teacher. At this point the 2 basic cards with no extra clothing items, and labelled "A" and "S", were introduced to the child.

In order to be able to tell the twins apart, the story unfolds, their teacher decided to buy them some extra little items of clothing which were different. At this point the clothing cut-outs were presented to the child, a pair at a time, and the child asked to name them. For example:

Experimenter: "She bought them two different hats like this - what sort of hats are they?"

Child: "A crown and a witch's hat"

Every day, it was agreed, the twins would wear some of their new clothes so that everyone could tell who was who. For example, they might decide on one particular day to wear their hats and their badges. However, the story continues, the twins decided to play a trick with their new clothes. Many times in the middle of the day, just when their friends were beginning to remember which twin was wearing which clothes, the twins would switch some of their clothes to get their friends mixed up. For example, they might switch their hats.

While the teacher didn't mind the twins playing tricks on their friends, however, she really did need to know who was who. So, it was agreed that each day the twins would have a secret that they only told to their teacher. The secret was the one different item of clothing that the twins promised not to switch the whole day.

The game is to find out the twins' secret, that is, which different item of clothing Anna wears all day and never switches.

The game was then demonstrated by placing items from 2 dimensions (both complementary) on the two basic cards and, after the child had listed what each twin was wearing, actually switching one pair of items in front of the child. Before and after the switch the child was asked to say what the twins' secret could still be and any mistakes were corrected by the experimenter. When the child had carried out 2 such problems in succession without error (i.e. no switched or irrelevant items named), 4 dimensional problems (2 complementary, 2 identical) were presented in the same manner. Once again problems of this type were presented until the child responded to 2 in succession without error, and then 4 dimensional problems (all complementary) were presented.

Apart from the fact that the child actually saw the switches of clothing items occurring, these last problems are, of course, identical to the standard problem to be used in the experimental phase of the study. When 2 problems of this type had been tackled in succession without error it was assumed, therefore, that the child was ready for the experimental problems. As a consequence of the story format and this careful pre-training procedure, it was hoped that as far as possible children's performance on the experimental problems should not be hindered or influenced by lack of understanding of the basic rules of the game.

Experimental Problems

For the experimental problems the children were reminded at the beginning of each problem that it is a new day and the twins could have a new secret. On trial 1 for each problem the child was asked to list what each twin is wearing when they arrive at school at the start of this new day. Throughout the children were allowed to use their own labels for the various clothing items, so that individuals did not have the additional burden of coping with unfamiliar terms (which, as we have reviewed earlier, might place extra load on working memory).

For each problem the game proceeded by showing the child cards which represented how the girls appeared after each successive switch of clothing items, up to a maximum of 16 occasions or trials. Each child was asked to solve six such problems, two each of the three different problem types:

a) the standard problem where each trial consisted of presenting two cards showing the girls wearing complementary items from 4 dimensions (see Appendix A.2)

b) the problem involving the use of negative information where each trial consisted of presenting only one card showing one girl wearing items from 4 dimensions

c) the problem with 'noise' or redundant information where each trial consisted of presenting two cards showing the girls wearing items from all 8 dimensions, complementary items from 4 dimensions and identical items from the other 4 dimensions (which are thus irrelevant or redundant) (see Appendix A.3).

For problem types (a) and (c), after each pair of cards had been presented the children were asked:

"Which one do you think is Anna?"

and the child's response was followed by verbal feedback ("Yes, it is" or "No, that's Sally") and by a second question:

"What could be the twins' secret today? Which clothes is Anna always wearing and never switching today?"

For problem type (b) it was explained to the children that this time they would only see one of the twins at once and, after each card had been presented, the children were asked a slightly different first question:

"Do you think this is Anna?"

and their response was followed by the same verbal feedback and second question as for the other problem types.

As there are 8 possible combinations of the clothing items from 4 dimensions which each twin can wear (with one item fixed) each problem consisted of a maximum of 16 trials during which each twin wore every possible combination twice. However, a problem was stopped before all cards had been shown if the child successfully achieved a solution. For this purpose the criterion was 5 successive correct identifications of Anna (not including trials 1-3 when feedback was predetermined - see below). If Anna was correctly identified on Trial 16, but the criterion had not been achieved up to that point, extra trials were presented (beginning the sequence again with the cards presented at Trial 1) until criterion was achieved or Anna was incorrectly identified, whichever occurred the sooner. For criterion to be achieved it was not necessary that correct identifications be associated with correct verbalisations of the 'secret'. This criterion was adopted because of the evidence, reviewed earlier, that children's ability to solve this kind of problem may precede their ability to correctly verbalise their hypotheses or understandings, and so it was important to clearly distinguish between the two achievements.

During the problems a record was kept on an MDL Record Card (see Appendix A.4) of the child's responses to the two questions asked, and the verbal feedback provided by the experimenter.

b) Experimental Design

Over the 6 problems tackled by each child it is important to control for preference effects related to clothing items, array positions and the two twins, for the effects of different patterns of item presentation and verbal feedback, and for learning effects. In order to try to cope with these various difficulties the following design features were adopted for the presentation of the experimental problems.

In order to attempt to control for preference and sequence of item presentation effects, two measures were taken. First, the 6 problems were designed so that each dimension was included as relevant in 3 problems, and was either not present or irrelevant (redundant) in the other 3 problems. Second, the sequence of switches and consequent pattern of item presentation was standardised across all 6 problems. This standardised sequence is reported in Appendix A.5. As will be seen upon examination, this sequence was further devised so that each successive set of 4 trials defines the solution. (In fact, with 4 dimensions, it is possible to define the solution within 3 trials so long as items are switched 'orthogonally' (as devised by Levine (1966) for his blank trial probes), and this has been done within the present sequence; the 4th trial array within each set of 4 trials simply reverses the positions of the two twins in the 1st trial of that set.) All 16 different possible arrays are presented once, so that whichever item is defined as the solution (or the twins' secret) each girl will appear 8 times on each side of the array in two card problems, and each girl will simply appear 8 times in the one card problems.

In order to control for the effects of feedback patterns, as identified by such as Fuchs & Turner (1981), rather than have pre-defined solutions to the various problems, the solutions were defined by predetermined patterns of feedback on Trials 1-3. As it happens, with at least one positive and one negative feedback over three trials there are only 6 possible patterns, thus:

1. + + -
2. - - +
3. + - +
4. - + -
5. + - -
6. - + +

It was therefore possible to present each child once with each feedback pattern. As it was also important to control for the effects of feedback patterns on particular problems, it had to be ensured that each problem was presented with each feedback pattern equally across children. As the order of presentation of problems had to be varied in order to control for learning effects (see below) this could be achieved by standardising the order of presentation of feedback patterns. This order of feedback patterns was, therefore, standard across children.

In order to control for learning effects, if we were to be able to compare the children's performance on the three different types of problems they had to be presented in all possible sequences. Further, in order to investigate learning or improvement in performance over the 6 problems, it was decided to present the 6 problems in 2 rounds, each round containing one problem of each type. The possible orders of problems were thus as follows:

1. a b c a b c
2. a c b a c b
3. b a c b a c
4. b c a b c a
5. c a b c a b
6. c b a c b a

As there are 6 orders of problems, 4 children (2 of each gender) within each age group were presented with the problems in the same order.

c) Analysis

The children's performance on the MDL task was analysed in terms of the strategies they apparently adopted in order to reach a solution, and in terms of various measures of their success at solving the problems. As indicated earlier, both the components of strategic behaviour and the indicators of successful performance identified and investigated are drawn from published analyses of children's and adults' performance on the discrimination learning tasks, principally those by Gholson, Levine & Phillips (1972), Kemler (1978) and Gholson (1980).

1. Strategies: the 10 Components

The strategies adopted by the children were analysed in terms of 10 Strategy Components. These consisted of recognisable patterns of choices made in response to the request on each trial to identify 'Anna' and of verbal 'introtacts' or hypotheses in response to the second question on each trial about current possible 'secrets' or solutions to the problem. The theoretical model adopted in the present study suggests that these Strategy Components are combined and recombined successively in different ways to form new patterns of strategic behaviour as children's ability to tackle the MDL task develops. They are as follows:

1. Number of Hypotheses per Trial: simply a measure of the average number of hypotheses verbalised by the child on each trial. In a 4 dimensional problem with an 'orthogonal' pattern of stimulus presentation, such as the ones used in the present study,

there are, of course, four possible solutions still available at Trial 1, two possible at Trial 2 and only one from Trial 3 onwards. As we have reviewed earlier, in the vast majority of early research on discrimination learning and hypothesis testing subjects were only ever permitted to verbalise , or presumed to be holding, one working hypothesis. Phillips & Gholson (1980), however, used 4 dimensional problems and asked subjects to indicate "which things could still be correct", and found interesting variations in the number of hypotheses being considered by different children.

2. Hypotheses Consistent with Local Feedback: this is a measure of the percentage of hypotheses produced which are consistent with the feedback the child has just received on that trial about their identification of Anna. The ability to respond to feedback has, of course, been a central feature of analyses of responses to the discrimination learning task. Gholson, Levine & Phillips (1972), Kemler (1978) and Gholson (1980) all found this to be perhaps the first significant strategic development. It marks the transition from 'response sets' or 'stereotypes' to what Kemler has characterised as short-term strategic behaviour. Tumblin & Gholson (1980) guided children's attention to the correct stimulus when the child chose incorrectly and taught the rule "wrong means look at the other picture", and found that the children made significant progress. We have reviewed earlier the discussion by Kemler (1978) and others as to whether this ability to respond to local feedback is a result of developing attentional control or understanding of the decision-making logic inherent in the problem. With the more meaningful task adopted in the present study we would expect to find high levels of local consistency with a sample within which the youngest children are 6 years old.

3. Choice Consistent with Previous Hypothesis: this measure is of the percentage of choices or identifications of 'Anna' consistent with the hypothesis or hypotheses verbalised on the previous trial. As we have reviewed, Kemler (1978) argues that the next developmental stage in terms of strategic behaviour is the ability to remember and use previous hypotheses. This marks the shift from short-term to long-term strategic behaviour. Phillips & Gholson (1980) found evidence to support this view. As the use of the verbal introtact methodology enabled Kemler (1978) to discover, however, to begin with young children often do not co-ordinate their memories of previous hypotheses and their stimulus choices. Phillips (1974) and Spiker and Cantor (1977) found children who verbalised about a value of the stimulus they chose, but whose verbalisations were largely unrelated to the process guiding the choices. They referred

to this pattern of response as 'stimulus describing'. We shall refer to this phenomenon again when we describe the indicators of successful performance on the MDL task used within the present study, and, in particular, the indicator related to verbalisation of the correct hypothesis during the criterion trials.

4. Lose/Shift Hypothesis: Schuepfer & Gholson (1980) identified two strategic developments which enabled children to respond to feedback. The first to emerge was the ability to shift from a hypothesis when it had been disconfirmed by negative feedback. This measure is, therefore, of the percentage of hypotheses which were not repeated on the next trial after negative feedback (irrespective of the choice or identification of Anna made on that trial). A child who scores 100% on Strategic Component 2 will, of course, also produce a 100% score on this measure. Differences will arise, however, where a child shifts from the disconfirmed hypothesis but to a new hypothesis which is also inconsistent with local feedback. Thus it is possible to score 100% on this measure but less than 100% on Strategic Component 2.

5. Lose/Shift Dimension: this measure is similar to the last one, except that it consists of the percentage of dimensions not repeated on the next trial after negative feedback relating to one of its two values (or clothing items). It is important to distinguish this pattern of strategic behaviour from the Lose/Shift Hypothesis strategy because a number of researchers, including Kemler (1978), as we have reviewed, found a common pattern of responding in young children generally referred to as 'attribute perseveration'. This consists of runs of verbalised hypotheses which simply alternate on the two values of the same dimension, whichever happens to be locally consistent with the current trial's feedback. Kemler (1978) found many examples of this pattern amongst kindergartners. The Lose/Shift Dimension strategy avoids this, and might be seen to suggest a more thorough grasp of the logic of the problem situation and a more sustained ability to co-ordinate information from previous trials. However, it must be recognised that random 'stimulus describing' will produce a pattern which would score quite highly on this measure (i.e. a score of 75%); at a certain stage 'attribute perseveration' might, therefore, represent a more sophisticated attempt to co-ordinate information.

6. Win/Stay: Schuepfer & Gholson (1980) identified this as the second, and perhaps more significant strategic development which enables children to respond to feedback. This measure is of the percentage of confirmed hypotheses repeated on the

next trial (again, as with Lose/Shift, irrespective of the choice or identification of Anna made on that trial).

7. Hypothesis Checking: both Gholson, Levine and Phillips (1972) and Kemler (1978) identify this strategy as the simplest which involves some long-term memory and co-ordination of information (i.e. over more than two trials). This is a measure of the percentage of hypotheses receiving negative feedback on the next trial which are not repeated throughout the remainder of the trials in that problem. As a strategy it does not involve, as Gholson, Levine and Phillips (1972) argue, any understanding of the logical relation of the two values of each dimension, and simply regards each value (or clothing item) as a separate hypothesis or possible solution. It does also not involve, as Kemler (1978) points out, any co-ordination of information beyond immediate feedback relating to verbalised hypotheses.

8. Dimension Checking: this is a similar measure of the percentage of disconfirmed dimensions not repeated throughout the remainder of the problem. As both Gholson, Levine and Phillips (1972) and Kemler (1978) argue, this strategic behaviour crucially implies an understanding of the logical relation of values within a dimension. Thus, if a hypothesis, which is locally consistent with feedback on one trial, is disconfirmed on the next, a child who is simply Hypothesis Checking could produce the other value of the same dimension as the new hypothesis. A child who is Dimension Checking, however, has in some sense come to understand that the other value of that dimension cannot be the solution either, since it was effectively disconfirmed on the previous trial. An item from another dimension must be advanced as a possible solution. Again, however, as with Strategy Component 7, it does not involve any co-ordination of information beyond immediate feedback relating to verbalised hypotheses.

9. Focusing over 2 Trials: the most sophisticated strategy involves an ability to respond to feedback, an ability to remember and use information about previously tested verbalised hypotheses, an understanding of the logic of the problem and crucially the ability, to varying degrees, to co-ordinate all this with information gained from feedback to previous stimuli. In Kemler's (1978) terminology this involves co-ordinating the 'hypothesis memory' involved in Hypothesis and Dimension Checking with 'stimulus memory'. Gholson, Levine and Phillips (1972), Kemler (1978) and others have referred to this strategic behaviour as Focusing. Phillips & Gholson (1980) confirmed that the ability to remember previous stimuli

co-ordinated with previous hypotheses was central to success on the MDL task. This is a sophisticated and complex pattern of strategic behaviour, and clearly develops over time. Within the present study it was, therefore, decided to measure Focusing at two levels. This measure is of the percentage of verbalised hypotheses consistent with local feedback on the current trial and consistent with all stimulus feedback on the previous trial.

10. Focusing over All Trials: this final measure is,therefore, of the percentage of verbalised hypotheses consistent with local feedback on the current trial and consistent with all stimulus feedback on all previous trials. After Trial 3, of course, this effectively means that the verbalised hypothesis must be the correct solution.

These descriptions of the 10 Strategy Components are intended to explain what they involved in terms of the children's patterns of responses, and to provide a rationale for their inclusion on the basis of previous research with MDL problems. While there may be some logical overlap between some measures (clearly some of the more sophisticated logically include some of the less sophisticated), it is intended that between them they should provide a comprehensive basis for discovering and describing different developmental patterns of strategic behaviour on the MDL task.

What has not been included here are precise details of the scoring procedures for each of the Strategy Components. In some cases (particularly in relation to cases where more than one hypothesis is verbalised on a trial, or where an irrelevant clothing item is produced as a verbalised hypothesis on the type (c) problems) these scoring procedures are quite complex. They are, therefore, detailed in Appendix A.6.

2. Performance Indicators

The success of the performance of the children on the MDL task was measured in three ways, each of which relates to a rather different aspect of performance. There is evidence, which we have reviewed earlier, which would suggest a developmental sequence between these different areas of performance, and the investigation of this developmental sequence is one of the aims of the present study. The three Performance Indicators are as follows:

1. Trial of Last Error: this measure simply records a score based on the last trial at which an incorrect choice or identification of 'Anna' is made; it is a standard measure of the efficiency with which a discrimination problem has been solved used by Kemler (1978) and throughout the literature. Obviously it is a finer measure than simply recording the number of problems solved within a fixed number of trials. For the purposes of the analysis of results the scores are reversed, since the lower the score, the better the performance.

2. Verbalisation of Correct Hypothesis During Criterion Trials: we have referred earlier, within the description of Strategy Component 3, to the phenomenon of 'stimulus describing'. This refers to children whose choice of stimuli is clearly being guided by some hypothesis, but who are unable to verbalise that hypothesis. When asked to verbalise their hypothesis, instead of reflecting upon the processes which guided their choice, they simply read off or describe a locally consistent attribute. As we have discussed earlier in our review of the literature, this lack of ability by young children at certain stages to monitor and report upon the mental processes which have guided their behaviour and decision-making is a commonly observed phenomenon. This has been recorded by Piaget (1977) amongst others. This measure was, therefore, used simply to record the number of criterion trials (of which there were 5 for each correctly solved problem) upon which the correct hypothesis was verbalised alone. It is predicted within the present study that the ability to verbalise the correct hypothesis consistently once the MDL problem has been solved will emerge later than the ability simply to solve the problem.

3. Number of Hypotheses on Trials 1,2 & 3: as we have discussed in relation to Strategy Component 1, Phillips & Gholson (1980) found that when given the opportunity to verbalise more than one hypothesis on each trial different children displayed different patterns of performance. Some indicated only one hypothesis on each trial while others indicated 3 or 4 hypotheses on each trial. Some, furthermore, were able to indicate with increasing accuracy the number of hypotheses which were actually still possible solutions after different numbers of trials (i.e. four on Trial 1, two on Trial 2 and one on Trial 3). This measure, therefore, is a score of how closely the number of hypotheses verbalised on Trials 1,2 & 3 matched this ideal performance. It is predicted within the present study that the ability to produce this ideal performance (which clearly involves the use of the most sophisticated Strategy Component,

Focusing) will develop after the ability to solve the MDL problem and verbalise the correct solution.

Details of the precise manner in which these three Performance Indicators were scored are recorded in Appendix A.7.

iii) Predictor Measures

a) Gender

While there are no specific predictions in relation to gender within the present study, it was felt important to record this information about the children involved. As described earlier different groups within the study were carefully matched so that they contained equal numbers of boys and girls. It is important, however, to analyse the results of the study to see if there were any significant gender effects. Any such effects might indicate a gender bias in the materials or the style of presentation of the experimental tasks (all presented by the male author), which have been reported in a number of areas related to the present study. Hort & Taylor (1990), for example, have reported effects on inductive inference resulting from the way in which items were described. It might also be, of course, that there is a gender variation in the development of problem-solving abilities related to the MDL task.

For the purposes of analysis, boys were scored 1 and girls 2; an equally mixed group would thus have a mean score of 1.5.

b) Age

The age of the children (in years and months) was also recorded. This was again partly as a safeguard. As we indicated earlier in the Introduction to this section, it is possible that other factors than those specifically included in the present study could be involved in determining the children's performance on the MDL task. Any large effects associated with Age (or Gender) but not associated with any of the cognitive factors included in the study, could be taken as evidence of the influence of contextual, maturational or other cognitive factors.

It was also important to record the Age of the children so that we could compare performance on the MDL task used with that on other similar tasks used in previous studies. Part of the rationale for the design of the present task was that it should allow young children to demonstrate their full capabilities unhindered by extraneous contextual effects, and it is important to monitor the extent to which this has borne fruit.

There are also, as we have seen, specific developmental patterns reported in the literature in relation to children's learning and performance, which it is an aim of the present study to investigate in relation to the MDL task. An analysis by age is carried out, for example, to reveal any tendency towards a pattern of U-shaped development (see Strauss & Stavy (1982)), and to investigate the possibility that the relationship between underlying cognitive and metacognitive abilities and performance strengthens as children grow older (see Schneider & Weinert (1989)).

c) Working Memory

As well as recording these two basic pieces of information tests were carried out, as indicated earlier, in an attempt to assess the level of development of each child in a number of cognitive areas which have been highlighted in the literature as potentially influential in the acquisition of problem-solving abilities.

The first of these cognitive areas is that of Working Memory. We have reviewed earlier the significance of this aspect of cognitive functioning within information processing and neo-Piagetian models, and evidence of the effects of memory factors on performance on the MDL task. A rationale has also been presented for including within the present study two complementary measures of working memory capacity. These measures were the FIT (Figural Intersections Test) devised by Pascual-Leone (1969) and a short-term memory test devised by the author to be used with the MDL materials. FIT, it was argued, has the advantage of being non-strategic, but the disadvantage of being unrelated in content to the MDL task. The measure devised with the MDL materials has the advantage of using content identical to the MDL task, but offers more opportunity for effective problem-solvers to devise memorial strategies.

The design, procedure and scoring for each of these tests is described below and in the associated appendices.

1. Working Memory Test with MDL Materials

This test was actually the first test administered to each child within the study. This was done to familiarise the children with the MDL materials before they were faced with the

MDL task itself. In order to avoid confusion between the two tasks (particularly with respect to the logical relationship of clothing items belonging to the same dimension in the MDL task, which was not a feature of the stimulus arrays used in this task) the Working Memory Test was always carried out on a separate day from the MDL task.

A pilot was carried out with this test to ensure that the procedures were clear and that it effectively discriminated between children and produced scores appropriate for the age group under investigation in the present study. The results of this pilot were encouraging on both counts and are recorded in Appendix B.1.

The test was devised as a test of Working Memory, rather than as a test of simple short-term memory. As we have discussed in our earlier review, a crucial point about working memory is that it involves holding items in the short-term memory store and operating upon them. The test, therefore, involves recognising clothing items seen on a display of Anna and Sally and allocating these items to one of three different boxes depending upon who was seen wearing them (i.e. either Anna or Sally or both of them).

Materials

The stimulus cards were drawn in exactly the same manner as those used for the experimental problems in the MDL task, except that cards of 'Anna' were marked with an 'A' and cards of 'Sally' were marked with an 'S'.

In the arrays of pairs of cards presented for this task there was also not the same logical relation between clothing items of the same dimension that there was in the MDL task. It was, thus, not the case that if Anna was wearing one item, Sally must be wearing the complimentary or identical item. In fact, in any array all the items displayed were from different dimensions. Any item could be worn just by Anna, or just by Sally, or by both Anna and Sally.

For the pre-training procedure there were three 1-item pairs of cards (showing both twins, but only one clothing item being worn by one or both of them), two 2-item pairs (showing two items being worn by one or both twins) and three 3-item pairs. Each of the 16 clothing items were featured once on these pairs of cards. (For example arrays and the full list of the cards displayed within the pre-training procedure, see Appendix B.2).

For the actual test trials there were three pairs of cards displaying each of 1 to 8 clothing items.

For both the pre-training and the test trials there were also 10 cut-outs of each of the 16 clothing items, each set of 10 displayed in their own little box. These cut-outs were identical to those used in the pre-training procedure for the MDL task (see Appendix A.1).

There were also three posting boxes labelled 'A', 'S' and 'A+S'. These boxes measured approximately 5 x 6" and were 3" deep, and on the top they had a slot large enough to receive the cut-outs of the clothing items. A stop-watch and a screen to conceal the array of cut-outs were also used.

Procedure

Pre-training

Each child was initially told that we were going to play a game about things you wear and presented with the collection of 16 little boxes containing the cut-outs of the clothing items and asked to name them. It was felt to be important that the children should name the items for themselves so that familiar names for items were used in the test. Having
to cope with unfamiliar names would obviously place extra load on the child's memory capacity.

The child was then presented with the first 1-item pair of cards and asked to select from the cut-outs the matching item and place it in the appropriate box, according to whether it was being worn by Anna (box 'A') or Sally (box 'S') or by both Anna and Sally (box 'A+S'). If the child made an error and selected the wrong item or placed an item in the wrong box, this error was pointed out by the experimenter and the child asked to try again (in practice very few errors occurred). This procedure was then repeated for a further two 1-item pairs, two 2-item pairs and three 3-item pairs, so that all 16 clothing items had been matched and correctly boxed by the end of the pre-training procedure. (see Appendix B.2).

Test Trials

The pre-training was followed immediately by the test trials. It was explained to the child that the game was obviously too easy for them so in the next part of the game, to make it more interesting, they had to remember what Anna and Sally had been wearing.

The child was presented in the same way with pairs of cards, but now they were only allowed to look at them for 15 seconds, after which they were turned over. The array of cut-outs was also concealed by a screen during this stimulus viewing time to prevent any premature selecting. After the stimulus cards had been turned over, the screen was removed and the child asked to place cut-outs in the appropriate boxes as before.

Each child was presented initially with a 1-item pair. If the child completed the trial successfully (i.e. recognised and correctly boxed the item displayed) the next trial involved a 2-item pair. So long as trials were completed successfully, the next trial involved one more item (up to a maximum of 8 items, which proved to be quite sufficient). When a child failed a trial, the next trial involved the same number of items up to a maximum of three trials with the same number of items. If, on either the second or third trial with that number of items, the child successfully recognises and boxes all items, then the next trial goes on to one more item as before. If the child is not completely successful on any of the three trials with a particular number of items, but successfully recognises all items on any one trial, then the test proceeded to trials with one more item. Each child was thus given the opportunity to demonstrate the maximum level of performance of which they were capable. At the point where the child fails to recognise all items on any of the three trials with a particular number of items, however, then the test was concluded.

Scoring

A record of each child's performance was kept on a WM Record card (see Appendix B.3). The WM (Working Memory) score for each child was calculated by awarding one point for each completely successful Trial 1 (i.e. the first trial with each number of items), and half a point for each completely successful Trial 2 or 3. For an example of this scoring procedure, see Appendix B.3.

2. The Figural Intersections Test (FIT)

The FIT is a group administered paper and pencil test for use with children and adults designed by Pascual-Leone (1969) as a measure of M-power or M-space i.e. the power or operating capacity of the working memory. We have reviewed earlier Pascual-Leone's contribution to the development of the notion of working memory. This test went through several versions during development, and it is the final version, referred to in the literature as FIT RAC-794, which was used here. Essentially the test consists of being asked to find and mark a common area which is simultaneously inside a number of intersecting shapes. This task, it is argued, requires the subject to simultaneously hold each of the shapes in working memory while they are being operated upon in the process of co-ordination and searching for the common area.

Materials

The FIT RAC-794 consists of 36 test items, plus 8 introductory or pre-training items. Each item consists of two sets of simple geometric shapes, a set on the right called the presentation set and a set on the left called the test set. The presentation set contains a variable number of shapes, physically separated from each other. The test set contains the same shapes as the presentation set, but arranged in an overlapping configuration so that there exists a common area of intersection, which is simultaneously inside all of the shapes.

The shapes in the test set may differ in size or orientation from those in the presentation set, but they match in shape and proportions. In some items there is also a misleading irrelevant shape in the test set (not present in the presentation set), which does not form a common area of intersection with all the other shapes.

Within the pretraining items (see Appendix C.1), the first three items involve only 1 shape and no overlapping, two items involve 2 shapes overlapping, two items involve 2 shapes overlapping and an irrelevant shape in the test set, and one item involves 3 shapes overlapping.

Within the test items, the number of shapes in the presentation sets varies between 2 and 8. This number designates the class of the item. Items from different classes appear in a random order. Within the 36 items there are five items for each class, one with an irrelevant shape, except that there are no items with an irrelevant shape in class 2 and there are six items in class 4, two with an irrelevant shape. Examples of test items appear in Appendix C.2.

Procedure

Pre-training

The test was administered to small groups of children, usually all the children from one school class, at a time. This was never more than eight children.

The pre-training procedure was carried out in accordance with the instructions in Pascual-Leone's test manual. Each child was issued with a brightly coloured felt-tip pen and a test booklet. The pre-training procedure essentially consists of working through the eight pre-training items with the group of children, and making sure that all the children understand the rules of this game about shapes. The concepts the children must understand are as follows:

- left and right: on each item they are trained to first make a dot inside all the shapes on the right (all items)
- inside: the dot must be inside the shape, on the line does not count (all items, particularly item 2)
- matching shape: they are trained to then find matching shapes on the left (all items); a matching shape can be a different size (they are asked to draw a smaller circle on the left in item 3, and then put a dot in it), and it can be turned on its side or even upside down (items 3-7)
- intersection of shapes: on the left we are only allowed one dot, so if there is more than one shape we must find a place to put our one dot that is inside all the shapes (items 4-7)
- multiple same shapes: if there are two squares on the right, then we must put our dot inside two squares on the left (items 5 & 7)
- irrelevant shapes: shapes which are not on the right don't count - you can ignore them when placing your one dot on the left (items 6 & 8)

Every effort was made to engage the children actively in this pre-training procedure, by asking for corrections to deliberate mistakes, asking for volunteers to give us the right answer, and so on. After each item was discussed all the children placed their dots and any errors were discussed and corrected. In each case the reason why a particular placement was correct was repeated.

At the end of the procedure it was repeated again that the children should first put one dot in each of the separate shapes on the right, and then go to the left and put just one dot in a place which is inside all the shapes. They were told to think very carefully before placing their dot on the left because you can't rub out felt-tip pen, and more than one dot counts as wrong.

Testing

The children were then asked to complete the 36 test items, and again the procedures detailed in the test manual were followed. No further help was given, although the procedure for completing an item could be repeated. The children were encouraged to make a dot on the left for all items, even if they were not sure. The random ordering of the class of items helps to keep the children interested, because they keep getting relatively easy items in amongst the more difficult ones. Where a child made a mistake and wanted to correct it, they were told they could do so on this one occasion, but the next one would be counted wrong. (In fact, the corrected items is still scored as incorrect).

While the children were completing the test items, the experimenter circulated amongst them and watched out for certain errors - such as multiple marks on the test set, dots on lines or so big that they cover more than one area etc - which were corrected. The test does not have a time limit, but, as Pascual-Leone suggests, most children completed it in about 20-30 minutes.

Scoring

The difficulty of an item is clearly largely determined by the number of shapes which have to be simultaneously considered. According to Pascual-Leone's (1969, 1970) theory subjects should successfully complete all those items in classes up to the capacity of their working memory, and no items beyond that point. However, the pattern of responses is never quite as neat as that and there are a number of issues which have to be addressed in order to arrive at a score.

Two principal issues are how to count items with irrelevant shapes (is the irrelevant shape counted or not in determining the class?), and whether to allow scores on more difficult items when simpler ones have been failed. In the FIT manual Pascual-Leone recommended a scoring method and presents evidence of the validity and reliability of the test on that basis, which is reproduced in Appendix C.3. Johnson (1982), however, reviewed the arguments published in the literature about the reliability and validity of different scoring procedures, and resolved the matter by taking four different ways of scoring the results and then taking the average of these as the final score. This procedure has been adopted in the present study. Details of this scoring procedure, and Johnson's (1982) justification of it, are also reported in Appendix C.3.

d) Metacognition

As we have argued, while the development of working memory might explain children's ability to carry out more and more complex strategies, it cannot explain the origins of new strategies in a child's repertoire. For this researchers have increasingly looked to the development of metacognition. We have reviewed earlier the common acceptance in the literature of the distinction first made by Flavell (1981) between metacognitive knowledge and metacognitive experience. One of the weaknesses in early studies of metamemory identified by such as Schneider (1985) was a tendency to rely on single measures. Within the present study, therefore, a range of activities were devised to test for both aspects of metacognitive development. In the analysis of results the scores on each of these measures is reported separately and as part of a combined Total Metacognition score (computed simply by weighting each of the separate measure scores equally and summing them).

1. Metacognitive Knowledge

On the whole attempts to link children's general level of metacognitive knowledge with their abilities on any particular task have been disappointing. Yussen (1985), Brown (1987) and others, however, have pointed to a lack of precision in the choice of metacognitive and performance variables as an area of difficulty here. Rather than attempt to measure the children's general level of metacognitive knowledge, therefore, it was decided within the present study to restrict our investigation to their developing metacognitive knowledge about the MDL task based upon their experiences of attempting that task. This knowledge, it is argued, might be taken as a measure of the extent to which the children monitored their experience. The quality of this knowledge, as we have also suggested, might also be taken as a measure of the efficacy with which the children internally represented the problem.

The test of metacognitive knowledge was administered soon after the child had completed the MDL task (i.e. later on the same day) and was split into three questions designed to find out if the child had developed an awareness of factors which made any particular MDL problem easier or more difficult. The form of Question 2, in particular, also derived to some extent from a suggestion by Lunzer (1968), developed in an earlier study (Whitebread (1983)) that requiring children to reproduce a problem is a good indication of their representation of it, and the metacognitive knowledge they have thus derived.

<u>Materials</u>

Stimulus cards of exactly the same kind as those used in the MDL task were used again for this test.

For Question 1, example cards were needed to represent each of the three different types of problem, i.e. one complimentary pair showing items from four dimensions (standard problem), one card showing four items from different dimensions (problem involving negative information) and one pair showing four complimentary and four identical items (problem with noise).

For Question 2, the two basic cards of Anna and Sally with no extra clothing items and two sets of cut-outs of the clothing items were used.

For Question 3, pairs of example cards were used with the following combinations of complimentary and identical items: two complimentary; two complimentary and two identical; four complimentary; four complimentary and four identical; eight complimentary.

Procedure

The children were seen individually for this test, and were told that we were going to play some more games about Anna and Sally. They were then presented with the following problems and asked the following questions:

Question 1

The child was reminded that in the game about the twins they had been presented with three different kinds of problems. The experimenter then reminded the child about the three problem types, describing what the child had been shown on each trial, and demonstrated each with example cards. With all the example cards laid out in front of him or her, the child was then asked to indicate the answers to two questions:

"Which type of problem was easiest ?"

and

"Which type of problem was hardest ?"

Question 2

The child was then shown the basic cards of Anna and Sally and the two sets of cut-outs of all the clothing items that their teacher had bought for them to wear. The child was again then asked to respond to two questions:

"Can you dress the twins so that it would be easy to find out their secret ?"

and

"Can you dress the twins so that it would be hard to find out their secret ?"

Question 3

The child was then told that they were going to be shown how the twins had arrived at school on some other days. They were then shown, in this order, the example pairs of cards with the following combinations of complimentary and identical items: two complimentary; two complimentary and two identical; four complimentary; four complimentary and four identical; eight complimentary. On each occasion they were asked the question:

"If the twins arrived at school dressed like this, how many times do you think they would need to swop clothes before you could work out what was their secret ?"

Scoring

In broad terms the children's responses to these three tasks were scored as follows.

For Question 1, one point was awarded for each correct assessment based upon the child's own performance in terms of the number of problems solved. This was taken to be a reasonable indication of how the child would have experienced relative difficulty, if they had monitored it. Where the number of problems solved had been the same for different problem types it was not felt to be justified to go on to look at Trial of Last Error scores. This was partly because any one child carried out the MDL problems in a particular order, which might be expected to influence T of LE scores, but which might not necessarily correlate to the child's own perception of the relative difficulty of the different problems. In these circumstances the standard problem was taken to be the easiest and either of the other two types of problem as the hardest.

For Question 2, points were awarded according to the number of dimensions of clothing items which the child put on the twins. The more dimensions the child put on the more points were scored in the "hard" condition and the fewer points were scored in the "easy" condition. The scoring system gave most weight to dimensions where the twins were dressed by the child in complimentary items, but some weight was also given to the addition of identical items.

For Question 3, the absolute number of "swops" suggested to be needed by the child was discounted. Rather, the scoring was based on the child indicating that they recognised, by steadily raising the number of swops needed, that the problems presented were increasingly more difficult.

Details of the exact calculation procedures for scores on these three questions, and the record sheet used, are reported in Appendix D.1.

2. Metacognitive Awareness and Control

Brown (1978), as we have reviewed earlier, has provided a detailed analysis of the necessary components of a metacognitive system. Based upon this and other analyses we have selected for inclusion in the present study two aspects of metacognitive experience or processing which might be argued to be particularly significant for the development of efficient problem-solving behaviour. These are those aspects referred to by Brown (1978) as Metacomprehension and Insight (referred to within the present study as Strategy Flexibility)

Metacomprehension

The test of Metacomprehension made use of a procedure devised by Berch and Evans (1973) to ascertain how confident a child is that their present response is correct. This involved carrying out two further standard MDL problems with each child, but asking them to stop the problem when they were confident that they had found the correct solution. The children indicated their level of confidence by pointing to one of two photographs of a child of their own gender looking either pleased or unsure. Berch and Evans (1973) have argued that this procedure compensates to some extent for children's conservative response bias in a recognition memory test. It seemed that this might, therefore, be a useful technique to adopt when asking children in the present study to indicate when they knew they had found the twin's secret.

Materials

Two sets of stimulus cards of exactly the same kind and structure as those used in the standard MDL task were used in this test. This comprised two further sets of 16 complimentary pairs of cards with each girl shown wearing all possible combinations of clothing items from 4 dimensions. Within these sets of cards the pattern of item presentation followed the standardised sequence used in the 6 MDL problems and reported in Appendix A.5. Over the two problems each of the 8 clothing dimensions was included once, with different combinations of items being used to those used in the MDL problems.

Two pairs of photographs were also used. One pair showed a boy and one a girl. Within each pair one photograph showed the child looking happy and confident, and the other showed the boy or girl looking unsure. These photographs are reproduced in Appendix D.2.

Procedure

This test was carried out with each child individually immediately after the test of Metacognitive Knowledge.

The two problems were carried out exactly as before for the standard MDL problems. The child was briefly reminded of the game (which they had played only the day before), but this time it was explained that it was up to them to stop the game when they were sure that they knew the twin's secret for that day.

They were then shown the two photographs of the child the same gender as themselves, which were discussed with the child. The child was asked to describe how the child in each photograph felt, and this was discussed with reference to everyday classroom experiences until the experimenter was happy that the child understood the difference between feeling unsure and being confident that you know something. As a check of this understanding, the experimenter then asked each child a few questions and asked the child to place their hand on the photo which indicated how they felt about their answer. For example:

Experimenter: "What is two add three?"

Child: "5 !" (places hand on confident photo)

Experimenter: "How old am I ?"

Child: "20 ?" (places hand on unsure photo)

After 5 or 6 questions of this type, if the child was clearly using the photos correctly, the MDL problems were started. If not, then the experimenter asked more questions and discussed the responses until the child was able to use the photos correctly. In practice, very few of the children had any difficulty with this procedure.

The child was then asked to place a hand on the unsure photo at the beginning of the MDL problems. The child was told to keep their hand on the unsure photo as long as they were not sure they knew the twin's secret, but as soon as they were sure that they did know it, then they were to stop the game by moving their hand to the confident photo and saying:

"I'm sure Anna always wears the ....".

The experimenter conducted the problems exactly as in the MDL problems, with the addition that after the child had offered their hypothesis or hypotheses at the end of each trial, he asked:

"Are you sure that is what Anna always wears today, or are you not sure yet? Do you want to keep your hand where it is or do you want to move it to the other photo now?"

For each problem the experimenter kept a record of the child's responses on an MDL record card as before (see Appendix A.4), but the presentation of stimulus cards stopped immediately the child declared him or herself sure about the twin's secret, and moved a hand onto the confident photo.

Experimental design

Within this test it was once again important to control for the effects of feedback patterns. The solution to each problem was again defined by one of the six possible feedback patterns used in the MDL task. On this occasion, however, as each child only tackled two problems, the feedback patterns were rotated between subjects so that within each age group the first child received patterns 1. and 2., the second child patterns 2. and 3., the third child patterns 3. and 4. and so on. As this produces six possible pattern combinations, four children within each age group received the same pair of feedback patterns.

Scoring

The children's performance on this test was scored according to the accuracy with which they stopped the game related to the trial upon which they should have been sure as to the solution (because of the structure of the card sequence this is always Trial 3 in these problems). There are essentially three possible types of performance. Either:

- the child stops before it is possible to be sure

- the child stops as soon as it is possible to be sure

- the child stops after it is possible to be sure.

The first response is clearly the weakest. Developmentally, as we have reviewed, we know that young children initially tend to be overconfident about their state of knowledge. The second response is clearly the strongest, and the third response is clearly somewhere in between. Some account has also to be taken of whether the child stops the game having actually discovered the correct solution or not. A simple scoring system was devised, therefore to take account of both of these factors. Thus, scores were awarded for each of the two problems according to the following scheme:

Score

0 child stops the problem before it is possible to be sure about the solution (i.e. before Trial 3)

1 child stops the problem when it is possible to be sure about the solution, but incorrect solution

2 child stops the problem when it is possible to be sure about the solution, with correct solution, but at least 2 Trials after the correct Hypothesis is first verbalised

3 child stops the problem when it is possible to be sure about the solution, with correct solution, and either immediately or on the next Trial after the correct Hypothesis is first verbalised

With any constructed scoring system of this kind, of course, there are dangers that the scoring system itself might influence the structure of the results. In the case of this measure this turned out to be a very real issue. The initial scoring system was, therefore, adapted, as is reported when we come to deal with it within the Results chapter. The adaptations carried out, however, did not substantially alter the pattern of results, suggesting that this original scoring system was adequately reflecting the real pattern of the children's responses.

Strategy Flexibility

Another aspect of metacognitive awareness and control highlighted by Brown (1978) is that referred to by her as 'Insight', which she contrasts with 'Blind-Rule Following'. Brown (1978) reviewed the studies of Butterfield and Belmont (1977), for example, concerned with changes in the employment of a strategy when it was more or less appropriate. In the present study a test of Strategy Flexibility was devised which consisted of teaching the child a strategy for solving the standard 4 dimension MDL problem, and then seeing whether the child would be able to change the strategy when it became inappropriate, or would blindly follow the rule.

Materials

For the strategy training trials 4 sets of stimulus cards of the same kind and structure as in the standard MDL task were used (i.e. with complimentary items for 4 clothing dimensions). The sets used here, however, differed in two respects from the standard sets. First, they contained only the first 8 complimentary pairs in the sequence, because this is all that is needed to reach a solution following the strategic procedure adopted in this test. Second, the solution to each set is predetermined, and the cards are labelled either "Anna" or "Sally" on the back.

For the test trials 6 further sets of the same kind were used, except that the clothing items were complimentary in only 2 dimensions and identical in the other 2 dimensions. These dimensions were arranged so that the 'solution' dimension was always nearer the bottom of the picture than the identical (and thus, irrelevant) dimensions. An example of these sets of cards is reproduced in Appendix D.3.

Procedure

This test was again carried out individually with each child immediately following the test of Metacomprehension.

The Experimenter began by explaining to the child that he had some further problems about Anna and Sally to which he did not know the solution (the twin's secret) himself. However, he had a good way of quickly working out what their secret must be. He then demonstrated the Dimension Checking strategy with one of the strategy training sets of cards (i.e. with 4 complimentary dimensions). This consisted of dimension checking each of the 4 dimensions, beginning with the dimension which was nearest the top of the picture and proceeding down in order from top to bottom. The Experimenter explained to the child that this was a good idea because then you couldn't get muddled and forget which pairs of clothing items you had already checked. The dimension checking procedure for each dimension was as follows:

- trial 1:
    - guess which twin is Anna
    - turn cards over to read names and discover which is Anna
    - verbalise which clothing item from the dimension under consideration is currently being worn by Anna

- trial 2:
    - guess that Anna is the twin wearing the verbalised clothing item
    - turn cards over to discover which is Anna
    - if Anna is still wearing verbalised item, proceed to next trial and repeat procedure;
    - if Sally is now wearing the verbalised item, discard that dimension, and verbalise the clothing item which Anna is wearing from the next dimension down

- Repeat this procedure until trial 8 is reached, by which time the solution will have been discovered.

Having carried out this procedure with the first set of cards, the Experimenter then repeated it with the second training set of cards, this time encouraging the child to join in. The child was then given the third and fourth sets to practise the strategy, helped if necessary by the Experimenter. If the child did not use the Top to Bottom Dimension Checking strategy perfectly on his or her own with the fourth set of training cards, then the first set was used again and so on until the child did master the strategy.

After the fourth set, or as soon as the child carried out the strategy successfully unaided with a repeat set, the test sets of cards with the irrelevant dimensions were introduced. With these sets, of course, the Top to Bottom strategy was inappropriate because the top two dimensions were irrelevant. A record was kept of the child's verbalised hypotheses on each trial for each of the problems (see Appendix D.4). New sets of cards were presented to the child until they completely ignored the irrelevant dimensions on two consecutive sets.

Scoring

The test of Strategy Flexibility was scored according to the trial on which the child changed from "blindly" following the strategy they had been given (dimension checking from top to bottom) to a strategy which ignored the top 2 irrelevant dimensions. In order to score a change of strategy had to be consistently maintained for two consecutive trials, as follows:

Performance	Score
No consistent change of strategy over all 6 trials	0
Eventual strategy change maintained over 2 consecutive trials (i.e. on trials 2-6)	1
Immediate strategy change maintained over 2 consecutive trials (i.e. on trials 1 & 2)	2

e) Attributional style: Locus of Control

We now come on to various aspects of learning style. This includes elements of what are referred to in the literature as 'patterns of attribution' and 'cognitive style'. For the purposes of the present study three aspects of individual difference were selected which have appeared in the literature to have some claim to be particularly significant. These are Locus of Control, perhaps the most heavily researched element in style of attribution, together with two cognitive style dimensions, Cognitive Tempo (Reflectivity-Impulsivity) and Field Dependence-Independence. We have reviewed earlier the literature which establishes the claims for each of these aspects of individual functioning.

This first section reports the manner in which each child's Locus of Control was assessed.

Materials

Within the study Locus of Control was measured by means of the Children's Attribution of Responsibility and Locus of Control Scale (CARALOC) developed by Gammage (1975, 1982), which was derived and adapted from reliable and well validated American scales and refined for use with English Primary school children. It attempts to measure the extent to which a child's Locus of Control is internal, as opposed to external. It was refined on the national cohort which formed the sample for the Child Health and Education Study (CHES), a longitudinal study carried out at Bristol University of all children in Britain born during one week in April 1970. As reported by Osborn and Milbank (1987), in their report based on that study, scores on the CARALOC scale proved to be the 'behavioural assessment' most strongly associated with mathematics, reading and other attainments at age ten.

The CARALOC scale comprises 20 items. Each item consists of a question about how the child feels about some aspect of school work or social relationships, and the child is simply asked to agree, disagree, or indicate that they are unsure about each of the questions, by placing a tick in one of three columns headed "Yes", "No" and "?". In order to make the test less transparent only 15 of the items measure Locus of Control. The other 5 items ask the child questions about attitudes to school and schoolwork unrelated to Locus of Control. A copy of the question and response sheets used in the present study appears in Appendix E.1.

Procedure

This test was administered in a separate session with the same small groups of children as those used for the FIT test.

The experimenter began by explaining to the children that he was going to ask them how they felt about a number of questions, which were written down on the sheet they had been given. It was explained that after each question there were three boxes, marked "Yes", "No" and "?" (which means "Don't Know") and that they had to put a tick in one of these boxes depending upon how they felt about each of the questions.

It was emphasised that there were no right or wrong answers to these questions, because different people feel differently about them.

It was further explained that they were not the sort of questions about which you need to think a long time. If they felt straight away that they agreed with a question then they should put a tick in the "Yes" box. If they knew straight away that they disagreed with the question they should put a tick in the "No" box. If they had to think about it for very long, it was explained, that meant they were not sure and they should put a tick in the "?" box.

It was then explained that the questions were about things that children do at home and at school, and things that sometimes happen. If one of the questions was about something that they had never done, or something that had never happened to them, then they were asked to try and imagine what they would feel about it. If they could not imagine how they would feel then they were told to just answer "Don't Know".

Following this preamble the experimenter then told the children that he was going to read Question 1, and that the children should follow it on their sheets. They should then put a tick in one of the three boxes. Then he would read Question 2, and so on.

The experimenter then read Question 1 and then said:

"Now, if you agree, put a tick in the 'Yes' box, if you disagree put a tick in the 'No' box, and if you can't decide, put a tick in the '?' box."

The children were then given 10 seconds to make their tick. If they had not made a tick after this interval, they were told to put it in the '?' box. The experimenter then read out Question 2 and so on, following the same procedure through the 20 questions.

Scoring

Each of the 15 Locus of Control items was scored according to the procedure devised by Osborn and his associates. The items are scored positively in the direction of an internal Locus of Control, so that the larger the score the more internalised the child's Locus of Control. Thus a child can score 0, 1 or 2 on each item. A "Don't Know" response always scores 1. On the positively directed items "Yes" scores 2 and "No" scores 0, while other items are negatively directed and the scoring is reversed. The maximum score achievable is thus 30. The details of the scoring for each of the items is reported in Appendix E.1.

f) Cognitive Tempo: Reflectivity-Impulsivity

As reviewed earlier, Kogan (1971, 1983) has produced comprehensive reviews of work in relation to children's cognitive styles, and possible theoretical and educational implications. From the multiplicity of different dimensions of 'style' proposed in the literature, one or two have emerged as worthy of further investigation. Amongst these, the dimensions of Reflectivity-Impulsivity (otherwise referred to as Cognitive Tempo) and Field Dependence-Independence have, as we have seen, been taken up within the literature, and have been shown to be of some significance in relation to other aspects of children's cognitive functioning and development. These are, therefore, the two aspects of cognitive style which were investigated within the present study.

This section reports the manner in which each child's Cognitive Tempo was assessed.

Materials

The instrument which has been very predominantly used to assess children's cognitive tempo is the Matching Familiar Figures Test (MFFT) developed by Kagan et al (1964). This test attempts to assess the extent to which a child delays a response in the course of searching for the correct alternative in a context of response uncertainty. The child is required to match a standard figure with one of six variants, only one of which is, in fact, identical to the standard. Latency of response and number of errors are obtained for each test item.

As Kogan(1983) reviews, however, the MFFT has been severely criticised as a psychometric instrument on a number of grounds. The principal criticisms relate to the unreliability of the error scores, and to the manner in which error and latency scores were originally used as a measure of cognitive tempo. We will deal with the latter criticism below when we consider scoring procedures. The most successful attempt to deal with the first criticism, however, has been that by Cairns and Cammock (1978), who developed a longer and more reliable version of the test. The original MFFT had a number of different forms, each containing 12 items, and reported test-retest and internal consistency reliabilities averaged only around .52. Cairns and Cammock investigated the item-total error correlations of 30 test items and selected the 20 items which discriminated most efficiently between 'impulsive' and 'reflective' 7-11 year old children.

On this basis they produced a much more reliable version of the test, with reliabilities calculated using the delayed split-halves technique of .89 for errors and .91 for latencies. They named this new version of the test the MFF20, and it is this version which was used within the present study.

In the administration of the MFF20 the test items are preceded by two practice items. Each item consisted of two cards, on one of which was printed the target picture or figure, and on the other the 6 variants. The cards were of standard A4 size. A copy of one of the practice items and a sample test item are reproduced in Appendix F.1.

A stopwatch was also used to record latency times.

Procedure

This test was administered individually to each of the children on a separate day within the testing programme.

The experimenter sat on the opposite side of a table from the child and placed the stack of cards on the table between them. The stack of cards was arranged with each of the target figure cards face down on top of its associated six variants card, so that when the experimenter lifted up the top card and stood it up vertically behind the stack the target and six variants were simultaneously revealed to the child.

The experimenter greeted the children and relaxed them with a little incidental talk, explained that they were going to play another game today and then followed the instructions issued with the MFF20 test. These began with the experimenter turning over the first practice item and saying:

"I am going to show you a picture of something you know and then some pictures that look like it. You will have to point to the picture on the bottom page (*points*) that is just like the one on this top page (*points*). Let's do some for practice."

The experimenter then helped the child to find the correct answer for the two practice items. These items are very straightforward and none of the children experience any difficulty in completing them successfully. The experimenter then said:

" Now we are going to do some that are a little bit harder. You will see a picture on top and six pictures on the bottom. Find the one that is just like the one on top and point to it."

The experimenter then lifted up the next card to reveal the first test item and simultaneously started the stopwatch. As soon as the child pointed to one of the six variants on the bottom card the stopwatch was stopped and the latency time recorded. If the child had pointed to the correct matching figure, the experimenter praised the child and said:

"Well done. That's right. Now see if you can do this one."

If the child's response was incorrect the experimenter said:

"No, that's not the right one. Have another go. Find the one that's just like this one (*points to target figure*)."

The child was allowed to keep trying on each item until the correct variant was pointed to or the child had made six errors. In this way all 20 items were worked through.

Scoring

For each item the experimenter recorded the time lapse (or latency) between the child first seeing the target and variants (when the top card was lifted up) and the child pointing to one of the variants, together with the number of errors made before the correct answer was identified. These were recorded on an MFF20 record sheet, a completed sample copy of which is reproduced in Appendix F.2. As shown on this sample, the total number of errors and the average latency per item were then calculated and recorded.

As Kogan (1983) reports, originally these error and latency scores were treated as separate measures, and much of the early literature was taken up with the debate as to which was the better measures of the Reflectivity-Impulsivity dimension. Early attempts to integrate the two measures consisted of simply plotting the two scores against one another on a scatterplot and splitting the resulting scatterplot into four quadrants around the median scores for each of the measures. This method was typically used to classify children as fast-inaccurate, fast-accurate, slow-accurate or slow-inaccurate.

These early scoring procedures were criticised, however, by Salkind and Wright (1977) on a number of grounds, principally that they resulted in the loss of valuable information. If only errors or latency are considered, this gives an incomplete picture of the children's strategies for processing information, and the quadrant method replaces continuous data with oversimplified dichotomies. They therefore proposed a model of Reflectivity-Impulsivity which conceptually and methodologically integrates speed (or latency) and accuracy (or errors). The resulting scoring procedure, which has been adopted for the purposes of the present study, synthesises the raw latency and error scores and converts them into the constructs of Impulsivity and Efficiency.

Within the present study only the score for Impulsivity was calculated and used according to the formula devised by Salkind and Wright (1977). Details of this scoring procedure are reported in Appendix F.2. For the purposes of the analysis of results these scores were reversed, so that Reflectivity, which is likely to be positively related to performance on the MDL task, is scored positively.

g) Field Dependence-Independence

No study concerned with stylistic variation in children could possibly exclude some consideration of Field Dependence-Independence (FDI). As we have reviewed earlier, and as Kogan (1983) illustrates in his review, no other cognitive style dimension has attracted anything like the sheer volume of research interest. A number of different tasks have been developed as measures of FDI, but two have emerged as the overwhelmingly dominant choices of researchers working in this area. These are the Rod & Frame Test (RFT) and the Embedded Figures Test (EFT). As Kogan (1971) reviews, both of these tests have been shown to be reliable and Witkin and his associates have produced evidence of a high level of intertask consistency for groups of children and adults. By the time of his second review, however, Kogan (1983) reviews the extensive debate carried out in the interim as to whether these two tests are measuring exactly the same cognitive construct, or two different constructs. The best advice at the present time, however, appears to be to use both measures and use both scores separately, or to produce a composite score. This is the procedure which has been adopted within the present study.

1. The Rod & Frame Test

This is the earliest test devised by Witkin and his associates, and arose out of work concerned with how people locate the upright in space. Witkin et al (1954) suggested that the upright can be located by means of information from the visual environment (or 'field') and from sensations within the body. The Rod & Frame test was devised to see which of these two sources of information was most dominant in individuals when the information coming from the two sources was contradictory. Interest in this test arises from the finding that there are marked individual differences in the responses to this test. Some individuals appear to rely mostly upon the information from the visual field, and are thus field-dependent, while others appear to pay most attention to information from their own body sensations, and are thus field-independent.

Materials

The materials needed to carry out this test were the Rod & Frame apparatus, a cardboard model of this apparatus and a tape recorder.

The Rod & Frame apparatus consisted of a luminous square frame pivoted at its centre so that it could be tilted to the left or right up to 28^{o} from the vertical. Pivoted at the same centre but moving independently of the frame is a luminous rod. A battery and red bulb were used in a circuit, attached to the apparatus, which allowed the experimenter to read the angle of the rod tilt from a protractor mounted at the back of the apparatus. This apparatus was essentially the same as that used by Witkin and his associates, a photograph of which appears in Appendix G.1.

Procedure

This test was carried out individually with each child on a separate day within the testing programme.

However, as this test has to be carried out in a totally darkened room, the task was explained to the children beforehand in small groups and in the light with the use of a cardboard model of the Rod & Frame apparatus. The children were told that they would be doing the next game in the dark, and all they would be able to see would be a square frame with a straight rod inside it. They were then shown how the rod and the frame could both be tilted in either direction, and it was explained that all they had to do was say when the rod was straight up or vertical. To ensure that they understood what was required, each child was asked to find a vertical line in the environment, which they all managed quite easily. As a reminder, they were all asked to do this again individually just before their turn at the test.

The experimenter then played the game with the group. This consisted of tilting the frame and the rod and gradually moving the rod towards the vertical until told to stop by the children. The children could say "Move" if they wanted the experimenter to move the rod more, "Back" if they wanted it moved back towards its original position, or "Stop" if they were happy that it was now upright.

As it was vital that they did not see the test apparatus and the surrounding room in the light, each child was led blindfolded into the room by an assistant and sat down in a chair positioned at about 8 feet from the Rod & Frame apparatus, which was mounted on a table so that the child would be looking directly at it. The assistant then closed the door to the room, turned off the light and removed the child's blindfold.

The experimenter, who was seated behind the Rod & Frame apparatus, greeted the child as he or she came in the room and, once the blindfold was off, reminded them about the square frame and the rod which they had played with earlier and demonstrated how they both tilted in either direction, making sure that the child understood which part of the apparatus was the rod. In the completely darkened room all the child would be able to see was the luminous rod and frame.

The frame was then tilted at 28^{o} to the left (as the child saw it) and the rod was tilted at 27^{o}, also to the left. The child was asked to say either "Move", "Back" or "Stop" as before. Each time the child said either "Move" or "Back" the rod was moved 3^{o} by the experimenter. When the child said "Stop" the experimenter recorded the reading (i.e. the angle of tilt as shown by the protractor) into the tape recorder.

Each child completed 8 trials. The frame was tilted 28^{o} to the left or right on the following schedule : LLRRLLRR. The rod was initially tilted 27^{o} to the left or right on the following schedule: LRRLLRRL. This ensured that of the 8 trials, 4 were with the rod initially tilted to the left, and 4 to the right. Also, in 4 trials the rod and frame were initially tilted in the same direction, and in the other 4 they were initially tilted in opposite directions.

Before each of the trials the child was asked to say if they could see anything else in the room other than the rod and frame. If the child became adjusted to the light, and could thus use other cues from the visual environment other than the frame, then the child was asked to turn round for a minute or two while the light was turned on.

Scoring

After the tests were complete the 8 readings for each child were simply transcribed and averaged to produce an overall score. For the purposes of the analysis of results these scores were reversed so that Field-Independence, which is likely to be associated with performance on the MDL task, is scored positively.

2. Children's Embedded Figures Test

The Embedded Figures test (EFT), also devised by Witkin and his associates, also attempts to assess the extent to which people's perceptions are dependent or independent of the surrounding visual field. In this case, however, the subject's task on each trial is to locate a previously seen simple figure within a larger complex figure which has been so organised as to obscure or embed the sought-after simple figure. Witkin et al (1971) present evidence from numerous research studies arguing that the EFT measures the same kind of perceptual style dimension as the Rod & Frame test, and that the FDI construct measured by these tests has broad ramifications for general cognitive functioning. They present evidence, for example, of gender and age-related differences for scores on the EFT. As we have noted earlier, however, Kogan (1983) has reviewed evidence produced subsequently to suggest that the EFT may be measuring a related but different aspect of Field Dependence-Independence.

As Witkin et al (1971) also review, the original EFT test proved to be too difficult for most children under the age of nine, and this led to the development first of CHEF by Goodenough & Eagle (1963), which was devised to be simpler and more appropriate for young children, and which proved to have good reliability and validity for children in the 5-9 age range, but had certain practical difficulties.

Stephen A. Karp and Norma Konstadt then developed the Children's Embedded Figures Test (CEFT), which incorporated many of the features of the Goodenough & Eagle test, but eliminated some of the practical disadvantages. Witkin et al (1971) report a test-retest reliability of .87 for the CEFT for children in the age range 5-12 yrs. Claims in respect of validity are based upon correlations with EFT and WISC subtests. The CEFT requires children to find two simple forms in the shape of a TENT and a HOUSE which are embedded within a number of more complex figures. The CEFT was used within the present study as being most appropriate to the age-range under consideration.

Materials

The CEFT consists of the following materials:

Simple forms: cut-out models of the two forms (TENT and HOUSE) which are embedded in the complex figures.

Discrimination series (D1-8): a set of 8 cards, each of which shows one of the simple forms and three similar, but obviously incorrect forms. There are 4 such cards for the TENT and 4 for the HOUSE forms.

Demonstration Series (E1 & 2): 2 cards, each of which has 3 incomplete pictures, representing stages of embeddedness of the simple TENT form.

Practice Series (P1-3): 3 complex figures which are designed to illustrate the procedure for the child, 2 for the TENT series, and 1 for the HOUSE series.

Test Series: a series of complex figures, 11 of which (T1-11) have the simple TENT form embedded in them, and 14 of which (H1-14) have the simple HOUSE form embedded in them.

Examples of all these materials are reproduced in Appendix G.2

Procedure

The test was administered individually on a separate day within the testing programme, broadly in accordance with the procedures laid out in the test manual prepared by Witkin et al (1971).

Pre-training

The experimenter began by training the child to discriminate the simple TENT form, using the Simple Form cut-out of the TENT and Discrimination cards D1-4. The child was shown the cut-out and it was discussed that it looked something like a tent. The child was then asked to find another tent that looked exactly like the cut-out on card D1. When the child had pointed to one of the forms the cut-out was placed over it to see if it matched. If it did not match the experimenter discussed with the child why it was incorrect. The concepts of correct shape, size and orientation were stressed. The child was then shown card D2 and so on, until he or she made two correct selections in succession. In practice, none of the children had any difficulty with this.

The experimenter then demonstrated the embedding process for the child using the Demonstration cards E1 & 2. With the TENT cut-out still visible on the table the experimenter pointed to each figure in turn on the two Demonstration cards and asked the child to show where the tent was by running his or her finger around the outline of the TENT shape hidden in the figure. In each case the cut-out was then used by the child to confirm the result. If the child had any difficulty in locating the TENT in any of these figures, the experimenter showed the child where it was by running his finger around the correct outline and then placing the cut-out over the correctly identified form. The fact that lines may cross the TENT form, and that different parts of it may be different colours was emphasised.

Finding the TENT form fully embedded in complex figures was then practiced using the Practice cards P1 & 2, using the same procedure as with cards E1 & 2. With card P2, however, the TENT cut-out was removed from view so that the child had to find the TENT form 'blind'. Once again the child's answer was checked using the cut-out, and the correct answer demonstrated if the child made a mistake.

Testing

The child was then required to locate the TENT shape on the Test cards in the same manner, without the TENT form in view. The 6 yr. olds began with card T1. The 8 and 10 yr. olds, however, in accordance with the Test Manual instructions, began with card T6 and were credited with items T1-5 providing they were successful on at least three of cards T7-11. If they had less than three successes on these cards, however, then they were tested on T1-5 as well. Testing was stopped upon completion of the TENT series if the child failed all cards T7-11. Otherwise the child then went on to tackle the HOUSE cards.

Before presenting the items in the HOUSE series (H1-14), a brief pre-training procedure was carried out as before using Discrimination cards D5-8 to introduce the HOUSE form, and the single Practice card P3.
The child then proceeded to work through the HOUSE Test cards until there had been five consecutive failures, when the test was stopped.

On cards T1-3 and H1-3, if the child failed to identify the simple form correctly, the experimenter demonstrated the correct answer, using the cut-out. After that, however, no feedback was given and the cut-out was not shown except if the child requested to see it, or if the child had three consecutive failures, or to verify the child's answer.

Scoring

A successful identification of the simple form was only scored as correct if it was made before the cut-out was seen on any particular item. Responses were simply scored 1 for a correct identification and 0 for a failure. The total score for any child thus equalled the number of items upon which the child was successful, 25 being the maximum score.

Chapter 5. RESULTS

Section A) Introduction: Review of Aims and Structure of Analysis of the Data

It is important that the methods of analysis used in a study of this sort are clearly related to the questions and hypotheses under investigation. This introduction, therefore, attempts to explain the main methods of analysis used on the data collected with reference to the aims of the study and the main hypotheses under investigation.

The first aim of the study was to explore the development of cognitive strategies amongst 6-10 year old children on the MDL task. Our hypothesis was that children's developing responses to this problem solving task can be described in terms of increasingly sophisticated and complex strategies. It was further hypothesised that this developing pattern of strategic behaviour is not simply a linear sequence, nor is it describable in terms of just one or two overriding factors. Rather the development of problem-solving strategies is a complex process involving successive recombinations of different strategic elements. At each stage of development the performance of an individual child is thus best described not in terms of their place on particular linear dimensions, or of their adoption of one particular strategy, but in terms of the pattern of their response relative to characteristically developing patterns of strategic behaviour.

A range of strategies adopted by children in response to the MDL task has been identified in the literature reviewed earlier. From this analysis, as described in the previous chapter, 10 Strategy Components were identified, and the children's responses to the MDL task scored for each of these components. The correlation matrix between these Strategy Components is reported in Table 5.1. at the beginning of the next section. It reveals a mixed pattern of predominantly middle range positive correlations (19 between .40 and .70), with a relatively smaller proportion of strong positive correlations (10 of more than .70) and quite a sprinkling of weak or negative correlations (16 less than .40).

The significance of some of these relationships for the development of strategic behaviour will be discussed at the beginning of the next section along with the table of correlations, but for the moment the overall pattern is the matter of interest. The rather complicated pattern of inter-relationships revealed by this table, and the evidence reviewed earlier about the complex nature of strategy acquisition and development, suggested that it might be profitable to analyse the children's strategic behaviour by means of Cluster Analysis. This method of analysis seemed most likely to accurately represent and reflect the complex nature of the development of children's problem-solving strategies, because it picks out typical patterns in multivariate data of this kind, rather than reducing complex patterns to one or two linear factors. Brennan (1971) demonstrated the efficacy of this kind of statistical technique for analysing multivariate data in the behavioural and social sciences some time ago. Since then it has, strangely, not been widely used. Within education its most celebrated use was within Bennett's study in the 1970's of teacher types (see, for example, Bennett & Jordan (1975)). It remains, nevertheless, in the view of the author of this thesis, a useful statistical tool; its utility is demonstrated by the light it throws on the pattern of children's strategic development within the present study.

The next section (B) describes the Cluster Analysis carried out, and the basis upon which a solution was reached indicating that the data grouped most reasonably into 7 clusters, 5 of which are numerous enough in terms of cases within the sample studied to be worthy of further detailed analysis. These Clusters are described in terms of their mean scores on the Strategy Components, by means of a closer examination of 5 'central' cases from each of the 5 main clusters, and by a Discriminant Function Analysis to explore the existence of any general factors distinguishing between the identified patterns of strategic behaviour. This analysis revealed a general developmental factor together with a 'style' factor clearly distinguishing between the different strategy clusters.

Section C) begins with an analysis of the children's performance on the MDL task, and compares the results of the present study with previous findings. It then goes on to examine the second main hypothesis of the study which is that a strong relationship exists between strategies and performance. Again, this was explored by a variety of means including the use of correlations, comparison of mean scores and the performance profiles of the 5 most "central" cases in each strategy cluster. The hypothesised strong relationship was indeed found, and the existence of such a strong relationship between strategy and performance acts as a kind of validation of the clusters of strategic behaviour identified. Examination of the mean scores of Strategy Clusters on each of the three Performance Indicators also revealed evidence to support the hypothesised developmental sequence in the quality of understanding and performance on the MDL task.

The third main area for investigation relates to the relationship between strategy and performance and a range of factors identified from the literature to be significant for general cognitive development, and the development of problem-solving skills. These relationships were explored again by the procedures outlined in the previous paragraph, and also, since it was felt likely to be difficult to distinguish the separate relationships or effects of particular Predictor Measures, by means of Multiple Linear Regression. Clear relationships were revealed between some of the Predictor Measures, Strategy Components and Performance Indicators, principally those related to metacognition and representation, with lesser effects related to field-independence.

Some relationships were revealed, however, of a non-linear and complex nature. The final section of this chapter reports the findings in relation to this issue. It was hypothesised that there would be significant interactions between the underlying cognitive factors, patterns of strategic behaviour and performance. For example, a previous study (Whitebread, 1983) had identified such an interaction between metacognition, working memory, strategy and performance on a reclassification task. This was examined principally by means of examining differential patterns of correlation within strategy clusters and other subgroups based upon scores on the tests of metacognition and the three age groups. Significant interactions were revealed, indicating support for the hypothesis that relationships between underlying cognitive factors and performance are mediated by strategic behaviour. There was also some evidence of non-linear or U-shaped development.

Section B) Analysis of Problem-solving Strategies

i) Correlations between Strategy Components

In Table 5.1 are reported the correlations between the Strategy Component scores across all three problem types. In the previous section the general pattern and range of these correlations was noted, and used as a justification for the use of Cluster Analysis to reveal the patterns of strategic behaviour amongst the sample of children studied. While it is clear that the pattern of inter-relationships between the Strategy Components overall is not straightforwardly linear, there are some overall patterns revealed in this table of interest, particularly as they relate to the general structure of strategic development suggested by such as Gholson, Levine & Phillips (1972), Kemler (1978) and Schuepfer & Gholson (1980).

Table 5.1
Correlations between Strategy Components

	1 No. of Hs per Trial	**2** H cons with local feedback	**3** Choices cons with prev H	**4** Lose/ Shift H	**5** Lose/ Shift D	**6** Win/Stay	**7** H checking	**8** D checking	**9**Foc/ 2 Trials	**10** Foc/ All Trials
1										
2	13									
3	59**	47**								
4	-30*	58**	04							
5	-37*	31**	-03	59**						
6	40**	55**	63**	-10	04					
7	-04	58**	41**	49**	67**	53**				
8	-10	46**	33**	33**	75**	55**	91**			
9	16	72**	54**	26*	50**	77**	81**	84**		
10	26*	63**	55**	17	44**	76**	78**	82**	96**	

In examining this table it has first to be recognised that some of the relationships are as much a result of the inter-connectedness of some of the components as of anything relating to the children's pattern of responses. Thus, for example, the strong relationship (.59) between Strategy Components 1 (No. of Hypotheses per Trial) and 3 (Choices consistent with previous hypothesis) is not very surprising. Clearly, the more hypotheses produced on any one trial, the greater likelihood there is, just by chance, that the next choice of Anna will be consistent with one or more of them. Similarly, scoring well on Strategy Component 2 (Hypotheses consistent with local feedback) inevitably results in scoring well also on Strategy Component 4 (Lose/Shift Hypothesis) and once again there is a reasonably strong relationship (.58).

Other results, however, tell us more about the pattern of responding. That this correlation between Strategy Components 2 & 4 is not stronger, for example, reveals that very often some children shifted away from a hypothesis which had just been disconfirmed, but then made a choice of new hypothesis which was not consistent with local feedback. As we shall see, this was mostly a consequence of the difficulties some of the children had dealing with MDL problems involving negative or irrelevant information.

A number of other more general patterns emerge which largely support the suggested developmental patterns of previous researchers. Thus, the separate development of short-term and long-term processing suggested by Kemler (1978) is supported by these figures. Thus, of the 10 strong correlations (> .70) it is noticeable that 8 of them are between the 5 most sophisticated, long-term Strategy Components (6-10). This is clearly a very cohesive group of behaviours. Correlations between these components and the short-term ones (2-5), on the other hand, are, generally weak or moderate, with only 2 strong correlations. The correlations amongst the less sophisticated components are themselves weaker.

The quite separate development of Lose/Shift (Strategy Components 4 & 5) and Win/Stay (Strategy Component 6) proposed by Schuepfer & Gholson (1980) is particularly well demonstrated. Both correlations are very close to zero. As Kemler (1978) found Lose/Shift also correlates very weakly with Strategy Component 3 (Choices consistent with previous hypothesis), which is perhaps the first element in a transition from short to long-term processing. Lose/Shift Hypothesis (Strategy Component 4) is also particularly weakly associated with any of the more sophisticated long-term components. As we shall see, analysis of the patterns of strategic behaviour revealed by the Cluster Analysis suggests that Lose/Shift Hypothesis is associated with a very early, simple pattern of responding, unconnected to any kind of planful or strategic behaviour, and this is borne out by the present figures.

The other notably weak relationships revealed in Table 5.1 are those between Strategy Component 1 (No. of Hypotheses per Trial) and most of the other components. Apart from the correlation discussed above with Strategy Component 3, the only other moderate correlation (> .4) is that with Strategy Component 6 (Win/Stay). Here again, however, this is at least partly an inevitable consequence of the scoring procedures. The percentage of confirmed hypotheses repeated is likely to be increased, by chance, where a larger number of hypotheses are being verbalised on each trial. All other correlations for Strategy Component 1 are weak, which suggests that No. of Hypotheses per Trial is largely unrelated to strategic development, and is perhaps a matter of style, as will be revealed and explored when we come to analyse the patterns of strategy behaviour revealed by the Cluster Analysis, which we come to next.

ii) Cluster Analysis

Cluster Analysis was carried out to identify patterns of strategic behaviour amongst the 72 cases in their performance on the MDL task. In order to explore patterns in the data thoroughly this was carried out at two levels. First, using the total scores on the 10 Strategy Components across the 3 problem types, and second, using the separate scores on each of the 3 problem types, again in relation to the 10 Strategy Components, producing 30 scores altogether.

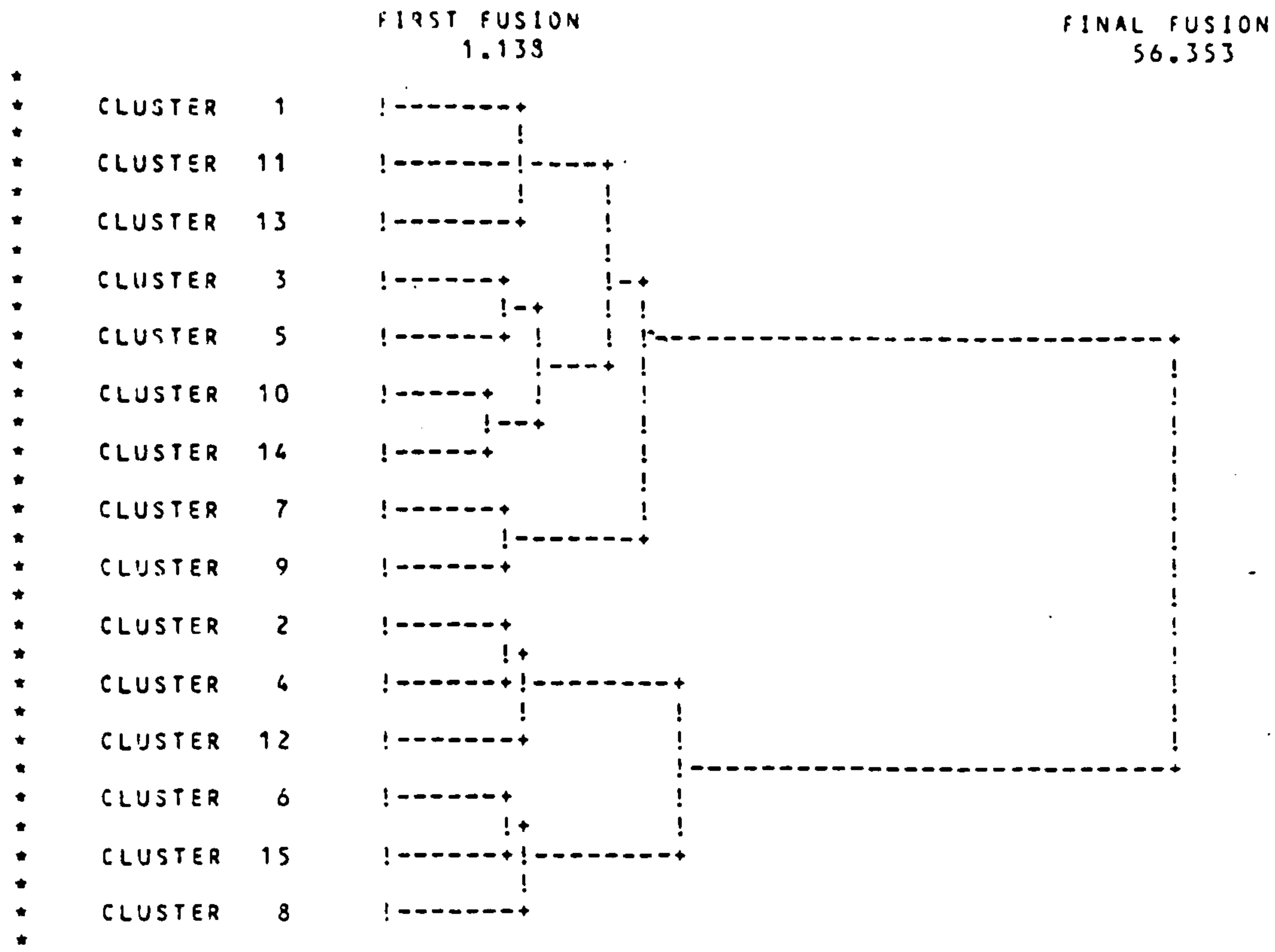
These analyses used the method of Iterative Relocation and were carried out with the CARM programme within the PMMD package of multivariate statistics produced by Youngman (1976). All other statistical analyses reported in this thesis were carried out using the PMMD package.

a) Using 10 Total Scores

This analysis is based on the total scores on the 10 Strategy Components across the 3 problem types. The Error Plot for this analysis is reproduced in Figure 5.1. The top half of this is produced in such a way as to represent the pattern of fusions of clusters, beginning with 15 and working all the way down to a final fusion of all the cases into 1 large cluster. The bottom half of the Error Plot records the error coefficients after each fusion, both numerically and in the form of a graph.

In order to make a decision about the number of clusters which best represents the pattern of the data, the size of the error after each successive fusion must be examined. The best method to get a realistic comparison of the effects of each fusion is to compare the percentage increase in the error coefficient produced by each fusion. The error coefficient is a measure of the loss of within-cluster similarity. So long as clusters are fused without any great increase in the error, then reasonably similar cases are being put together in clusters. When a large percentage increase occurs in the error coefficient, however, this is an indication that rather dissimilar cases are being artificially fused into clusters. A good representation of the data is therefore achieved by taking the cluster solution immediately prior to a fusion producing a large percentage increase in the error. The relevant figures are reported in Table 5.2.

Fig. 5.1
Error Plot for 10 Total Strategy Component Scores



FUSION	CLUSTERS	COEF
1	14	1.14
2	13	1.89
3	12	1.93
4	11	2.16
5	10	2.19
6	9	3.03
7	8	3.40
8	7	3.42
9	6	3.69
10	5	5.23
11	4	10.48
12	3	14.50
13	2	16.76
14	1	56.35

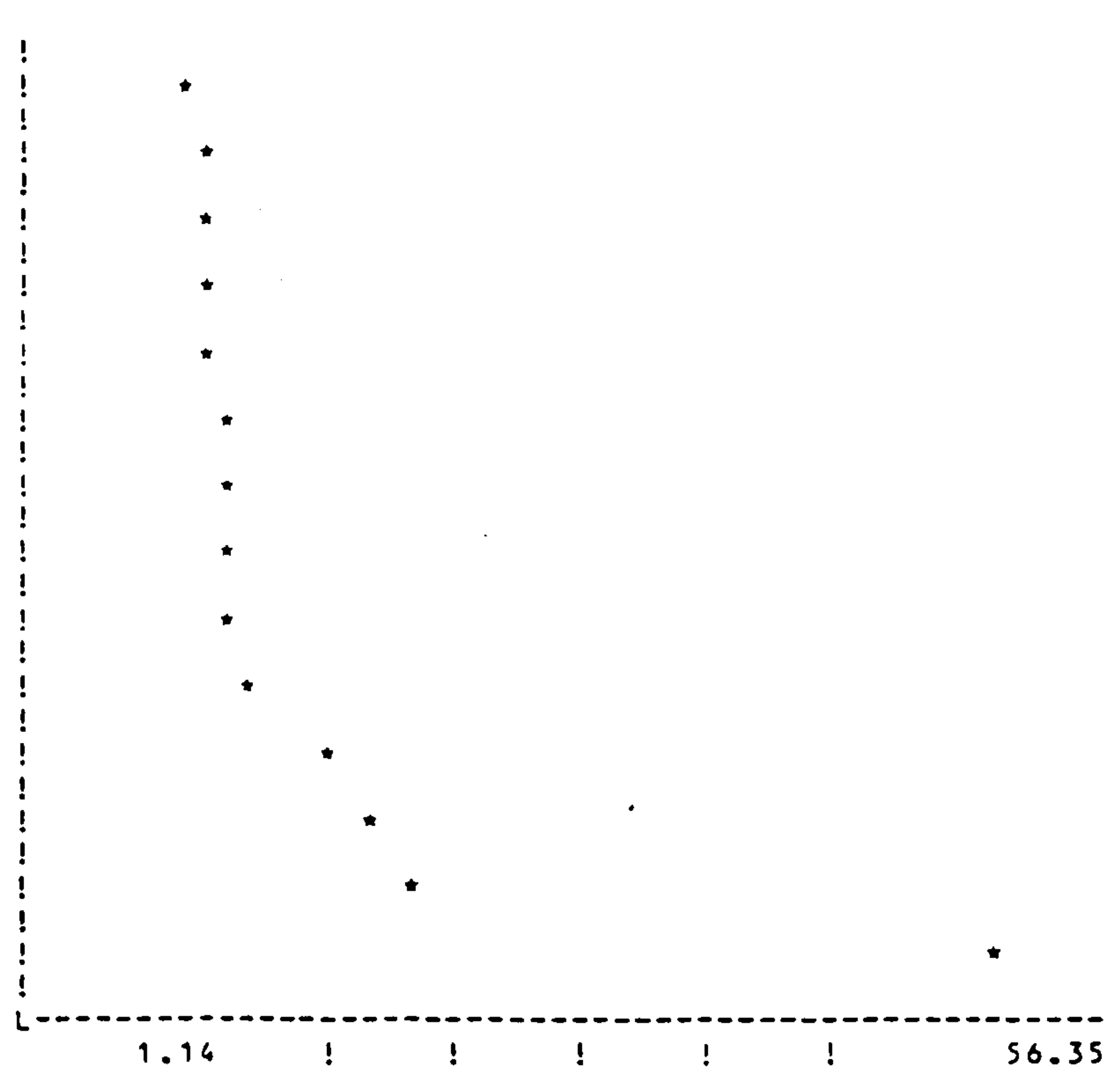


Table 5.2

Error Increases for 10 Strategy Component Total Scores

Fusion	No. of Clusters	Coeff.	% Increase of Coeff.
1	14	1.14	
2	13	1.89	65.8
3	12	1.98	4.8
4	11	2.16	9.1
5	10	2.19	1.4
6	9	3.03	**38.4**
7	8	3.40	12.2
8	7	3.42	0.6
9	6	3.69	7.9
10	5	5.28	**43.1**
11	4	10.48	98.5
12	3	14.50	38.4
13	2	16.76	15.6
14	1	56.35	236.2

The first two major losses in within-cluster similarity are highlighted in bold type and occur when fusing 10 clusters into 9 and 6 clusters into 5. A 10 Cluster solution, however, would produce very small average cluster sizes and a level of detail which is not justified by the total sample size of 72 cases or by the general theoretical model underpinning this investigation. On this basis the 6 Cluster solution would appear to be the more reasonable and valuable solution to pursue at this time.

b) Using 30 scores on different problem types

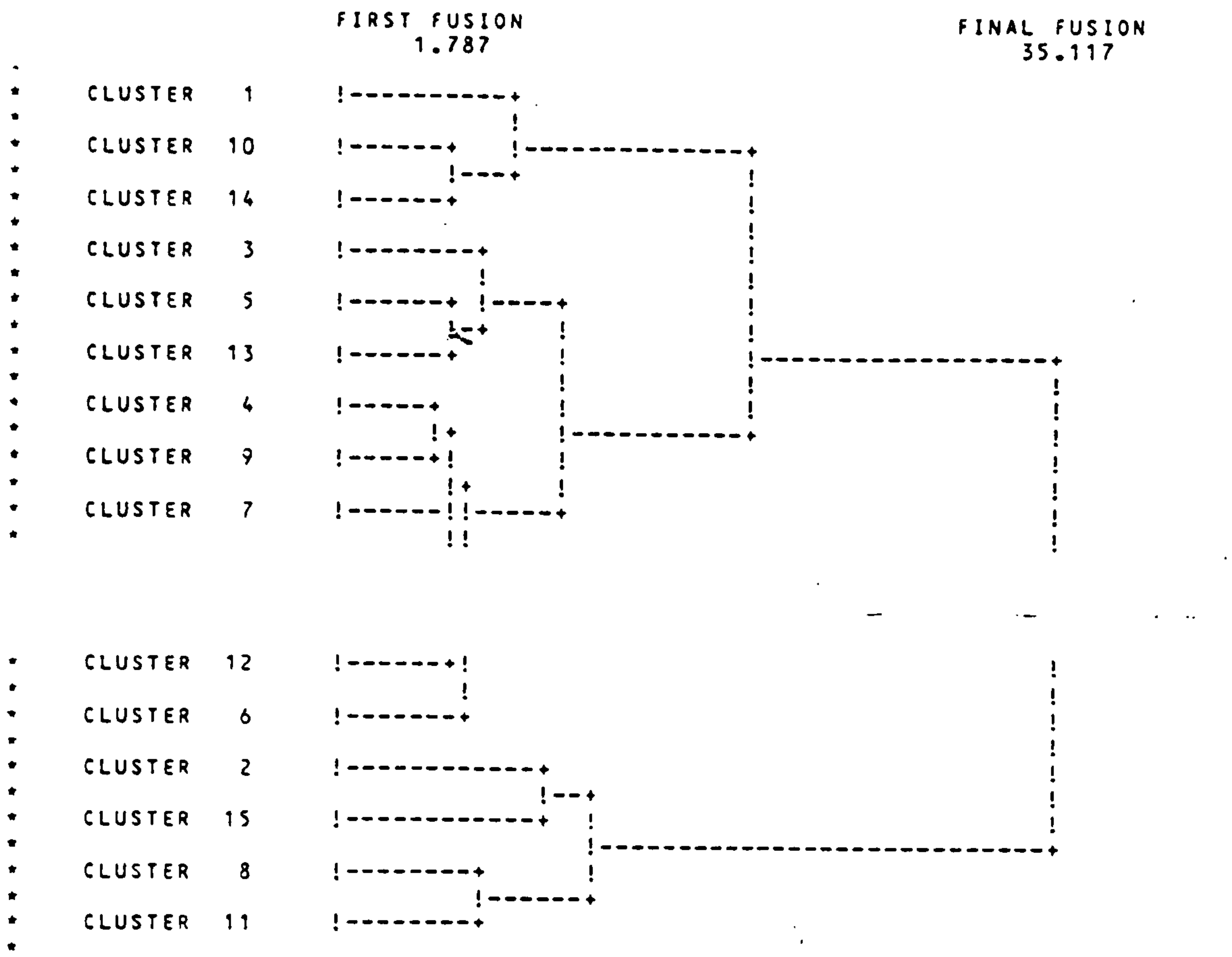
This analysis is based on the three problem types which, as outlined in the previous chapter, relate to important factors identified by previous research as contributing to the difficulty of the MDL task. These three problem types were the standard 4-dimensional MDL task (problem type a), the task with negative information (only one card revealed; problem type b) and the task with noise or redundant information (8-dimensional: 4 relevant & 4 irrelevant; problem type c).

The Error Plot for this analysis is reproduced in Figure 5.2, and once again percentage increases in the error coefficient after each fusion have been computed and are reported in Table 5.3.

The first two major increases in loss of within-cluster similarity are highlighted in bold type and occur here when fusing 11 clusters into 10 and 7 clusters into 6. On similar grounds to those discussed in relation to the 10 Total scores analysis, the 7 Cluster solution looks the more valuable. While the pattern of loss of within-cluster similarity is somewhat less discontinuous here than in the 10 Variable analysis, the choice of the 7 Cluster solution as a cut-off point is strengthened by its relation to the 6 Cluster solution which was strongly indicated in the simpler analysis. This relationship is examined in the next section.

Fig. 5.2

Error Plot for 30 Strategy Component Scores on different problem types



FUSION	CLUSTERS	COEF
1	14	1.79
2	13	2.33
3	12	2.36
4	11	2.40
5	10	2.91
6	9	3.47
7	8	4.00
8	7	4.50
9	6	5.76
10	5	7.66
11	4	8.73
12	3	10.21
13	2	18.97
14	1	35.12

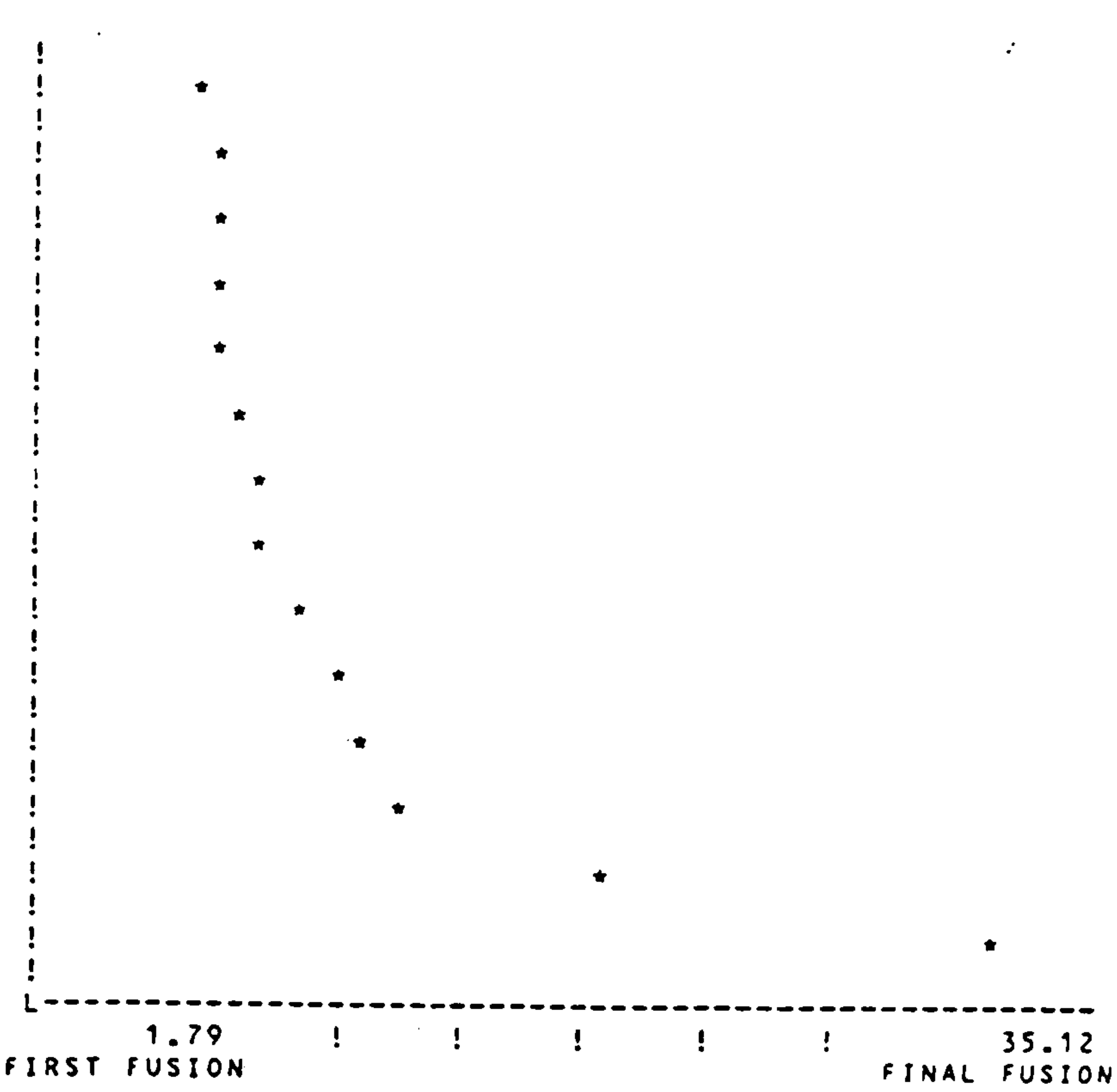


Table 5.3

Error Increases for 30 Strategy Component Scores on different problem types

Fusion	Clusters	Coeff.	% Increase of Coeff.
1	14	1.79	
2	13	2.33	30.2
3	12	2.36	1.3
4	11	2.40	1.7
5	10	2.91	**21.25**
6	9	3.47	19.2
7	8	4.00	15.3
8	7	4.50	12.5
9	6	5.76	**28.0**
10	5	7.66	33.0
11	4	8.73	14.0
12	3	10.21	17.0
13	2	18.97	85.8
14	1	35.12	85.1

c) The 7 Cluster Solution

With what is for these purposes a relatively small sample size of 72 cases, examining the reliability of this clustering solution by a split-halves procedure is not possible. The stability of the solution between the 10 and 30 scores analyses, however, is quite striking and enhances confidence in the 7 Cluster solution. The close relationship between the 6 & 7 Cluster solutions is demonstrated by the Contingency Table reported in Table 5.4.

Table 5.4

Contingency Table: Allocation of cases for the 10 scores/6 clusters & 30 scores/7 cluster solutions

30 Problem Type Scores Analysis: 7 Clusters	10 Total Scores Analysis: 6 Clusters 1	2	3	4	5	6
1	1,15,17 19,22,34 42,				5,6,66	
2		2,13,26 27,28,37 38,40,45 50,51,		58		
3		20,31,48	3,29,33 36,43,49 52,53,54 56,57,64 65	4,23,30 46		
4		21,41			7,8,9,10 11,12,14 24,32,47, 68	
5	16					
6				18,39,44 60,61,62 69,71		55,59,63 67,72
7		35				25,70

The allocation of cases to the 7 and 6 cluster solutions which emerges from this table is reported in Table 5.5.

Table 5.5

Allocation of cases to 7 & 6 Strategy Cluster solutions

7 Clusters	6 Clusters	
Cl.1: 10 cases	Cl.1: 8 cases	- case 16 to Cl.5 + cases 5, 6 & 66 from Cl.5
Cl.2: 12 cases	Cl.2: 17 cases	- cases 20, 31 & 48 to Cl.3 - cases 21 & 41 to Cl.4 - case 35 to Cl.7 + case 58 from Cl.4
Cl.3: 20 cases	Cl.3: 13 cases	+ cases 20,31 & 48 from Cl.2 + cases 4, 23, 30 & 46 from Cl.4
Cl.4: 13 cases	Cl.5: 14 cases	- cases 5,6, & 66 to Cl.1 + cases 21 & 41 from Cl.2
Cl.5: 1 case		+case 16 from Cl.1
Cl.6: 13 cases	Cl.4: 13 cases	- case 58 to Cl.2 - cases 4, 23, 30 & 46 to Cl.3
	Cl.6: 7 cases	- cases 25 & 70 to Cl.7
Cl.7: 3 cases		+ case 35 from Cl.2 + cases 25 & 70 from Cl.6

This analysis provides strong evidence for the 7 Cluster solution as a robust feature of the data. The extra information contained in the 30 scores analysis allows the 4 atypical cases in Cls. 5 & 7 to be separated out and Cls. 4 & 6 from the simpler analysis are combined. Apart from these changes, which clearly result from the more detailed data and the extra cluster in the 30 scores analysis, only 13 cases (18 %) switch clusters between the two analyses. Thus there is effectively 82% agreement between the two analyses in allocation of cases to clusters.

iii) The 7 Cluster Solution

Analysis of the 7 Cluster solution reveals quite clear differential patterns of strategic behaviour amongst the sample of 72 cases. Reference to Table 5.6 (Diagnosis of the 7 Clusters incorporating the raw and standardised means for each cluster on each of the 30 Strategy Component scores across the 3 problem types) shows that each of the 30 Strategy Component scores discriminates between the clusters at the 0.01 level of significance (tested using one-way Analysis of Variance). Furthermore, as we shall see, each of the clusters represents a pattern of strategic behaviour predictable from the previous research on hypothesis testing behaviour with the MDL task, as outlined in the earlier review of this work.

Before coming on to an examination of the individual Strategy Clusters, however, some general points arise from the overall pattern of scores reported in Table 5.6.

As regards Strategy Component 1 (No. of Hypotheses per Trial) the finding of Eimas (1969) and others that young children tend to consider one hypothesis at a time appeared to be the case only for the least sophisticated strategically. As will emerge, Clusters 4 & 5 were developmentally the simplest strategically, and it can be seen that the raw mean no. of hypotheses was one, or very nearly one, for these groups across all 3 problem types. However, the finding of Phillips & Gholson (1980) that, given the opportunity, many children will produce more than one hypothesis at a time was also supported. The raw means for Clusters 1 & 6 are mostly well over 2. As we will see, this element in strategic approach to the MDL task emerged as a pivotal factor in relation to strategic style.

The first crucial element in developing a strategic approach to the MDL task, identified by Gholson, Levine & Phillips (1972), was the ability to respond to feedback. As we have reviewed, they found kindergartners (5/6 yr. olds) failed to respond to negative feedback nearly half of the time. However, Kemler (1978) found children in this age group much more reliably responded to feedback with her more meaningful task. The results within the present study for Strategy Component 2 (Hypotheses consistent with Local Feedback) would appear to support those of Kemler (1978). As can be seen, on the standard version of the task (problem type a) all the clusters, with the exception of Cluster 5 (containing one 6 yr. old), produced locally consistent hypotheses over 90%

Table 5.6

Diagnosis of the 7 Clusters: Raw and Standardised Mean Scores on the 30 Strategy Components

Strat Comp	Prob Type	F	p	Clusters 1(10)	2(12)	3(20)	4(13)	5(1)	6(13)	7(3)
1	a	14.60	0.00**	0.87*	-0.64?	-0.11	-0.98**	-0.99	1.06**	0.38
				2.11	*1.20*	*1.53*	*1.00*	*1.00*	*2.23*	*1.82*
	b	7.21	0.00**	0.09	-0.44	-0.05	-0.70?	-0.72	1.20**	0.47
				1.41	*1.21*	*1.43*	*1.06*	*1.05*	*2.15*	*1.73*
	c	11.12	0.00**	0.63	-0.57	-0.22	-0.73*	-0.75	0.67?	2.19**
				2.54	*1.20*	*1.58*	*1.02*	*1.00*	*2.58*	*4.28*
2	a	12.91	0.00**	0.25	0.06	0.23	-0.62?	-5.52**	0.36	0.36
				98.90	*97.08*	*98.70*	*90.38*	*42.00*	*100.00*	*100.00*
	b	8.85	0.00**	-0.79?	-0.48	0.91**	-0.25	-0.40	-0.34	1.19
				59.00	*64.50*	*89.55*	*68.62*	*66.00*	*67.15*	*94.67*
	c	10.86	0.00**	-0.54	0.45	0.59*	-0.63?	-2.21	0.36	-1.99**
				65.70	*87.50*	*90.75*	*63.69*	*29.00*	*85.62*	*33.67*
3	a	12.65	0.00**	0.05	0.08	0.25	-1.43**	-0.41	0.88**	0.37
				82.50	*83.08*	*86.10*	*55.00*	*74.00*	*97.92*	*88.33*
	b	8.88	0.00**	-0.24	-0.28	0.45	-1.11**	-0.83	0.88**	0.25
				65.90	*65.08*	*80.00*	*48.23*	*54.00*	*88.85*	*76.00*
	c	6.37	0.00**	-0.34	0.11	0.63*	-0.87*	0.57	0.34	-1.38
				71.30	*80.50*	*91.20*	*60.54*	*90.00*	*85.23*	*50.00*
4	a	281.01	0.00**	0.07	0.16	0.16*	-0.01	-8.25**	0.16	0.16
				99.50	*100.00*	*100.00*	*99.00*	*50.00*	*100.00*	*100.00*
	b	5.00	0.00**	-0.69	-0.44	0.69*	0.34	-1.69	-0.37	0.12
				78.80	*82.50*	*99.10*	*94.00*	*64.00*	*83.46*	*90.67*
	c	15.15	0.00**	-0.82*	0.43	0.42	0.44	-2.67*	-0.05	-2.57**
				77.40	*98.00*	*97.75*	*98.15*	*47.00*	*90.00*	*48.67*
5	a	9.65	0.00**	-1.51**	0.38	0.44	-0.21	-1.60	0.33	0.60
				52.00	*91.33*	*92.65*	*79.15*	*50.00*	*90.46*	*96.00*
	b	6.25	0.00**	-0.68	-0.42	0.74**	0.37	-0.59	-0.67	0.48
				61.80	*67.75*	*93.95*	*85.69*	*64.00*	*62.15*	*88.00*
	c	12.04	0.00**	-1.30**	0.53	0.51*	0.49	-1.21	-0.31	-1.49?
				44.90	*88.25*	*87.80*	*87.38*	*47.00*	*68.31*	*40.33*
6	a	11.32	0.00**	-0.18	0.12	0.48?	-1.39**	-0.75	0.52	0.92
				67.10	*76.17*	*86.90*	*30.77*	*50.00*	*88.15*	*100.00*
	b	10.30	0.00**	-0.53	-0.37	0.86**	-0.97**	0.34	0.14	1.01
				36.90	*41.75*	*80.05*	*23.23*	*64.00*	*57.69*	*84.67*
	c	16.92	0.00**	-0.38	0.24	0.61**	-1.50**	-0.54	0.52	0.69
				55.40	*76.42*	*88.80*	*17.69*	*50.00*	*85.85*	*91.67*
7	a	13.63	0.00**	-1.42**	0.16	0.52*	-0.59?	-1.34	0.63?	0.94
				48.10	*82.75*	*90.70*	*66.31*	*50.00*	*93.08*	*100.00*
	b	17.65	0.00**	-1.34**	-0.18	1.04**	-0.28	-0.47	-0.29	0.87
				33.70	*60.75*	*89.20*	*58.31*	*54.00*	*58.23*	*85.33*
	c	13.66	0.00**	-1.24**	0.75*	0.66**	-0.30	-2.16	-0.04	-1.09
				38.50	*84.67*	*82.70*	*60.23*	*17.00*	*66.46*	*42.00*

Strat Comp	Prob Type	F	p	Clusters 1(10)	2(12)	3(20)	4(13)	5(1)	6(13)	7(3)
8	a	11.72	0.00**	-1.40**	0.21	0.54*	-0.63?	-0.60	0.51	0.94
				26.20	*74.25*	*83.85*	*49.15*	*50.00*	*83.08*	*96.00*
	b	18.36	0.00**	-1.01**	-0.20	1.13**	-0.44	-0.15	-0.55?	0.97
				19.50	*42.58*	*80.35*	*35.69*	*44.00*	*32.38*	*76.00*
	c	12.64	0.00**	-1.18**	0.93**	0.63**	-0.35	-1.48	-0.28	-0.78
				25.10	*81.08*	*73.05*	*47.15*	*17.00*	*48.92*	*35.67*
9	a	20.92	0.00**	-0.82**	0.06	0.63**	-1.22**	-1.84	0.72**	1.09
				57.00	*75.83*	*88.05*	*48.38*	*35.00*	*90.08*	*98.00*
	b	19.00	0.00**	-1.06**	-0.38	1.11**	-0.56?	0.09	-0.23	1.07
				33.50	*48.50*	*81.50*	*44.46*	*59.00*	*51.77*	*80.67*
	c	16.66	0.00**	-0.76*	0.80**	0.72**	-1.01**	-1.66	0.12	-1.06
				39.30	*78.42*	*76.45*	*33.08*	*17.00*	*61.31*	*32.00*
10	a	18.01	0.00**	-0.87**	-0.22	0.57**	-1.06**	-1.15	0.86**	1.28?
				36.70	*54.42*	*76.20*	*31.31*	*29.00*	*84.23*	*96.00*
	b	14.10	0.00**	-0.87*	-0.53	1.08**	-0.51**	0.07	-0.21	0.91
				21.90	*30.67*	*71.70*	*31.08*	*46.00*	*38.69*	*67.33*
	c	11.68	0.00**	-0.60	0.87**	0.57*	-0.07**	-1.56	0.09	-0.53
				28.40	*71.50*	*62.65*	*14.54*	*0.00*	*48.46*	*30.33*

Plain = Standardised score
Italic = Raw score
The significance of the variation of each standardised Cluster Mean from the population mean is tested using the Scheffe´ Atypicality test. The degree to which each Strategy Component discriminates between Clusters overall is tested using one-way Analysis of Variance (F-ratio on left hand side of table) Levels of significance: ? = 0.1
* = 0.05
** = 0.01
The numbers in brackets after the Cluster numbers indicate the number of cases in each Cluster.

of the time. These figures drop with the more difficult versions of the task, but even then are generally well above those reported by Gholson, Levine & Phillips (1972), even for Clusters 1 & 4, which, as will be seen, mostly contained 6 yr.olds.

We have discussed the issue of attentional control in relation to this issue of responding to negative feedback. Tumblin & Gholson (1980), it will be recalled, directed children that 'wrong means look at the other picture'. Given that no attentional aid was used in the present study whatever (in which respect the procedure varied from Kemler's (1978)), the results for Strategy Component 2 would seem to support the view that children's difficulties with the standard MDL task, such as that used by Tumblin & Gholson (1980), arose from its abstractness, and children's consequent failure to understand its internal logic, rather than from their inability to control their attention.

As regards Strategy Component 3 (Choices consistent with Previous Hypothesis), Kemler (1978) did find that often young children's stated hypotheses did not predict their next choice of stimulus, but presented evidence that this was not a result of the kind of 'stimulus describing' first identified by Phillips (1974). The present figures would tend to support the view that the verbal 'introtacts' or hypotheses provided by the children were, generally, a valid indication of the real working hypotheses. On the standard problem type a stated hypotheses predicted the next choice well over 80% of the time for all but Clusters 4 & 5 (the two developmentally simplest strategy clusters). As we shall see, this and other evidence suggest that Cluster 4 might contain an element of 'stimulus describing'.

These results combined with those for Strategy Component 4 (Lose/Shift Hypothesis) provide strong evidence of a good deal of Kemler's (1978) 'short-term efficiency'. As will be seen, for all but Cluster 5, disconfirmed hypotheses were abandoned a very high proportion of the time. The figures for problem type a are almost 100%, and even for the more difficult problem types b and c they do not drop too dramatically. A comparison of these scores with those for Strategy Component 6 (Win/Stay), however, clearly supports the finding of Schuepfer & Gholson (1980) that Lose/Shift Hypothesis is the earlier developing element in the development of full short-term efficiency. The figures for Win/Stay are dramatically lower than those for Lose/Shift Hypothesis; this is particularly the case for the developmentally earlier and younger Clusters 1 & 4, but is also the case to a lesser extent for all clusters.

The scores for Strategy Component 5 (Lose/Shift Dimension) are also generally lower than for Lose/Shift Hypothesis, confirming that this element of strategic behaviour requires more understanding of the logic of the MDL task, and more co-ordination of information across trials. As we shall see, however, there are some interesting variations in scores between clusters on this component which are helpful in analysing the different strategic patterns.

The figures for Strategy Components 7-10 confirm, as Gholson, Levine & Phillips (1972), Kemler (1978) and others have found, that these elements, requiring 'long-term efficiency' are later developing. The scores drop quite dramatically for the youngest groups (Clusters 1, 4 & 5), and even many of the older children in Clusters 6 & 7 find it difficult to maintain their scores on the more difficult problem types b and c. Only Cluster 3, which we shall see emerges as strategically the most sophisticated group, managed to maintain scores in the region of 70-80% on these elements of long-term processing across all problem types.

Kemler (1978) did find evidence of 7 and 11 yr. old children using the 'hypothesis memory' necessary for long-term efficiency and carrying out Hypothesis and Dimension Checking strategies. Within the present study the older Clusters 3,6 & 7 maintained Hypothesis Checking (Strategy Component 7) on problem type a over 90% of the time, and Dimension Checking (Strategy Component 8) over 80 %. Kemler (1978), in her Experiment 2, exploring the upper bounds of the capabilities of 7 and 11 yr. olds, found no evidence, however, of Primary school aged children using 'stimulus memory' and carrying out the Focusing strategy. In this respect, the results of the present study differ. The scores for Strategy Component 9 (Focusing over 2 Trials) show that the pattern of behaviour for children in Strategy Clusters 3,6 & 7 were consistent with this component on problem type a around 90% of the time. Even on Strategy Component 10 (Focusing over All Trials) the average figure for these clusters stays at around 80%.

It is interesting to speculate as to the reasons why this better long-term efficiency appeared in the present study. The most likely explanation would seem to be that Kemler's (1978) version of the problem in her Experiment 2 was significantly more difficult than the version used within the present study. She used 5 and 8-dimension problems with randomly sequenced stimuli, compared to the 4-dimensional problems with orthogonally sequenced stimuli used here. As we have reviewed, there is ample evidence that, when faced with a more difficult problem, children (and adults) revert to simpler strategies which are less demanding, particularly in relation to working memory load.

The other clear pattern which emerges from Table 5.6 is that, as predicted, problem types b and c, involving children in dealing with negative and redundant information, were more difficult and resulted in simpler strategies. We have reviewed earlier research which has identified the necessity of dealing with negative or redundant information as a factor making the MDL task more difficult. We also reviewed the debate as to whether this was a consequence of the extra demands made by this kind of information on memory load, or whether it was a consequence of particular difficulties with these kinds of information. Scardamalia (1977), among others has provided evidence of the simplification of strategies resulting from extra load on memory. On the other hand, difficulties with negative information might be related to the 'confirmatory bias' originally identified by Wason (1960) and reconceptualised as a 'positive test strategy' by Klayman & Ha (1987). Difficulties with irrelevant information might be related to attentional deficits. Kemler, Shepp & Foote (1976) found 5 & 7 yr. olds attending to incidental information about attributes significantly more than 10 yr. olds.

The results of the present study would tend to suggest that, whatever the source of these difficulties, they are probably different. Thus, while all the children tended to perform less efficiently on problem types b and c, there are clear differential patterns between the two problem types. Thus, as we shall see, children in Strategy Cluster 2 had particular difficulty with problem type b (negative information), while Clusters 6 & 7 performed relatively poorly on problem type c (irrelevant information). This would tend to support the view that these difficulties at least partly reflect inferential and attentional deficits; if these types of problems were more difficult simply because of extra memory load, then you would expect the same children to perform relatively less efficiently on both.

a) Description of the Strategy Clusters

There follows in Table 5.6a a detailed analysis of all 7 clusters. Within these analyses, a list of constituent cases is presented followed by the number of cases in the cluster and an analysis of the age range principally represented in the cluster (Cases 1-24 were 6 yr. olds; cases 25-48 were 8 yr. olds; cases 49-72 were 10 yr. olds). The analysis of Strategy Component scores first looks at the general position relative to all other clusters, and then, where applicable, at the position relative to the other cluster at the same general level of performance on the Strategy Components. Finally, an overall label is ascribed to each of the clusters which describes their pattern of strategic behaviour relative to the patterns found in previous studies of behaviour on the MDL task, as discussed in the second section of chapter 3.

While they have some theoretical validity, Clusters 5 & 7 are excluded from much of the rest of the analysis because of the small number of cases. Since it is possible that they represent significant types of strategic behaviour, however, of which more cases would have been found with a wider sample (eg: a younger sample would probably produce more cases of Cluster 5: Object Preference) it will be interesting to note on occasion the way in which these cases relate to particular features of the analysis.

Table 5.6a

Analysis of Strategy Clusters

Cluster 1

Cases: 1,5,6,15,17,19,22,34,42,66 (10)

Age range: mostly **6 yr. olds** (7 out of 10)

Analysis of component scores:

- **generally weak** (on components 2-10: 24 out of 27 standard scores negative)

- **particularly weak on more long-term, complex strategies** (components 7-10: 9 out of 12 scores sig. at 0.01 level and a further 2 at the 0.05 level)

- **relative to other generally weak Cl.4:**

- **high on 1. Number of H's per T** (mean over 2.00 on 1a &c; Cl.1 component 1a sig. at 0.05 level; Cl.4 component 1a sig. at 0.01 level, 1b at 0.1 level & 1c at 0.05 level), **3. Choices cons. with prev. H** (Cl.4 components 3a & b sig. at 0.01 level & 3c at 0.05 level) & **6. Win/Stay** (Cl.4 components 6a,b & c sig. at 0.01 level)

- **low on 4. Lose/Shift H** (Cl.1 components 4b &c negative; 4c sig. at 0.05 level; Cl.4 components 4b & c positive), **5. Lose/Shift D** (Cl.1 components 5a & c sig. at 0.01 level), **7. H checking** (Cl.1 components 7a,b & c sig. at 0.01 level) & **8. D checking** (Cl.1 components 8a,b & c sig. at 0.01 level)

Strategic behaviour: **Attribute (Dimension) Perseveration**

Cluster 2

Cases: 2,13,26,27,28,37,38,40,45,50,51,58 (12)

Age range: mostly **8 yr. olds** (10 out of 12)

Analysis of component scores:

- generally **intermediate** (25 out of 30 scores not sig.)

- **low on type b problems: negatives** (on components 2-10: score for b is lowest in each case; all b standard scores negative; all a & c scores positive with single exception of 10a)

- **relative to other generally intermediate Cl.6:**

- **high on type c problems: noise** (component 7c sig. at 0.05 level; components 8c, 9c & 10c sig. at 0.01 level)

- **low on 1. Number of H's per T** (Cl.2 standard scores all negative - component 1a sig. at 0.1 level; Cl.6 standard scores all positive - components 1a &b sig. at 0.01 level and 1c at 0.1 level)

Strategic behaviour: **Negative Information Difficulties**

Cluster 3

Cases: 3,4,20,23,29,30,31,33,36,43,46,48,49,52,53,54,56,57,64,65 (20)

Age range: mostly **8 & 10 yr. olds** (16 out of 20)

Analysis of component scores:

- generally **strong** (on components 2-10 all standard scores positive; 22 out of 27 sig.)

- **particularly strong on more long-term, complex strategies** (components 7-10: 9 out of 12 scores sig. at 0.01 level and remaining 3 at the 0.05 level)

- **intermediate on 1. Number of H's per T** (standard scores all near zero);

Strategic behaviour: **Focusing**

Cluster 4

Cases: 7,8,9,10,11,12,14,21,24,32,41,47,68 (13)

Age range: mostly **6 yr. olds** (9 out of 13)

Analysis of component scores:

- **generally weak** (on components 2-10: 23 out of 27 standard scores negative)

- **particularly weak on 9. & 10. Focusing** (components 9-10: 4 out of 6 scores sig. at 0.01 level and a further 1 at the 0.1 level)

- **relative to other generally weak Cl.1:**

  - **low on 1. Number of H's per T** (mean practically at basic minimum of 1.00 ; Cl.1 component 1a sig. at 0.05 level; Cl.4 component 1a sig. at 0.01 level, 1b at 0.1 level & 1c at 0.05 level), **3. Choices cons. with prev. H** (components 3a & b sig. at 0.01 level & 3c at 0.05 level) & **6. Win/Stay** (components 6a,b & c sig. at 0.01 level)

  - **high on 4. Lose/Shift H** (Cl.1 components 4b &c negative; 4c sig. at 0.05 level; Cl.4 components 4b & c positive), **5. Lose/Shift D** (Cl.1 components 5a & c sig. at 0.01 level), **7. H checking** (Cl.1 components 7a,b & c sig. at 0.01 level; Cl.4 component 7a sig. at only 0.1 level) & **8. D checking** (Cl.1 components 8a,b & c sig. at 0.01 level; component 8a sig. at only 0.1 level)

Strategic behaviour: **High/Random Shift of Hypotheses; Stimulus Describing**

Cluster 5 (located in Cl.1 in Totals solution)

Case: 16

Age range: **6 yr. old**

Analysis of component scores:

- generally **weak** (on components 2-10: 23 out of 27 standard scores negative)

- **particularly weak on 2. Locally cons. H** (component 2a sig. at 0.01 level) & **4. Lose/Shift H** (component 4a sig. at 0.01 level & 4c at 0.05 level)

- **low on 1. Number of H's per T** (mean practically at basic minimum of 1.00; standard scores all negative)

Strategic behaviour: **Object Preference**

Cluster 6

Cases: 18,39,44,55,59,60,61,62,63,67,69,71,72 (13)

Age range: mostly **10 yr. olds** (10 out of 13)

Analysis of component scores:

- generally **intermediate** (21 out of 30 scores not sig.)

- **relative to other generally intermediate Cl.2:**

- **high on 1. Number of H's per T** (Cl.2 standard scores all negative - component 1a sig. at 0.1 level; Cl.6 standard scores all positive - components 1a &b sig. at 0.01 level and 1c at 0.1 level)

- **high on type a problems: standard** (components 2-10: Cl. 6 scores higher on 8 out of 9 components; components 3a, 9a & 10a sig. at 0.01 level, 7a at 0.1 level)

- **low on type c problems: noise** (Cl.2 component 7c sig. at 0.05 level; components 8c, 9c & 10c sig. at 0.01 level)

Strategic behaviour: **High Hypotheses per Trial**

Cluster 7 (located in Cls. 2 & 6 in Totals solution)

Cases: 25,35,70 (3)

Age range: **8 & 10 yr. olds**

Analysis of component scores:

- generally **strong** (25 out of 30 scores not sig. but this is largely a product of the small group size)

- **high on type a problems: standard** (on components 2-10: 8 out of 9 scores are the highest of all clusters)

- **high on component 1c: Number of H per T/noise problems** (sig. at 0.01 level)

- **low on type c problems: noise** (on components 2-10: score for c is lowest and standard scores negative in 8 out of 9 cases; all a & b scores positive; components 2c & 4c sig. at 0.01 level, 5c at 0.1 level)

Strategic behaviour: **Noise Difficulties**

The interpretation of the one case in Cluster 5 is very straightforward; it is a clear example of the 'object preference' stereotype or response-set identified by Gholson, Levine & Phillips (1972), amongst others. The distinctively weak scores on Strategy Components 2 (Hypotheses consistent with Local Feedback) and 4 (Lose/Shift Hypothesis), noted in Table 5.6a, tell a very clear story. As was observed by the author during this child's responses to the MDL task, quite consistently on each problem, a preferred object was chosen and then adhered to, irrespective of feedback.

The 3 children in Cluster 7 present a more complicated picture, and a rather enigmatic one. They produced a pattern of a generally sophisticated strategic response to the MDL task, but, as can be seen from the analysis in Table 5.6a, had very particular difficulties with type c problems (irrelevant information). As can be seen by their score of 4.28 on Strategy Component 1c, they verbalised very large numbers of hypotheses, many of them irrelevant. Whether this was a problem of attention or a lack of understanding of the logic of the problem is difficult to assess. It would be interesting in a future study to see if a larger sample of children behaving in this way could be identified, and their responses analysed across a variety of inductive reasoning tasks, to see if their difficulty with the present task represents a more general deficit.

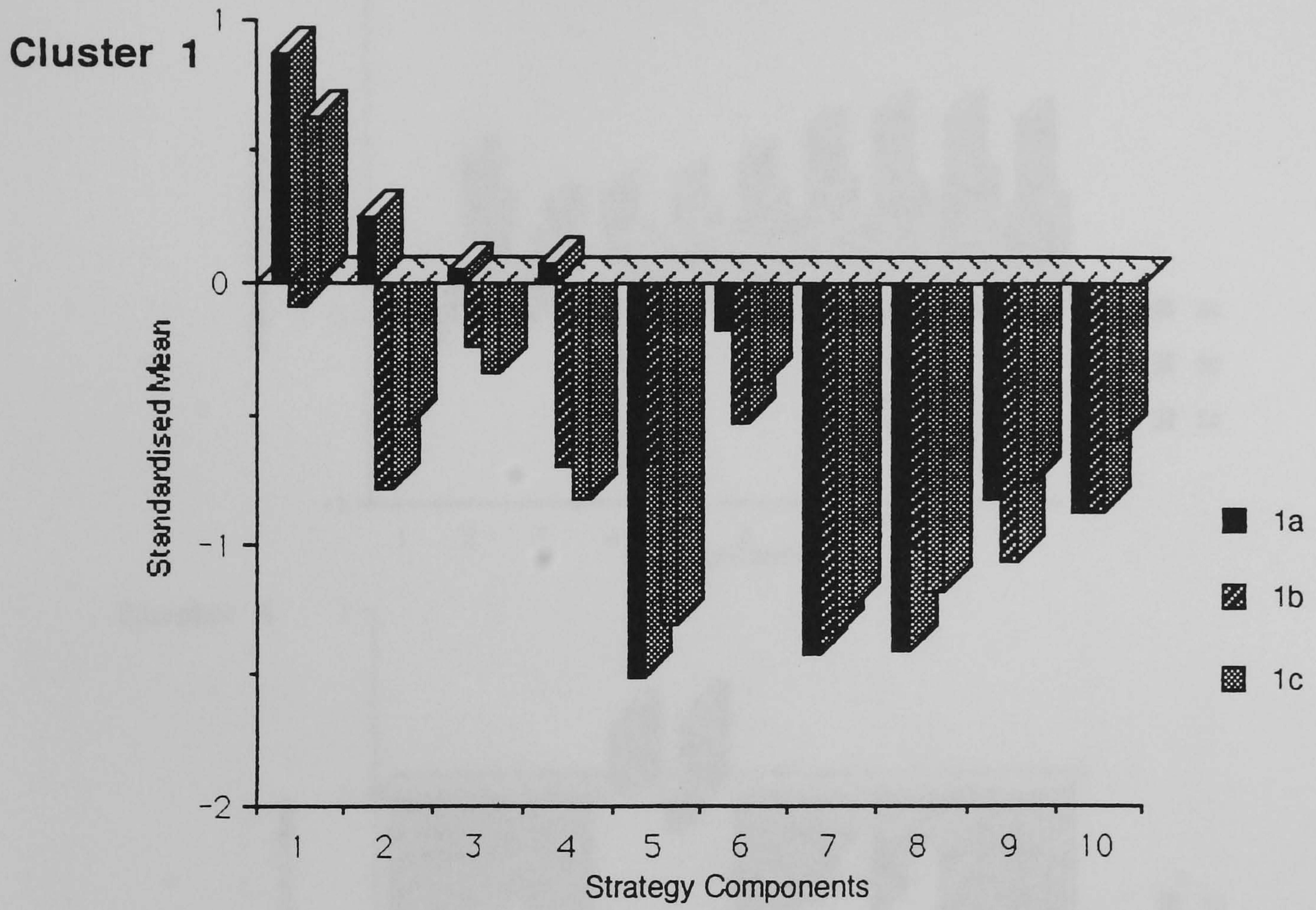
The different patterns of strategic behaviour for the 5 main clusters (i.e. Clusters 1,2,3,4 & 6, each of which have a reliable number of cases within the current sample) are illustrated by separate Standardised Mean bar charts (Fig. 5.3) and the Atypicality Chart of standardised means, which compares all 5 main clusters (Fig. 5.4.) These demonstrate well the very different patterns of strategic behaviour contained within these clusters.

Clusters 1 & 4 are evidently the developmentally earliest and strategically simplest. In Fig. 5.3 it can be seen that their scores were predominantly below the sample mean; the atypicality analysis reported in Fig. 5.4 shows that their scores were all either average or significantly below the mean. These groups are largely made up of 6 yr. olds.

The analysis of Cluster 1 in Table 5.6a demonstrates that this group conformed to the pattern of 'attribute perseveration' identified by Kemler (1978), as we noted earlier, as a common pattern of response among kindergartners (5/6 yr. olds). This involves alternating between the two values of a dimension or attribute, consistent with local feedback. The really telling scores for this Cluster are those for Strategy Component 5

Figure 5.3

Strategy Components for 5 Main Clusters: Standardised Mean scores



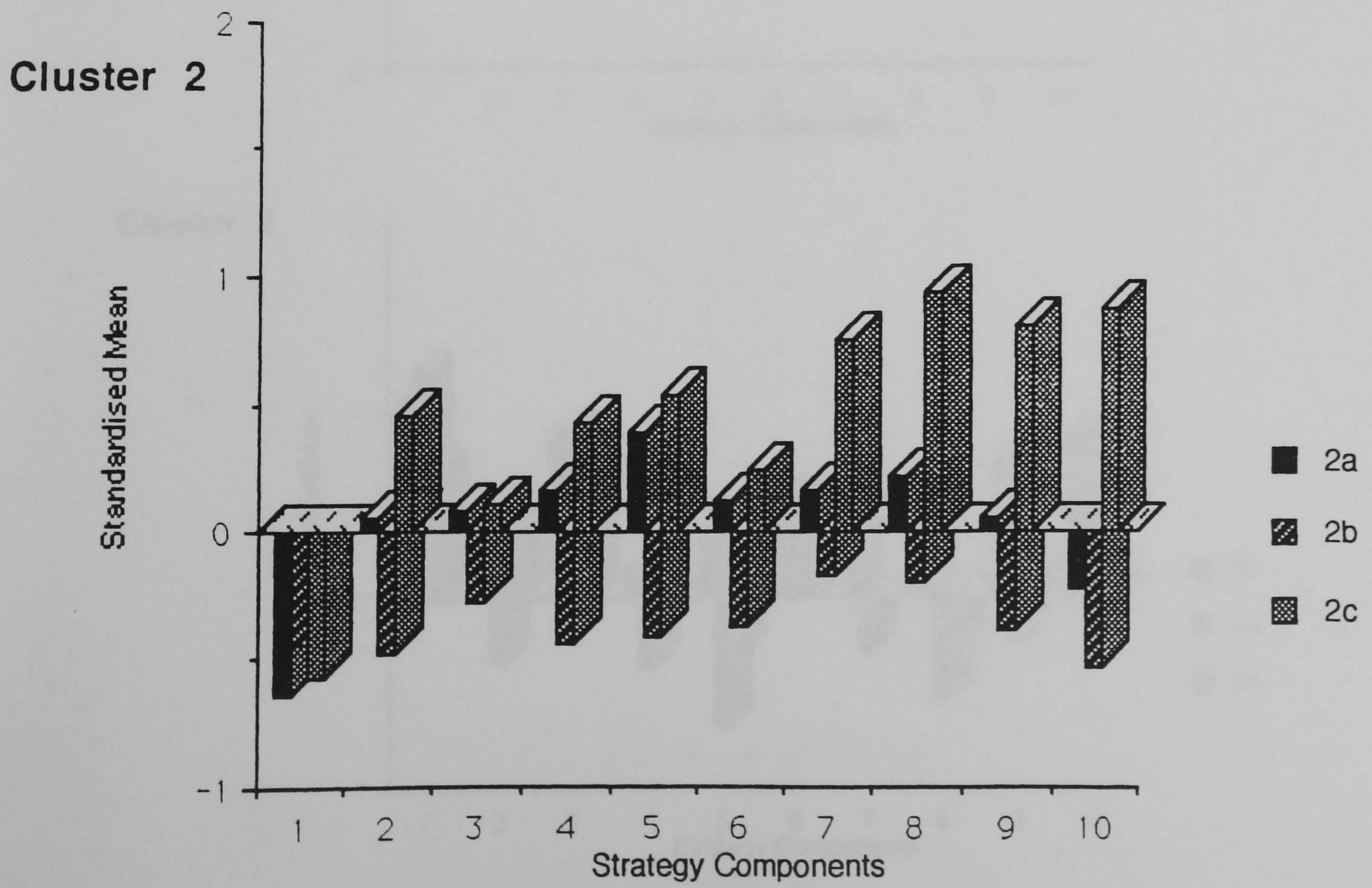


Figure 5.3 cont'd

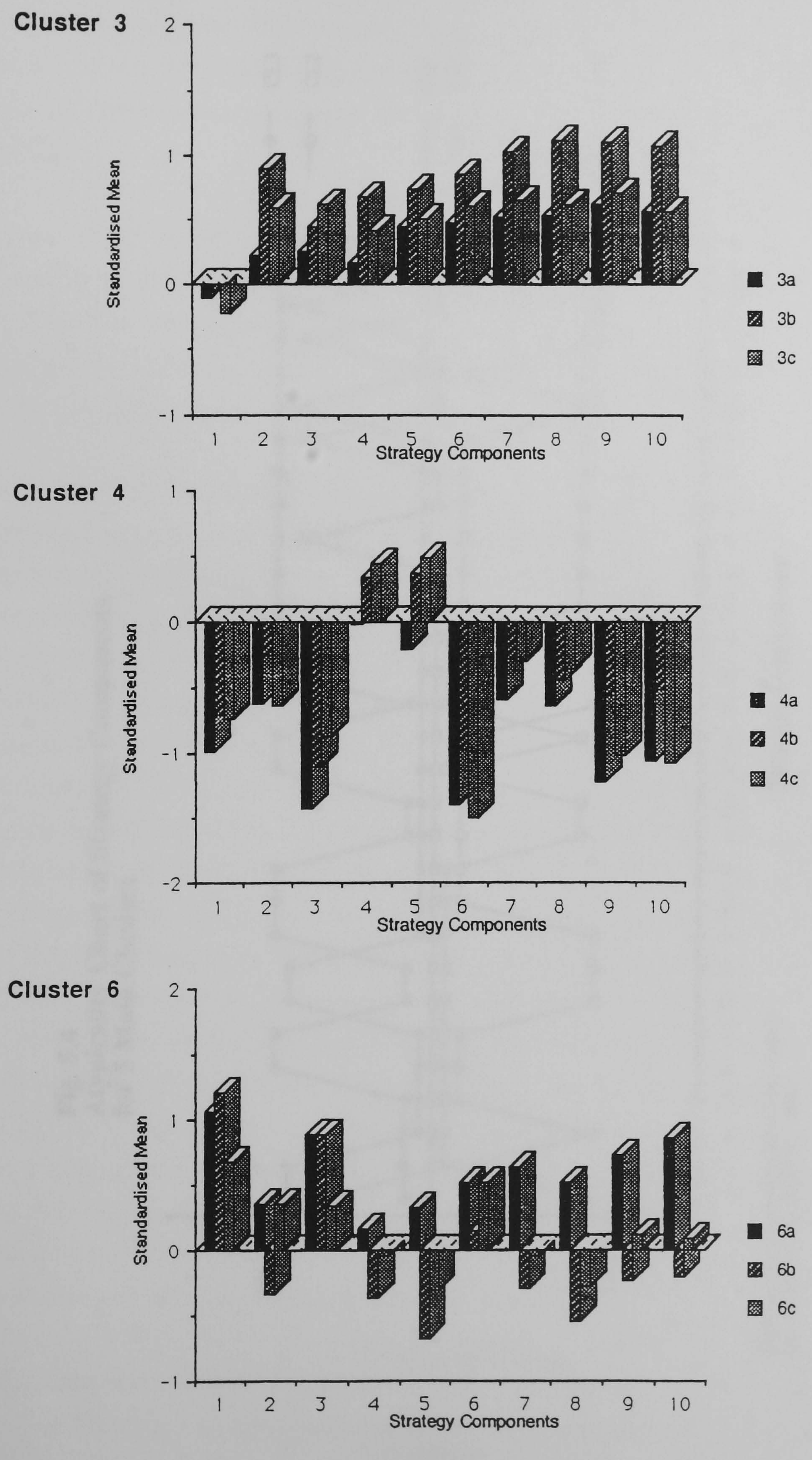
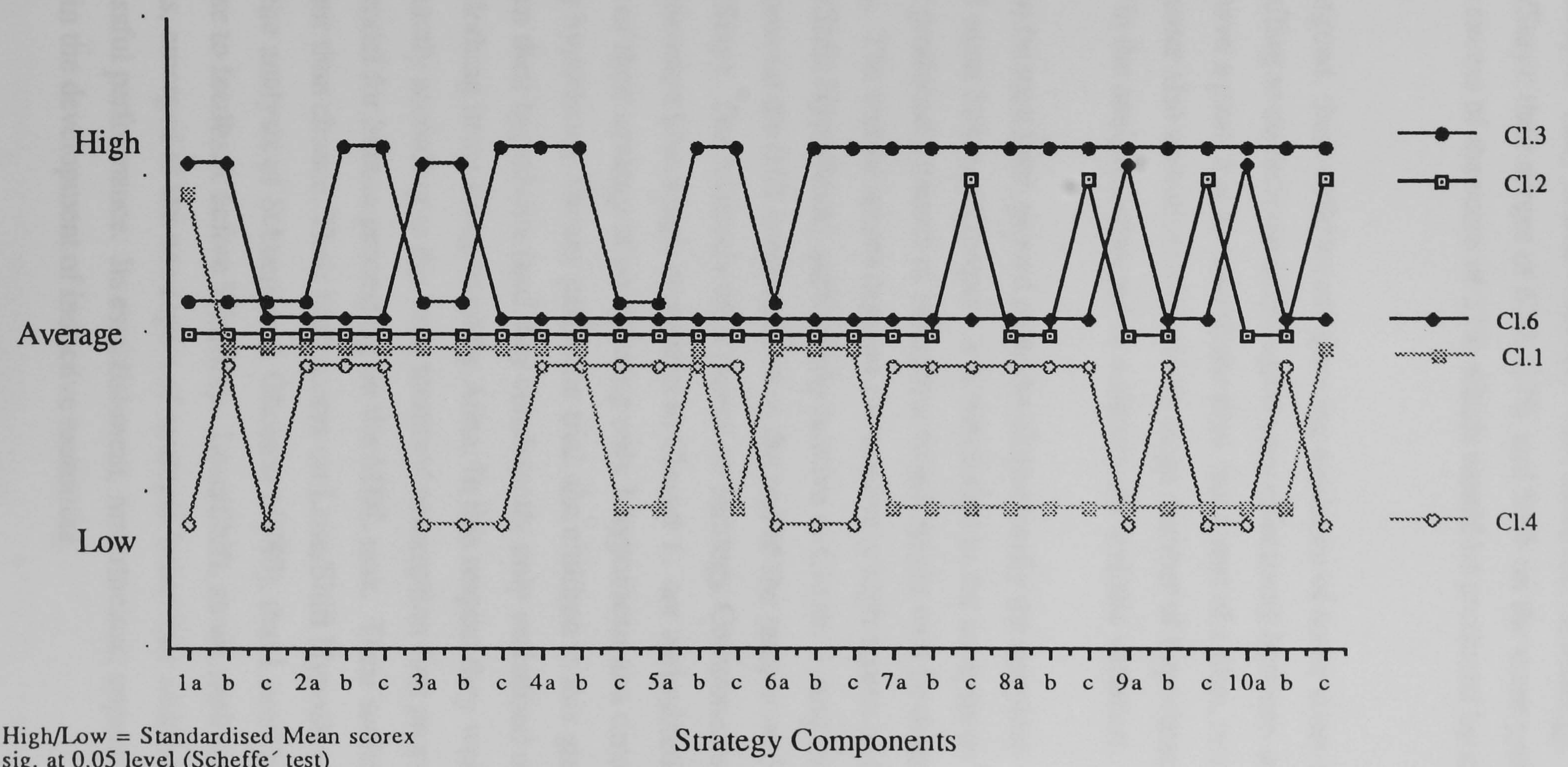


Fig. 5.4
Atypicality Chart of Strategy Components for 5 Main Clusters



High/Low = Standardised Mean scorex sig. at 0.05 level (Scheffe´ test)

(Lose/Shift Dimension). As can be seen from Table 5.6, on two out of the three problem types, Cluster 1 scored significantly lower (at the 0.01 level) on this component than the rest of the sample. They scored relatively well, however, on Strategy Component 6 (Win/Stay); their scores of 67%, 37% and 55% on the three problem types are all well in excess of the score of 25% which would be produced by chance responding.

As Kemler (1978) argued, these children are showing evidence of some short-term efficiency, but are failing to co-ordinate information very effectively between trials. They do, however, have a plan; it is an inadequate plan, but a sort of a plan, nevertheless. Interestingly, this cluster also verbalised a relatively large number of hypotheses, which, as will be seen later in the analysis, emerged as a significant stylistic variation.

Cluster 4, as will also be seen later, proved to be developmentally the simplest strategically of the 5 main Strategy Clusters. It is concluded in the analysis in Table 5.6a that this cluster produced a pattern of behaviour which might well be described as 'stimulus describing'. The crucial scores here are the relatively high scores on Strategy Component 4 (Lose/Shift Hypothesis), particularly relative to Cluster 1, and the significantly low scores (at the 0.01 level) relative to the rest of the sample on Strategy Component 6 (Win/Stay). The relatively high scores on Strategy Components 7 and 8 (Hypothesis and Dimension Checking), compared to Cluster 1, are undoubtedly an artificial by-product of their strategy of considering only 1 hypothesis at a time and constantly switching hypotheses. On any particular trial, the children in this group appear to have chosen their hypothesis (and they consistently only verbalised one) at random from the 4 clothing items being worn by Anna. In this respect they were actually behaving exactly according to the 'zero memory' assumption first proposed by Restle (1962) as a model for human processing on the MDL task. Their scores on Win/Stay are no better than chance. Their high scores on Lose/Shift Hypothesis suggest support for the analysis of Schuepfer & Gholson (1980), that Lose/Shift emerges as a response to feedback before Win/Stay. Lose/Shift, as we shall see later in the analysis of results, emerged as the one aspect of strategic behaviour which bore no relationship to successful performance. Its establishment, nevertheless, appears to be a necessary early step in the development of inductive reasoning.

The next cluster developmentally appears to be Cluster 2. The bar chart of standardised scores in Fig. 5.3 reveals a mixed pattern of scores above and below the sample mean, and the atypicality chart in Fig. 5.4. shows an overwhelming preponderance of average scores, with just a few significantly above average. The analysis in Table 5.6a records that this group was largely composed of 8 yr. olds, and that the main distinguishing feature of their pattern of behaviour was relative difficulty with type b problems (negative information). Compared to Cluster 6, however, they performed well on type c problems (irrelevant information). As we have argued above, this suggests that these two sources of difficulty are related to different cognitive deficits. It will be interesting when we come to examine the relationships between underlying cognitive factors and performance with Strategy Clusters to compare the patterns of relationships within Clusters 2 and 6. This may help to interpret the nature of their different difficulties with the MDL task. Cluster 2 children produced a relatively low number of hypotheses per trial.

Cluster 6 also showed a mixed pattern of behaviour. As is recorded in Table 5.6a, this was a predominantly 10 yr. old group, and in some ways the pattern of behaviour was more advanced than that of Cluster 2. The scores reported in Table 5.6 for Strategy Component 3 (Choices consistent with Previous Hypotheses), and 9 &10 (Focusing) are all significantly above the sample mean, and indicate planfulness and long-term efficiency. This cluster also had their difficulties with problem type b (negative information), but, perhaps most interestingly, scored lower than Cluster 2 on problem type c. Their relative difficulties with irrelevant information may well be connected to the other key distinguishing feature of this cluster, which was the high number of hypotheses verbalised per trial (Strategy Component 1). As can be seen in Table 5.6, this cluster produced significantly more hypotheses per trial (at the 0.01 level for problem types a & b) than the rest of the sample. They produced their largest number of hypotheses, however, on problem type c. Scores on Strategy Component 1, as we have already indicated, emerged as pivotal in distinguishing different strategic styles of approach to the MDL task.

Cluster 3 emerged as clearly the most sophisticated strategically, and has been characterised in Table 5.6a as the 'focusing ' group. Examination of Figs. 5.3 and 5.4 reveals that this group of children scored at levels significantly above the mean for the sample; this is particularly the case, as noted in the analysis in Table 5.6a, on the more long-term Strategy Components. What is perhaps most notable of all is the way that this group maintained their high level of performance on type b and c problems. Thus, as reported in Table 5.6, while Cluster 6 scored 84% on Strategy Component 10

(Focusing over All Trials) for problem type a, this figure fell to 39% and 48% for problem types b and c. The equivalent scores for Cluster 3 on problem types a, b and c were 76%, 72% and 63%. It is also of interest that this group produced a number of hypotheses per trial intermediate between the low of 1.00 and 1.20 recorded by Clusters 4 and 2, and the high of over 2.00 recorded by Clusters 1 and 6.

The mostly 8 & 10 yr. old children in this group were producing a level of strategic sophistication which Kemler (1978) failed to find with Primary aged children. Some children in this group produced 'perfect processing' on a number of problems, and, as we will see, there were 'ceiling effects' in some areas of the results of the study as a consequence. What is particularly striking is that this group included 4 children who were just 6 yrs. of age.

The different patterns of strategic behaviour represented by the 5 main clusters are now further explored by examining in more detail the strategic behaviour of the 5 most central cases in each of these clusters. This is followed by a Discriminant Function Analysis of the Strategy Component scores of the 5 main clusters, as a means of investigating the relationships between the various cluster groups.

b) Description of Central Cases in each Strategy Cluster

As a further method of investigating the qualities of the different strategic patterns identified by the Cluster Analysis the 5 most central cases within each cluster were selected for more detailed study.

These can easily be identified by reference to the table of Case-Cluster Similarity Coefficients reproduced in Appendix H.1. The cases with the lowest coefficients are those most similar to the cluster centroids. Thus the cases identified for each cluster are as follows:

Cluster	Cases
1	5,6,15,19,42
2	13,26,37,51,58
3	36,43,46,56,64
4	10,12,24,47,68
6	39,44,59,69,71

In Table 5.7 the pattern of scores is recorded for each of these cases on each of the 30 Strategy variables, according to whether they were High, Average or Low relative to the sample mean. For this purpose these categories are defined thus:

High = > Mean + $^1/_2$ S.D.
Average = < Mean + $^1/_2$ S.D. and > Mean - $^1/_2$ S.D.
Low = < Mean - $^1/_2$ S.D.

The raw means, standard deviations and figures for Mean + $^1/_2$ S.D. and Mean - $^1/_2$ S.D. for the whole sample, used to produce these results, are reproduced in Appendix H.2.

Examination of the scores of these Central Cases serves to reinforce aspects of the analysis of clusters based on overall means; in particular, it can serve to highlight those variables upon which Central Cases are strongly consistent, as opposed to those variables where even the Central Cases show some variation. This will help to enhance interpretation of the essental nature and characteristics of particular clusters.

Thus, in the present case, to begin with, the relative positions of the 5 main clusters, so clearly illustrated in the bar charts and atypicality chart in the previous section, is clearly reinforced. The central cases of Cluster 3, which exhibited the strongest, most sophisticated pattern of strategic behaviour (focusing), score average or high in every case on all Strategy Components except for some low scores on No. of Hypotheses per

Table 5.7
5 Main Strategy Clusters: Strategy Component scores of Central Cases

	Strategy Component/Problem Type																													
	1			2			3			4			5			6			7			8			9			10		
Case	a	b	c	a	b	c	a	b	c	a	b	c	a	b	c	a	b	c	a	b	c	a	b	c	a	b	c	a	b	c
Cl. 1																														
5	H	L	L	H	L	L	A	L	L	H	A	A	L	A	A	A	L	L	L	L	L	L	L	L	L	L	L	L	L	L
6	A	A	L	A	L	L	A	L	L	H	A	L	L	L	A	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L
15	H	A	H	H	L	L	H	L	A	H	A	L	A	A	L	A	L	L	A	L	L	L	L	L	L	L	L	L	L	L
19	H	A	L	A	L	L	H	A	A	L	L	L	L	L	L	A	L	H	L	L	L	L	L	L	A	L	L	A	L	L
42	A	A	H	A	L	A	A	A	A	H	L	L	L	L	L	A	A	A	L	L	A	L	L	L	A	L	A	L	A	A
Cl.2																														
13	L	A	L	A	A	A	A	L	A	H	L	A	H	L	H	A	A	A	A	L	A	A	L	H	A	A	A	A	A	A
26	A	L	L	H	A	H	A	A	A	H	A	H	H	A	L	A	A	H	A	A	A	A	A	A	L	A	H	L	L	A
37	L	L	L	H	L	A	H	L	A	H	H	H	H	H	H	H	L	L	H	A	H	H	A	H	H	L	A	H	L	A
51	A	A	A	H	A	A	A	A	A	H	L	H	A	L	H	H	L	A	A	A	H	A	A	H	A	A	H	A	H	H
58	A	H	H	H	L	A	L	H	L	H	L	H	H	L	A	H	A	H	A	A	H	A	A	H	H	A	H	A	A	H
Cl.3																														
36	L	A	A	H	H	H	H	H	H	H	H	H	A	H	A	A	A	H	A	H	H	A	H	A	H	H	H	A	A	H
43	A	A	A	H	H	H	H	A	H	H	H	H	H	H	A	H	H	H	H	H	A	H	H	A	H	H	H	H	H	H
46	H	H	H	H	H	H	H	A	H	H	H	H	A	H	A	A	H	A	H	A	A	H	A	A	H	H	A	H	H	A
56	L	L	L	H	H	H	A	A	H	H	H	H	A	H	H	H	H	H	A	H	H	A	H	H	A	H	H	A	H	H
64	H	A	A	H	H	H	H	A	H	H	H	H	H	H	H	H	A	A	H	A	A	H	A	A	H	H	H	H	H	H
Cl.4																														
10	L	L	L	L	A	L	L	L	L	H	H	H	H	A	H	L	L	L	L	A	A	L	L	A	L	L	L	L	L	L
12	L	L	L	H	A	A	A	L	A	H	L	A	A	A	A	L	L	L	A	A	A	A	L	L	L	A	L	L	A	L
24	L	L	L	A	A	L	L	L	L	H	H	H	A	A	H	L	L	L	L	A	L	L	A	L	L	A	L	L	A	L
47	L	L	L	A	A	A	L	L	A	H	A	A	H	A	A	A	L	L	L	A	A	L	A	A	L	L	L	L	A	L
68	L	L	L	H	L	L	L	L	A	H	H	H	L	H	H	L	L	L	L	A	A	L	L	A	L	L	L	L	L	L
Cl.6																														
39	H	H	H	H	A	A	H	H	A	H	A	A	H	A	A	H	H	A	H	A	A	H	A	H	H	A	H	H	H	H
44	H	H	H	H	H	H	H	H	H	H	H	H	A	L	A	A	H	H	A	H	A	A	L	A	A	A	A	A	A	A
59	H	H	H	H	A	L	H	H	H	H	L	L	H	A	A	A	H	H	H	A	A	H	H	A	H	H	A	A	A	A
69	H	A	A	H	L	H	H	A	A	H	A	H	A	A	A	A	A	A	H	L	A	A	L	L	A	L	A	H	L	A
71	H	A	A	H	L	H	H	H	L	H	A	H	H	A	L	A	A	A	H	A	H	H	A	A	H	L	A	H	L	A

H = High (> M+1/2S.D.) A = Average (< M+1/2S.D. & > M-1/2S.D.) L = Low (< M-1/2S.D.)

trial, which is in a rather different category to all the other components as an average score is probably reflective of the most sophisticated response. This cluster is the only one with no low scores on the more long-term, sophiticated Strategy Components 7-10. Clusters 1 & 4, clearly the weakest groups, exhibit a preponderance of low scores amongst their central cases, particularly on the more sophisticated, long-term Strategy Components. On the highly significant Strategy Component 6 (Win/Stay) and on the more long-term Strategy Components 7-10, the central cases in these two clusters do not score once above average. The central cases of the two intermediate Clusters 2 & 6 present the kind of mixed picture of high, average and low scores throughout the full range of Strategy Components which we would predict.

For Cluster 3 the other point of interest is the varability in pattern of scores on Strategy Component 1. While the cluster mean, as we have noted earlier, suggests that children in this group produce an average number of Hypotheses per trial, in fact, the central cases tell a different story. Here we have case 46 producing high numbers of Hypotheses, case 56 low numbers, and the other somewhere in between. It would, therefore seem that producing an average number of Hypotheses is not an essential element of this pattern of strategic performance.

The pattern of scores on Strategic Component 1 is, however, clearly indicative of a strong element in the strategic behaviour of children in Cluster 4. All 5 central cases scored low for each problem type on this component. This Cluster is also distinguished by a noticably low profile of scores on Strategy Component 6 (Win/Stay); only one of the central cases scores is other than low. This may well directly result, as we have suggested above, in their relatively good showing on Strategy Components 7 & 8 (Hypothesis & Dimension Checking) compared to the other generally weak Cluster 1. These scores, however, would appear to be an artificial consequence of a very weak strategy of simply 'reading off' an Hypothesis after each trial, with little or no co-ordination of information between trials. We have discussed the significance of the Win/Stay component for the development of a strategic approach to the MDL task in our earlier review of previous work on this task, and the pattern exhibited by Cluster 4 supports this view.

Between the two intermediate Clusters 2 & 6 Strategy Component 1 also distinguishes clearly; the predominant strong pattern here amongst the central cases is the high scoring of cases in Cluster 6, which picks it out from all the other clusters (although even here there are two rather different patterns between Cases 39, 44 & 59, who produced a high number of Hypotheses on all problem types, and Cases 69 & 71 who were only average on type b & c problems). There is also some support for the analysis suggested by looking at cluster means that Cluster 2 were distinguished by difficulties with type b problems (negative information). On Strategy Components 2-10 the central cases score high on only 4 occasions out of 45 scores (as opposed to 22 on both type a and type c problems). Cluster 6 score 32 highs on type a problems, 13 highs on type b problems and 14 highs on type c problems, all of which confirms the relative strengths of these two clusters on the different problem types. As we discussed above, Cluster 6 would seem to be generally stronger than Cluster 2; the former's relatively poor scores on type c problems (noise/ irrelevant information) may be a consequence of their tendency to produce high numbers of Hypotheses, which may be a damaging strategy for this type of problem.

Analysis of the Strategy Clusters by examining mean scores on the Strategy Components, and the pattern of strategic behaviour of central cases within the clusters, has suggested a developmental pattern from relatively weak to stronger strategic responses. There also appear to be possible stylistic variations. These two conjectures were further examined using Discriminant Function Analysis, as reported in the next section.

iv) Discriminant Function Analysis of 5 Main Clusters

Discriminant Function Analysis was carried out on the 5 main clusters to explore the essential factors distinguishing between these different patterns of strategic behaviour on the MDL task.

The Function/Strategy Component correlations are reported in Table 5.8. As can be seen from an inspection of that table, the analysis extracted 4 Functions, 3 of which accounted for a sig. percentage of the variance. An interpretation of the functions was carried out as follows:

Function 1: this function accounts for 61.32% of the variance and loads heavily on Strategy Components 3(Choices cons. with prev. H), 6(Win Stay), 7 & 8(H & D Checking) and 9 &10(Focusing). As such it may be interpreted as reflecting the developing ability to integrate new with previously received information. The key role of the Win/Stay component in the development of strategies on the MDL task has already been noted, and this is reinforced here.

Function 2: this function accounts for 26.56% of the variance; it loads negatively on Strategy Component 1(Number of Hs per T) and positively on components 4c(Lose/Shift H: noise), 5(Lose/Shift D) and 7 & 8(H & D Checking). This would appear to reflect a style variation or dimension essentially involving preference for a low or high number of verbalised hypotheses.

Function 3: this function accounts for 8.10% of the variance and is difficult to interpret because of the very few Strategy Components upon which it loads at all significantly. It appears to discriminate between Clusters 1 & 2 and all the other clusters. Beyond the fact that these clusters follow on from one another on the developmental sequence, and therefore score fairly similarly on some of the strategic components, it is difficult to assign any particular significance to this function.

Function 4: this function is not statistically significant (p= 0.0948) and accounts for only 4.02% of the variance. It is interesting, however, that it loads negatively at around the -0.4 level on 8 out of 9 of components 2-10 on type b problems (negative information).

Table 5.8

Discriminant Function Analysis of 30 Strategy Components: Function/Strategy Component Correlations

Strat Comp	Prob Type	Functions 1	2	3	4
1 H's per T	a	26	**-77**	08	07
	b	33	-45	32	32
	c	17	**-72**	07	06
2 H cons/local Feedback	a	35	-27	-13	05
	b	45	30	21	**-48**
	c	57	12	-05	18
3 Choice cons/ previous H	a	**60**	-41	-10	28
	b	**62**	-31	15	12
	c	**63**	-03	-04	01
4 Lose/Shift H	a	30	-04	-09	12
	b	17	36	28	-43
	c	14	56	17	10
5 Lose/Shift D	a	45	41	26	34
	b	14	43	20	-53
	c	17	**69**	16	08
6 Win/Stay	a	**67**	-23	-14	13
	b	**67**	00	09	-27
	c	**77**	-15	-15	16
7 H Checking	a	**61**	23	31	33
	b	57	49	24	-31
	c	50	52	-02	22
8 D Checking	a	**61**	26	25	30
	b	58	44	07	48
	c	46	56	-16	20
9 Focusing/ 2 T's	a	**79**	-06	11	22
	b	**65**	33	20	-42
	c	**70**	24	-25	22
10 Focusing/ All T's	a	**73**	-11	28	19
	b	**60**	26	22	-48
	c	**62**	18	-33	26
	%Variance	61.32	26.56	8.10	4.02
	p	< 0.01	< 0.01	< 0.01	N.S.

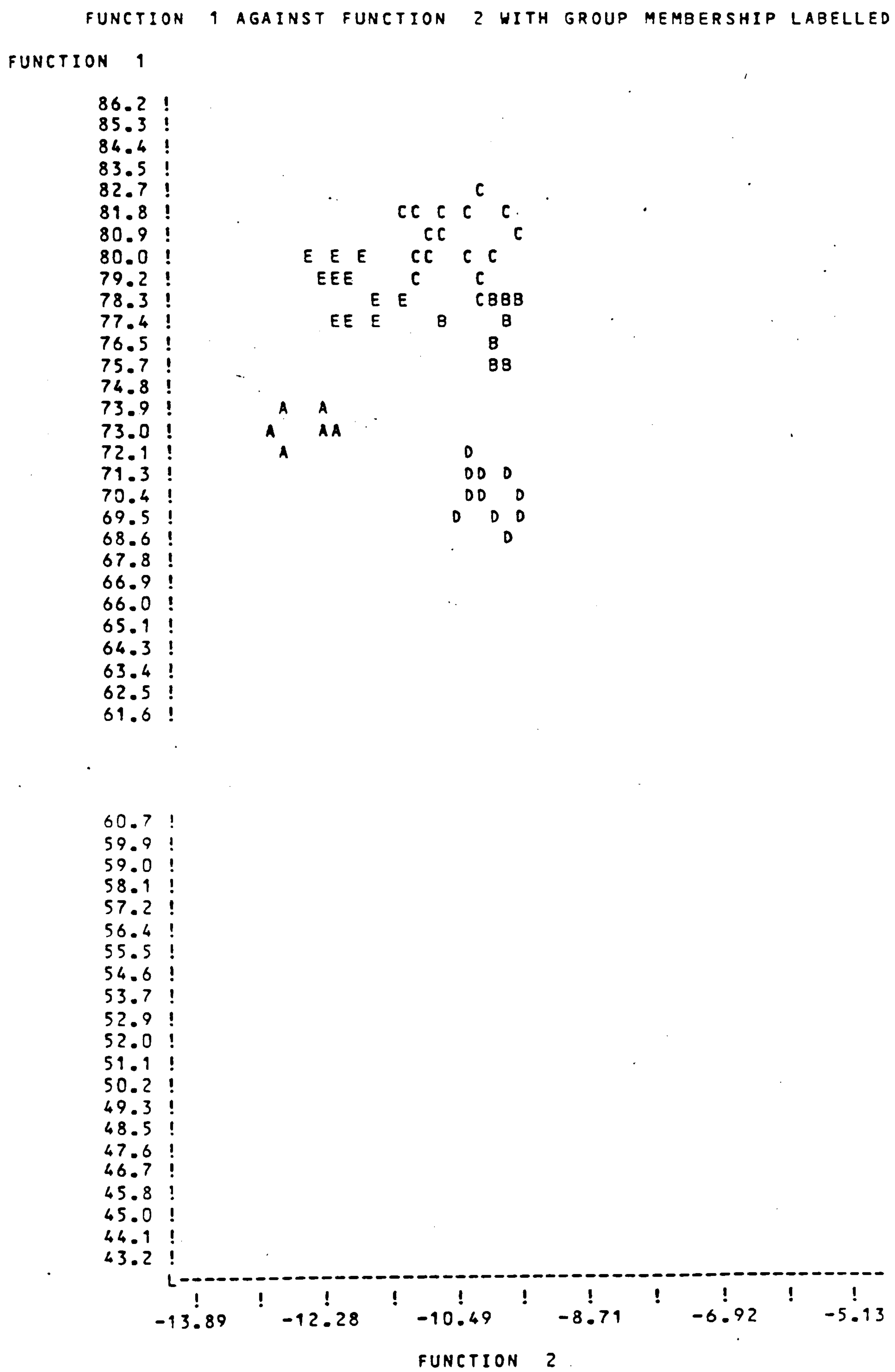
Correlations > 60 in bold

Correlations > 30 underlined

The loadings of individual cases in the 5 main clusters on Function 1 and Function 2 (the two main functions which together account for 87.88% of the variance) are displayed on the scatterplot presented in Fig. 5.5. From this it can be seen that the 5

Fig 5.5

Discriminant Function Analysis: scatterplot of individual loadings on Functions 1 & 2



A = Cluster 1, B = Cluster 2, C = Cluster 3, D = Cluster 4, E = Cluster 6 main Strategy clusters separate out well, and would seem to represent distinctive patterns of strategic behaviour. This is further validation of the structure of Strategy Clusters identified.

It also lends support to an analysis which suggests that there emerges from the present results both a developmental sequence of strategic behaviour on the MDL task, and a stylistic variation centred around the number of Hypotheses verbalised by children on each trial.

Group centroids for each of the 5 main clusters on these Functions are reported in Table 5.9.

Table 5.9
Discriminant Function Analysis: centroids for 5 Main Clusters

		Functions		
Cluster	1	2	3	4
1	72.96	-12.45	-15.64	-7.49
2	76.45	-9.97	-15.87	-6.39
3	80.33	-10.37	-14.46	-7.55
4	70.24	-9.97	-13.70	-7.17
6	78.17	-11.89	-13.50	-6.47

These cluster centroids, associated with the analysis of Function/Strategy Component correlations, support the following analysis:

- Development of strategic behaviour: the scores of the 5 main clusters on Function 1 suggest a developmental sequence of strategic behaviour on the MDL task. From simplest to most complex strategy pattern this developmental sequence runs through the clusters in the order 4 (High/Random Shift of Hypotheses), 1 (Attribute/Dimension Perseveration), 2 (Negative Information Difficulties), 6 (High Hypotheses per Trial), 3 (Focusing), as demonstrated by Table 5.9a.

Table 5.9a
Discriminant Function Analysis: centroids for 5 Main Clusters on Function 1 in ascending order

Cluster	Score/F 1
4 (High/Random Shift of Hypotheses)	70.24
1 (Attribute/Dimension Perseveration)	72.96
2 (Negative Information Difficulties)	76.45
6 (High Hypotheses per Trial)	78.17
3 (Focusing)	80.33

While clusters 5 and 7 are two small to have formed part of the DSFN analysis it is also interesting to note their mean scores on Function 1. Cluster 5 (Case 16) scores 44.56, clearly placing this pattern of behaviour (Object Preference) at the simplest developmental level of all cases within the present sample. Cluster 7 (Cases 25,35 & 70) scores 76.07, which places this pattern (Noise Difficulties) on a par with Cluster 2.

- Strategic Style: the scores of the 5 main clusters on Function 2 suggest a variation in strategic style principally associated with the number of hypotheses verbalised per trial. Thus it can be seen that at both the 'weak' and 'intermediate' levels of strategic development there is a low and a high H's per T variant, while at the level of focusing an intermediate (and more accurate) level is evident, as illustrated by Table 5.9b.

While the mean H's per T for Cluster 3 may suggest an intermediate number was produced by the children in this cluster, however, it will be recalled that the analysis of the 5 most central cases has suggested that this mean may be to some extent misleading. Some central Cluster 3 individuals had High, and some Low, No. of Hypotheses per Trial scores. The figures for Standard Deviation also reported in Table 5.9b tend to give some support to this picture. It can be seen that the S.D. for Cluster 3 is the largest for any of the clusters, particularly when it is viewed as a proportion of the mean number of hypotheses produced.

Table 5.9b

Discriminant Function Analysis: centroids for 5 Main Clusters on Function 2 related to Mean Hypotheses per trial

Strategic level	Cluster	Score/F2	Mean H's per T	S.D H's per T	S.D.as a % of Mean
Weak	4	-9.97	1.03	0.07	7.0
	1	-12.45	2.02	0.50	24.8
Intermediate	2	-9.97	1.20	0.30	25.0
	6	-11.89	2.32	0.28	12.1
Strong	3	-10.36	1.51	0.50	33.3

It is perhaps interesting to note that on Function 2 Cluster 5 (Object Preference) scores -5.21 and Cluster 7 (Noise Difficulties) scores -12.09.

The scatterplot of Function 1 against Function 2 (Fig. 5.5) shows the 5 main clusters to be tightly grouped, and illustrates clearly the relationship of each of the clusters to the development of efficient, strategic processing (Function 1) and strategic style (Function 2). This evidence, together with consideration of Strategy Cluster mean ages, suggests a developmental pattern including two alternative routes, based upon strategic style, rather than one universal developmental route. The mean ages for each of the 5 main clusters, by strategic styles, is presented in Table 5.10.

Table 5.10

Strategy Cluster Mean ages related to scores on Strategy Component 1(No. of Hypotheses per trial)

High H's per T

Cluster 1: 7.23 yrs.

Cluster 6: 9.75 yrs.

Low H's per T

Cluster 4: 7.09 yrs.

Cluster 2: 8.68 yrs.

Intermediate H's per T

Cluster 3: 8.79 yrs.

This pattern again suggests that the sequence of development for individual children may not be through the whole sequence of increasingly more complex strategic patterns of behaviour, but may rather tend to follow one of two stylistic routes. In relation to the MDL task these stylistic alternatives manifest themselves in the number of hypotheses the child tends to produce (and, arguably, consider) on each trial.

The age-group patterning shown above further tends to suggest that, for this particular type of problem-solving, the cognitive style associated with producing a low number of hypotheses is the more effective and leads to children achieving Cluster 3 type strategic behaviour at a younger age than the high H's per T style. Thus, the mean age for Cluster 6 is actually older than for Cluster 3. This might be taken to suggest that most of the children in Cluster 3 in this sample have come through the low H's per T route, although the evidence from the examination of central cases, and the S.D. for No. of H's per T for Cluster 3, did identify the possibility of some high H's per T children being already in Cluster 3. A tally of the children in Cluster 3 in relation to their ages and their individual mean No. of H's per T, furthermore, revealed that only one out of the four 6 yr. olds and two out of the eight 8 yr.olds had above average scores for the cluster, while this was the case for five out of the eight 10 yr. olds. This would also fit into a model that suggested that children with High H's per T may tend to have followed a route through Clusters 1 and 6 and arrived in Cluster 3 at a relatively late stage. To find more children with a high H's per T route who have successfully moved into a Cluster 3 type of strategic pattern, we may have to sample older children than are included in the present study. Certainly, the transition from Cluster 1 to Cluster 6 appears to occur at a later age than that between Cluster 4 and 2, if these are indeed alternative developmental routes.

Determining complex developmental routes such as is suggested by the present data is, of course, difficult within a cross-sectional study of this type. This is an issue which we shall return to in later parts of the analysis of results (for example, when we come to consider the relationship between strategy and performance scores in the next section, and when we come to consider the underlying cognitive abilities and qualities of the children in each of the Strategy clusters). We shall also want to return to it within the discussion of methodological issues.

Section C) Relationships between Strategies and Performance

i) Performance Indicators

a) Correlations between Performance Indicators

As discussed in the previous section, indicators of performance on the MDL task were selected on the basis of features of performance which have been highlighted and explored in the literature. Subjects were, therefore, scored on the trial of their last error, the accuracy with which they verbalised the correct hypothesis during the criterion trials, and the extent to which the number of hypotheses they produced on Trials 1,2 & 3 matched the actual number of 'live' hypotheses on each of these trials.

If we are to use these three indicators of performance it is first worth establishing whether they are indeed measuring separate aspects of performance, as suggested by the literature, or whether they appear, on this occasion, to be simply different ways of measuring the same general competence. This can most easily be explored by means of a correlation analysis between the Performance Indicators for the scores of the whole sample, as reported in Table 5.11.

While a lot of the correlations in this matrix are statistically significant, showing that there are clear relations between at least some of these Performance Indicators, it is important to recognise the true strength of these relationships. The matrix reveals 37 weak correlations (less than + or - .40), 20 in the middle range (between + or - .40 and .70) and only 7 which are relatively strong (more than .70). Most of the weak correlations relate to scores for Learning, and it is clear that improvement in performance between Rounds 1 & 2 is quite unrelated to overall performance on the other indicators.

Scores for Hypotheses on Trials 1,2 & 3 are also only weakly or moderately related to the other two indicators. The highest correlation with any of the scores on the other indicators is .51 (accounting for only just over 25% of the variance). The relatively weak relationships between this indicator and the other indicators may well be a product of the variation in strategic style related to the overall number of hypotheses per trial revealed

Table 5.11

Correlations between Performance Indicators

		Trial of Last Error a	b	c	L	Verb. of Hypothesis a	b	c	L	H's on T's 1,2 & 3 a	b	c	L
Trial of Last Error	a												
	b	**55**											
	c	**67**	**70**										
	L	06	-01	07									
Verb. of Hypothesis	a	**79**	**69**	**69**	07								
	b	**59**	**85**	**73**	02	**73**							
	c	**65**	**70**	**86**	11	**74**	**79**						
	L	04	03	14	**57**	07	01	05					
H's on T's 1,2 & 3	a	**51**	**42**	**51**	-05	**44**	**40**	**43**	00				
	b	**40**	**40**	**48**	-18	**42**	**38**	**35**	-03	**68**			
	c	12	15	13	02	13	25	24	04	13	10		
	L	15	16	22	-02	15	16	21	03	22	19	17	

Bold = sig. at 0.01 level
Underlined = sig. at 0.05 level

by the Discriminant Function Analysis earlier. Correlations for scores on H's on T's 1,2 & 3 between type c problems and the other two indicators are notably weak. Clearly the presence of redundant information has markedly affected the sample's ability to verbalise the correct number of hypotheses on these trials, and in a way that is largely unrelated to general performance levels. This would not seem to support the view expressed by some researchers, as we have reviewed in chapter 3, that inhibitory abilities (i.e. the ability to inhibit the effects of irrelevant information) are central to development of problem-solving performance on this kind of task.

The strongest relationship appears to be between scores for Trial of Last Error and Verbalisation of the Correct Hypothesis during the Criterion Trials. The correlations of scores on these two indicators for the three problem types are .79, .85 and .86. While this is an indication of a clear relationship between these two aspects of performance, the average correlation of .83 still only accounts for 69% of the variance. It seems worthwhile, therefore, to include both indicators in our subsequent analysis; we are particularly interested, for example, to explore any variation between Strategy Clusters in the relationship between these two aspects of performance. In our previous discussion of performance on the MDL task the possibility of a developmental sequence between the different aspects of performance measured by the different Performance Indicators has been suggested. The theoretical relationships between the ability to verbalise one's active hypothesis and various aspects of metacognitive functioning also make this an important area of performance to explore.

It is finally worth noting that the correlations between different problem types for each of the Performance Indicators are generally moderate but not very strong, varying mostly between .55 and .79 (at the most, accounting for little more than 50% of the variance). This is an indication that the problem type has implications for performance, as we would expect from the role played by problem type in the Cluster Analysis of strategic behaviour. Again, an interesting feature is the very weak correlations for scores on H's on T's 1,2 & 3 between type c problems and the other two problem types. Whether this is an effect which varies between different patterns of strategic behaviour may be seen when we examine the Performance scores for the Strategy Clusters a little later in the analysis

b) Performance scores for the three Age-groups and the Whole Sample

The scores on the three Performance Indicators for the three age-groups and the whole sample of 72 children are reported in Table 5.12. These indicate clear developmental trends, with scores on all three indicators improving from the 6 yr. olds to the 8 yr. olds, and again to the 10 yr. olds on all problem types.

Some support is offered in these figures for the suggestion that there might be a developmental sequence between different aspects of performance measured by the three Performance Indicators. The major gains in terms of Trial of Last Error (i.e. how quickly problems are solved) would appear to be between the 6 yr. olds and the 8 yr. olds. For all problem types the difference in means between the two youngest age-groups is 5.3 trials (roughly one S.D.), whereas the difference between the 8 yr. olds and the 10 yr. olds is only 1.6 trials. This picture is fairly accurately repeated for Verbalisation of Hypotheses. Here the differences are, respectively, 1.7 hypotheses (one S.D.) and 0.5 hypotheses. For both of these Performance Indicators the difference in scores between the 6 and 8 yr. olds is a little over 3 times that between the older two age-groups. However, for Hypotheses on Trials 1, 2 & 3 the picture changes. Here the

Table 5.12

Means and Standard Deviations for Performance Indicators by Age groups and Problem types and for Whole Sample

Age group	a Mean	S.D.	Problem type b Mean	S.D.	c Mean	S.D.	All Mean	S.D.	Learning Mean	S.D.
Trial of Last Error										
6 yrs.	8.9**	6.8	11.2**	6.6	11.3**	7.1	10.5**	5.6	1.5	7.7
8 yrs.	3.5	4.6	6.5	5.4	5.6	5.5	5.2	4.5	2.3	5.3
10 yrs.	2.8	5.0	4.9*	5.4	3.0**	4.8	3.6**	4.3	2.0	3.5
Whole sample	5.1	6.2	7.5	6.4	6.7	6.8	6.4	5.7	1.9	5.8
Verb of Hypothesis										
6 yrs.	2.1**	1.6	1.5**	1.9	1.8**	2.0	1.8**	1.7	0.6	1.5
8 yrs.	4.1	1.5	3.2	1.7	3.3	1.7	3.5	1.4	0.2	1.3
10 yrs.	4.2*	1.4	3.7**	1.6	4.1**	1.3	4.0**	1.3	0.5	0.9
Whole sample	3.5	1.8	2.8	2.0	3.1	1.9	3.1	1.7	0.5	1.3
Hs on Ts 1,2 & 3										
6 yrs.	3.1**	0.6	3.2*	0.5	2.9	0.9	3.1**	0.4	0.0	0.4
8 yrs.	3.6	0.9	3.4	0.7	2.9	0.9	3.3	0.6	0.2	0.6
10 yrs.	4.5**	1.3	4.1**	0.9	3.3	1.2	4.0**	0.8	0.6	1.1
Whole sample	3.7	1.1	3.6	0.8	3.0	1.0	3.5	0.7	0.3	0.8

Scheffe´ test (compares group mean to the mean of the rest)
Levels of sig: * = 0.05 level
** = 0.01 level

respective figures are 0.2 points for the younger groups and 0.7 points (one S.D.) for the older groups. In fact, the picture is exactly reversed. This indicates that the major gains in verbalising, and possibly processing, the optimum number of hypotheses on the first three trials of each MDL problem does not occur until the children are between 8 and 10 yrs. old.

There is further support for this conclusion from an analysis of the number of children in each age group who actually produced the perfect processing pattern of 4, 2 ,1 hypotheses on the first 3 trials. This is an analysis suggested by the study carried out by Phillips & Gholson (1980), which we have discussed earlier, in which a memory aid was used permanently displaying all 8 possible hypotheses and children were asked to indicate "which things could still be correct". They found, for their task, 4 out of 40 children aged 8 (10%) and 13 out of 40 children aged 11 (32.5%) who produced the perfect 4, 2, 1 pattern of hypotheses on at least one problem (out of 4). In the present study, with no memory aid, but with the task placed in a meaningful context, the figures were 2 out of 24 children aged 6 (8.3%), 4 out of 24 children aged 8 (16.7%) and 15 out of 24 children aged 10 (62.5%).

In relation to the developmental sequence of aspects of performance issue, the figures for both the present study and those of Phillips & Gholson (1980) reveal a major advance in performance after the age of 8. We will return to this issue again when we come to consider Performance scores for the Strategy Clusters, where more supportive evidence for a developmental sequence may also be found. A comparison of these two sets of figures also lends support to the view, however, that the performance on the MDL task is enhanced for young children when it is placed in a meaningful context. As we have argued earlier, children's reported memory difficulties with the MDL task are clearly at least in part a product of the abstract manner in which the task has most often been presented.

This view is also supported by comparison of the Trial of Last Error scores for the standard problem (type a) in the present study with those reported by Kemler (1978) and Phillips & Gholson (1980). The relative figures are reported in Table 5.12a. For the purposes of comparison, 3 has been deducted from the scores reported by Kemler (1978), since it is clear that she reported the total number of trials before the last error, including the first three trials which define the solution.

As can be seen from the figures reported in Table 5.12a, the results of the present study are very much in line with those reported by Phillips & Gholson (1980), as are Kemler's (1978) . It must be concluded that the advantages of the memory aid provided by Phillips and Gholson (1980) were cancelled out by the abstractness of the problem materials. That the results of the present study are so close to those of Kemler (1978), allowing for the difference in age groups and number of dimensions, also suggests that

Table 5.12a

Means for Trial of Last Error on standard problem in present study, Kemler (1978) and Phillips & Gholson (1980)

Present study		Kemler		Gholson & Phillips	
Age group	T of LE	Age group	T of LE	Age group	T of LE
6 yrs.	8.9	5 yrs.	12.1		
8 yrs.	3.5	7 yrs.	7.8 (5 dims)	8 yrs.	4.64
10 yrs.	2.8	11 yrs.	2.7 (5 dims)	11 yrs.	3.26

the attentional aid used by Kemler (1978) served no very useful purpose in the context of a meaningful task, as we had suspected. The case we have argued earlier, that young children's reported problems of attending to the correct stimulus in the MDL task have been a function of the abstract, meaningless nature of the task, rather than of children's control of their attention, would seem to be supported by this result.

The results also support the conclusion, predictable from previous findings discussed in chapter 3, that the problem types which involved processing negative information and ignoring irrelevant information were more difficult for the children than the standard problem. In all the figures there is only one case where a score on problem types b or c is at a higher level than that on problem type a (problem type b for 6 yr. olds on the Hs on Ts 1,2, & 3 indicator). It is interesting to note that the differences between the standard problem type and the other versions of the task appear to be generally smaller for the Hs per Ts 1,2 & 3 indicator than for the other two indicators. This may be related to it being the latest developing aspect of performance, as noted above, which would tend to depress scores on the standard problem.

It is notable that no significant differences appear between the age-groups for Learning (measured as the difference between the scores on the first and second problems of each type). It is possible that this apparent similarity may be masking two rather different effects. Many of the younger children may well not be in a position to learn about the task as a result of inadequate encoding. On the other hand some of the older children's performance may be subject to a ceiling effect, where their initial level of performance was so high that there was very little room for improvement. What is clear from the

S.D. figures is that there is very considerable variation within age-groups. It is clear that age is not a major determinant of the amount of improvement (or 'learning') between the first and second round of problems. Whether this kind of improvement on the MDL task is related to some other factor will emerge in the later parts of the analysis.

ii) Strategies and Performance

Having established and explored the pattern of development of the sample's problem-solving strategies on the MDL task, and having selected our Performance Indicators, it is important to establish that strategic development is related to improved performance. The existence of a clear relationship between strategic behaviour and performance will act as a kind of validation of the Strategy Clusters identified.

This relationship has been explored in three ways. First, by examining the correlations between Strategy and Performance scores for the whole sample. Second, by examining Performance scores for the Strategy Clusters; and third, by looking at the Performance profiles of the 5 most "central" cases in each of the clusters.

a) Correlations between Strategy Components and Performance Indicators

Table 5.13 contains correlations between the Total scores (i.e. on all three problem types) for the 10 Strategy Components and the Total and Learning scores for the 3 Performance Indicators.

This table provides evidence that there is a clear relationship between the strategy components identified and overall level of performance on the MDL task. The Total columns for the 3 Performance Indicators contain a large percentage of highly statistically significant positive correlations. Of these 8 come into the weak category (less than .40), 13 are moderate (between .40 and .70) and 10 are strong (more than .70).

When we look more closely it is particularly significant that all 10 of the strong correlations are for the 5 most sophisticated Strategy Components related to the Trial of Last Error and Verbalisation of Hypotheses scores. These 5 scores in relation to Hypotheses on Trials 1,2 & 3 are also all highly statistically significant in the moderate range. Clearly performance is strongly related to the use of these strategies. That a large proportion of the variance is not accounted for by simple linear relationships between particular Strategy Components and Performance Indicators is perhaps also an indication that an approach looking at patterns of strategic behaviour may be more fruitful.

As we would predict, performance is also clearly but less strongly related to the use of simpler strategies, with the notable exception of Lose/Shift. This is a particularly good example, in fact, of the need to look at patterns of strategic behaviour through some technique such as Cluster Analysis, rather than at just simple linear relationships. If we refer back to the earlier analysis of the Strategy Clusters, it will be recalled that Cluster

Table 5.13
Correlations between Strategy Components and Performance Indicators

	<u>Performance indicators</u>					
<u>Strategy Components</u>	Trial of Last Error		Verb. of Hypotheses		H's on T's 1,2 & 3	
	<u>Total</u>	<u>L</u>	<u>Total</u>	<u>L</u>	<u>Total</u>	<u>L</u>
1.H's per T	**42**	07	<u>28</u>	05	**50**	17
2.H cons/local Fback	**53**	-16	**56**	16	**35**	<u>25</u>
3.Ch. cons/ prev H	**68**	-23	**63**	14	**53**	<u>24</u>
4.Lose/Shift H	05	-02	11	-10	08	14
5.Lose/Shift D	22	-01	**30**	-11	<u>27</u>	06
6.Win/Stay	**81**	-17	**79**	**31**	**43**	13
7.H Checking	**75**	-07	**75**	02	**46**	10
8.D Checking	**70**	-10	**73**	05	**45**	09
9. Focusing/2 T's	**81**	-14	**86**	14	**54**	<u>26</u>
10.Focusing/All T's	**84**	-09	**87**	07	**61**	<u>27</u>

Bold = sig. at 0.01 level
<u>Underlined</u> = sig. at 0.05 level

4, which we have some indications is the least sophisticated group in terms of development of strategic behaviour, scored relatively highly on Lose/Shift. In the commentary upon this result we discussed possible interpretations of this phenomenon, from which we could predict that a simple linear correlation with performance on the MDL task would not be much in evidence. Thus, while Lose/Shift is an important component of a successful hypothesis-testing strategy on the MDL task, it can be the result of the child simply 'reading off' a locally consistent hypothesis on each different trial with no reference to information available from previous trials. The strategic behaviour of children in Cluster 4 appeared to contain this element.

When we were looking at the relationships between Performance Indicators we noted that Learning was apparently unrelated to overall level of performance. From this present table it is clear that it is also largely unrelated to overall level of strategic behaviour. It is interesting to note, however, that there is a weak association between improvement in the number of Hypotheses on Trials 1,2 & 3 and some Strategy Components, namely the relatively simple components of strategic behaviour concerned with local consistency (Components 2 & 3), and the more sophisticated components concerned with focusing (Components 9 & 10). Whether any stronger relationships exist between patterns of strategic behaviour and learning may emerge when we look at Performance related to Strategy Clusters in the next section.

Lastly, in relation to this table, it is necessary to comment upon the relation between overall number of Hypotheses per Trial (Component 1) and the Performance scores. The number of Hypotheses per Trial is a rather different kind of measure to the other Strategy Components. To produce more hypotheses is not in itself a direct measure of better strategy in the same way as a high score on the other Strategy Components might usually be interpreted (although there are exceptions e.g. the high score of Cluster 4 on Lose/Shift to which we have just referred). The number of Hypotheses produced is to some extent, as we have discussed earlier, a matter of style. We have also argued that for the MDL task a low H's per T style appears to lead to earlier development of more sophisticated strategies. Nevertheless, examination of the overall average H's per T scores for the two stylistic developmental routes (see Table 5.9b) reveals a gradual increase in number of H's per T through both which would account for the weak to moderate correlations produced between Strategy Component 1 and performance.

b) Performance Scores for Strategy Clusters

We have seen from the previous section that some simple linear relations exist between our measures of strategy and performance. However, it is clear that this is not an adequate method of describing the full nature of these relationships. Performance needs to be looked at in relation to the different patterns of strategic behaviour revealed by the Cluster Analysis. The patterns of these relationships is represented by the raw and standardised mean scores on the Performance Indicators for each of the 7 Strategy Clusters reported in Table 5.14.. These patterns are further illustrated by separate

Table 5.14

Raw and Standardised Mean Scores on the Performance Indicators for the Strategy Clusters

Perf Ind	Prob Type	F	p	1(10)	2(12)	3(20)	4(13)	5(1)	6(13)	7(3)
				Clusters						
T of	a	10.21	0.00**	-0.74	0.12	0.47	-1.10**	-0.80	0.73*	0.74
Last				*9.60*	*4.29*	*2.18*	*11.85*	*10.00*	*0.58*	*0.50*
Error	b	14.90	0.00**	-1.01**	-0.01	0.85**	-0.89**	-1.94	0.40	0.55
				14.05	*7.58*	*2.10*	*13.27*	*20.00*	*4.96*	*4.00*
	c	21.46	0.00**	-0.49	0.28	0.59**	-1.44**	-1.95	0.60*	0.88
				10.00	*4.75*	*2.63*	*16.50*	*20.00*	*2.58*	*0.67*
	L	2.95	0.013*	-0.26	0.86?	0.03	-0.59	0.83	-0.01	-0.47
				0.44	*6.86*	*2.13*	*-1.49*	*6.70*	*1.87*	*-0.77*
Verb	a	22.25	0.00**	-0.95**	0.21	0.76**	-1.29**	-0.56	0.50	0.84
of H				*1.80*	*3.87*	*4.85*	*1.19*	*2.50*	*4.38*	*5.00*
	b	17.84	0.00**	-0.96**	-0.04	0.91**	-1.03**	-1.45	0.36	0.69
				0.95	*2.75*	*4.60*	*0.81*	*0.00*	*3.54*	*4.17*
	c	16.29	0.00**	-0.55	0.33	0.70**	-1.34**	-1.58	0.50	0.05
				2.00	*3.71*	*4.42*	*0.46*	*0.00*	*4.04*	*3.17*
	L	2.54	0.028*	-0.37	0.60	0.05	-0.68	0.98	0.27	-0.02
				0.04	*0.30*	*0.05*	*-0.11*	*0.30*	*0.02*	*0.00*
H's on	a	9.28	0.00**	-0.40	-0.67	0.20	-0.67?	-0.67	1.15**	0.82
T1,2,3				*3.30*	*3.00*	*3.98*	*3.00*	*3.00*	*5.04*	*4.67*
	b	4.96	0.00**	-0.25	-0.52	0.27	-0.63	-0.67	0.59	1.55
				3.35	*3.13*	*3.78*	*3.04*	*3.00*	*4.04*	*4.83*
	c	7.37	0.00**	-1.02*	0.16	0.71**	0.03	-0.05	-0.08	-1.67?
				2.00	*3.21*	*3.78*	*3.08*	*3.00*	*2.96*	*1.33*
	L	1.51	0.19	0.03	-0.26	0.30	-0.43	-0.34	0.39	-0.75
				0.30	*0.06*	*0.51*	*-0.08*	*-0.00*	*0.59*	*-0.33*

Plain = Standardised score
Italic = Raw score

The significance of the variation of each standardised Cluster Mean from the population mean is tested using the Scheffe´ Atypicality test. The degree to which each Performance Indicator discriminates between Clusters overall is tested using one-way Analysis of Variance (F-ratio on left hand side of table) Levels of significance: ? = 0.1
* = 0.05
** = 0.01

The numbers in brackets after the Cluster numbers indicate the number of cases in each Cluster.

Standardised Mean bar charts for the 5 main clusters (Figure 5.6) and an Atypicality Chart (Figure 5.7), which compares all 5 main clusters.

Examination of the pattern of performance for the Strategy Clusters revealed by these tables and charts shows that, as we have predicted, a very strong set of relationships exists between the Performance Indicators and different patterns of strategic behaviour. Table 5.14 shows that the scores for the 3 Performance Indicators on the three problem types all discriminate between the clusters at the 0.01 level of significance. Scores for Learning discriminate at the 0.05 level of significance for Trial of Last Error and Verbalisation of Hypotheses during the Criterion Trials.

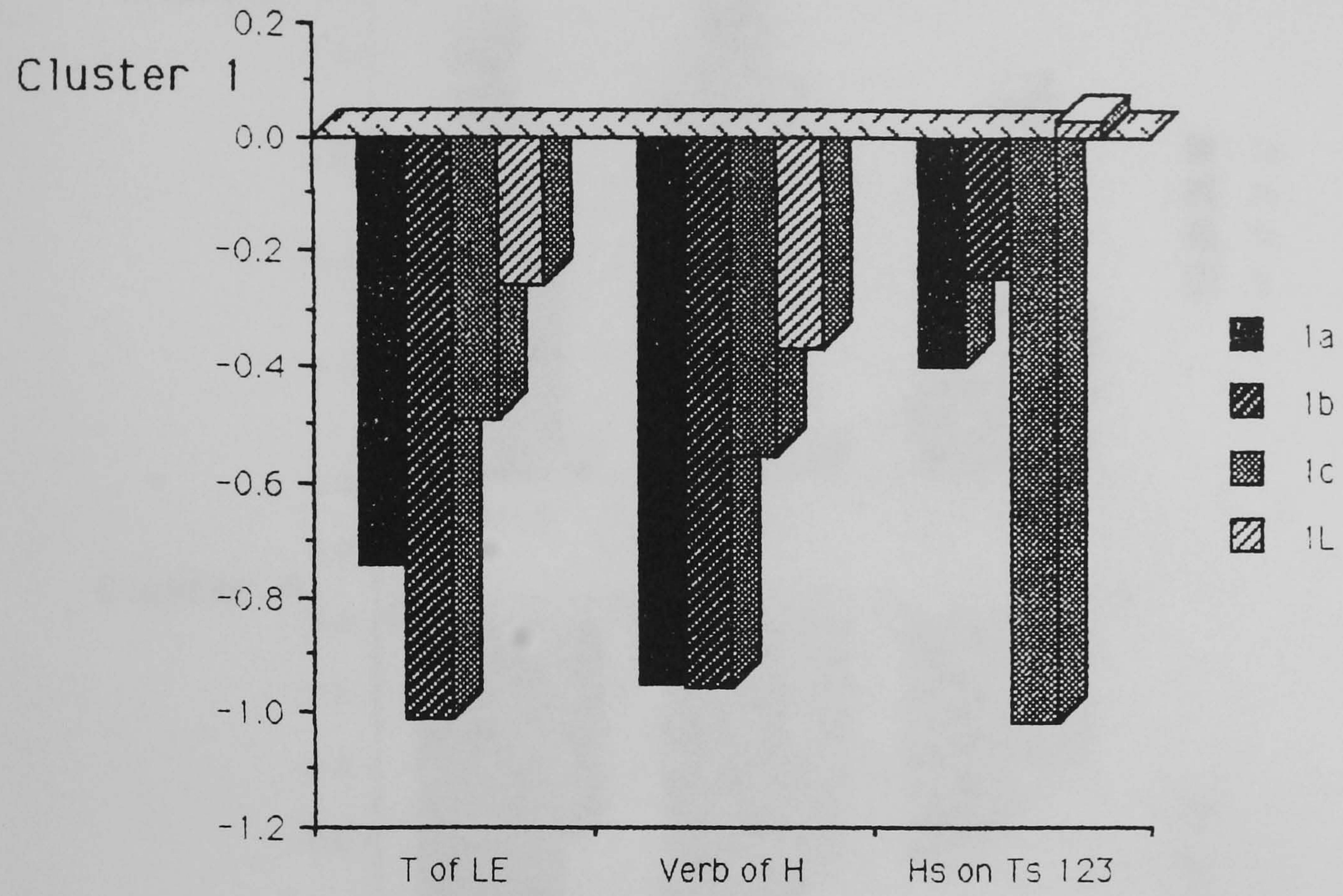
Inspection of the Standardised Mean bar charts (Figure 5.6) and the Atypicality chart (Figure 5.7) reveals a developmental pattern of improving performance which matches exactly the developmental sequence of strategic behaviour suggested by the Discriminant Function Analysis of cluster strategy scores discussed earlier (see Table 5.9a). Thus, the developmental sequence of performance develops from the weakest to the strongest through the clusters in the order 4, 1, 2, 6, 3, which is exactly the same sequence of development in strategic sophistication. This developmental sequence of improvement in performance is seen very clearly when a tally is done of the number of Performance Indicators on which each of the Strategy Clusters performed at the High, Average or Low levels identified by means of the Scheffe´ test, as illustrated in Table 5.14a.

Table 5.14a
Levels on 12 Performance Indicators for the 5 Main Strategy Clusters

Cluster	Scheffe´ scores		
	Low	Average	High
4	6	6	
1	4	8	
2		12	
6		9	3
3		6	6

Figure 5.6

Performance Indicators for 5 Main Clusters: Standardised Mean scores



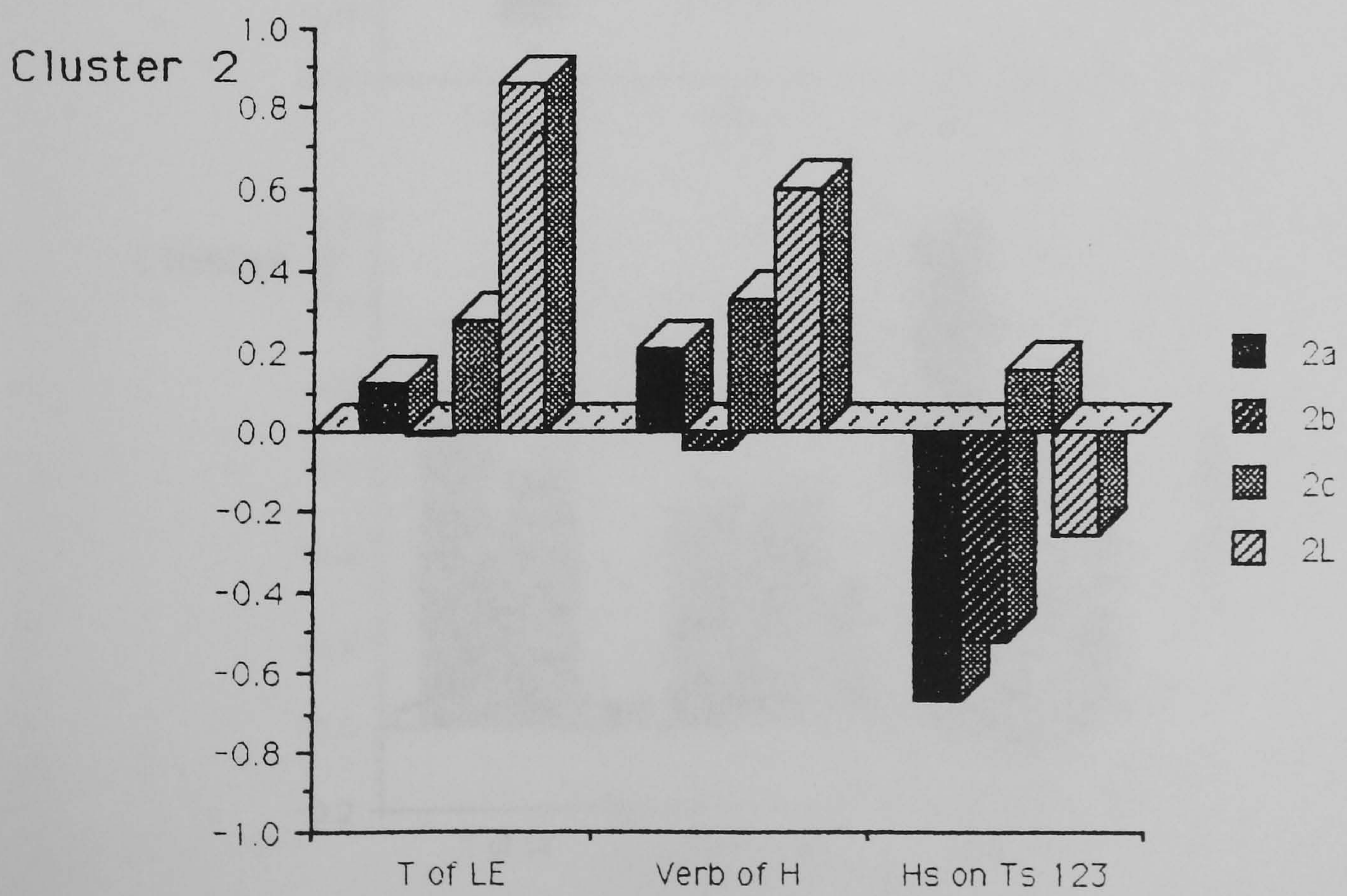


Figure 5.6 cont'd

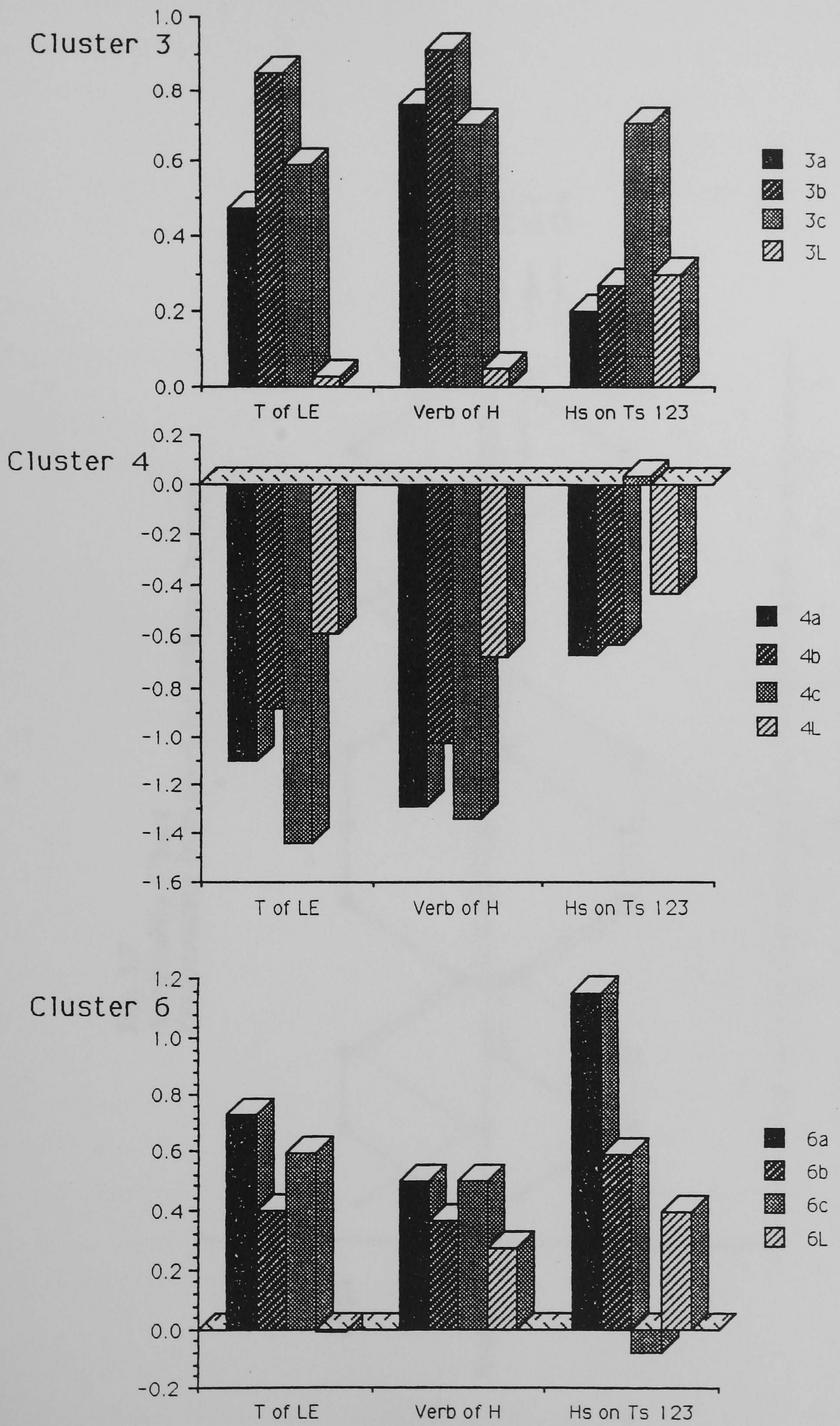
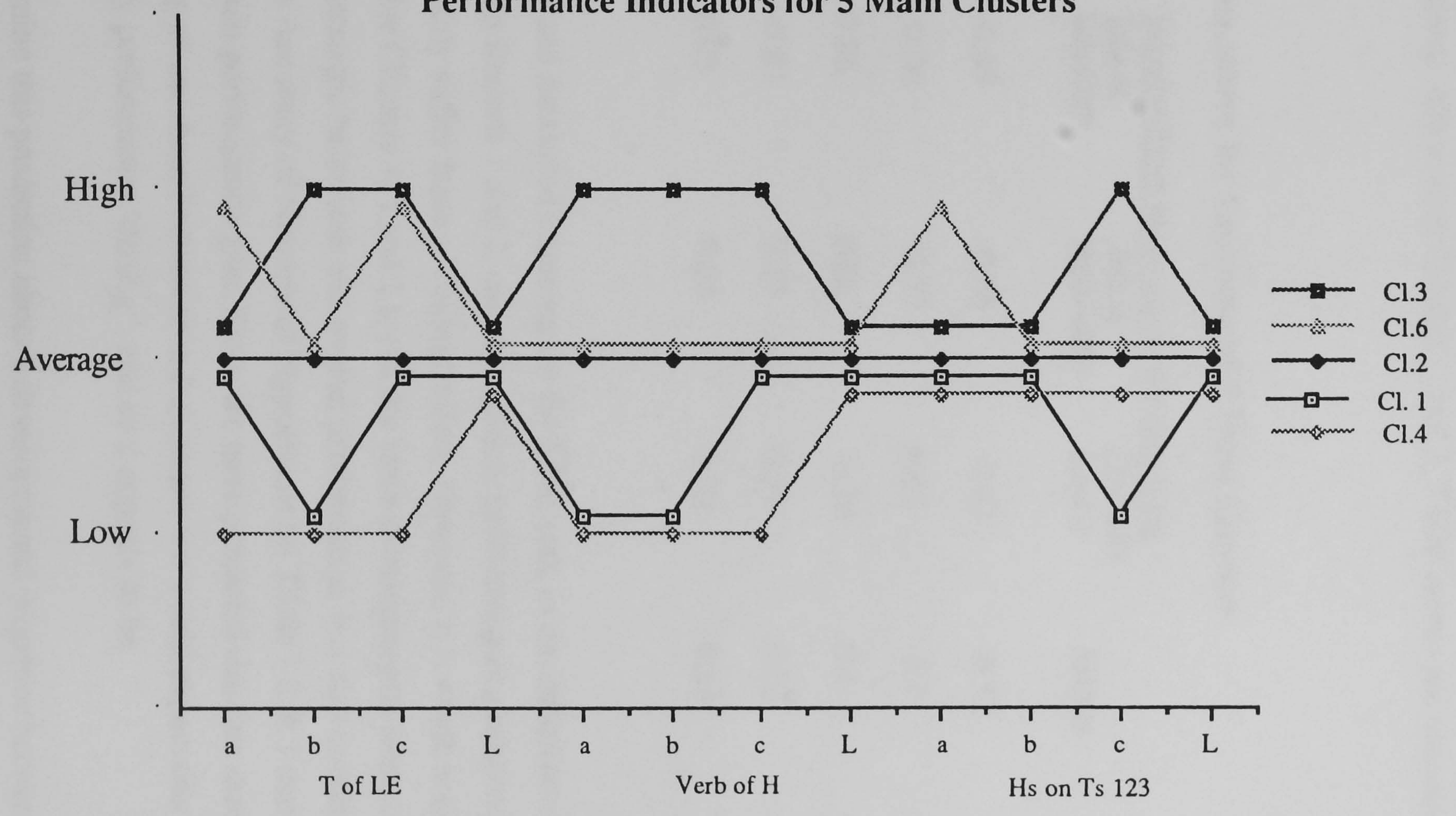


Fig. 5.7
Atypicality Chart
Performance Indicators for 5 Main Clusters



High/Low = Standardised Mean Score
sig. at 0.05 level (Scheffe´ test)

While the analyses in the previous sections have revealed positive correlations between Performance scores and between Performance and Strategy scores, it was noted that Learning appeared to be unrelated or only weakly related to overall levels of performance and strategic behaviour. Examination of Learning scores for the Strategy Clusters, however, suggests a clear developmental pattern but one which is not linear, largely due to a "ceiling" effect with Clusters 6 and 3. These scores are recorded in Table 5.14b.

Table 5.14b

Standardised Mean scores for Learning of 5 Main Clusters

Cluster	Standardised Mean score for Learning			
	Trial of Last Error	Verb. of Hypotheses	H's on T's 1,2 & 3	Average
4	-0.59	-0.68	-0.43	-0.57
1	-0.26	-0.37	0.03	-0.2
2	0.86	0.60	-0.26	0.4
6	-0.01	0.27	0.39	0.22
3	0.03	0.05	0.30	0.13

As we have defined and measured Learning on the MDL task as the difference in performance between Rounds 1 and 2, subjects already performing at a relatively high level in Round 1 clearly suffer from a "ceiling" effect. However, it is worth noting that the average scores for Clusters 4, 1 and 2 are in the same developmental sequence that we have found for strategic behaviour and overall performance. It is also interesting to note that it is on the Accuracy of Number of Hypotheses on Trials 1,2 & 3 that Clusters 6 and 3 do show some performance gain. Since we have predicted that this should be the latest developing of our three Performance Indicators, we would expect this to be least affected by any performance "ceiling", and so it appears to be.

We can further examine this prediction about a developmental sequence between the different Performance Indicators by looking at the pattern of development of scores on them overall, across the 3 problem types. These average scores are reported in Table 5.14c.

Table 5.14c

Average Standardised Mean scores for the 5 Main Clusters on Performance Indicators across all 3 problem types

Cluster	Average Standardised Mean score		
	Trial of Last Error	Verb. of Hypotheses	H's on T's 1,2 & 3
4	-1.14	-1.22	-0.42
1	-0.75	-0.82	-0.56
2	0.13	0.17	-0.34
6	0.58	0.45	0.45
3	0.64	0.79	0.39

This analysis would seem to offer some mild support for the suggested sequence of different aspects or qualities of performance. The suggestion that the accuracy with which subjects are able to verbalise the "correct" number of Hypotheses on Trials 1,2 & 3 is the last developing aspect of performance is borne out by the lack of improvement in score on this indicator between Clusters 4, 1 and 2. It is not until the transition between Cluster 2 and 6 that any real progress appears in this aspect of performance. By contrast there is clear improvement from the start on the other two indicators. The ability to solve MDL problems in fewer trials and to verbalise the correct hypothesis upon problem solution do indeed appear to be very closely linked, as was suggested by the strong positive correlations found between these two indicators reported earlier. However, it is interesting to note that all the improvement on Trial of the Last Error appears to have been made by the transition between Clusters 2 and 6, whereas there is continuing improvement between Clusters 6 and 3 in respect of Verbalisation of the Correct Hypothesis. This would seem to support some developmental lag between these two indicators. The general model of a developmental sequence between the three aspects of performance measured by our Performance Indicators thus seems to be in line with our results.

We have also previously noted, in discussing the correlations between Performance Indicators reported in Table 5.11, the weak correlations between performance on H's on T's 1,2 & 3 for type c problems (irrelevant information or 'noise') and performance on the other two indicators and on the other two problem types. Again, it was suggested that this may well be the result of meaningful but not linear relationships which might be explored in relation to Strategy Clusters. To explore this we need to look at the pattern of development of scores on type c problems. This is reported in Table 5.14d.

Table 5.14d
Standardised Mean scores for the 5 Main Clusters on Performance Indicators for type c problems

Cluster	Type c Problem Standardised Mean scores		
	Trial of Last Error	Verb. of Hypotheses	H's on T's 1,2 & 3
4	**-1.44**	**-1.34**	0.03
1	-0.49	-0.55	<u>-1.02</u>
2	0.28	0.33	0.16
6	<u>0.60</u>	<u>0.50</u>	-0.08
3	**0.59**	**0.70**	**0.71**

Bold = sig. at 0.01 level
<u>Underlined</u> = sig. at 0.05 level

This table reveals that while scores on type c problems follow the normal developmental sequence for Trial of Last Error and Verbalisation of Correct Hypotheses during the Criterion Trials, for the Accuracy of Number of Hypotheses on Trials 1,2 & 3 a very different pattern emerges. This would be responsible for the low overall correlations between scores on this indicator for type c problems and other scores which we have discovered. Comparison with the previous table shows that Clusters 1 and 6 score more or less in line with the general developmental pattern overall on Hypotheses on Trials 1, 2 & 3, but relatively poorly on type c problems on this Performance Indicator. Indeed, they are the weakest two clusters on this Performance Indicator on type c problems.

As we have reported earlier, Clusters 1 & 6 are distinguished by their High Hypotheses per Trial strategic style, and the suspicion must be that this is related to their relatively poor performance here. It will be recalled from the analysis of the mean scores on the Strategy Components, reported in Table 5.6, that Cluster 6 scored poorly on type c problems relative to Cluster 2, particularly on the more sophisticated, long-term Strategy Components. We have suggested earlier that the High Hypotheses per Trial strategic style may not be helpful to development on the MDL task, possibly because of the resulting extra load on working memory, and the scores on this indicator reflect this. The figures reported in Table 5.6 for the mean Number of Hypotheses per Trial (Strategy Component 1) on type c problems for Clusters 1 and 6 were 2.54 and 2.58 respectively. These were higher figures than for the other problem types, and have resulted directly in the relatively poor performance in terms of accurately verbalising the correct number of hypotheses on the first three trials. The strategic style of Clusters 1 and 6 clearly causes them particular difficulties when there is irrelevancy or 'noise' present in a problem situation. This effect is particularly striking, as investigation of the individual Standardised Mean bar charts produced in Figure 5.6 reveals that these two clusters performed relatively well on this Performance Indicator on problem types a and b. It is possible that more light may be shone on these relationships when we come to look at underlying cognitive factors in the next section.

As regards the results for other individual Strategy Clusters, it will be noted from examination of the individual Standardised Mean bar charts produced in Figure 5.6 that Cluster 2's difficulties with type b problems (negative information) (reported earlier in the discussion of Table 5.6) are reflected to some degree in their performance. On both Trial of Last Error and Verbalisation of Hypothesis during Criterion the Standardised Mean is negative on type b problems, yet positive on everything else. The interpretation of Cluster 4's strategic pattern as a kind of 'stimulus describing' is also supported by examination of their performance on Verbalisation of Hypothesis during Criterion. As Table 5.14 indicates, Cluster 4 is the weakest group on this Performance Indicator, both in terms of level of performance and learning, and is significantly weaker at the 0.01 level than the rest of the sample on all three problem types.

c) Performance scores of Central Cases in each Strategy Cluster

As a further method of investigating the patterns of performance of the different strategic patterns identified by the Cluster Analysis the performance scores of the 5 most central cases previously identified within the 5 main Strategy Clusters were selected for more detailed study.

In Table 5.15 the pattern of scores is recorded for each of these cases on each of the Performance Indicators, according to whether they were High, Average or Low relative to the sample mean. For this purpose these categories are defined as before, thus:

High = > Mean + $^1/_2$ S.D.
Medium = < Mean + $^1/_2$ S.D. and > Mean - $^1/_2$ S.D.
Low = < Mean - $^1/_2$ S.D.

The raw means, standard deviations and figures for Mean + $^1/_2$ S.D. and Mean - $^1/_2$ S.D. for the whole sample, used to produce these results, are reproduced in Appendix H.3.

As with the earlier analysis of scores on the 30 Strategy Components, examination of the scores on the Performance Indicators of these Central Cases serves to reinforce aspects of the analysis of clusters based on overall means; in particular, it can serve to highlight those variables upon which Central Cases are strongly consistent, as opposed to those variables where even the Central Cases show some variation. This will help to enhance interpretation of the essential nature and characteristics of particular clusters.

Thus, once again, to begin with, the relative positions of the 5 main clusters, so clearly illustrated in the bar charts and atypicality chart in the previous section, is clearly reinforced. The central cases of Cluster 3, which exhibited the strongest levels of performance, score average or high in every case on all Performance Indicators except for 3 low scores on No. of Hypotheses on Trials 1,2 &3. This cluster is the only one with no low scores on the other two Performance Indicators. Clusters 1 & 4, clearly the weakest groups, exhibit a preponderance of low scores amongst their central cases. Cluster 4 is confirmed as the weakest group of all with only one High score on any Performance Indicator amongst its 5 most central cases. The central cases of the two intermediate Clusters 2 & 6 present the kind of mixed picture of high, average and low scores throughout the full range of Performance Indicators which we would predict, with Cluster 6 looking rather the stronger. Overall, the patterns look remarkably consistent within Strategy Clusters, confirming the strong links between patterns of strategic behaviour and performance.

Table 5.15

5 Main Strategy Clusters: Performance Indicator scores of Central Cases

	Performance Indicator/Problem Type											
	T of LE				Verb of H				Hs on Ts 1,2,3			
Case	a	b	c	L	a	b	c	L	a	b	c	L
Cl. 1												
5	L	L	L	A	L	L	L	A	L	L	A	H
6	L	L	L	A	L	L	L	A	L	L	A	A
15	H	L	A	L	L	L	L	L	H	H	L	H
19	L	L	L	H	L	L	L	H	L	A	L	A
42	A	A	A	A	H	A	H	L	L	A	L	H
Cl.2												
13	L	A	A	H	L	L	A	H	L	L	A	L
26	A	A	A	H	H	A	A	H	L	L	A	A
37	H	A	A	H	H	L	A	L	L	L	A	A
51	A	H	H	A	H	H	H	A	L	H	H	H
58	H	H	H	A	A	H	H	A	A	H	H	A
Cl.3												
36	H	H	H	A	H	H	H	A	A	A	A	H
43	H	H	H	A	H	H	H	A	H	H	A	H
46	H	H	H	A	H	H	H	A	H	L	A	A
56	A	H	H	A	H	H	H	A	L	L	A	A
64	H	A	A	H	H	H	A	A	H	H	H	H
Cl.4												
10	L	L	L	L	L	L	L	L	L	L	A	A
12	A	L	L	A	L	A	L	L	L	L	A	A
24	L	A	L	L	L	L	L	L	L	L	A	A
47	L	L	L	L	L	L	L	L	L	L	H	L
68	L	L	L	A	L	L	L	A	L	L	A	A
Cl.6												
39	H	H	H	A	H	H	H	A	H	H	H	H
44	A	H	H	A	L	H	L	H	A	L	L	H
59	H	H	H	L	H	H	A	A	H	H	A	L
69	H	L	H	A	H	A	H	H	H	H	L	H
71	H	L	H	H	H	A	H	H	H	H	A	L

H = High (> M+1/2 S.D.)
A = Average (< M+1/2 S.D. & > M-1/2 S.D.)
L = Low (< M-1/2 S.D.)

As regards Learning, it will be recalled from the analysis of the Standardised Means for the 5 main clusters, reported in Table 5.14b, that, overall, Cluster 4 exhibited the least, and Cluster 2 the most improvement on the MDL problems between rounds 1 and 2. The weak position of Cluster 4 is certainly confirmed by the performance of the central cases, who do not produce one High score for Learning between them. The picture as regards the cluster showing most Learning is a little more complicated. Cluster 2 appears the strongest on Trial of Last Error, and at least as strong as Cluster 6 on Verbalisation of Correct Hypothesis during Criterion. However, Clusters 1, 3 and 6 come through the strongest in terms of improvement on Hypotheses on Trials 1, 2 & 3.

This result may be a combined reflection of two factors. First, this being the most sophisticated, and therefore latest developing, aspect of performance, as we have discussed earlier, it becomes relevant for the two oldest and strategically most developed Clusters, 3 & 6. Second, we have noted the difficulties of Clusters 1 & 6 on this aspect of performance as a consequence of their High Hypotheses per Trial strategic style; these difficulties may well afford individuals in these clusters greater opportunity for improvement in this area.

There is some support here also for the notion of a developmental sequence of different aspects of performance on the MDL task. If we look at the scores in Table 5.15 in the order of development of the Strategy Clusters (i.e. in the order Cluster 4, 1, 2, 6, 3) then, for Trial of Last Error and Verbalisation of Hypothesis during Criterion, the major change in pattern of scoring occurs between Clusters 1 and 2. Thus, in Cluster 2's scores there are markedly more Highs than for Clusters 4 and 1 on these first two Performance Indicators. For Number of Hypotheses on Trials 1, 2 & 3, however, the major change occurs between Clusters 2 and 6 (eg the number of Lows for Clusters 4, 1 & 2 is 9, 9 & 8, and for Clusters 6 & 3 it is 5 & 3).

Finally, although the performance score patterns within the Strategy Clusters are generally strongly consistent, it will be noted that there are some within cluster differences. Most notably, the oldest members of Clusters 1 & 2 (cases 42, 51 & 58) do appear to perform a little more strongly than the other central cases in their groups. Clearly strategy influences performance, but it is not the whole story. There are likely to be significant interactions between strategies adopted on any task, performance on that task, and general cognitive abilities and qualities. It is to these interactions that we turn in the final section of the analysis of results.

Section D) Relationships between Predictor measures, Strategy and Performance

i) Predictor Measures

Having established some of the ways in which performance on the MDL task is related to the development of increasingly sophisticated and complex problem-solving strategies, we now turn our attention to underlying features of cognitive development which may be related to the development of these strategies. We have outlined earlier the literature concerned with working memory capacity, metacognition, locus of control, cognitive tempo (reflectivity-impulsivity) and field dependence -independence, all of which has indicated that these may be factors which crucially affect the development of children's ability to solve problems and to learn. To this list we have also added gender and age, which are clearly different kinds of predictor. It is important to establish to what extent the theoretically generated predictors of cognitive development are associated with performance on the MDL task, and to what extent there are other factors, currently unidentified but associated with gender or age, which predict performance. As with the measures of strategic behaviour and performance it is first of all helpful to look at the relationships between the Predictor Measures. These are reported in Table 5.16.

This table overall provides good evidence of the relative independence of the Predictor Measures. There are no strong correlations (more than .70). The pattern of weak and moderate correlations does provide, however, evidence of some interesting relationships.

First, it is interesting to note that Gender does not correlate with any of the other Predictor Measures. Not surprisingly, on the other hand, nearly all of the Predictor Measures do seem to be associated with Age, but only moderately so. The strongest relationship appears to be with scores on the Children's Embedded Figures Test (CEFT), but this is only at the .57 level accounting for 32.5% of the variance.

The two measures of Working Memory, the WM test using the MDL materials and Pascual-Leone's FIT test, correlate at the 0.01 level of statistical significance, but only at the moderate level of .39. This suggests that the two measures may give us a more complete and reliable measure of the subjects' Working Memory capacities than either one of them alone. Both measures correlate with all the other Predictor Measures, with

Table 5.16

Correlations between Predictor Measures

		Gen	Age	Wk Mem WM	FIT	Meta Know Q1	Q2	Q3	Meta A&C M/c	SF	Meta Tot	L/C	R-I	Field Ind RFT
Age		-04												
Wk Mem	WM	-10	**46**											
	FIT	04	**50**	39										
Meta Know	Q1	01	30	28	23									
	Q2	08	28	29	26	22								
	Q3	-03	**36**	**33**	28	**35**	13							
Meta A&C	M/c	13	23	23	**32**	02	28	02						
	SF	14	**31**	25	**33**	15	29	07	**35**					
Meta Tot		11	**50**	**46**	**48**	**60**	**58**	**55**	**54**	**68**				
L/C		-06	**44**	30	**40**	12	25	07	13	**41**	**34**			
R-I		03	**50**	**45**	**50**	18	**37**	24	23	29	**44**	**41**		
Field Ind	RFT	-21	**32**	**38**	**44**	05	19	24	14	17	27	**32**	**-47**	
	CEFT	-13	**57**	**63**	**55**	**35**	**38**	28	23	25	**49**	**40**	**60**	**44**

Bold= sig. at 0.01 level
Underlined = sig. at 0.05 level

the exception of Gender, at statistically significant weak or moderate levels. Again, the strongest relationship is with the CEFT.

The pattern of interrelationships between the various measures of Metacognition consists entirely of weak correlations (less than .40), only 4 (out of 10) of which are even statistically significant. The relatively strong correlations between Q1 and Q3, and between Metacomprehension and Strategy Flexibility (both at the 0.01 level of significance) offers some small support for the notion of Metacognitive Knowledge and Metacognitive Awareness and Control being relatively distinct aspects of Metacognition, as suggested by previous research. (The relatively strong correlations between individual measures and the Total Metacognition score are simply a product of the fact that the Total score is computed from the individual scores, as explained earlier, and so can be safely ignored.)

Correlations between the individual measures of different aspects of metacognition and other Predictor Measures are also all weak, although 26 (out of 35, if we ignore Gender) are statistically significant. The Total Metacognition score, however, correlates with all the other Predictor Measures at the 0.01 level of significance, with the exceptions of the Rod and Frame test RFT), with which it correlates significantly at the 0.05 level, and Gender. All this tends to suggest that the overall score is perhaps a more complete and reliable measure of the children's metacognitive capabilities than any of the individual measures.

The two measures of Field Dependence-Independence (FDI) correlate positively at the 0.01 level of statistical significance, but only at the moderate level of .44. This suggests that, like the two measures of Working Memory, the two measures are related, but may give us a more complete and reliable measure of the children's FDI than either one of them alone. If we ignore Gender and look at Total Metacognition rather than the individual measures, then Locus of Control, Reflectivity-Impulsivity (R-I) and the two measures of FDI each moderately correlate with all other Predictor Measures at the 0.01 level of significance (with the single exception of the Rod and Frame test (RFT) and Total Metacognition, as indicated above). As indicated in chapter 4, R-I is scored in the direction of Reflectivity and the RFT is scored in the direction of Field-Independence (this is so throughout the ensuing analysis). These weak or moderate positive correlations between all the Predictor Measures indicate that we are looking here at relatively independent measures, but ones which are nevertheless associated together in a general way as different aspects of the development of cognitive abilities, as would be predicted from the developmental research.

In our earlier review of work related to the analysis of children's developing problem solving, we examined the 4 transparadigmatic principles proposed by Sternberg & Powell (1983), and some suggestions arose from this about relationships between different aspects of cognitive functioning. For example, it was suggested that we might expect a relationship to exist between Reflectivity and Metacognitive Knowledge, since a more reflective style might be expected to allow more thorough representation of problems. The notion of a strong and simply linear relationship here, however, is not particularly well supported by the figures in Table 5.16. As can be seen, the correlations with Qs 1, 2 & 3 are .18, .37 and .24. R-I correlated more strongly with the scores for Working Memory and Locus of Control. Similarly, the notion that Strategy Flexibility might be closely associated with Field-Independence did not receive strong support, with correlations of .17 and .25 on this occasion. However, the correlation of .41 between Strategy Flexibility and Locus of Control (the strongest relationship between Strategy Flexibility and any other measure) did lend some support to the view that attributional style might be significant at a general level for problem-solving performance. Whatever the relationships are between these various aspects of cognitive functioning, it is clear that they are likely to be complex rather than simply linear, as are their relationships with strategy development and problem-solving performance, to which we now turn.

ii) Predictors, Strategies and Performance

The final stage of the analysis of results attempts to explore the relationships between the Predictor Measures and the development of strategic behaviour and performance on the MDL task.

This analysis is in four parts. First, in order to explore the possibility of any simple linear relationships between the underlying aspects of cognitive functioning which we have included in the study as Predictor Measures and performance, correlations between the Predictor Measures and the Performance Indicators are examined. Second, as it is fundamental to the theoretical view taken in this study that performance will be mediated by strategies, it is necessary to examine the extent to which cognitive factors are associated with the level and pattern of strategic behaviour. This is done by examining correlations between Predictor Measures and Strategy Components, together with mean scores for the Strategy Clusters, and the profiles of the 'central cases' in each of the 5 main clusters. Third, in an attempt to examine the interrelationships between underlying cognitive factors, strategic behaviour and performance a Multiple Regression Analysis of the contributions to performance of the Predictor Measures and patterns of strategic behaviour represented by the Strategy Clusters is carried out and examined. From these three analyses it is hoped to identify the aspects of cognitive functioning most closely related to the ability to solve and to learn about the MDL type of problem. Finally, because it is predicted by our model of the development of problem-solving strategic behaviour that there will be important interactions between different aspects of cognitive functioning, strategic behaviour and level of performance, we have explored these interactions by means of examining correlations within Strategy Clusters and other subsets of the sample population.

a) Correlations between Predictor Measures and Performance Indicators

Table 5.17 below contains correlations between the 14 Predictor Measures and the Total and Learning Scores for the 3 Performance Indicators. It reveals a number of clear and consistent patterns.

Table 5.17
Correlations between Predictor Measures and Performance Indicators

Predictor Measures	Performance Indicators: Trial of Last Error Total	L	Verb. of Hypotheses Total	L	H's on T's 1,2 & 3 Total	L
Gen	-06	07	-04	-06	12	-05
Age	**49**	03	**53**	-02	**47**	28
Wk Mem WM	**48**	05	**46**	-04	**42**	07
FIT	**46**	23	**45**	05	**40**	09
Meta Know Q1	**49**	00	**51**	02	**34**	01
Q2	**34**	-13	**33**	-16	27	-03
Q3	28	-01	**32**	-12	22	00
Meta A&C M/c	**43**	-11	**39**	-05	**43**	17
SF	**38**	24	**42**	-02	**38**	24
Meta Tot	**64**	03	**67**	-10	**56**	15
L/C	24	13	26	-16	29	21
R-I	**35**	-02	37	-08	**34**	23
Field Ind RFT	20	12	21	03	24	-07
CEFT	**59**	-07	**54**	01	**40**	18

Bold = sig. at 0.01 level
Underlined = sig. at 0.05 level

First, simple inspection reveals that scores on the Predictor Measures are generally positively correlated at a statistically significant level with overall performance, but that no simple linear correlation exists between the underlying aspects of cognition considered and the ability to improve performance on the MDL task as measured by our Learning indicator. Of the 42 correlations between the Predictor Measures and Learning Indicators only 4 are statistically significant at the 0.05 level, and the strongest correlation of these is only .28.

Perhaps the two slight indications of note are that 3 of these 4 significant correlations are in relation to Hypotheses on Trials 1,2 & 3 (related to Age, Strategy Flexibility (SF) and Reflectivity (R-I) and that 2 significant correlations are with Strategy Flexibility. We have noted earlier that H's on T's 1,2 & 3 seems to be the latest developing and thus most sophisticated aspect of performance. Here we have mild support for the conclusion that ability to improve on this aspect of performance is related to age. It is also interesting that Reflectivity and Strategy Flexibility appear to some extent to be related to short-term improvements in this respect. From the cognitive factors considered in the present study, Reflectivity and Strategy Flexibility might be predicted to be among those more directly related to learning on a new task.

In relation to general performance levels on the MDL task, the vast majority of our Predictor Measures show positive correlations at statistically significant levels. The exceptions are Gender, which does not appear to be related to performance at all, and the Rod & Frame test (RFT), which just scrapes one significant correlation but at a very weak level. We have already noted that Gender appears unrelated to the other Predictor Measures. These two results combined would seem to confirm that neither the performance or predictor measures used in the present study are in any way gender biased, which is very reassuring. It is perhaps also of interest that the RFT was the one other Predictor only weakly related to the Total Metacognition score, and that it is the latter which emerges here as the Predictor Measure most strongly related to overall performance. By contrast to the RFT scores, the Children's Embedded Figures Test (CEFT) scores emerge as quite strongly related to performance (at the 0.01 level) on all three indicators. Once again, this supports the view that the RFT and CEFT are measuring distinctly different aspects of FDI.

The other three Predictor Measures with the weakest linear relationship to overall performance appear to be Locus of Control (all at the 0.05 level only), Q3 in the test of Metacognitive Knowledge (one insignificant, one at the 0.05 level, and one just at the 0.01 level) and Q2 in the same test (one at the 0.05 level and two just at the 0.01 level). As we have reviewed, the measures we have described as Metacognitive Knowledge are to some extent an indication of the efficacy of the children's representation of the MDL problem. It is interesting that this would appear, on the basis of these results, to be less strongly related to performance than metacognitive awareness and control. All 6 correlations for Metacognitive Awareness and Control are comfortably at the 0.01 level of significance.

However, it is worthy of note that the aspect of performance which does emerge as consistently and significantly related to the measures reported under the heading of Metacognitive Knowledge is Verbalisation of the Correct Hypothesis during the

Criterion Trials. The scores on all three questions are related to this Performance Indicator at the 0.01 level. We have suggested in earlier discussions that these aspects of cognition and performance are linked by underlying representational processes, and the strength of the relationship which has emerged lends some support to this view.

The level of performance on all 3 of our Performance Indicators for the MDL task is positively related at the 0.01 level of significance for 30 of the 42 correlations with the Predictor Measures. These correlations are at a moderate level, ranging between .34 and .67. While this suggests some degree of simple linear relationship, it also suggests that there may be important interactions between our cognitive predictors, or that there may be patterns of interaction between underlying cognitive factors, pattern of strategic behaviour and level of performance. The moderate correlations between performance and age certainly suggest that we are not looking at a simple maturational process; the strongest correlation for Age is .53 accounting for only just over a quarter of the variance.

b) Predictors and Strategies

It is a central assumption of the present study that the relationship between underlying cognitive abilities and performance on the MDL task will be mediated by the pattern of strategic behaviour adopted. In order to explore our results in relation to this model, it is important to determine next, therefore, the nature of the relationships between cognitive factors and strategic behaviour. This analysis is carried out by examining three sets of results: correlations between Predictor Measures and scores on Strategic Components, mean scores on the Predictor Measures for the Strategy Clusters, and the profiles of the 'central cases' within each of the 5 main clusters.

1. Correlations between Predictor Measures and Strategy Components

Table 5.18 contains correlations between the 14 Predictor Measures and the Total scores on the 10 Strategy Components. Not surprisingly, given the high levels of intercorrelations noted earlier between the Strategy Components and the Performance Indicators (see Table 5.13), this table reveals some patterns very similar to those noted above in relation to correlations between Predictor Measures and Performance Indicators (see Table 5.17).

Thus, once again, all Predictor Measures show moderate positive correlations at statistically significant levels with the exception of Gender. The Rod & Frame test is again clearly the next weakest in its relationships with just two significant correlations at very low levels (this again contrasts with the CEFT which correlates strongly, particularly with the more long-term, sophisticated Strategy Components 6 - 10). Q2 and Q3 in the test of Metacognitive Knowledge again also show relatively weak linear relationships to scores on Strategy Components. Q2 has just three significant correlations, and only one of these just at the 0.01 level; Q3 has 4 significant relationships with two just at the 0.01 level.

Locus of Control, however, which had only weak relationships (at the 0.05 level of significance) with the Performance Indicators, correlates at statistically significant levels with six of the Strategy Components, and with five of these at the 0.01 level. While these correlations are only at very modest levels, with the strongest of them at .41, there

Table 5.18
Correlations between Predictor Measures and Strategy Components

Predictor Measures	Strategy Components									
	1.H's per T	2.H cons/F	3.Ch. cons/H	4.Lose/ Shift H	5.Lose/ Shift D	6.Win/ Stay	7.H Check	8.D Check	9.Foc/ 2 T's	10.Foc/ All T's
Gen	-14	-11	03	16	11	-19	-00	03	-08	-13
Age	29	**37**	**40**	13	30	**39**	**45**	**43**	**54**	**56**
Wk WM	29	21	**36**	-14	18	**46**	**36**	**38**	**40**	**45**
Mem FIT	17	**38**	**37**	29	**33**	**35**	**52**	**46**	**46**	**47**
Meta Q1	10	23	25	-03	15	**41**	**43**	**42**	**46**	**49**
Know Q2	15	14	24	18	18	19	**36**	24	21	23
Q3	-02	10	14	01	22	18	32	**34**	28	27
Meta M/c	**61**	14	**61**	-08	-06	**37**	13	11	25	28
A&C SF	20	**45**	**39**	21	21	33	39	**34**	**48**	**47**
Meta Tot	**34**	38	**54**	10	25	**51**	**56**	**51**	**59**	**61**
L/C	03	28	21	21	**37**	11	**41**	**37**	**40**	**40**
R-I	06	28	**37**	18	**34**	-28	**45**	**42**	**39**	**37**
Field RFT	21	08	28	-07	12	25	21	20	19	20
Ind CEFT	24	38	35	10	33	**52**	**54**	**53**	**55**	**56**

Bold = sig. at 0.01 level

Underlined = sig. at 0.05 level

is some modest support here perhaps for the hypothesis that Locus of Control may influence the strategic approach of individuals to problem-solving, but may not directly influence overall performance. Some interesting interactions between Locus of Control and other Predictors may emerge to account for this differential pattern of correlations, when we come to look at patterns of relationships within Strategy Clusters and other subgroups in the last part of this analysis.

As before, the other nine Predictor Measures all show evidence of generally significant relationships, although these are once again at moderate levels. Interactions between Predictor Measures at different
levels of strategic behaviour are once again indicated (as we noted when we examined the linear relationships between Predictor Measures and performance) , and these will be explored later. Overall the strongest linear relationships exist with the Total Metacognition and CEFT scores.

Within the Metacognition scores a number of interesting patterns emerge. To begin with, the scores for Metacognitive Knowledge appear to be much more strongly related to the more long-term, sophisticated Strategy Components 6 - 10 (8 significant at the 0.01 level and 3 at the 0.05 level out of 15 relationships) than they are to the simpler aspects of strategic behaviour. This would tend to support the view that the development of a sophisticated strategic approach is dependent upon representation of the problem.

As regards Metacognitive Awareness and Control, while Strategy Flexibility appears to correlate broadly with the whole range of Strategy Components (7 out of 10 at the 0.01 level of significance), Metacomprehension correlates with fewer but, in two instances (H's per T and Ch.cons/H), at much higher levels. The two measures of Metacognitive Awareness and Control thus appear to relate very differently to the different components of strategic behaviour. Metacomprehension scores appear to be much more weakly associated with the more sophisticated Strategy Components, but more strongly associated with the simpler component of making choices consistent with the current hypothesis, and, very interestingly, with the number of hypotheses verbalised per trial (although it should be borne in mind that a high score on the latter makes a high score on former more likely, since there are more hypotheses for the choice on the next trial to be consistent with; in Table 5.1 these two Strategy Components were, therefore, not surprisingly found to be strongly correlated at the 0.01 level of significance).

The association between Metacomprehension and Number of Hypotheses per Trial, at .61 (accounting for approx 36% of the variance), could indicate either of two types of relationship. It might be an indication that scoring well on the Metacomprehension test is associated for some reason with the High H's per T stylistic developmental route associated with Strategy Clusters 1 & 6. Alternatively, it may be consistent with the finding that, within both stylistic developmental routes, the number of hypotheses per trial gradually increases (see Table 5.9b). Within the low H's per T style, at least, this clearly marks a gradual move towards optimum performance, which would, of course, be predicted to be associated with increasing Metacomprehension in relation to the problem-solving task. The analysis of mean scores for Predictor Measures by Strategy Clusters which follows may help to determine which of these interpretations is indicated.

Moving on to examine the pattern of correlations in relation to the Strategy Components, it is helpful to compare these results with those contained in Table 5.13 (Correlations between Strategy Components and Performance Indicators). Once again, it is noticeable that there is no simple linear relationship between the Lose/Shift Strategic Components and the Predictor Measures, in just the same way as no such relationship was evident between these Strategic Components and performance. Lose/Shift H is particularly weak with only 1 statistically significant correlation at the 0.05 level; Lose/Shift D has 6 statistically significant correlations, but nothing above .37, and is clearly weaker in its relationships than both the other two remaining simpler components (H cons/F which has 8 and Ch. cons/H which has 11 statistically significant correlations, 8 at the 0.01 level). The non-linear nature of the development of the Lose/Shift component of strategic behaviour, which we have discussed earlier, is thus once again reinforced.

When we looked at the results in Table 5.13 it was noted that all 10 of the 'strong' correlations (> .70) with Performance Indicators were for the 5 most sophisticated Strategy Components. The picture is not quite so clearcut in relation to Predictor Measures. It is still the case that the 5 most sophisticated Strategy Components show the strongest pattern of relationships (ranging from 8 to 11 correlations at the 0.01 level of significance, and 10 to 11 statistically significant correlations overall). However, there are no strong correlations and 2 of the highest correlations (.61), to which we have referred above (in relation to Metacomprehension), are with Strategy Components 1 &

3. The pattern of relationships between Predictor Measures and Strategy Components thus appears to be more varied and diffuse than that between Strategy Components and Performance Indicators.

As with relations between Predictor Measures and Performance Indicators, however, the strength of simple linear relationships between individual Predictor Measures and particular Strategy Components is clearly no more than moderate. This is not surprising and indicates once again that interactions between the underlying cognitive factors (Predictor Measures) themselves, and between these cognitive predictors, styles of strategic behaviour and performance may well be fruitfully investigated. Such interactions will be explored below within the Regression Analysis, and when we come to examine relations between Predictor Measures, Strategic Components and Performance Indicators within Strategy Clusters and within other subsets of the sample population. First, however, we will go on to look at the relationships between the Predictor Measures and the styles of strategic behaviour identified by our Strategy Clusters.

2. Predictor Scores for Strategy Clusters

The analyses conducted so far of correlations between individual Predictor Measures and both measures of strategy and performance on the MDL task have indicated that, of the cognitive factors considered in the study, aspects of Metacognition (and particularly Metacognitive Awareness & Control) and of Field-independence (particularly as measured by the Children's Embedded Figures Test) appear to be most strongly associated with the development of appropriate strategies and the achievement of improved performance. We have argued earlier, however, that to look at the Strategy Components individually does not relate well to the developing patterns of strategic behaviour adopted by children in response to the MDL task. It may, therefore, be more illuminating to examine the relation of underlying cognitive factors to Strategy Clusters. Table 5.19 contains raw and standardised means for the Predictor Measures for each of the 7 Strategy Clusters. The patterns of relationships revealed are further illustrated for the 5 main clusters by separate standardised mean score bar charts (Fig 5.8) an Atypicality Chart (Fig 5.9), and a table of the scores of the 5 most central cases (Table 5.20).

Table 5.19

Raw and Standardised Mean scores on Predictor Measures for the Strategy Clusters

Predictor Measures	F	p	1(10)	Clusters 2(12)	3(20)	4(13)	5(1)	6(13)	7(3)
Gen	0.92	0.51	-0.17	0.19	-0.07	0.26	-0.97	0.10	-0.97
			1.40	*1.58*	*1.45*	*1.62*	*1.00*	*1.54*	*1.00*
Age	5.77	0.00**	-0.69	0.18	0.24	-0.77?	-1.43	0.81*	0.29
			7.23	*8.68*	*8.79*	*7.09*	*6.00*	*9.75*	*8.87*
Wk WM	3.76	0.00**	-0.50	-0.30	0.50	-0.66	1.31	0.30	0.69
Mem			*2.55*	*2.71*	*3.35*	*2.42*	*4.00*	*3.19*	*3.50*
FIT	5.19	0.00**	-0.80	0.19	0.48	-0.57	-2.28	0.42	0.12
			2.75	*3.92*	*4.26*	*3.02*	*1.00*	*4.19*	*3.83*
Meta Q1	2.48	0.03*	-0.82	-0.08	0.40	-0.31	-0.41	0.32	0.49
Know			*0.70*	*1.25*	*1.60*	*1.08*	*1.00*	*1.54*	*1.67*
Q2	1.80	0.11	-0.32	-0.45	0.35	-0.14	-1.42	0.21	0.71
			3.40	*3.13*	*4.87*	*3.81*	*1.00*	*4.58*	*5.67*
Q3	2.07	0.06?	-0.79	0.18	0.32	-0.24	0.74	-0.04	0.74
			1.20	*2.33*	*2.50*	*1.85*	*3.00*	*2.08*	*3.00*
Meta M/c	5.85	0.00**	0.24	-0.43	0.16	-0.90*	-0.98	0.89*	0.20
A&C			*3.40*	*2.08*	*3.25*	*1.15*	*1.00*	*4.69*	*3.33*
SF	1.89	0.09?	-0.27	0.27	0.38	-0.65	-0.81	0.10	-0.09
			0.50	*1.00*	*1.10*	*0.15*	*0.00*	*0.85*	*0.67*
Meta Tot	5.19	0.00**	-0.69	-0.09	0.55	-0.77?	-0.87	0.46	0.64
			47.80	*63.38*	*80.02*	*45.58*	*43.00*	*77.73*	*82.33*
L/C	2.09	0.06?	-0.95?	0.14	0.29	-0.08	0.40	0.14	0.28
			9.60	*15.58*	*16.40*	*14.38*	*17.00*	*15.62*	*16.33*
R-I	3.22	0.00**	-0.70	-0.17	0.66*	-0.37	-0.14	0.13	-0.35
			-13.90	*-4.42*	*10.30*	*-8.12*	*-4.00*	*0.88*	*-7.67*
Field RFT	1.31	0.26	-0.34	-0.01	0.22	-0.41	0.28	0.08	1.04
			-16.60	*-14.17*	*-12.45*	*-17.15*	*-12.00*	*-13.46*	*-6.33*
Ind CEFT	6.59	0.00**	-0.78	0.03	0.66*	-0.73?	-1.35	0.15	1.05
			13.60	*17.33*	*20.20*	*13.85*	*11.00*	*17.85*	*22.00*

Plain = Standardised score
Italic = Raw score

The significance of the variation of each standardised Cluster Mean from the population mean is tested using the Scheffe´ Atypicality test. The degree to which each Performance Indicator discriminates between Clusters overall is tested using one-way Analysis of Variance (F-ratio on left hand side of table) Levels of significance: ? = 0.1

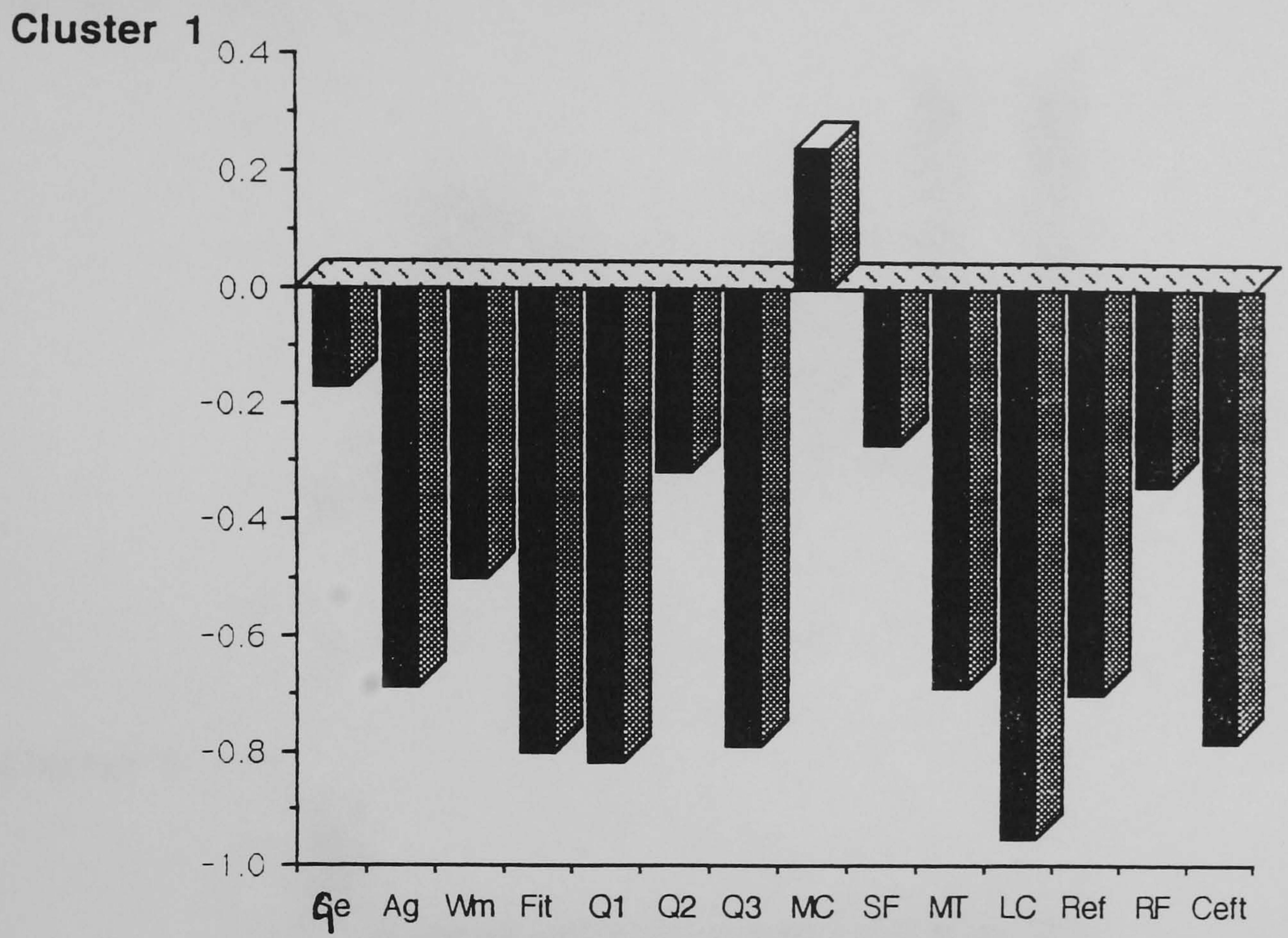
* = 0.05

** = 0.01

The numbers in brackets after the Cluster numbers indicate the number of cases in each Cluster.

Figure 5.8

Predictor Measures for 5 Main Clusters: Standardised Mean scores



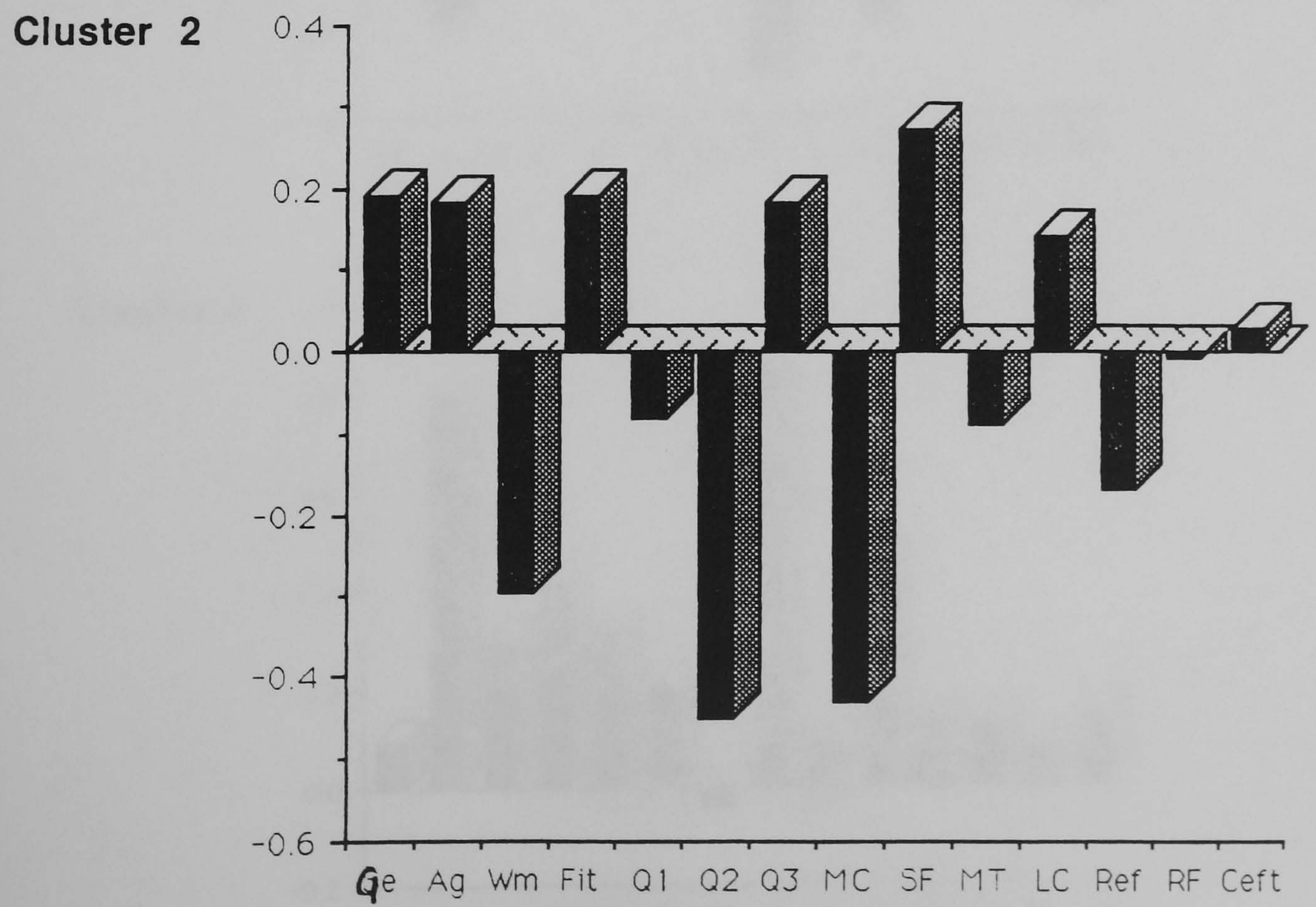
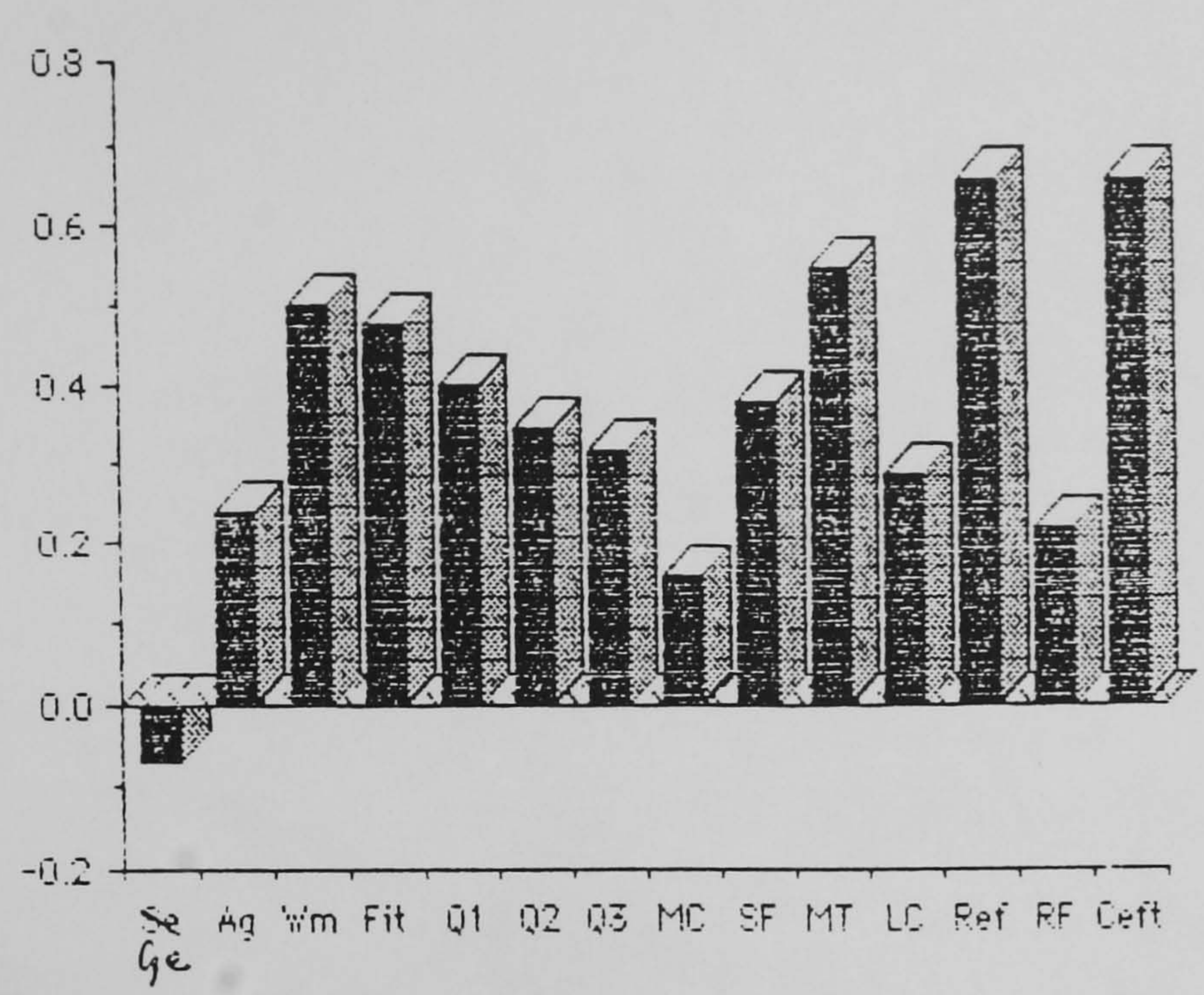
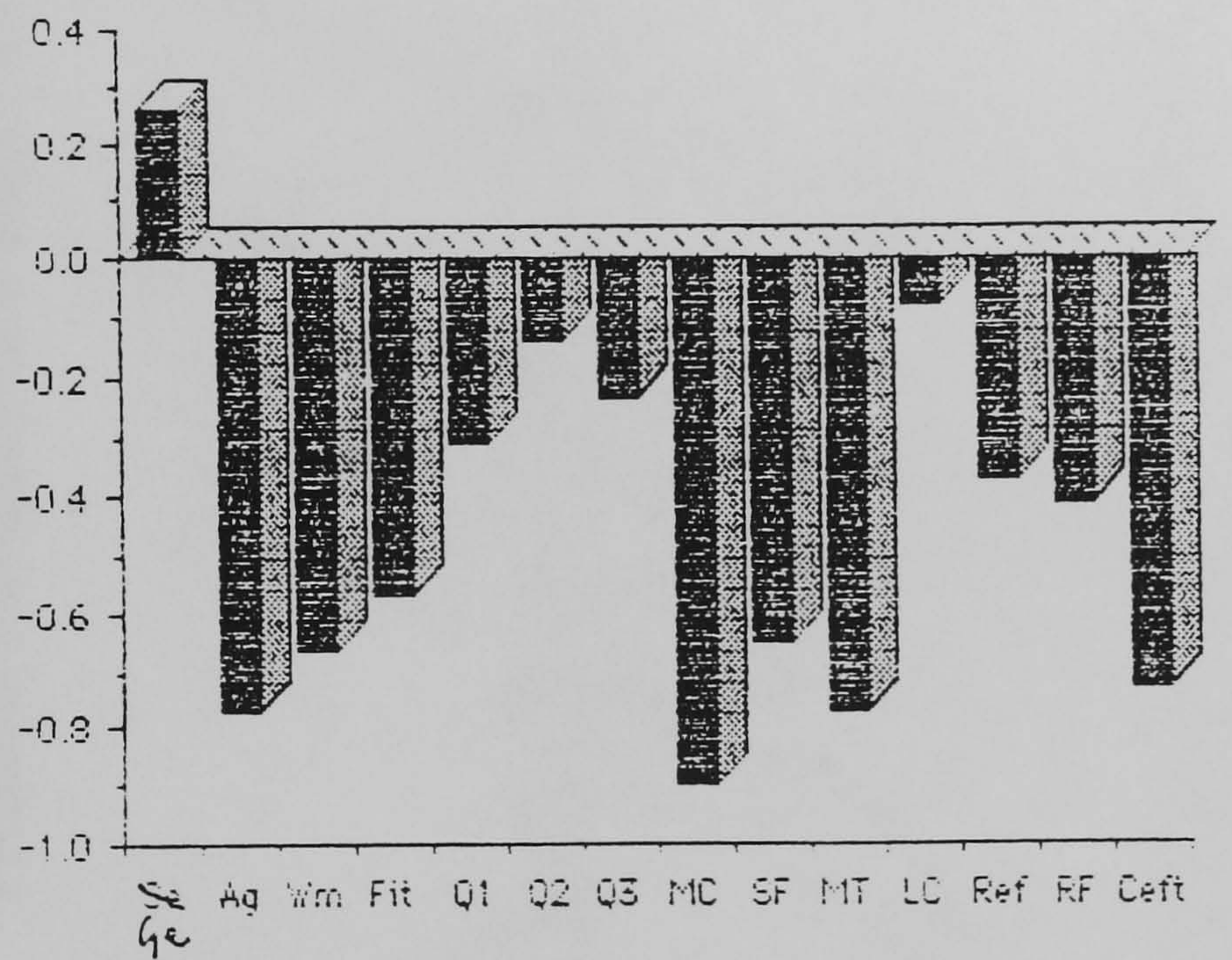


Figure 5.8 cont'd

Cluster 3



Cluster 4



Cluster 6

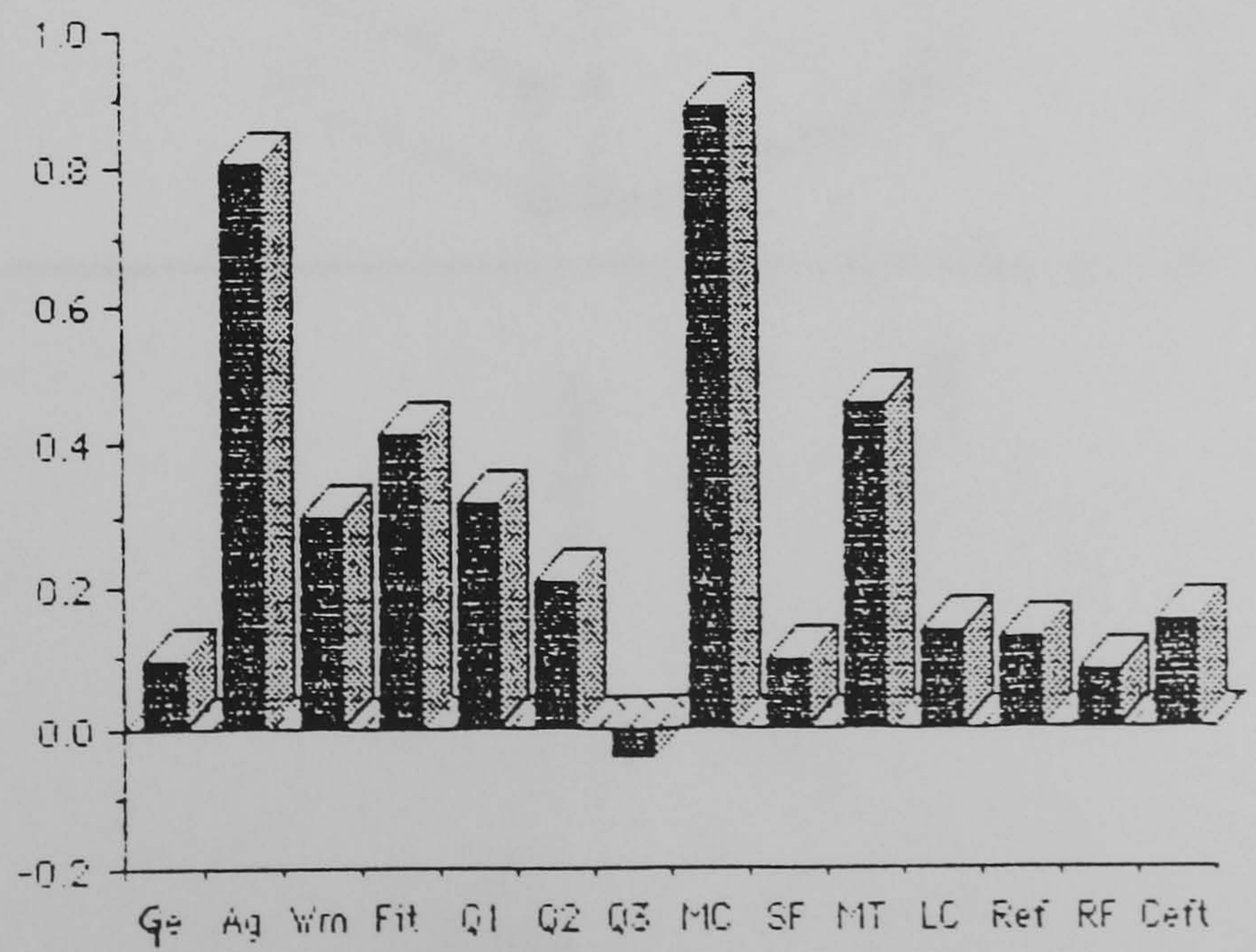
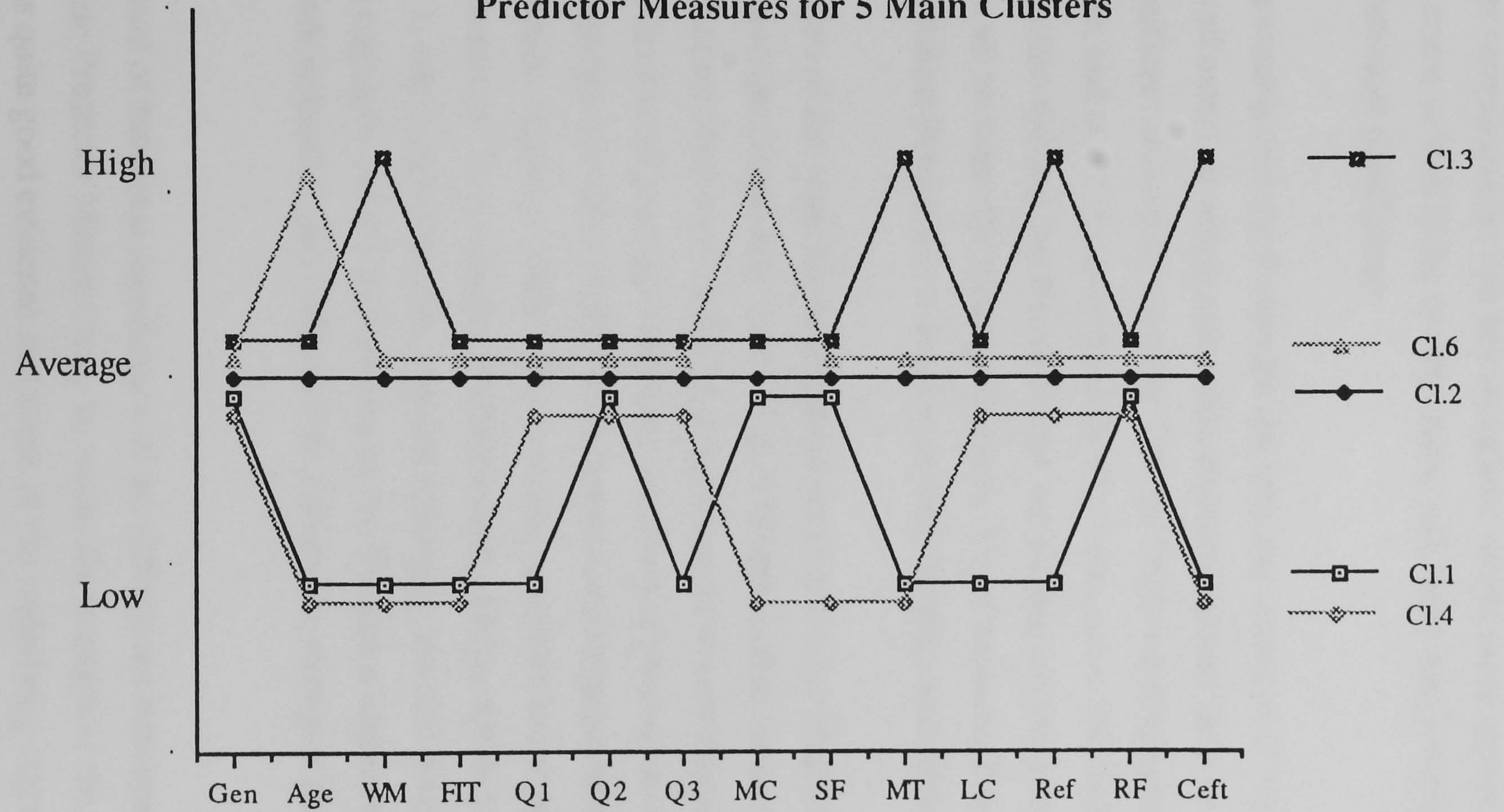


Fig 5.9
Atypicality Chart
Predictor Measures for 5 Main Clusters



High/Low = Standardised Mean
Score = > 0.5 or < -0.5

The first point to be noted in our analysis of the pattern of relationships between the Predictor Measures and strategic patterns of behaviour as represented by Strategy Clusters is that the statistical significance of the differences which appear is far less marked than that for the previous comparisons of Predictor Measures with overall Strategies and Performance. This is, of course, not surprising, since here we are dealing with much smaller sample groups and any variations within these groups (which we will explore when we come to look at the central cases) will fairly easily obviate the achievement of statistical significance.

Nevertheless, it is notable that the F-ratio for the one-way Analysis of Variance, which measures the overall extent to which each measure discriminates between the Clusters, is statistically significant at the 0.01 level for 7 of the Predictor Measures, at the 0.05 level for 1 measure, and at the 0.1 level for a further 3 measures. This leaves only Gender, Metacognition Q2 and the Rod & Frame test failing to discriminate at any significant level at all between the Strategy Clusters. These measures have been consistently the weakest throughout in relation to both strategy and performance.

Further, examination of the separate standardised mean score bar charts for the 5 main clusters (Fig 5.8) and the Atypicality Chart (Fig. 5.9) reveals that the general pattern of scoring on the Predictor Measures by the Strategy Clusters is very much in line with the scoring for sophistication of strategic behaviour and level of performance. The developmental sequence identified earlier in our analysis of strategic behaviour using Discriminant Function Analysis (Table 5.9a) is clearly mirrored in the pattern of Predictor Measure scores. Thus, simply by observation of Figs. 5.8 & 5.9 it is evident that Clusters 4 & 1, which produced the simplest strategies, are also weakest in relation to the underlying cognitive factors represented by the Predictor Measures. Cluster 2 is intermediate in both instances, and Clusters 6 & 3 show the strongest performance in both regards.

Thus, while the level of statistical significance of the differences between particular Clusters on any one Predictor Measure may be weak, the strength of the overall pattern of scores provides quite good evidence that some of the underlying cognitive factors related to the Predictor Measures are indeed related to the pattern of strategic behaviour on the MDL task.

Analysis of the overall correlations of Predictor Measures to Strategic Components (see Table 5.18) revealed that the Total Metacognition (and within that, the scores for Metacognitive Awareness & Control) and CEFT scores were most strongly related in a general way to strategic behaviour. The current analysis reveals that CEFT and Metacognition Total again appear as amongst the most significant predictors (Cluster 3 was significantly more field-independent on the CEFT than the remainder at the 0.05 level, while Cluster 4 was significantly weaker metacognitively and significantly more field-dependent at the 0.1 level). However, it is notable that, in this instance, within Metacognition it is Metacomprehension which appears as most significant (i.e. at the 0.01 level) in its own right, and in a particularly interesting way which we shall discuss below.

The other most significant measures to emerge are those related to Working Memory, Cognitive Tempo (Cluster 3 children were significantly more reflective as a group than the remainder at the 0.05 level) and, not surprisingly, Age (Cluster 6 was significantly older at the 0.05 level, and Cluster 4 was significantly younger at the 0.1 level). The one other result worth noting is that Cluster 1 emerged as significantly more external in terms of Locus of Control than the remainder at the 0.1 level. Given that a number of these measures correlate with one another, even if only at relatively moderate levels (see Table 5.16), it is difficult from this analysis to disentangle their relative contributions to the behaviour of different Strategy Clusters. For this purpose we have carried out a Multiple Linear Regression Analysis, the results of which are reported below.

A number of interesting issues have arisen in relation to particular Predictors upon which the mean score data may shed some light. We have discussed earlier the age compositions of the various Strategy Clusters (see Table 5. 10) within our discussion of the developmental sequence and the two strategic styles revealed by the Discriminant Function Analysis. It was noted then that Cluster 3 is apparently more advanced strategically than Cluster 6, despite the fact that Cluster 6 is older than Cluster 3. Subsequently, it has been seen that Cluster 3 Performance is also at a higher level than that of Cluster 6 (see Table 5.14a). From this previous data, however, the question remains open as to the explanation of this apparent anomaly. It could be that the subjects in Cluster 6 have followed a developmental route direct from Cluster 1 explained by a High Hypotheses per Trial strategic style which has delayed their development. On the other hand, it could be that the developmental route for any individual child passes through Cluster 3 and on to Cluster 6 as a result of some kind of U-shaped learning development, as discussed in our earlier theoretical review.

The evidence on this point from the mean scores for the Predictor Measures is, however, not entirely clear and gives some support to both possible developmental routes. This is an issue which may require longitudinal study for it to be definitively clarified, as we shall discuss later when we come to look at research implications of the present study.

The evidence we do have, however, is intriguing and well worth examination. Thus, if we compare Clusters 3 and 6, while the differences for individual Predictor Measures are not statistically significant, it is worth noting that, ignoring Gender and Age, for the remaining 12 Predictor Measures Cluster 3 scores more strongly than Cluster 6 on 11, while the reverse is true only for Metacomprehension (of which, more below). This gives some support to the notion that Cluster 3 is more developmentally advanced than Cluster 6, the subjects within which are hampered on the MDL task by using an inappropriate strategic style.

The data related to the scores on the test of Metacomprehension, however, appear to give some support to the conclusion that Cluster 6 is more developmentally advanced, according to some kind of U-shaped developmental pattern, with performance being depressed as a result of a more sophisticated strategy being attempted than that carried out at the Cluster 3 stage. We noted in the previous section that the scores for Metacomprehension for all subjects produced the strongest correlations of any of the Predictor Measures with individual Strategy Components (see Table 5.18). At .61 the correlations with Strategy Components 1 (High H's per T) and 3 (Ch. cons/H) are moderate but significant at the 0.01 level. We also indicated in that section that the current analysis of mean scores on Predictor Measures for Strategy Clusters might help to interpret these results, particularly in relation to the High Hypotheses per Trial component. The relationship with this component is particularly interesting because of its key role in determining the two strategic styles identified in our analysis.

The first question to be resolved is whether Metacomprehension is particularly associated with the High Hypotheses per Trial strategic style, or whether the correlation is the result of the general increase in H's per T which, as we noted in the previous section, appears in both stylistic developmental routes. The standardised mean scores for Metacomprehension for each of the Strategy Clusters (taken from Table 5.19) are reported in Table 5.19a.

Table 5.19a

Standardised mean scores for Metacomprehension for 5 Main Strategy Clusters

Hypotheses per Trial		
High	Intermediate	Low
Cluster 1: 0.24	Cluster 3: 0.16	Cluster 4: -0.90*
Cluster 6: 0.89*		Cluster 2: -0.43

* = sig. at 0.05 level (Scheffe´ test)

These results would seem to confirm that while Metacomprehension scores do improve within both stylistic routes, the High H's per T style is associated with Metacomprehension. As can be seen from the results, Cluster 6 scores at a significantly higher level than Clusters 2 & 3, while Cluster 1 scores at least as well as these Clusters and significantly better than Cluster 4. The relationship between Metacomprehension score and number of hypotheses verbalised on each trial is clearly evident from simple visual inspection of the overall pattern revealed in Table 5.19a.

This pattern of results for Metacomprehension is highly intriguing as it seems to suggest that in this respect, at least, those subjects with good Metacomprehension are, nevertheless, adopting an apparently less appropriate pattern of strategic behaviour and being less successful in terms of their performance on the MDL task. The three possible explanations that suggest themselves are as follows. First, that there is some systematic error in the scoring of the test for Metacomprehension which artificially inflates the scores of subjects adopting a High H's per T strategy. Second, that this is a robust result and some phenomena associated with developing a more sophisticated strategy, resulting in a dip in performance, is occurring, for example, for the slightly older Cluster 6. Third, that the development of children in Strategy Clusters 1 and 6 in terms of strategic behaviour and performance on the MDL task is delayed because of their adoption of an unhelpful strategic style. Their Metacomprehension is relatively developed because they are older, but this has not helped them to develop strategically.

In order to examine the first possibility, of systematic error in the scoring of the test for Metacomprehension, two possible ways in which this may have occurred were investigated. First, since 3 points were scored only if the subject correctly pronounced themselves confident of their hypothesis immediately this was possible (i.e. on Trial 3) there may have been a bias towards the more impulsive child. An examination of the standardised mean scores for Reflectivity of the Strategy Clusters lends some support to this hypothesis. These scores are recorded in Table 5.19b, from which it can be seen that Cluster 1 is easily the most impulsive group (although this is not statistically significant) and Cluster 6 is significantly more impulsive than Cluster 3. However, it must be noted that the direct correlation between Metacomprehension score and Reflectivity was a very modest 0.23 (see Table 5.16).

Table 5.19b
Standardised mean scores for Reflectivity for 5 Main Strategy Clusters

Hypotheses per Trial High	Intermediate	Low
Cluster 1: -0.70	Cluster 3: 0.66*	Cluster 4: -0.37
Cluster 6: 0.13		Cluster 2: -0.17

* = sig. at 0.05 level (Scheffe´ test)

The second possible way in which systematic error might have occurred emerges from an examination of the pattern of responses on the Metacomprehension test. If we look at the tests upon which subjects scored 2 points, where they correctly pronounced themselves confident of their hypothesis, but after it should have been possible to do so, and where the correct hypothesis was stated more than once before the subject pronounced themselves confident, a very interesting pattern emerges. If we just count those tests, for example, in Cluster 3 we find this occurring in 26 out of the 40 tests carried out by those 20 subjects (or 65% of tests). For Cluster 6, however, the figure is only 10 out of 26 tests carried out by 13 subjects (or 38% of tests).

This finding prompted recalculation of scores on the Metacomprehension test, in two ways. First, a score of 2 was adjusted to a score of 3 where the subject had stopped the test just one trial after the trial upon which they should have been sure of the answer. It was felt that this would make some allowance for the more careful, perhaps more Reflective subjects, and this simple change resulted in the scores for 26 subjects being adjusted. Second, the existing method of scoring assumes that, whatever strategy the subject is adopting, all the information from each trial is available to them, and, therefore, they should be able to be sure of the solution by Trial 3 (or 4 in the second way of calculating scores described above). This is almost certainly an oversimplification, and so a third scoring system was adopted which allowed for differences in strategy and assumed that the only information available to each subject was that which related to items about which hypotheses had been verbalised. This meant that the Trial at which each subject could be deemed to be in a position to be certain about their solution varied according to which hypotheses they generated. Adopting this system resulted in changes to a further 11 subjects scores. New mean scores for Metacomprehension for each of the Strategy Clusters were then calculated based on these two new ways of calculating subjects' scores. These are reported in Table 5.19c.

Table 5.19c

Standardised mean scores for Metacomprehension for 5 Main Strategy Clusters: 3 alternatives scoring systems

Hypotheses per Trial		
High	Intermediate	Low
Score 1: Original		
Cluster 1: 0.24	Cluster 3: 0.16	Cluster 4: -0.90*
Cluster 6: 0.89*		Cluster 2: -0.43
Score 2: Trial 4 allowed		
Cluster 1: 0.08	Cluster 3: 0.23	Cluster 4: -0.93**
Cluster 6: 0.95**		Cluster 2: -0.46
Score 3: Hypotheses sampled considered		
Cluster 1: 0.07	Cluster 3: 0.25	Cluster 4: -0.88*
Cluster 6: 0.84*		Cluster 2: -0.39

** = sig. at 0.01 level

* = sig. at 0.05 level (Scheffe´ test)

Inspection of the scores achieved be each of the Strategy Clusters as a result of the different scoring methods reveals, however, that the relative positions in respect to Metacomprehension are remarkably robust. Under all three systems Cluster 6 scores significantly higher than the remainder, and Cluster 4 significantly lower. Clusters 1, 2 & 3 are not significantly different, although it may be that the original scoring system slightly overestimated the performance of Cluster 1. Cluster 1 is the most impulsive which, as suggested above, may be related to some slight artificial overestimation of the Metacomprehension score for this group. That Cluster 6 is the group with the most awareness of their own comprehension, as measured by the test used within the present study, cannot, however, be seriously doubted.

We are, therefore, left with the remaining two possibilities. Either, that some kind of U-shaped developmental growth pattern associated with developing a more sophisticated strategy, resulting in a dip in performance, is occurring, for example, for the slightly older Cluster 6. Or, that the development of children in Strategy Clusters 1 and 6 in terms of strategic behaviour and performance on the MDL task is delayed because of their adoption of an unhelpful strategic style. Their Metacomprehension is relatively developed because they are older, but this has not helped them to develop strategically. There are, as we have noted, limitations on the extent to which such an issue can be resolved with cross-sectional data. However, the evidence reported above of the overwhelming strategic and performance superiority of Cluster 3 relative to Cluster 6 would seem to argue in favour of the latter possibility. This pattern of results, combined with the statistically significant but moderate correlation (reported in Table 5.17) between Metacomprehension and performance, would seem to support the view, reviewed earlier in relation to critiques of Piaget's model of cognitive conflict, that being aware of one's own level of understanding may be a necessary, but is not a sufficient condition for the development of effective strategic processing on a problem-solving task.

In the discussion of the correlations between Predictor Measures and Strategy Components overall some indication was also highlighted that Locus of Control may not be related to Performance, but that it might be related to choice of strategies. This possibility is only mildly supported by the present results in relation to Strategy Clusters. The Scheffe´ test result for Locus of Control (see Table 5.19) suggests that it discriminates between the Clusters only at a very weak level of statistical significance (0.1), and it is observable from the same table and from the Atypicality Chart (Fig. 5.9) that only Cluster 1 varies in any notable way from the population mean, again only at the very weakest level of statistical significance. It may, of course, be that Locus of Control interacts in interesting ways with other underlying cognitive factors within Strategy Clusters, and this will be investigated below when we come to look at the relationships within subgroups.

3. Predictor Scores of Central Cases in each Strategy Cluster

As a further method of investigating the patterns of underlying cognitive factors of the different strategic patterns identified by the Cluster Analysis the Predictor Measure scores of the 5 most central cases previously identified within the 5 main Strategy Clusters were selected for more detailed study.

As before, the pattern of scores is recorded according to whether they were High, Average or Low relative to the sample mean. For this purpose these categories are defined as before, thus:

High = > Mean + $^{1}/_{2}$ S.D.
Medium = < Mean + $^{1}/_{2}$ S.D. and > Mean - $^{1}/_{2}$ S.D.
Low = < Mean - $^{1}/_{2}$ S.D.

The raw means, standard deviations and figures for Mean + $^{1}/_{2}$ S.D. and Mean - $^{1}/_{2}$ S.D. for the whole sample, used to produce these results, are reproduced in Appendix H.4. The two exceptions to this procedure on this occasion are Gender, where males and females are indicated with M and F, and Age, where this is recorded as 6, 8 or 10.

Inspection of the scores on the Predictor Measures of the 5 Central Cases in each Cluster (Table 5.20) confirms the variations between Clusters already identified and discussed, but also reveals that there are clear variations within Clusters. This suggests both that the pattern of strategic behaviour adopted may be mediated by other factors than those included in the present study, and that there may be interesting interactions between Predictors.

Table 5.20

5 Main Strategy Clusters: Predictor Measure scores of Central Cases

			Predictor Measure												
			Wk Mem		Metacog						FDI			
Case	Gen	Age	WM	FIT	Q1	Q2	Q3	M/c	SF	Tot	L/C	R-I	RFT	CEFT
Cl. 1														
5	F	6	L	A	L	L	L	A	L	L	L	L	L	L
6	F	6	L	A	L	L	L	H	A	L	A	A	L	L
15	M	6	H	L	L	A	L	H	L	L	A	A	L	A
19	M	6	A	L	L	L	L	H	L	L	A	L	H	L
42	M	8	A	L	H	L	H	L	L	A	L	L	A	L
Cl.2														
13	M	6	L	L	H	A	H	L	H	H	L	L	H	L
26	M	8	L	L	L	L	A	L	L	L	L	A	L	L
37	M	8	H	H	A	A	H	L	H	A	H	H	H	H
51	M	10	A	H	H	A	H	H	H	H	H	A	H	A
58	F	10	A	A	H	A	H	H	H	H	H	A	A	H
Cl.3														
36	F	8	H	H	A	H	H	H	H	H	A	H	L	H
43	F	8	L	L	H	A	A	H	H	H	A	H	L	A
46	M	8	H	A	H	L	H	A	L	A	H	A	A	H
56	M	10	H	H	H	L	H	A	H	H	H	H	H	H
64	F	10	H	H	H	H	H	A	H	H	H	H	H	H
Cl.4														
10	F	6	L	L	A	H	L	A	L	L	H	A	H	A
12	M	6	A	A	A	H	H	L	L	A	L	A	L	L
24	M	6	L	L	A	L	L	L	L	L	A	L	L	A
47	M	8	H	L	H	A	L	L	L	L	A	L	A	A
68	F	10	L	A	L	A	A	L	L	L	H	H	A	L
Cl.6														
39	F	8	L	A	H	L	A	H	H	H	A	L	L	L
44	M	8	H	A	A	A	L	H	H	A	H	A	L	A
59	F	10	H	H	H	H	H	H	L	H	L	H	H	H
69	M	10	H	H	A	H	L	H	L	A	A	A	A	A

H = High (> M+1/2 S.D.)
A = Average (< M+1/2 S.D. & > M-1/2 S.D.)
L = Low (< M-1/2 S.D.)

Thus, once again, the relative positions of the 5 main clusters, illustrated in the bar charts and atypicality chart in the previous section, is reinforced. The central cases of Cluster 3, which exhibited the strongest levels of performance, score more Highs (39) and fewer Lows (7) than any other cluster. Cluster 6 scores the next strongest with 26 Highs and 13 Lows. When we did this analysis on performance Cluster 6 looked rather stronger than Cluster 2, and so it is here. Clusters 1 & 4, clearly the weakest groups, once again exhibit a preponderance of low scores amongst their central cases.

While the patterns of the central cases looked generally very consistent when we looked at Strategy Components and Performance Indicators, here we find some intriguing variations. The clearest example of this variation within clusters appears in the intermediate Cluster 2. Here we have Case 26 (an 8 yr. old) with nearly all Low scores and a few Averages, Case 13 (a 6 yr. old) with a mixture of Lows and Highs, and the other 3 cases (an 8 yr. old and two 10 yr. olds) with a preponderance of Highs and Averages. This may be another example, as we found with performance, of the older members of clusters scoring a little more strongly than the younger central cases. There would appear to be a similar pattern , also, within Cluster 6, although here it is really just Case 59 which looks atypically strong.

Overall the evidence of these Central Cases would seem to be that the relationships between underlying cognitive factors, strategies and performance on the MDL task are not straightforwardly linear. Some interesting interactions between these different aspects of cognitive functioning in relation to this kind of task may emerge when we look at relations within subgroups at the end of this analysis.

One feature of interest are the scores on Metacomprehension for the cases within Clusters 1 and 6. It will be recalled that these two clusters scored particularly well on this aspect of metacognition, and this is reinforced here. All the cases in Cluster 6 and three cases in Cluster 1 score High on Metacomprehension. This is particularly striking because the scores within Cluster 1 for other metacognitive aspects are predominantly Low (4 out of 5 cases score Low overall for Metacognition), and even in Cluster 6 there are a number of Low scores also.

From the previous analyses we have carried out of the relationships between Predictor Measures and Performance Indicators, Metacognition and CEFT have emerged as the most strongly related overall to performance. This is once again borne out here. The scores on Total Metacognition and CEFT for the weakest Clusters 1 & 4 are all Low or Average. Cluster 2 has a mix of scores at all levels, while Cluster 6 contains only one Low score on CEFT. Cluster 3, the strongest performing cluster, scores 8 Highs and 2 Averages on these two measures. In a situation where many of the Predictor Measures correlate at reasonable levels with one another, however, it is not easy to disentangle the separate effects of individual factors. In order to help clarify this situation, a regression analysis was carried out, and this is reported next.

c) Multiple Linear Regression Analysis of Predictor Measures and Strategy Clusters in relation to Performance Indicators

The previous analyses have suggested that interesting relationships exist in the data between some of the Predictor Measures and both strategic behaviour and performance on the MDL task.

The strongest linear relationships, as revealed by the correlation matrices, with both Strategy Components and Performance appear to be exhibited by the Total Metacognition score and CEFT, a measure of Field-Independence. Within the Total Metacognition score, there is some evidence that Metacognitive Awareness & Control is more strongly related than Metacognitive Knowledge. When relationships with Strategy Clusters are examined these factors continue to be relatively strong, but Age and Working Memory also exhibit significant relationships.

We have also discussed some interesting variations in relationships. Locus of Control, for example, appears to be relatively strongly related to Strategy Components, but not to Strategy Clusters or Performance. Metacomprehension, one of the two measures of Metacognitive Awareness & Control, appears to be significantly related overall to Performance, and yet is quite strongly associated with Strategy Clusters 1 & 6, which exhibit the High H's per T strategic style which appears to result in relatively weak Performance.

In order to attempt to disentangle the separate relationships of the various underlying cognitive factors and patterns of strategic behaviour with performance, Multiple Linear Regression and Covariance Analysis was carried out for indicators of Performance and Learning. In this context, the Covariance Analysis carried out involved calculation of variance attributable to a series of reduced regression models which contained all but one of the Predictor Measures contained in the total regression (or 'full') model. The variance attributable to each Predictor Measure was then calculated by subtracting the variance explained by the reduced model from that explained by the full model. The results of these analyses are reported in Table 5.21 for Performance and Table 5.22 for Learning. The results for Performance are also illustrated by the bar charts in Fig. 5.10.

Table 5.21
Multiple Linear Regression Analysis: Performance Totals

Perf. Indicator		N	Total R^2%	Age	WM	Metacognition K	Metacognition A/C	Metacognition total	L of C	Ref.	F.Ind.	Strat.	Inter-action
					Covariance Results % of Total Explained Variance								
Trial of Last Error	1)	72	54.5**	1.3	2.1			20.3**	1.0	1.0	9.6*		64.7
	2)	72	58.2**	1.6	1.7	11.6*	13.7**		0.8	0.6	6.6		63.4
	3)	68	77.2**	0.4	1.8			4.3**	0.0	0.0	1.0	31.7**	60.8
	4)	68	78.5**	0.1	1.9	4.6*	1.1		0.0	0.0	0.4	27.3**	64.6
Verb. of H.	1)	72	54.2**	3.5	0.9			25.2**	0.6	0.3	4.5		65.0
	2)	72	57.2**	3.6	0.8	15.2*	13.9**		0.6	0.1	3.0		62.8
	3)	68	79.2**	0.3	0.8			5.4**	0.0	0.1	0.2	33.6**	59.6
	4)	68	80.5**	0.6	0.8	4.8*	1.9		0.0	0.0	0.1	30.3**	61.5
H's on T's 1,2, & 3	1)	72	37.9**	5.9	3.8			21.6**	0.0	0.0	0.1		68.6
	2)	72	42.2**	6.3	3.2	8.4	21.1*		0.0	0.0	0.3		60.7
	3)	68	48.7**	1.9	1.3			8.9*	0.1	0.5	0.7	21.6	65.0
	4)	68	51.1**	3.9	1.3	2.5	10.7		0.1	0.5	0.9	17.7	62.4

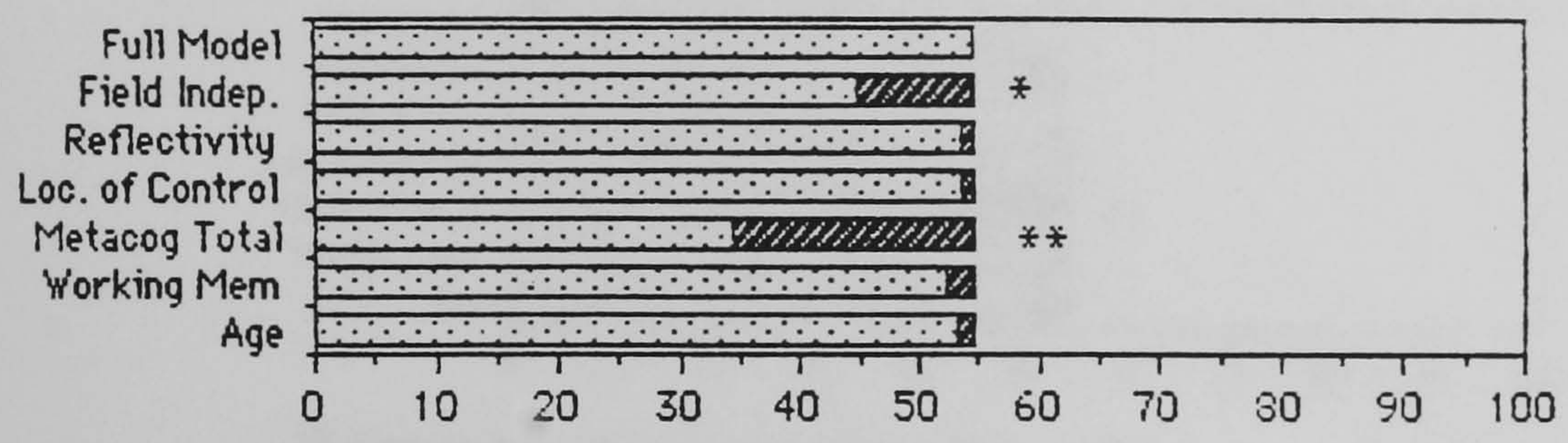
** = sig. at 0.01 level
* = sig. at 0.05 level

Figure 5.10

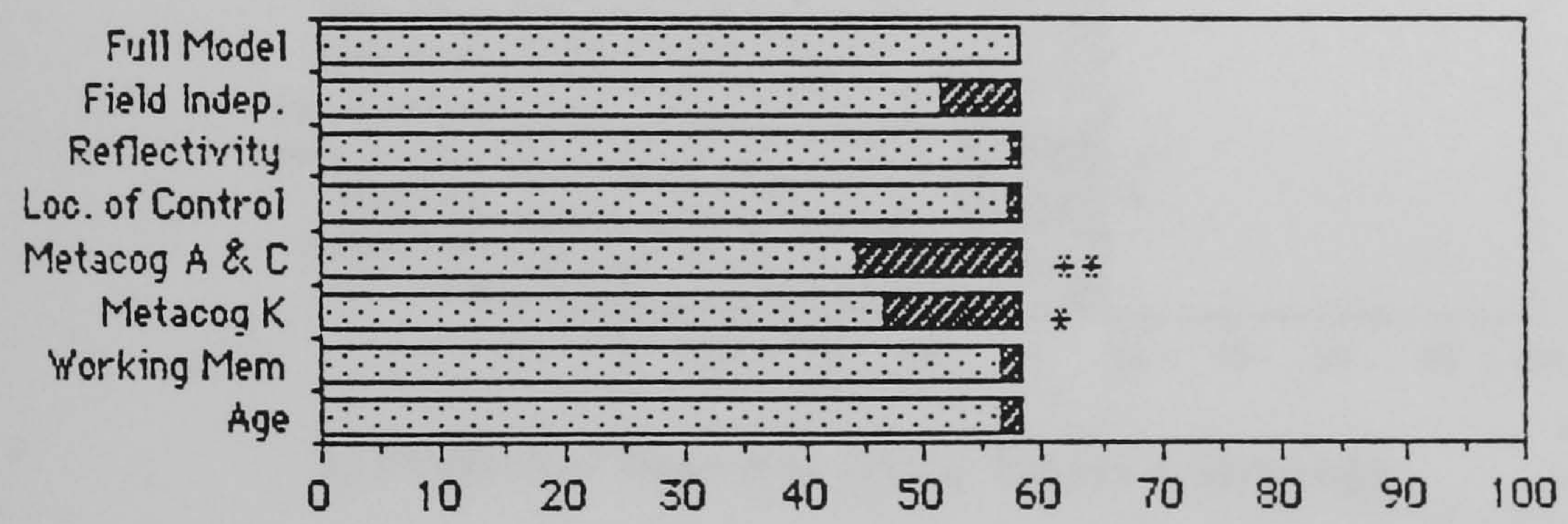
Proportion of variance on Performance Indicators attributable to full and reduced regression models

Trial of Last Error

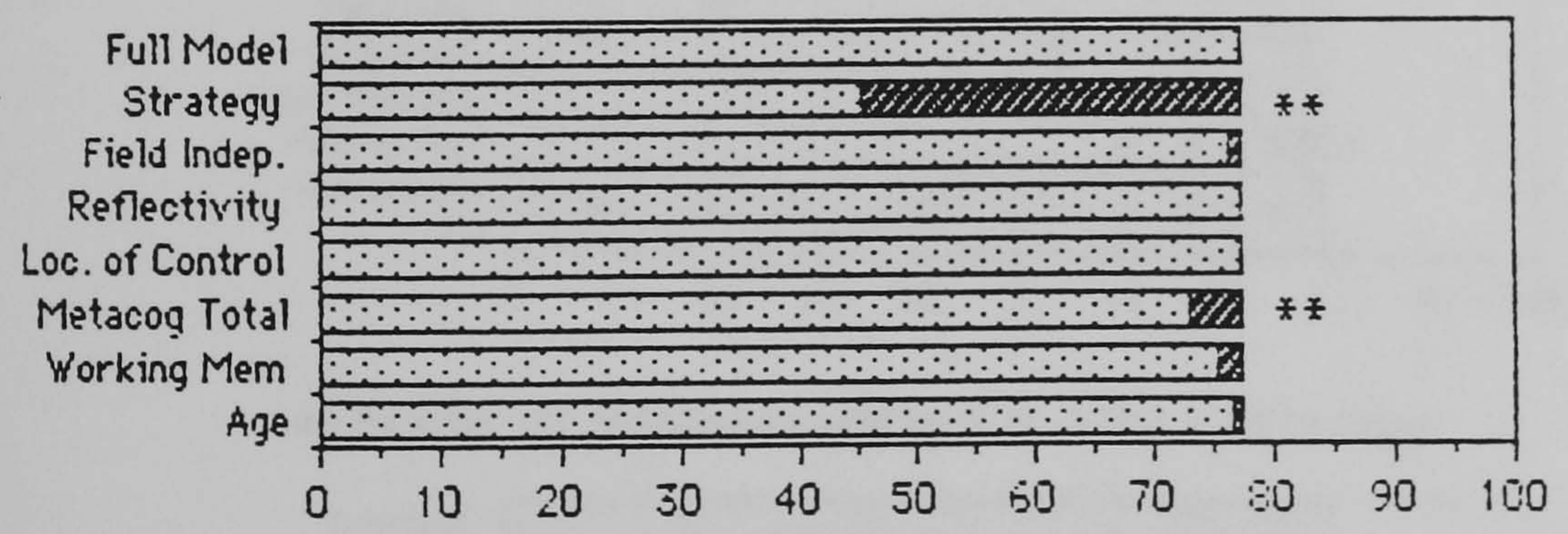
1) Predictor Measures (Meta Total)



2) Predictor Measures (Meta K and A/C)



3) Predictor Measures (Meta Total) + Strategy



4) Predictor Measures (Meta K & A/C) + Strategy

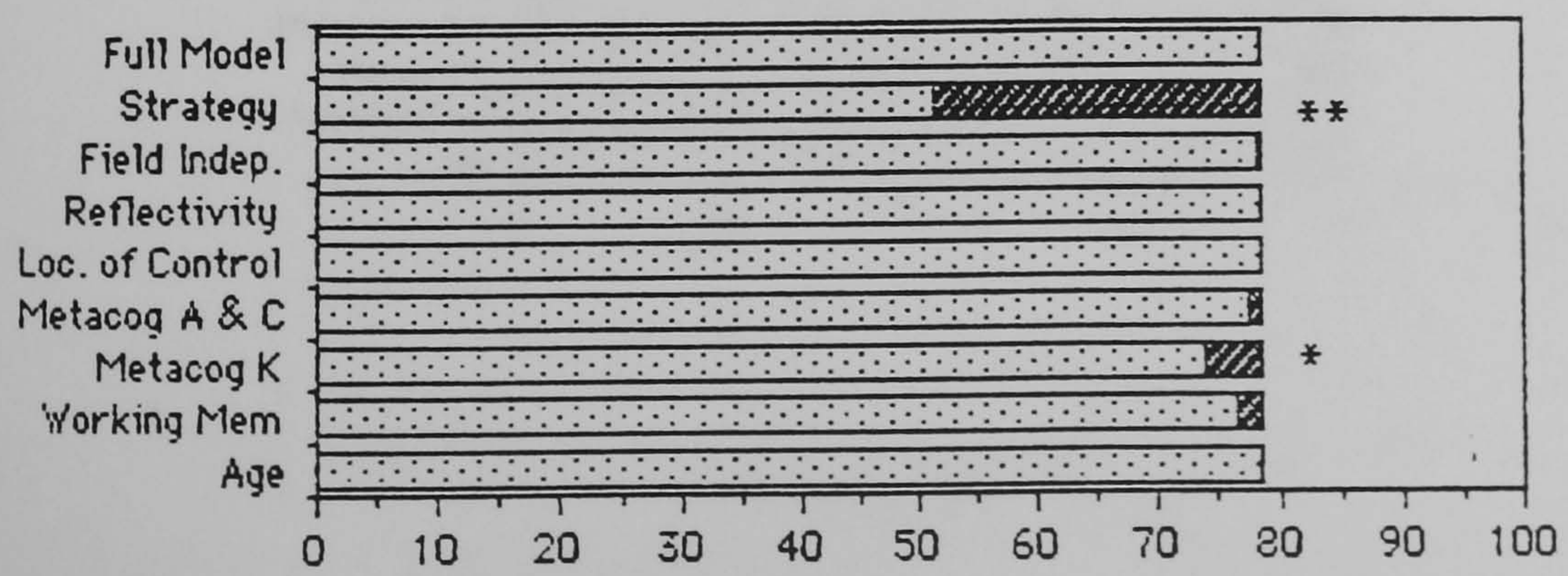


Figure 5.10 cont'd

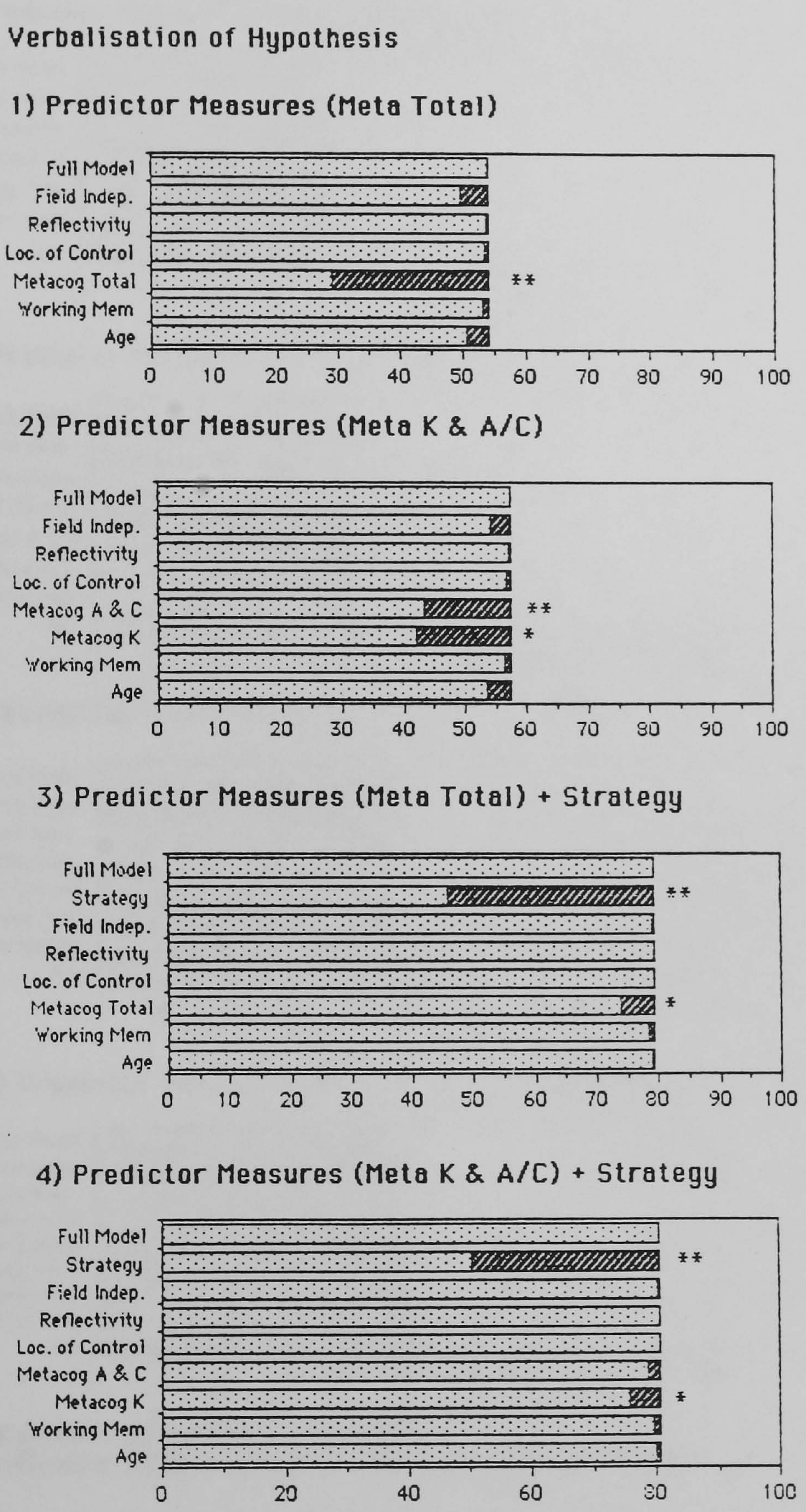
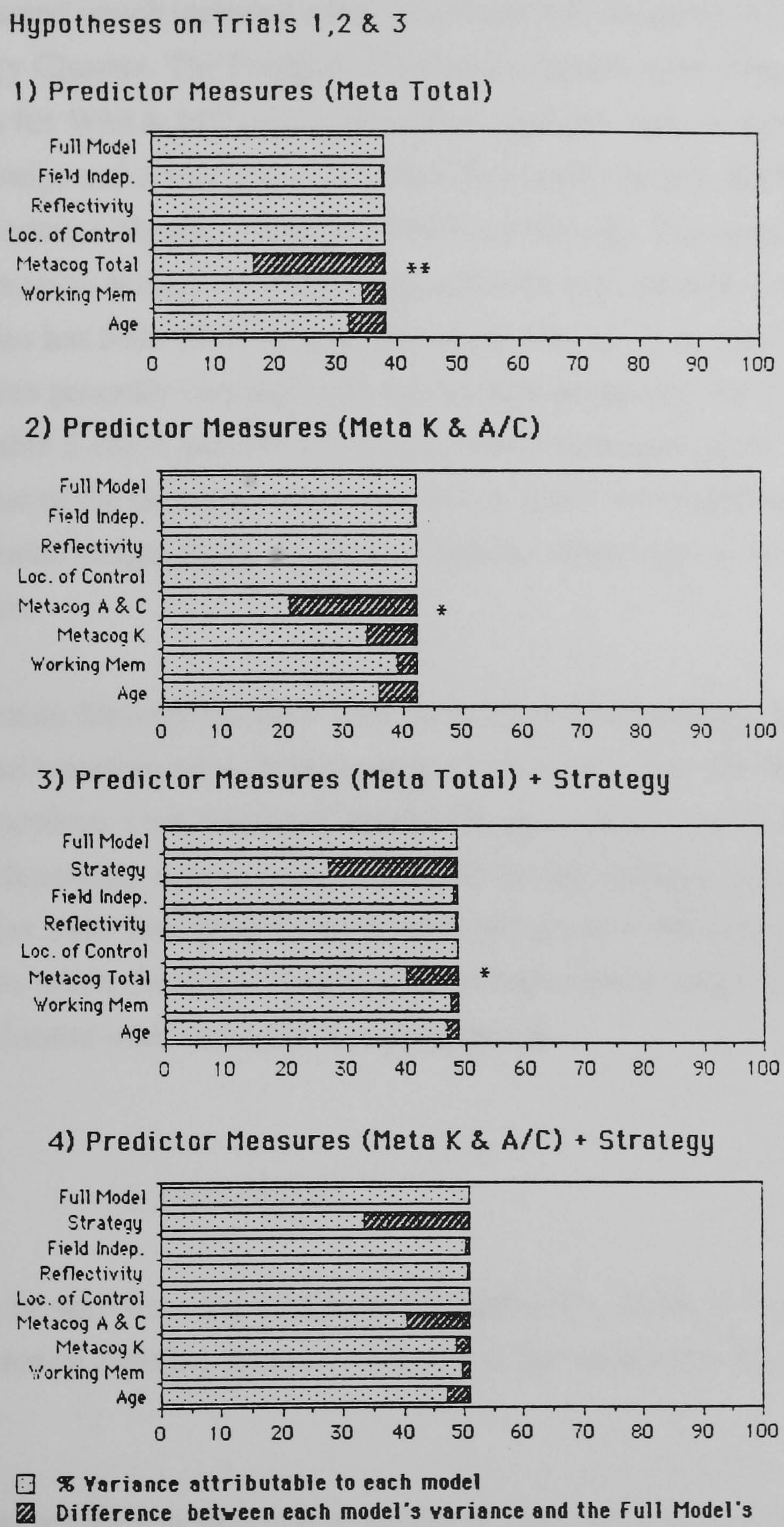


Figure 5.10 cont'd



For the purposes of these analyses the various Performance Indicators have been taken as the criterion variables, and 4 slightly different total regression models were constructed which included either just Predictor Measures or Predictor Measures and Strategy Clusters. The Predictor Measures included were Age, Working Memory (scores for WM & FIT combined), Metacognition (split in separate analyses into Knowledge and Awareness & Control), Locus of Control, Reflectivity and Field Independence (Rod & Frame and CEFT combined). The opportunity afforded by regression analysis to examine the variance explained by combinations of related variables has been taken up as indicated by this list. In as much as the combined measures generally correlate with one another positively, but at weak or moderate levels (see Table 5.16), it was felt that the combined measures might be a more robust indicator of the particular cognitive factors under investigation. In this kind of analysis, also, undue weight might be given to aspects represented by more than one individual measure.

The 5 main Strategy Clusters were included in the regression model by means of the standard transformation of such categoric data known as 'dummy variable coding'. In this procedure, each Strategy Cluster became a variable and each case was simply coded 1 or 0 depending upon whether they were in that Strategy Cluster or not. These variables were then looked at as a combined group within the regression analysis. In the analyses where Strategy Clusters were included, the 4 subjects who were not in the 5 main clusters were excluded from the analysis.

1. Performance

As can be seen from the R^2 figures in Table 5.21 , all the full models related to Performance criteria explained sufficient of the variance to be significant at the 0.01 level.

The Covariance results reveal a number of interesting features of the data.
First, it is apparent that for all three Performance Indicators a substantial proportion of the explained variance is attributable to interactions between the predictors. These figure range from 59.6% to 68.6%. This is very much in line with the view that there are significant interactions between underlying cognitive factors, choice of strategy and

performance in problem-solving behaviour. As has been previously indicated, it is the intention to explore these interactions further in the final section of this analysis.

Second, these results give considerable support to the view that performance on the MDL task is largely associated with Strategic Behaviour and various aspects of Metacognition. In all the analyses in which it is included (models type 3 & 4), Strategic Behaviour is the predictor which on its own accounts for the largest proportion of the explained variance, and this contribution is significant at the 0.01 level for analyses related to Trial of Last Error and Verbalisation of Hypothesis during Criterion. It is also notable that models type 3 & 4, which include Strategy Cluster as a predictor, consistently account for more of the total variance than models type 1 & 2, which do not include Strategy Cluster.

In analyses where Strategy is not included in the Full Model (model types 1 & 2) Metacognition clearly emerges as the most significant predictor. In model type 1 the contribution of Total Metacognition score is significant at the 0.01 level for all three Performance Indicators. In model type 2, both Metacognitive Knowledge and Metacognitive Awareness & Control emerge as significant predictors, in each case Awareness & Control being slightly more significant than Knowledge.

It is particularly interesting to compare the results for Metacognition when Strategy is and is not included in the regression model. Comparison of model types 1 & 2 with model types 3 & 4 shows that when Strategy is included much of the independent contribution of Metacognition disappears. This is further evidence of the relationship between Metacognition and Strategic Behaviour. However, although in model type 3 analyses the contribution of Total Metacognition is much reduced, it is nevertheless still significant in relation to all three Performance Indicators.

When we look at the model type 4 analyses, it is clearly apparent that the inclusion of Strategy reduces the independent contribution of Metacognitive Awareness & Control significantly more than it does that of Metacognitive Knowledge. Thus, for the analyses related to Trial of Last Error and Verbalisation of Hypothesis during Criterion, while the contribution of Metacog A/C almost disappears in model type 4, the contribution of Metacog K remains significant at the 0.05 level. This suggests that while Metacognitive Knowledge may have a somewhat independent relationship with performance on the MDL task, Metacognitive Awareness & Control is much more closely associated with strategic behaviour. This relates well with the general pattern of earlier results indicating stronger relationships for Metacognitive Awareness & Control than for Metacognitive Knowledge with both measures of strategic behaviour and performance.

The only other statistically significant result is that for Field Dependence-Independence in relation to Trial of Last Error when Strategy Cluster is not included in the analysis. This confirms to some extent the results obtained in other analyses for CEFT, in particular.

2. Learning

Analyses of the various models related to Learning are reported in Table 5.22. As we have seen earlier, the relationships between the Predictor Measures and Learning appear to be weaker than those with Performance (see, for example, Table 5.17). In line with this the regression models related to scores for Learning account for less of the variance than those related to Performance. However, although fewer of these full models are statistically significant, there are nevertheless some interesting patterns in the results.

To begin with, the pattern of relationships revealed is a much more diffuse and variable one than that for Performance, with a number of different Predictors making relatively large contributions to the explained variance. It is also clearly the case that the variance which is explained by the various models is accounted for much more by the independent effects of individual Predictors. The contributions of interactions between Predictors are much smaller than in the previous analysis, and even disappear altogether in several cases.

The strongest relationship which emerges from these analyses, however, is that between scores for Learning and membership of particular Strategy Clusters. On both Trial of Last Error and Verbalisation of Hypothesis during Criterion the full models explain sufficient variance to be statistically significant only when they include Strategy Clusters (model types 3 & 4).

This result is very much in line with the evidence produced earlier in the section dealing with Performance scores for the Strategy Clusters, where a clear developmental pattern was identified in relation to Learning (see Table 5.14b). The present data would thus

Table 5.22
Multiple Linear Regression Analysis: Learning

Perf. Indicator		N	Total R^2%	Age	WM	Metacognition K	Metacognition A/C	Metacognition total	L of C	Ref.	F.Ind.	Strat.	Inter-action
					Covariance Results % of Total Explained Variance								
Trial of Last Error	1)	72	14.1	0.1	56.3			0.8	7.8	5.8	36.7		-
	2)	72	24.9	0.0	33.3*	9.5	34.1*		0.2	2.2	15.9		4.8
	3)	68	34.1*	1.8	16.1			2.2	3.3	1.0	18.7	58.4*	-
	4)	68	41.2*	2.7	15.6	1.6	15.8		1.0	0.4	12.3	39.5*	11.1
Verb. of H.	1)	72	6.5	1.7	25.0			15.9	44.7	11.2	12.2		-
	2)	72	11.2	2.1	12.3	45.4	5.6		36.9	4.0	10.7		-
	3)	68	32.4*	1.9	1.6			11.5	8.9	0.6	1.0	70.5**	4.0
	4)	68	36.1	0.5	2.1	14.6	4.1		12.2	0.7	1.6	57.5*	6.7
H's on T's 1,2, & 3	1)	72	15.8	17.2	4.6			0.1	6.8	17.1	28.6		25.6
	2)	72	23.3	11.6	5.3	19.8	18.3		2.1	13.3	21.6		18.0
	3)	68	22.8	5.1	8.5			0.4	11.0	6.7	18.0	33.4	16.9
	4)	68	31.0	2.1	8.8	22.1	9.1		4.3	6.5	19.9	22.3	4.9

** = sig. at 0.01 level
* = sig at 0.05 level

seem to offer some support to the view that the Strategy Clusters not only represent different stages in the development of strategic behaviour in relation to the MDL task, but also imply different stages in the development of the ability to learn quickly about new tasks. This has important implications for our understanding of the development of problem-solving abilities in young children which we will discuss in the concluding chapter.

d) Interactions: Correlations between Predictors and Performance within subsets of the sample population

Throughout the foregoing analysis of the relationships between cognitive factors, strategic behaviour and performance the non-linear nature of these relationships has been evident. Some Strategy Components have appeared relatively strongly in otherwise rather weak and simple overall patterns of strategic behaviour. The analysis of the Strategy Clusters has revealed a stylistic variance in the development of strategic behaviour. Some cognitive factors relate clearly to strategic behaviour but less clearly to performance. There is some evidence of the possibility of a U-shaped development of strategic behaviour, as is commonly observed in the development of problem-solving abilities. Finally, for example in the regression analysis, we have seen evidence of interaction effects between Predictors and Strategy in relation to Performance.

In this final part of the analysis of the data an attempt was made to explore these interactions a little further by examining correlations between Predictor Measures and Performance Indicators within significant subsets of the sample population. The earlier examination of the significant differences between mean scores for Predictor Measures of the Strategy Clusters revealed that different cognitive factors appear to be significant at different stages of development (see Table 5.19). Thus, amongst the least sophisticated Strategy Clusters, while Cluster 4 was distinctively weak on Metacomprehension and overall Metacognition, Cluster 1 was distinctively external in terms of Locus of Control. Among the more sophisticated Strategy Clusters, Cluster 6 was noticeably strong on Metacomprehension, while Cluster 3 children were distinguished by their Reflectivity and Field Independence. The present examination was intended to explore the ways in which the relationship between cognitive factors and performance may be mediated by interactions with other cognitive factors and with the pattern of strategic behaviour.

Three types of subset were examined. First, we looked at subsets determined by the subjects' scores on Metacognition. This was selected as generally the most significant of the Predictor Measures. It is also worth noting that subsets selected on this basis in the previous study referred to earlier (Whitebread, 1983) yielded some highly significant comparisons. Second, in order to look at the ways in which the effects of cognitive factors on performance are mediated by strategic behaviour, the subsets determined by

Strategy Clusters were examined. Finally, relationships within the different age groups were investigated, within which it might be possible to explore the possibilities of U-shaped growth, and of relationships between underlying cognitive factors and performance strengthening as children grow older.

1. Metacognition subsets

The correlations between Predictor Measures and Performance Indicators for subsets determined by scores for Total Metacognition are reported in Table 5.23. The two subsets were produced simply by using
the population mean score as a cut off point. Examination of the correlations within this table reveal that, in a number of ways, the cognitive factors most strongly associated with performance on the MDL task do indeed appear to vary as a function of metacognitive knowledge and processes.

To begin with, it is notable that a number of Predictor Measures are associated at statistically significant levels with Performance within the Weak subset, but not within the Strong subset. These are, in order of strength of the correlations, CEFT, Metacognition Total itself, and both scores for Working Memory. This relates well to the earlier finding (Whitebread, 1983) that where weak metacognition is associated with the use of relatively simple strategies the level of performance will be dependent upon other abilities. In the previous study Working Memory appeared to be a strong factor in this context, and to this the present data would suggest we should add Field Independence. That the Metacognition score itself is a factor where metacognition is weak is perhaps a further indication of its pivotal significance in relation to the development of problem-solving skills on novel tasks.

For the Strong subset only Age, Metacomprehension (in relation to Learning) and one aspect of Metacognitive Knowledge are statistically significant at all. This result tends to support the view that once metacognitive ability and knowledge have been developed very little else matters in relation to the successful development of problem-solving skills. The Age and Metacognitive Knowledge result perhaps indicate that the acquisition and utilisation of experience continues to refine skills up to a point. That Metacomprehension is so strongly related to improvement in the Trial of Last Error

Table 5.23

Metacognition Subsets: Correlations between Predictor Measures & Performance Indicators

Predictor Measures		Performance Measures: Performance T of L.E	Performance Verb/H	Performance H's on T123	Learning T of L.E	Learning Verb/H	Learning H's on T123
Age		23	38*	11	-06	03	06
		43**	25	40*	13	-04	32
Wk Mem	WM	34*	31	38*	-07	13	-03
		25	18	19	09	-19	00
	FIT	32	32	33*	-27	04	06
		11	02	14	-12	13	-00
Meta Know	Q1	25	27	04	-03	08	-31
		30	33*	17	24	01	-01
	Q2	25	15	32	18	-20	08
		-04	09	-00	21	-10	-19
	Q3	06	12	02	11	-11	-19
		-08	-03	-01	00	-13	-04
Meta A/C	M/c	09	02	22	03	04	24
		32	20	22	50**	-13	04
	S F	22	21	12	-17	17	22
		-12	03	11	-27	-08	18
Meta Total		47**	44**	36*	08	-02	-07
		10	27	24	18	-21	05
L of C		-05	-04	07	08	-18	-21
		19	20	16	-25	-13	27
R-I		16	-19	-25	12	09	-06
		06	-06	-10	-25	05	-23
F Dep-Indep	RFT	11	-10	-05	-02	15	09
		-12	06	-12	19	-19	14
	CEFT	57**	52**	52**	25	-01	-06
		18	10	07	01	08	20

* sig at 0.05 level
** sig at 0.01 level

Subgroup 1: Weak: 35 cases
Subgroup 2: Strong: 37 cases

(In each pair of rows, the first row gives Subgroup 1 and the second, printed in italics, gives Subgroup 2.)

score for the Strong subset, and not for the Weak subset, would appear to indicate that this ability is dependent upon other cognitive factors associated with the development of general metacognitive abilities for any effect it might have upon performance. This would tie in with the view that being aware of one's own level of understanding is a

Table 5.24

Correlations between Predictor Measures & Performance Indicators within the 5 Main Strategy Clusters

	Performance Indicators					
	Performance			Learning		
Predictor Measures	T of L.E	Verb/H	H's on T123	T of L.E	Verb/H	H's on T123
Age	-27	10	16	-03	-13	-19
	-01	21	-21	14	-39	38
	61*	46	52	51	-43	59*
	-29	-22	29	-07	10	19
	27	33	39	09	-36	10
Wk Mem WM	25	52	52	-04	-27	-52
	70*	46	54	32	-41	11
	57	27	22	16	-28	23
	28	-16	-37	-04	04	-22
	01	08	46*	-27	-14	-01
FIT	27	20	-30	-53	-04	31
	-44	-35	10	-38	29	-65*
	70*	42	27	22	-52	48
	-04	-24	03	35	16	-04
	-09	-08	25	-24	-06	-14
Meta Know Q1	11	-02	13	-25	44	-17
	58	81**	11	25	-59	-39
	48	33	53	14	-07	05
	43	51	30	33	-13	-09
	-22	14	09	09	-07	-08
Q2	34	44	-20	09	-33	17
	69*	38	54	31	-24	02
	35	13	25	-18	-12	00
	-49	-09	06	19	28	-29
	02	25	07	11	-46*	-11
Q3	-00	35	-06	20	-54	08
	27	53	14	31	-70*	-11
	09	-06	22	-21	-08	06
	43	10	30	58*	-34	13
	-13	-19	04	-29	11	-17
Meta A/C M/c	39	51	05	36	-73**	-04
	05	-27	50	03	19	-36
	38	59*	41	38	-04	41
	14	-09	07	-13	25	-34
	14	26	23	15	-44	15
S F	54	88**	-12	09	-51	11
	22	16	42	17	-37	-09
	25	24	45	-33	13	01
	10	10	05	-52	-27	03
	-05	03	44*	-17	-12	50*
Meta Total	47	78**	-05	15	-58*	04
	61	62	53	38	-66*	-33
	42	34	55	-11	-02	14
	41	38	49	24	-33	-20
	06	16	37	-08	-31	20

Table 5.24 cont'd

Predictor Measures	Performance Indicators: Performance — T of L.E	Performance — Verb/H	Performance — H's on T123	Learning — T of L.E	Learning — Verb/H	Learning — H's on T123
L of C	-11	11	-01	-08	11	-01
	-01	**-11**	**-29**	**-13**	**35**	**10**
	_57_	_33_	_35_	_22_	_-68*_	_43_
	_-35_	**_-28_**	**_-14_**	**_-42_**	**_-30_**	**_26_**
	05	19	41	-10	-44	16
R-I	-03	19	-41	-42	05	41
	40	**22**	**51**	**36**	**-48**	**-05**
	_26_	_17_	_09_	_34_	_-64*_	_26_
	_-31_	**_-49_**	**_17_**	**_57*_**	**_60*_**	**_26_**
	-03	23	09	-02	-47*	03
F Dep-RFT Indep	-10	-01	21	08	-04	-18
	-01	**03**	**-21**	**-60**	**40**	**14**
	_04_	_-08_	_15_	_-21_	_-29_	_14_
	_-15_	**_-21_**	**_-01_**	**_34_**	**_22_**	**_-04_**
	-12	03	30	-19	-17	-34
CEFT	02	32	33	46	-24	-32
	62	**22**	**63***	**33**	**-29**	**07**
	_67*_	_39_	_33_	_24_	_-46_	_20_
	_-25_	**_-50_**	**_-09_**	**_24_**	**_49_**	**_18_**
	06	22	20	-22	-42	13

* sig at 0.05 level
** sig at 0.01 level

Plain = Cluster 4
Bold = Cluster 1
Plain Italic = Cluster 2
Bold Italic = Cluster 6
Plain Underlined = Cluster 3

necessary but not sufficient requirement for learning how to tackle new problems. This relates to criticisms of Piaget's model of cognitive conflict as a mechanism for learning.

2. Strategy Clusters

In Table 5.24 are reported the correlations between Predictor Measures and Performance Indicators within each of the 5 Main Strategy Clusters. These results provide further support for the view that the relation between general cognitive factors and performance is mediated by the pattern of strategic behaviour. There are numerous cases where a significant relation exists between a Predictor and some Performance Indicators for a particular Strategy Cluster which does not exist for other strategic groups. In this sense the overall analysis of the relationships between Predictor

Measures and performance in relation to the MDL task clearly masks the very different and, in some cases, highly significant relationships which exists at different stages in the development of strategic behaviour.

For ease of comparison Table 5.24a below lists those Predictors most strongly related to Performance Indicators for each of the Strategy Clusters.

Table 5.24a

Significant relations between Predictor Measures and Performance Indicators for the 5 Main Strategy Clusters

Cluster	Predictors sig. related to: Performance	Learning
4	Strat Flex/Meta Tot	Metacomp/Meta Tot
1	WM/Meta K Q1,Q2/ CEFT	FIT/Meta K Q3/Meta Tot
2	Age/FIT/Metacomp /CEFT	Age/Loc of Control/R-I
6	-	Meta K Q3/R-I
3	WM/Strat Flex	Meta K Q2/Strat Flex/R-I

At a general level it is perhaps notable to begin with that a wide range of different cognitive factors appear to be relevant to performance at different stages in strategic development. Once again, however, it is also notable that different aspects of Metacognition are significant for each of the Strategy Clusters in some way.

For Cluster 4, at which stage children were commonly found to be 'stimulus describing' and failing to co-ordinate verbal hypotheses and stimulus choices, it is on the Performance Indicator of Verbalisation of Correct Hypothesis during Criterion that metacognitive processes are revealed to have the greatest impact. All four of the highly significant relationships highlighted in Table 5.24a relate to this aspect of Performance. For Cluster 1, where a high number of Hypotheses per Trial were produced, aspects of working memory, not surprisingly, become relevant to both performance and learning. It is interesting that the FIT score is significantly related to Trial of Last Error for

Cluster 2, which is the cluster which had difficulties with negative information, suggesting that this may be a problem of excess load on memory. Cluster 6, however, which, relative to Cluster 2, had difficulties with irrelevant information, is notably unaffected by working memory constraints. One measure of working memory is also relevant for Cluster 3's level of performance; here we have the cluster attempting the most sophisticated strategy of 'focussing' involving remembering and co-ordinating all hypothesis and stimulus information.

Perhaps the most intriguing feature of these results are the relationships between cognitive tempo (R-I) and Learning, which are significant for Clusters 2, 6 and 3, the most sophisticated strategy groups. While for Cluster 6 this is in what might perhaps be the expected direction of reflectivity being related to improved learning (on both Trial of Last Error and Verbalisation of Correct Hypothesis during Criterion), for Clusters 2 and 6 the reverse is the case (for Verbalisation of Correct Hypothesis). It can only be assumed that here we either have a case of children being over-reflective, and seeing more in the task than actually exists, or that this is a 'ceiling' effect. Thus, if the more reflective children scored at a high level in Round 1, then their room for improvement in Round 2 is more limited, and their Learning score will be correspondingly depressed. It will be recalled that this kind of ceiling effect was evident (see Table 5.14b) for Clusters 6 and 3 in the earlier analysis of improvements in performance within the 5 main clusters.

3. Age groups

The correlations between Predictor Measures and Performance Indicators within each of the three age-groups are reported in Table 5.25. This table contains very striking evidence of differential patterns between the three age-groups, particularly in relation to level of Performance.

Thus the number of significant correlations between the Predictor Measures and performance for the three age groups are 5 for the 6 yr. olds, 1 for the 8 yr. olds and 15 for the 10 yr. olds. We have reviewed earlier evidence that aspects of metacognition, for example, may become more closely related to performance with increasing age amongst children in these age-groups. Here we would appear to have a very clear effect of this kind, except that it would appear to more generally apply to measures of Working

Table 5.25

Age-group Subsets: Correlations between Predictor Measures & Performance Indicators

Predictor Measures		Performance Indicators: Performance T of L.E	Verb/H	H's on T123	Learning T of L.E	Verb/H	H's on T123
Wk Mem	WM	_37_	_32_	_32_	_06_	_07_	_17_
		-00	**-08**	**-36**	**14**	**-11**	**-41***
		52**	52**	62**	-20	-08	-02
	FIT	_26_	_25_	_15_	_23_	_-07_	_-15_
		22	**19**	**05**	**-53****	**17**	**06**
		45*	38	31	06	11	-12
Meta Know	Q1	_43*_	_43*_	_35_	_29_	_45*_	_-52**_
		-01	**09**	**20**	**38**	**-50***	**-08**
		75**	75**	27	24	01	-08
	Q2	_40_	_24_	_20_	_-14_	_-23_	_04_
		08	**11**	**-14**	**29**	**-39**	**-21**
		22	30	35	02	25	-16
	Q3	_05_	_15_	_09_	_09_	_10_	_-45*_
		-04	**06**	**04**	**07**	**-34**	**-10**
		37	23	08	36	-24	03
Meta A/C	M/c	_28_	_34_	_10_	_-12_	_-24_	_16_
		38	**28**	**45***	**24**	**-04**	**34**
		61**	49*	44*	-11	22	-08
	S F	_26_	_31_	_34_	_28_	_24_	_-18_
		15	**16**	**29**	**-14**	**-07**	**48***
		39	47*	26	-44*	-21	09
Meta Total		_63**_	_68**_	_50*_	_23_	_22_	_-53**_
		20	**24**	**33**	**23**	**-41***	**22**
		81**	79**	48*	-05	-03	01
L of C		_-19_	_15_	_-19_	_-12_	_-16_	_-04_
		03	**-08**	**02**	**-32**	**-06**	**05**
		19	29	24	-44*	-34	16
R-I		_-34_	_34_	_32_	_-05_	_-24_	_19_
		12	**00**	**-01**	**-13**	**-23**	**-27**
		-10	01	15	26	46*	06
F Dep-Indep	RFT	_11_	_-23_	_-06_	_18_	_09_	_-26_
		-01	**01**	**18**	**-13**	**-23**	**-38**
		12	-01	-23	-07	25	-08
	CEFT	_33_	_26_	_34_	_-25_	_-05_	_13_
		29	**18**	**-08**	**02**	**-03**	**-30**
		60**	53**	34	05	31	15

* sig at 0.05 level
** sig at 0.01 level

6 year olds
8 year olds
10 year olds

Memory and Field-Independence. Both of these measures are significantly related to performance for the 10 yr. olds, but are not related at all for the younger age groups. For Metacognition, however, there is some kind of U-shaped pattern evidenced in the figures reported here, with a significant relationship to performance for the 6 yr. olds as well as the 10 yr. olds, but little or no such relationship for the 8 yr. olds.

As regards Learning the patterns of relationships are much more complex. 8 of the statistically significant relationships are negative, and some of these may well be due to the kinds of 'ceiling' effects we have discussed above. There is one positive relationship for each of the three age-groups, each with a different predictor.

While the efficacy of representation of the task (6 yr. olds: Meta K Q1) degree of strategy flexibility (8 yr. olds: SF) and reflectivity (10 yr. olds: R-I) might all well be related in complex ways to learning ability on the MDL task, the nature of these relationships is not clear from the current data and would need to be much more closely examined. What is clear, however, is that the present data suggests that complex relationships do exist between underlying cognitive processes, problem-solving strategies and performance on such as the MDL task. In the review of methodological issues and implications of the present study for theory and research, ways in which these relationships will need to be addressed will be discussed.

Chapter 6. SUMMARY & DISCUSSION

While it is important to recognise the methodological limitations of the present study, and significant ways in which the issues addressed need to be examined in further work making use of complementary methodologies, the present study has produced some interesting and useful findings. The first section of this chapter reviews the main results reported in relation to the four aims of the study. The following sections in this chapter discuss methodological issues and implications of the present study for psychological theory and educational practice.

Section A) Evidence in relation to Aims of the Study

i) The Development of Problem-solving Strategies

Previous research has suggested that children's responses to a problem-solving task can best be described in terms of increasingly sophisticated and complex patterns of strategic behaviour, involving successive recombinations of different strategic elements. The first main aim of the present study was to investigate the pattern of development of strategic behaviour amongst Primary school aged children on the Multidimensional Discrimination Learning (MDL) Task, a task which simulates in a controlled manner learning through the processes of rule induction. Three different versions of Kemler's (1978) story-and-game MDL task were used to allow the 6, 8 & 10 yr. old children in the study to demonstrate their problem-solving abilities optimally, and to examine their responses to different sources of difficulty (i.e. negative and irrelevant information).

The children's responses were analysed according to 10 Strategy Components derived from previous analysis of strategic behaviour on the MDL task, principally within the hypothesis testing literature. In an attempt to identify patterns within the children's responses, correlations between the scores on the Strategy Components were examined and the scores on the 3 different MDL problem types for the Strategy Components were analysed using Cluster Analysis.

The correlations between the Strategy Components overall were predominantly positive and in the middle range. Thus, the pattern of inter-relationships revealed was not straightforwardly linear, which suggested that analysis by clustering was particularly appropriate. A number of general patterns did emerge, however, which largely supported the suggested developmental patterns of previous researchers. Thus, the separate development of short-term and long-term processing suggested by Kemler (1978) was supported, as was the separate development of Lose/Shift and Win/Stay proposed by Schuepfer & Gholson (1980). The Number of Hypotheses per Trial verbalised by the children was found to be largely unrelated to the other Strategy Components, which accorded well with its status as a pivotal element in the two strategic styles later revealed in the analysis.

The Cluster Analysis produced valuable data, both in relation to individual Strategy Components and in relation to the clusters of strategic behaviour it revealed. As regards Strategy Component 1 (No. of Hypotheses per Trial) the finding of Eimas (1969) and others that young children tend to consider one hypothesis at a time appeared to be the case only for the least sophisticated strategically. Many children produced more than one hypothesis at a time, in line with the finding of Phillips & Gholson (1980).

The results for Strategy Component 2 (Hypotheses consistent with Local Feedback) supported the view that children's difficulties with the standard MDL task partly arose from its abstractness, and children's consequent failure to understand its internal logic, rather than from their inability to respond to feedback or control their attention. Even the youngest children in this study, which used Kemler's (1978) more meaningful task, responded to local feedback a very high proportion of the time, despite the lack of any attentional aid.

As regards Strategy Component 3 (Choices consistent with Previous Hypothesis), the results broadly supported the view that the verbal 'introtacts' or hypotheses provided by the children were a valid indication of their real working hypotheses. These results combined with those for Strategy Component 4 (Lose/Shift Hypothesis) provided strong evidence of a good deal of Kemler's (1978) 'short-term efficiency'. Disconfirmed hypotheses were abandoned a very high proportion of the time. A comparison of these scores with those for Strategy Component 6 (Win/Stay), however, again clearly supported the finding of Schuepfer & Gholson (1980) that Lose/Shift Hypothesis is the earlier developing element in the development of full short-term efficiency. The scores for Strategy Component 5 (Lose/Shift Dimension) were also generally lower than for Lose/Shift Hypothesis, confirming that this element of strategic behaviour requires more understanding of the logic of the MDL task, and more co-ordination of information across trials.

The figures for Strategy Components 7-10 confirmed, as Gholson, Levine & Phillips (1972), Kemler (1978) and others have found, that these elements, requiring 'long-term efficiency' are later developing. However, the results of the present study differed from Kemler (1978) in that evidence was clearly found of children within this age group capable of using 'stimulus' memory and using a Focusing strategy. The most likely explanation of this different result would seem to be that Kemler's (1978) version of the problem was significantly more difficult than the version used within the present study. As we have reviewed, there is ample evidence that, when faced with a more difficult problem, children (and adults) revert to simpler strategies which are less demanding, particularly in relation to working memory load.

The other clear overall pattern which emerged from the Cluster Analysis was that, as predicted, problem types b and c, involving children in dealing with negative and redundant information, proved to be more difficult and resulted in simpler strategies. The results tended to suggest that, whatever the source of these difficulties (working memory load, inferential difficulties, or attentional deficits) they were probably different, because different groups of children performed relatively well or badly on the different versions of the problem.

As regards the developing patterns of response to the MDL task, the Cluster Analysis revealed a pattern of 7 clusters of increasingly complex strategic behaviours, within which 5 main clusters appeared in sufficient numbers to be worthy of further analysis. Each of these clusters represented a pattern of strategic behaviour predictable from the previous research on hypothesis testing behaviour with the MDL task.

Clusters 5 & 7 had to be excluded from much of the rest of the analysis because of the small number of cases within the present sample. However, they both had some theoretical validity, and appeared to possibly represent significant types of strategic behaviour of which more cases might have been found with a wider sample. The interpretation of the one case in Cluster 5 was particularly straightforward, as it was a clear example of the 'object preference' stereotype or response-set identified by Gholson, Levine & Phillips (1972), amongst others. A younger sample would very probably have produced more cases of this type of response, where feedback was largely ignored. The 3 children in Cluster 7 presented a more complicated picture, producing a generally sophisticated strategic response to the MDL task, but with very particular difficulties with type c problems (irrelevant information). They verbalised very large numbers of hypotheses on type c problems, many of them irrelevant, and this was an obvious source of their difficulties. Whether this was a problem of attention or a lack of understanding of the logic of the problem was difficult to assess.

Amongst the 5 main clusters, Clusters 1 & 4 were developmentally the earliest and strategically simplest. They were largely made up of 6 yr. olds. Cluster 1 conformed to the pattern of 'attribute perseveration' identified by Kemler (1978) as a common pattern of response among kindergartners (5/6 yr. olds). This involves alternating between the two values of a dimension or attribute, consistent with local feedback. As Kemler (1978) argued, these children showed evidence of some short-term efficiency, but failed to co-ordinate information very effectively between trials. As research in a number of areas has found, young children are often planful in their problem-solving behaviour, but their plans are often inadequate. Such was the case with the children in Cluster 1. The children in this cluster also verbalised a relatively large number of hypotheses, which emerged as a significant stylistic variation.

Cluster 4 proved to be developmentally the simplest strategically of the 5 main Strategy Clusters, producing a pattern of behaviour which might well be described as 'stimulus describing'. On any particular trial, the children in this group appear to have chosen their hypothesis (and they consistently only verbalised one) at random from the 4 clothing items being worn by Anna. In this respect they were actually behaving exactly according to the 'zero memory' assumption first proposed by Restle (1962) as a model for human processing on the MDL task. Most significantly, their scores on Win/Stay were no better than chance. Their high scores on Lose/Shift Hypothesis again suggested support for the analysis of Schuepfer & Gholson (1980), that Lose/Shift emerges as a response to feedback before Win/Stay. Lose/Shift, as emerged later in the analysis of results, was the one aspect of strategic behaviour which bore no relationship to successful performance. Its establishment, nevertheless, appears to be a necessary early step in the development of inductive reasoning on this kind of task.

Thê next cluster developmentally appeared to be Cluster 2. This group was largely composed of 8 yr. olds. The main distinguishing feature of their pattern of behaviour was relative difficulty with type b problems (negative information). Compared to Cluster 6, however, they performed well on type c problems (irrelevant information). This finding, as indicated above, was taken to support the view that these two sources of difficulty are related to different cognitive deficits.

Cluster 6 also showed a mixed pattern of behaviour. This was a predominantly 10 yr. old group, and in some ways the pattern of behaviour was more advanced than that of Cluster 2. The scores for Strategy Component 3 (Choices consistent with Previous Hypotheses), and 9 &10 (Focusing) were all significantly above the sample mean, and indicated planfulness and long-term efficiency. This cluster, however, also had their difficulties with problem type b (negative information), but, perhaps most interestingly, scored lower than Cluster 2 on problem type c (irrelevant information). Their relative difficulties with irrelevant information may well have been connected to the other key distinguishing feature of this cluster, which was the high number of hypotheses verbalised per trial. As we have already indicated, Number of Hypotheses per Trial emerged as pivotal in distinguishing different strategic styles of approach to the MDL task.

Cluster 3 emerged as clearly the most sophisticated strategically, and was characterised as the 'focusing ' group. This group of children scored at levels significantly above the mean for the sample particularly on the more long-term Strategy Components. What was perhaps most notable of all was the way that this group maintained their high level of performance on type b and c problems. This group produced an intermediate number of hypotheses per trial. However, subsequent examination of 'central cases' within this cluster revealed that this mean might be misleading. There appeared to be children present within the cluster who verbalised relatively low and high numbers of hypotheses. The mostly 8 & 10 yr. old children in this group were producing a level of strategic sophistication which Kemler (1978) failed to find with Primary aged children. Some children in this group produced 'perfect processing' on a number of problems. What is particularly striking is that this group included 4 children who were just 6 yrs. of age.

Discriminant Function Analysis of the 5 main strategy 'clusters' revealed that they appeared to be clearly distinct groupings (although detailed analysis of individual 'central cases' within clusters revealed some interesting variations within groupings). The different patterns of strategic behaviour revealed by the Strategy Clusters were principally differentiated by an increasing ability to integrate information gained from different trials. Two stylistic variations were also identified which appeared to be principally related to the number of hypotheses verbalised on each trial. The evidence from this part of the analysis tended to suggest that the strategic style associated with producing a low number of hypotheses was the more effective for this kind of task, and led to children achieving Cluster 3 type strategic behaviour at a younger age than the high H's per T style.

ii) Strategies and Performance

The second main aim of the study was to examine the relationship with performance of the revealed patterns of strategic behaviour. Again derived from the work of Gholson (1980) and others reviewed above, 3 different measures of performance were devised within the present study. These Performance Indicators consisted of a measure of how quickly each problem is solved (Trial of Last Error), whether the solution to each problem is correctly verbalised once it has been discovered (Verbalisation of Correct Hypothesis during Criterion) , and to what extent 'perfect processing' is produced in the pattern of verbalised hypotheses on the first 3 trials of each problem (Hypotheses on Trials 1,2 & 3). A subsidiary aim of the study was to investigate the possibility that improvement on these Performance Indicators will not occur simultaneously, but will follow a developmental sequence representing a deeper understanding of the task.

Examination of correlations between Performance Indicators indicated that reasonably strong positive relationships existed, but that there was enough independence between them to make it worthwhile to use all three. The relationships between Trial of Last Error and Verbalisation of the Correct Hypothesis during Criterion were much stronger than those of either of these indicators with Hypotheses on Trials 1,2 & 3. Correlations between scores on H's on T's 1,2 & 3 for type c problems and the other two indicators were particularly weak. This evidence did not seem to support the view expressed by some researchers that inhibitory abilities (i.e. the ability to inhibit the effects of irrelevant information) are central to development of problem-solving performance on this kind of task.

The scores on the three Performance Indicators for the three age-groups indicated clear developmental trends, with scores on all three indicators improving from the 6 yr. olds to the 8 yr. olds, and again to the 10 yr. olds on all problem types. Some support was offered, however, for the suggestion that there might be a developmental sequence between different aspects of performance measured by the three Performance Indicators. The major gains in terms of Trial of Last Error and Verbalisation of Hypotheses appeared to be between the 6 yr. olds and the 8 yr. olds, whereas that for Hypotheses on Trials 1, 2 & 3 did not occur until the children were between 8 and 10 yrs. old. This view was also supported by analysis of scores for the Strategy Clusters. That Hypotheses on Trials 1,2 & 3 is the last developing aspect of performance was borne out by a lack of improvement in score on this indicator between Clusters 4, 1 and 2. It was not until the transition between Cluster 2 and 6 that any real progress appeared in this aspect of performance. By contrast there was clear improvement from the start on the other two indicators. However, while all the improvement on Trial of the Last Error appeared to have been made by the transition between Clusters 2 and 6, there was continuing improvement between Clusters 6 and 3 in respect of Verbalisation of the Correct Hypothesis. This would seem to support some developmental lag between these two indicators. The general model of a developmental sequence between the three aspects of performance measured by our Performance Indicators thus seems to be supported.

The children in the present sample performed at least as well as those in Kemler's (1978) study, if not better, thus confirming that the form of the MDL task used enabled 6-10 yr. old children to use their problem-solving abilities effectively. Comparison of the performance of children within the present study with those in previous studies lent support to the view that the performance on the MDL task, as for so many other problem-solving tasks, is enhanced for young children when it is placed in a meaningful context. This view was supported by comparison of the Trial of Last Error scores, and the number of children producing instances of 'perfect processing'. It was concluded that young children's reported problems of memory and of attending to the correct stimulus in the MDL task may have been a function of the abstract, meaningless nature of the task, rather than of children's poor memories or control of their attention.

The results for the Performance Indicators also supported the conclusion that the problem types which involved processing negative information and ignoring irrelevant information were more difficult for the children than the standard problem.

There were strong relationships between patterns of strategic behaviour revealed by the Strategy Clusters and performance. Evidence in support of the strength of these relationships came from examination of correlations between Strategy and Performance scores, Performance scores for the Strategy Clusters and the Performance profiles of the 5 most "central" cases in each of the clusters.

Examination of correlations between Strategy and Performance scores revealed that the relationship was particularly strong for the most sophisticated Strategy Components related to the Trial of Last Error and Verbalisation of Hypotheses scores. Performance was also clearly but less strongly related to the use of simpler strategies, with the notable exception of Lose/Shift. While some simple linear relations were shown to exist between the measures of strategy and performance, however, it was clear that this was not a completely adequate method of describing the full nature of these relationships.

Investigation of the scores for Performance of the Strategy Clusters revealed a developmental pattern of improving performance which matched exactly the developmental sequence of strategic behaviour suggested by earlier by the Discriminant Function Analysis of cluster strategy scores. Thus, the developmental sequence of performance developed from the weakest to the strongest through the clusters in the order 4, 1, 2, 6, 3, which was exactly the same sequence of development in strategic sophistication.

The performance of individual Strategy Clusters was also shown to be clearly related to their strategic behaviour. Thus, Cluster 2's difficulties with type b problems (negative information) were reflected to some degree in their performance. The interpretation of Cluster 4's strategic pattern as a kind of 'stimulus describing' was also supported by examination of their performance on Verbalisation of Hypothesis during Criterion. Cluster 4 was the weakest group on this Performance Indicator, both in terms of level of performance and learning. The difficulties of Clusters 1 and 6 with type c problems (irrelevant information) were also reflected, particularly in their scores on Hypotheses on Trials 1, 2 & 3.

Some interesting findings also emerged in relation to Learning from this part of the analysis. While the correlations between Performance Indicators related to scores for Learning had been weak, and no significant differences had appeared between the age-groups for Learning (although it was argued that this apparent similarity might have been masking two rather different effects), examination of Learning scores for the Strategy Clusters suggested a clear developmental pattern. This pattern was not linear, however, largely due to a ceiling effect with Clusters 6 and 3. The average scores for Clusters 4, 1 and 2 were in the same developmental sequence as that found for strategic behaviour and overall performance.

The Performance profiles of the 5 most "central" cases in each of the clusters confirmed the strong links between patterns of strategic behaviour and performance, and the developmental sequence of different aspects of performance. There were, however, some interesting within cluster differences. Most notably, the oldest members of Clusters 1 & 2 appeared to perform a little more strongly than the other central cases in their groups. While the strong influence of strategies on performance was thus supported, it was also clear that this was not the whole story. The effect of underlying cognitive factors also needed to be examined, and it was to this that the next part of the analysis was devoted.

iii) Predictors of the Development of Problem-solving Abilities

It was the third main aim of the study to establish to what extent the patterns of strategic behaviour and performance on an inductive reasoning task such as the MDL task appeared to be related to a range of underlying cognitive factors proposed in the literature to be major contributors to the development of children's cognitive functioning.

The influence of these factors were explored in two different ways within the present study. First, within the MDL task itself it was attempted to examine the influence of certain factors by varying the form of the problem. The results in relation to both strategic behaviour and levels of performance have indicated that problems involving negative or irrelevant information were more difficult for the children within the present study. Further, whatever the source of these difficulties (working memory load, inferential difficulties, or attentional deficits) they were probably varied, because different groups of children performed relatively well or badly on the different versions of the problem.

Second, separately from the MDL task, subjects were assessed on Predictor Measures related to Working Memory capacity, Metacognitive Knowledge and Awareness and

Control, Attributional style (Locus of Control), Cognitive Tempo (Reflectivity-Impulsivity) and Field Dependence-Independence. In order to cover the possibility that other factors might be involved, the children's Gender and Age were also included in the analysis. Any large effects associated with these factors, and not associated with any of the cognitive factors included in the study, could be taken as evidence of the influence of contextual, maturational or other cognitive factors not included in the present study.

Weak or moderate positive correlations between all of these Predictor Measures were recorded, with the notable exception of Gender, which indicated that we were looking at relatively independent measures, but ones which were nevertheless associated together in a general way as different aspects of the development of cognitive abilities. It appeared likely that overall relationships between these factors were not simply linear, but involved complex inter-relationships between themselves, and with strategies and performance, as was found by the author in a previous study (Whitebread (1983)).

These relationships between the various cognitive factors considered and the children's behaviour and performance on the MDL task were examined in four ways. First, correlations between the Predictor Measures and Performance Indicators, and between the Predictor Measures and Strategy Components were investigated. These proved to be generally positive at statistically significant levels. Gender was once again an exception to this, however; the present study provided no evidence of Gender effects in relation to this version of the MDL task in any of the analyses. It would appear that we can be reasonably confident that the task, both in content and presentation, was gender neutral. The correlations between performance, strategies and age were moderate and suggested that we were not looking at a simple maturational process. The strongest relationships with performance and strategic behaviour appeared for Total Metacognition and the CEFT (while the Rod & Frame test, interestingly, was amongst the weakest in this respect).

Within metacognition, there was some evidence from these analyses that Metacognitive Awareness and Control was more strongly related to performance than Metacognitive Knowledge. However, the aspect of performance which did emerge as consistently and significantly related to Metacognitive Knowledge was Verbalisation of the Correct Hypothesis during the Criterion Trials. The strength of these relationships lent support to the view that these two aspects of functioning are linked by a common relation to underlying representational processes. The finding in relation to strategic behaviour, that scores for Metacognitive Knowledge were more strongly related to the long-term, sophisticated Strategy Components than to the simpler components, furthermore, gives an indication that these representational processes play an important part in the development of a sophisticated strategic approach to the MDL task.

Within Metacognitive Awareness and Control, while Strategy Flexibility appeared to correlate broadly with the whole range of Strategy Components, Metacomprehension was more weakly associated with the more sophisticated Strategy Components, but more strongly associated with the simpler component of making choices consistent with the current hypothesis, and, very interestingly, with the number of hypotheses verbalised per trial (although it should be borne in mind that a high score on the latter makes a high score on the former more likely, since there are more hypotheses for the choice on the next trial with which to be consistent). The relationship between Metacomprehension and No. of Hypotheses per Trial was reflected, as reported below, in the Metacomprehension scores for different Strategy Clusters. This is an intriguing result which we will consider in a little bit more detail below.

For the Predictor Measures generally, the strength of relationships with performance and strategic behaviour were very similar. For Locus of Control, however, an interesting distinction emerged. While this element of underlying cognitive functioning had only weak relationships with the Performance Indicators, it correlated at statistically significant levels with six of the Strategy Components. This was taken to suggest that attributional style may influence the strategic approach of individuals to problem-solving, but may not directly influence overall performance.

Little evidence was found for simple linear correlations of any significance between the underlying aspects of cognition considered and the ability to improve performance on the MDL task as measured by the Learning scores. Significant but relatively weak positive correlations were reported for Strategy Flexibility and Cognitive Tempo (Reflectivity).

Amongst the Strategy Components, Lose/Shift Hypothesis was the one aspect of strategic processing which appeared to be relatively unrelated to the underlying cognitive factors considered, as it had similarly been unrelated to performance.

Second, the mean scores for Predictor Measures within each of the Strategy Clusters were examined (together with the profiles of central cases in each of the clusters). While the levels of statistical significance here were not as strong, these analyses revealed clearly distinct patterns of underlying cognitive factors associated with each of the clusters. Furthermore, the developmental sequence between the Strategy Clusters identified earlier in the analysis of strategic behaviour using Discriminant Function Analysis was clearly mirrored in the pattern of Predictor Measure scores.

As regards the relationships with particular aspects of cognitive functioning, once again, the CEFT and Metacognitive Awareness and Control were the most strongly discriminating between clusters. Thus, Cluster 3 was significantly more field-independent on the CEFT than the remainder of the sample, and Cluster 4 was significantly weaker metacognitively and significantly more field-dependent than the rest. The other most significant measures to emerge were those related to Working Memory (on both measures the pattern of scores matched the developmental sequence very closely) , Cognitive Tempo (Cluster 3 children were significantly more reflective as a group than the remainder) and, not surprisingly, Age (Cluster 6 was significantly older at, and Cluster 4 was significantly younger than the rest of the sample). The one other result worth noting is that Cluster 1 emerged as significantly more external in terms of Locus of Control than the other Strategy Clusters.

Within Metacognition, the individual measure which discriminated most strongly between Strategy Clusters was Metacomprehension, and in a particularly interesting way to which we have referred above. Clusters 1 and 6, which shared the strategic style of producing a high number of hypotheses on each trial, scored particularly strongly on the test of Metacomprehension. Cluster 6 scored at a statistically significantly higher level on this measure than all the other clusters, and Cluster 1 scored at a level at least equal to that of Cluster 3 on this measure. On the face of it, this appears to be an intriguing and strangely anomalous result, since Cluster 3 has been shown to be more developed than both of these clusters, both in terms of strategic sophistication and level of performance. It is also worth reminding ourselves that Cluster 6 had a mean age older than that for Cluster 3.

Various possible explanations were examined, but there are limitations on the conclusions which can be reached with the kind of cross-sectional data gathered in this kind of study. What does appear to be clear, however, is that the children in Clusters 1 and 6 performed relatively poorly on the MDL task, perhaps partly as a consequence of adopting an unhelpful strategic style which increased the memory load and made the task less manageable, despite being relatively aware of their own state of comprehension. This pattern of results would seem to support the view that being aware of one's own level of understanding may be a necessary, but is not a sufficient condition for the development of effective strategic processing on a problem-solving task.

In recognition of the fact that a number of the Predictor Measures correlated with one another, even if only at relatively moderate levels, the third means of disentangling the relationships between cognitive factors, patterns of strategic behaviour and performance was to carry out Multiple Linear Regression Analyses. They revealed that the major factor which predicted strategic behaviour and performance on the MDL task was Metacognition, with, arguably Awareness & Control emerging as slightly more significant than Knowledge. Pattern of strategic behaviour was also confirmed as a clear predictor of performance, and even some relation with learning emerged in this analysis. The only other statistically significant result was that for Field Dependence-Independence in relation to Trial of Last Error when Strategy Cluster was not included in the analysis. This confirms to some extent the results obtained in other analyses for CEFT, in particular.

Although the relationships between the Predictor Measures and Learning were weaker than those with Performance, some support was offered for the view that the Strategy Clusters not only represented different stages in the development of strategic behaviour in relation to the MDL task, but also a development in the ability to learn quickly and apply general strategies in relation to new tasks. This has important implications for our understanding of the development of problem-solving abilities in young children which we will discuss in the final section of this chapter.

For all three Performance Indicators a substantial proportion of the explained variance was attributable to interactions between the predictors. This was in line with the view that there were significant interactions between underlying cognitive factors, choice of strategy and performance on the MDL task. These interactions were pursued further in the final section of the analysis, by means of looking at relations within subgroups.

iv) Interactions between Predictors, Strategy & Performance

As we have indicated earlier, a previous study (Whitebread (1983)) had revealed significant interactions between underlying cognitive factors, patterns of strategic behaviour and performance on a reclassification task. In particular, this study concurred with other research which has suggested that significant interactions might be expected between metacognition and working memory. Interactions were also found between age, working memory and performance. The fourth main aim of the present study was, therefore, to examine the possibility that the relationships between different elements of problem-solving behaviour are complex and non-linear.

Evidence from earlier parts of the analysis, for example, has suggested that different aspects of cognitive functioning might be significant at different points in development. Thus, amongst the least sophisticated Strategy Clusters, while Cluster 4 was distinctively weak on Metacomprehension and overall Metacognition, Cluster 1 was distinctively external in terms of Locus of Control. Among the more sophisticated Strategy Clusters, Cluster 6 was noticeably strong on Metacomprehension, while Cluster 3 children were distinguished by their Reflectivity and Field Independence. Earlier evidence has also indicated significant interactions between underlying cognitive factors, strategic behaviour and performance, and suggested that there might be non-linear developmental relationships present.

These analyses were carried out, as in the previous study, by examining correlations between Predictor Measures and Performance Indicators within sub-groups of the sample. Subgroups were investigated defined by Metacognition (as was the case in the earlier study), by Strategy Cluster, and by Age. These analyses very largely confirmed interactions of the kinds predicted.

Thus, for the Metacognition subgroups, a number of Predictor Measures were associated at statistically significant levels with Performance within the Weak Metacognition subset, but not within the Strong Metacognition subset. These were CEFT, Metacognition Total itself, and both scores for Working Memory. This relates well to the earlier finding (Whitebread, 1983) that where weak metacognition is associated with the use of relatively simple strategies the level of performance will be dependent upon other abilities. In the previous study Working Memory appeared to be a strong factor in this context, and to this the present data would suggest we should add Field Independence.

For the Strong Metacognition subset only Age, Metacomprehension and one aspect of Metacognitive Knowledge were statistically significant at all. This result tends to support the view that once metacognitive ability and knowledge have been developed very little else matters in relation to the successful development of problem-solving skills. That Metacomprehension is so strongly related to improvement in the Trial of Last Error score for the Strong subset, and not for the Weak subset, would appear to indicate that this ability is dependent upon other cognitive factors associated with the development of general metacognitive abilities for any effect it might have upon performance. This would once again confirm the view that being aware of one's own level of understanding is a necessary but not sufficient requirement for developing strategies to tackle new problems.

Investigation of relations within Strategy Clusters revealed that there were numerous cases where a significant relation existed between a Predictor and some Performance Indicators for a particular Strategy Cluster which did not exist for other strategic groups. A wide range of different cognitive factors were thus found to be relevant to performance at different points in strategic development. It was also the case, however, that different aspects of Metacognition were significant for each of the Strategy Clusters in some way. Working Memory was also significant for a number of clusters.

For particular clusters relationships emerged that had a clear link with their pattern of strategic behaviour. For Cluster 4, for example, the 'stimulus describing' strategy clearly tied in to the revealed correlation between metacognitive processes and Verbalisation of Correct Hypothesis during Criterion.

For Clusters 2, 6 and 3, the most sophisticated strategy groups, significant relationships were also found between Cognitive Tempo (Reflectivity-Impulsivity) and Learning. This is a good example of an instance where the weak overall correlation, reported above, between Reflectivity and performance was, in fact, masking stronger relationships for particular groups.

The analysis of age subgroups revealed striking evidence of differential patterns between the three age-groups. For some Predictor Measures a picture emerged of a developing relation with performance. Thus, the scores for Working Memory and Field-Independence were significantly related to performance for the 10 yr. olds, but not related at all for the younger age groups. For Metacognition, however, there was clear evidence of a U-shaped pattern of development, with a significant relationship to performance for the 6 yr. olds as well as the 10 yr. olds, but little or no such relationship for the 8 yr. olds.

The data from the present study would therefore seem to support the view that complex relationships do exist between underlying cognitive processes, problem-solving strategies and performance on such as the MDL task. In the ensuing review of methodological issues and implications of the present study for theory and research, ways in which these relationships will need to be addressed will be discussed.

v) Summary of Main Findings

At the end of the literature review, the intentions concerning the major contributions of the present study to the investigation of children's problem solving were outlined. It is perhaps worth reviewing at this point the extent to which these general intentions have been fulfilled.

First, it was a major intention of the present study to identify the developmental sequence of strategies developed by children on an inductive reasoning task, and, in particular, to provide a more systematic and comprehensive analysis of the development of children's strategies on the MDL task. In order to achieve this, a new methodology was developed involving the analysis of the children's responses in terms of Strategy Components, and the identification of developing patterns and combinations of these components by Cluster Analysis.

This methodology would appear to be a valuable development. As we have seen from the foregoing review of the results of the study, this analysis produced valuable data, both in relation to individual Strategy Components and in relation to the clusters of strategic behaviour it revealed. A pattern of 7 clusters of increasingly complex strategic behaviours was revealed, 5 of which appeared in sufficient numbers within the present sample to be thoroughly analysed. Discriminant Function Analysis of the 5 main strategy 'clusters' revealed that they appeared to be clearly distinct groupings, principally differentiated by an increasing ability to integrate information gained from different trials. Two stylistic variations were also identified which appeared to be principally related to the number of hypotheses verbalised on each trial. All of this is a clear advance on previous analyses of the development of children's strategic responses to this kind of task.

This analysis of increasingly sophisticated patterns of strategic behaviour was strongly validated by investigation of the performance of the Strategy Clusters. This revealed a developmental pattern of improving performance which matched exactly the developmental sequence of strategic behaviour. Some support was also offered for the view that the Strategy Clusters not only represented different stages in the development of strategic behaviour in relation to the MDL task, but also a development in the ability to learn quickly and apply general strategies in relation to new tasks.

The second major aim of the study was to investigate underlying cognitive factors which might be related to this development of strategic behaviour and performance on a novel task. Attempts to relate the development of strategies and performance on the MDL task to underlying cognitive factors are almost non-existant in the previous literature. Much of the literature concerned with children's cognitive development, furthermore, has been devoted to advancing the cause of one particular feature of the cognitive system as the fundamental determinant of cognitive change and development. The present study, by contrast, emphasises the need to get away from simple, single factor models of cognitive change and development, and instead investigate the significant interactions between a range of underlying cognitive factors, strategy use and performance.

Some simple linear relations were shown to exist between the measures of the various cognitive factors, strategy and performance. The strongest linear relationships with performance and strategic behaviour appeared for metacognition and the CEFT (a measure of field dependence-independence). Within metacognition, there was some evidence, in line with previous findings, that metacognitive awareness and control was more strongly related to performance than metacognitive knowledge. The results of the present study also strongly support the view that being aware of one's own level of comprehension may be a necessary, but is not a sufficient cause of strategy development and improved performance.

It was also clear from the results, however, that significant interactions were present between cognitive factors, strategy use and performance. Analysis of different subsets of the data revealed strong relationships which were not apparent by looking at the data overall. Thus, for example, while Locus of Control appeared to have only weak relationships with performance, it appeared to be quite strongly related to the strategic approach of individuals to problem-solving. Different Strategy Clusters, representing different stages in the development of strategic processing, were distinguished from the remainder of the sample by different cognitive factors. Some support was also offered for the finding of the previous study (Whitebread, 1983) that metacognition interacts with other cognitive factors in relation to strategies and performance. Thus, where weak metacognition was associated with the use of relatively simple strategies the level of performance was dependent upon other cognitve factors. In the previous study working memory appeared to be a strong factor in this context, and to this the present data would suggest we should add field-independence.

For Clusters 2, 6 and 3, the most sophisticated strategy groups, significant relationships were also found between cognitive tempo (reflectivity-impulsivity) and learning. This was a good example of an instance where a weak overall correlation was, in fact, masking stronger relationships for particular groups.

The analysis of age subgroups revealed striking evidence of differential patterns between the three age-groups. For some cognitive factors a picture emerged of a developing relation with performance. Thus, the scores for working memory and field-independence were significantly related to performance for the 10 yr. olds, but not related at all for the younger age groups. For metacognition, however, there was clear evidence of a U-shaped pattern of development, with a significant relationship to performance for the 6 yr. olds as well as the 10 yr. olds, but little or no such relationship for the 8 yr. olds.

The data from the present study would therefore seem to support the view that complex relationships do exist between underlying cognitive processes, problem-solving strategies and performance on inductive reasoning tasks such as the MDL task. The exploration of these kinds of complex interactions has only recently begun to emerge in the literature, and the present study clearly makes a contribution to the beginnings of this kind of analysis. This will undoubtedly be an area of considerable research development in the immediate future.

Section B) Methodological Issues

It is important to recognise the methodological limitations of the present study, as well as the strengths and advantages of the methods adopted. This will enable us to evaluate the extent of the claims which may be made based upon the evidence presented, as well as identifying complementary approaches which might indicate directions for further research.

The first point to recognise is that the present study is experimental and has used a task which, although constructed in a way to make sense to young children, is nevertheless artificial. As we have reviewed, research on problem-solving has traditionally used artificial tasks. This approach offers clear advantages in terms of being able to define with some precision the parameters, procedures and goals involved. It also permits the setting up of controlled experimental procedures, as in the present study, which allows variables, to some degree, to be separated out. An example of this, for example, within the present study, would be the controlled pattern of negative and positive feedback; as Bruner et al (1956) pointed out, in real-world problem-solving this is an uncontrolled variable which might have a profound impact upon the pattern of the subject's strategic behaviour.

At least within the present study, furthermore, the task was made meaningful to the children, by using Kemler's (1978) story-and-game version of the MDL task. Kemler (1978) claimed that this would enable children to use their problem-solving capabilities optimally, and we have presented results for performance which would seem to support this contention. The children certainly performed at levels which earlier researchers, using abstract versions of the MDL task, had thought to be beyond children in this age group. It was thus hoped to make use of some of the strengths of the experimental approach, while at least mitigating some of its more obvious shortcomings.

Increasingly, however, as Siegler & Jenkins (1989), Achtenhagen (1991) and others have indicated, research into problem-solving has been carried out in 'natural' settings, and concerned itself with 'real life' problems and learning. This approach offers ecological validity, but at the cost of dealing with relatively ill-defined problems. As McKeachie (1987) has argued, it seems probable that both kinds of research will have something of value to offer, providing that we remain aware of the limitations of both and recognise the findings as complementary. Different methodologies are perhaps better suited to the investigation of different kinds of questions.

The approach adopted in the present study is perhaps more appropriate to examine the abilities of children to develop strategies on new tasks; as English (1992) has reviewed, the development of domain-general strategies has been clearly established as a vital element in the development of problem-solving abilities. Thus, in the case of the MDL task used within the present study, although it clearly requires inductive reasoning, which has been demonstrated to be an important element in human learning, it might be argued that the kind of inductive reasoning required is explicit and formal, and this may only be indirectly related to the everyday processes of induction. A case might be made, however, that an important element in the development of cognitive functioning is the gradual bringing under conscious control of relatively autonomic processing. As Siegler & Jenkins (1989) and others have indicated, there has been considerable debate in the literature about what constitutes a strategy, but some element of control would seem to the present author to be a necessary requirement. The MDL task, presented in the kind of way it is within the present study, may be seen to require some deliberate strategy construction. To this extent, this kind of task may be an important indicator of the development of cognitive functioning. It might, for example, be particularly related to the ability to transfer learning from one domain to another.

The more naturalistic approach, on the other hand, is perhaps more appropriate to investigate, for example, the processes of development of expertise within a particular domain. The results of both of these kinds of studies, and others, should not be seen as competing, but as information about different aspects of human learning and problem-solving, all of which can contribute to the development of unified models of human cognitive functioning.

Alongside the development of study of more naturalistic problem-solving, different and appropriate methodologies have been devised. The present study was cross-sectional in design, and while this has been valuable for identifying the different patterns of strategic behaviour children produce, we have seen that, for example, questions about the pattern of development of individual children, and their transition from one kind of strategic behaviour to another, have been difficult to answer with the present data. As we have suggested, a more longitudinal design would be helpful in addressing this kind of question (see, for example, Hoppe-Graff (1989) for a detailed assessment of the potential of the longitudinal approach). Questions of causality are, of course, amongst the most difficult to answer in this kind of area, and, again, longitudinal research has a contribution to offer in this respect.

Another crucial area which it has not been possible to address properly within the present study is that concerned with the detail of the processes of strategy construction through experience. Siegler and Jenkins (1989) have reviewed a number of approaches to studying the detailed processes of complex real-world skills learning. These have included focusing on the quantitative changes in performance with practice, the examination of how children and adults learn from explicit instruction, and the approach favoured by Siegler and Jenkins (1989), which they term the 'microgenetic' approach. This approach involves the detailed observation of individual subjects over an extended period of time, and the intensive trial-by-trial analysis of their learning.

While this approach is directed at, and suited to investigating, different kinds of questions to the present study, there is a common element which is shared between the two approaches. This is the analysis of subject's behaviour into strategy components. This methodology was adopted within the present study and can be seen, for example, in Kuhn & Phelps' (1982) microgenetic study of 8-10 yr. olds development of scientific reasoning strategies. As we have argued earlier, and as it is hoped the present study has demonstrated, this is a clear methodological advance on the previously common procedure within the literature of categorising children's behaviour in terms of strategies determined a priori by some kind of logical analysis of the task. As we shall indicate in the next section, this methodology has helped to reveal the complex nature of strategy construction and development.

While Kuhn & Phelps (1982) used their analysis of their relatively small number of subjects (15) to produce detailed protocol analyses of each individual's pattern of behaviour, scores on the Strategy Components in the present study, with a larger sample (72), were used to find common patterns of behaviour by means of Cluster Analysis. This is precisely the technique used by Swanson, O'Connor & Carter (1991) to analyse the performance of a similarly sized sample (68) of 8-10 yr. olds on three problem-solving tasks (the Tower of Hanoi, a Combinatorial task and a Pendulum task), and it seems likely that this technique could be usefully employed more widely in this kind of analysis. As we have seen, the value of Cluster Analysis is that it is capable of finding complex patterns in multivariate data of the kind produced within the present study, rather than reducing them to one or two linear factors. This method of analysis is, therefore, particularly well suited to attempts to accurately represent and reflect the complex nature of the development of children's problem-solving strategies, and the underlying cognitive factors which are involved.

There are two further limitations of the methodology of the present study which need to be recognised. First, we have examined the patterns of children's strategic behaviour on just one task. While, as has been argued, there are reasons for thinking that the MDL task involves important aspects of children's developing abilities to learn, reason and solve problems, the work of the present study could usefully be extended to analyses of strategic behaviour on other tasks, both involving rule induction and other significant reasoning processes. This is essential in order to be able to determine which aspects of cognitive behaviour discovered to be significant for the MDL task have more general application. It would be interesting and important to investigate, for example, whether the children who had difficulties with negative or irrelevant information on the MDL task had a general processing difficulty in this area, or whether this was simply an artefact of the particular task.

The other limitation of the present study relates to the validity of the various measures used. While some of the measures used were published instruments with a long research history, within which their reliability and validity has been to various extents established, some of the measures used were constructed within the present study, and the results obtained from them need to be viewed with some caution. The measurement of children's metacognitive processing has proved to be a particularly difficult area. While in this study the early mistakes of relying on children's self reports about general aspects of their metacognition were avoided, as identified by such as Schneider (1985), it would be useful in further studies to extend the range of measures of such aspects as Metacomprehension.

In a recent study using the balance-scale task to investigate the interaction between self-monitoring abilities and cognitive strategies in children aged 8-14 yrs., for example, Normandeau (1992) used as indicators of self-monitoring all of the following: latencies before and after the solution of a problem, self-evaluation of one's ability to make the balance scale stay level, proportion of oriented moves on the balance scale, persistence on a problem, reacting to failure by changing strategies, verbal explanations and self-evaluation of performance. This mixture of different sources of evidence relating to children's internal processing would seem to be a useful model of sound methodology in this area.

Nevertheless, in defence of the present study, an attempt was made to collect evidence in ways which previous research in the field had shown to be more helpful. Swanson, O'Connor & Carter's (1991) analysis of problem-solving strategies, for example, relied entirely on children's verbal commentary. The methodology used within the present study to analyse children's strategies, where verbal introtacts were combined with analysis of patterns of choice behaviour, is clearly an advance in this regard. The measures used to assess the children's metacognitive processing, while they might not have been as thorough and varied as those employed by Normandeau (1992), were based on behavioural assessments and children's reports of their particular experiences with the MDL task, rather than simple assessments of children's declarative knowledge about general metacognitive processes, as used in many earlier studies.

Siegler & Jenkins (1989) also review and make proposals about the use of the methodology of computer modelling. Given the complexities of the range of factors which would seem to be implicated in the development of children's strategy construction and problem-solving behaviour, and of the interactions between these factors, as reported elsewhere and in the present study, this would seem to be a further methodological approach which might very well make a useful contribution. We now turn, however, to a consideration of the psychological and educational of the findings which have emerged from the present study.

Section C) Implications for psychological theory and educational practice

i) Psychological implications

The present study, combined with much of the associated research in the area of children's problem-solving, has significant implications for psychological theory and research, and for educational practice.

As regards developing models of the development of children's cognitive processing, the value of analysing their behaviour on tasks in terms of their cognitive strategies has been supported. The present study has demonstrated that this kind of analysis produces a clear picture of the increasing sophistication of children's approaches to problem-solving and reasoning tasks, and one which has considerable explanatory power in relation to their performance. Throughout the foregoing analysis, the patterns of strategic behaviour revealed have been closely related to all aspects of performance. Furthermore, the different Strategy Clusters were shown to represent not only different stages in the development of strategic behaviour, but also a development in the ability to learn quickly and apply general strategies in relation to new tasks

The present study has further revealed and confirmed the complexities of the patterns of strategic behaviour produced by children, and this finding complements well the complex patterns of strategy construction revealed by microgenetic studies. A major finding of Kuhn & Phelps (1982), confirmed by Siegler & Jenkins (1989) has been that children do not proceed from one discrete strategy to another, simply abandoning the simpler strategy and adopting the more sophisticated at a stroke. By contrast, in both studies children used a variety of strategies at any one time. The first use of a more sophisticated strategy was commonly followed by the continued use of simpler strategies, with the more sophisticated approach only gradually establishing itself as the dominant element in the child's repertoire. Even then, apparently abandoned simpler strategies were returned to when the child was confronted with a more difficult problem (we have reviewed the experimental work of such as Scardamalia (1977) and Butterfield & Belmont (1977) which has also demonstrated this kind of phenomenon).

New strategies, furthermore, have been shown by such as Kuhn & Phelps (1982) and Siegler & Jenkins (1989) not to be separate and discrete procedures. They are often constructed by recombining elements of previous strategies or by adding on new elements to existing procedures. This is a picture which is well supported by the results of the present study.

The present study has also supported the move within current research away from simple, single factor models of cognitive change and the development of problem-solving skills. While it is still valuable, of course, to study the effects of particular factors, analyses of problem-solving, including that contained within the present study, have increasingly suggested that it involves a wide variety of different cognitive processes. CLuster 3, the most successful group on the MDL task, scored at a higher level on nearly the whole range of cognitive factors considered in the present study, and were statistically significantly more Field-Independent and more Reflective than all the other groups.

It is, furthermore, particularly important to look at the ways in which these various cognitive factors interact with one another. A growing amount of research in recent years has begun to address this issue. For example, Folds et al (1990), Bjorklund et al (1990) and Howe & O'Sullivan (1990) all contained within Bjorklund's (1990) useful collection of recent work on children's strategies, each address different aspects of cognitive processing which interact with children's use of strategies. Bjorklund et al (1990), for example, discuss the relationships among children's knowledge base, the efficiency of mental processing, a child's metacognitive knowledge, and the ways in which these factors interact with strategy development. English (1992)) has examined the interactions between domain-specific knowledge and domain-general strategies. Schneider & Weinert (1990) have edited a collection of studies devoted to the analysis of interactions between aptitudes, knowledge components and cognitive strategies. In a review of work related to memory development, they have themselves (Schneider & Weinert (1989)) produced an integrative model of the contribution of basic capacities, strategies, metamemory and content knowledge to memory development, each of which makes a contribution at different stages. Clearly, this work needs to be continued and developed. Schneider & Weinert (1990), however, point to the fuzziness of some of the central concepts as an important area for development.

Various particular interactions between cognitive factors have been revealed by the present study. Thus, a relationship was revealed between Reflectivity and Learning, but only for the more sophisticated Strategy Clusters. Metacomprehension was clearly related to strategy development and performance overall, but some groups of children scored well on this measure while performing relatively poorly. Attributional style appeared to be related to Strategy Components, but was not directly related to performance. Each of these results tend to support the view that these elements may be necessary, but are not sufficient in themselves as explanations of problem-solving development. In each case, their effect is dependent upon interaction with other factors.

In line with much recent and current research, metacognitive aspects of processing emerged as being most closely related to strategy development and performance on the MDL task. Here again, however, the picture was not one of a simple linear relationship. Schneider & Weinert (1989) have reviewed evidence suggesting that metacognitive abilities might become more closely related to performance as children grow older. In the present study, however, the relationship had a more U-shaped pattern. This is clearly a finding which it would be very interesting to explore further. As in the previous study carried out by the present author (Whitebread (1983)), an interaction was found between Metacognition and Working Memory, and a similar interaction was also found here for Field Dependence-Independence. For children who were weak metacognitively these two factors made a significant contribution to their performance on the MDL task. For children who were stronger metacognitively, their impact was much reduced.

As regards Field Dependence-Independence, the very different results reported for scores on the RFT and CEFT would seem to support the view, reviewed by Kogan (1983), that these measures are related to different aspects of this construct. Not surprisingly, the aspect related to the ability to selectively attend to elements in a visual field were more closely related to performance on the MDL task than were those related to being able to detect the vertical. As we have seen, in fact, children's scores on the CEFT were amongst the Predictor Measures most strongly associated with performance on the MDL task. As we shall discuss in a moment, this may have important educational implications.

One final area to which it is hoped the present study has made some contribution is the study of inductive reasoning. As we have reviewed, this has, until recently, been a relatively neglected area of cognitive functioning. At the moment, however, the recognition of the importance of the processes of induction for human learning, as indicated by such as Glaser & Pellegrino (1987), has led to a revival of interest.

Holland et al (1986) have produced an important model which needs to researched and explored. A number of researchers are currently engaged in exploring the possibilities of teaching inductive skills, and analysing the consequences for general cognitive functioning (see, for example, Klauer (1989,1992)). The MDL task was chosen for use within the present study because it involves the processes of rule induction. As we have indicated in our methodological review, it would be interesting and useful to carry out further study of a similar nature with other inductive reasoning tasks to discover the general applicability of some of the current findings.

ii) Educational implications

Within the educational sphere, a number of issues arise. Teachers need to know which factors are involved in the development of children's abilities to think, to reason and to solve problems. A substantial literature now exists which has established a number of the most significant factors, and it is hoped that the present study makes a contribution to that. As we reviewed at the beginning of the thesis, there is a strong, emerging interest in active, problem-solving approaches to learning and in teaching children to think. There is still much to be done, however, in raising teachers' understanding of the cognitive skills which enable children to tackle novel tasks and problems effectively, or how they 'learn how to learn'.

One central area of interest, well supported by the findings of the present study, is that related to the development of metacognitive abilities. The work in Britain of such as Nisbet & Shucksmith (1986) and in America of such as Borkowski , Brown and their co-workers (see, for example, Pressley, Borkowski & O'Sullivan (1985) and Campione (1987)) has demonstrated that metacognitive abilities can be developed through teaching, and has begun to indicate the kind of pedagogical principles upon which such teaching must be based. Nisbet & Shucksmith (1986), in particular, argue that just making children aware of what they do not know or understand will not necessarily foster the ability or the desire to learn more effectively. Children also need to be shown how to learn. This is well supported by the evidence from the present study of children who scored well on Metacomprehension, but nevertheless performed relatively poorly. While, as we have reviewed at the beginning of the thesis, there is a resurgence of interest in 'active learning' within education at the moment, its impact is relatively limited, and many teachers could be much better informed about this kind of issue. English

(1992), amongst others, for example, has shown that within the mathematics curriculum children as young as 4 yrs. old can usefully be helped to engage in self-monitoring, and in the more explicit use of strategies. Many children, however, are still encouraged by their teachers to rely on algorithmic procedures which does not encourage the development of these kinds of metacognitive experiences and skills.

As we also noted at the start of the thesis, the role of the teacher as mediator has increasingly been recognised, particularly with a resurgence of interest in Vygotskian approaches to learning in social contexts. English (1992) refers to the evidence that emerging teaching models based upon this kind of approach, such as the 'cognitive apprenticeship' model of Collins, Seely-Brown & Newman (1987) have appeared to be particularly helpful in terms of developing young children's metacognitive abilities.

Some other elements which need to be addressed more clearly in relation to educational contexts have also been reinforced by the present study. For example, the impact of cognitive style, and in particular Field Dependence-Independence, has been a significant finding. Globerson (1985) and her colleagues, for example, have followed up Pascual-Leone's (1969, 1970) original analysis of the impact of FDI on performance on different kinds of tasks, and have shown that Field-Dependent children can benefit from particular kinds of teaching. In particular, they were shown to be just as able to develop scientific reasoning abilities as Field Independent children, providing that the processes involved, and the features of the task to which they should attend, were made explicit.

Two further elements of a teaching strategy that are likely to help young children become effective learners and problem-solvers are worth mentioning. First, the results of the present study support the general finding, first properly articulated by Donaldson (1978) and her colleagues, that children perform most effectively on tasks which are meaningful to them. In particular, the present study supports the finding that children can develop more sophisticated strategic approaches on this kind of task. Given the interaction between initial strategy use, declarative knowledge about strategies, and the development of more extensive strategic behaviour suggested by the bi-directionality hypothesis of Flavell (1978) and the Metamemory Acquisition Procedures (MAPS) model of Pressley, Borkowski & O'Sullivan (1985), it seems possible that encouraging the early use of strategies by young children through the use of meaningful contexts may have long-term beneficial consequences for them as learners.

Second, the work of Sweller et al (1983), which we have reviewed earlier in the thesis, has suggested that the shift in strategy from working backwards to working forwards that characterises the change from novice to expert, may be facilitated where problems are set which have more open-ended or non-specific goals. These results would appear to link well with findings in relation to 'exploration learning' by such as Sylva, Bruner & Genova (1976). They produced results which showed that children allowed free play with materials were then able to use them more flexibly and more effectively in problem-solving situations than children who had been given specific instruction. This work, together with that related to meaningful contexts, suggests that the efficacy of playful approaches to learning and problem-solving need to continue to be explored. Many teachers are actively engaged in encouraging young children to learn through play, and it seems probable that this likely to be constructive. However, as Vandenberg (1990) and others have demonstrated, there is an essential exploratory feature of the kinds of play which would appear to be most beneficial.

As we reviewed at the beginning of the thesis, the general interest within education concerning problem-solving approaches has manifested itself particularly in the development of a number of programmes designed to teach children to think. Some of these, such as Feuerstein et al's (1980) Instrumental Enrichment and Bono's (1976) CoRT, are aimed at general thinking skills. Others, such as Adey et al's (1989) CASE materials, Lipman et al's (1980) Philosophy for Children and so on, are aimed at developing thinking skills within a particular knowledge domain. As we reviewed, many of these programmes contain similar elements, such as an emphasis on metacognitive skills, a recognition of the mediating role of the teacher, and a recognition of the significance of the attributional as well as the purely cognitive responses of the learner.

Within psychological research Pressley et al (1987) have produced a model of the 'Good Strategy User' which helpfully integrates a number of the features, including strategies, metacognition, motivation and knowledge, which have been highlighted by research related to children's and adult's problem-solving. At a more practical level, Sellwood (1991) has recently produced a 'Practical Problem-solving Model' which emerges from the new curriculum area of Design & Technology, but which is claimed to have applicability across the curriculum. It contains many of the same elements, but has usefully detailed the practical implications for the whole range of teaching activities from preparation and planning to assessment.

For all of these programmes a central issue is to facilitate transfer of learning and strategies to new domains and new tasks. What would seem to be supported by the findings of the present study is the view that problem-solving ability cannot simply be explained by expertise in a particular domain. Children faced with a novel task which relates to no particular domain of knowledge clearly vary enormously in the level of sophistication of response. We have found 6 yr. olds responding at almost adult levels to the MDL task, and 10 yr. olds whose level of response is very much more undeveloped. Thus, the current results would seem to support the view that there are general problem-solving abilities which children can apply across domains.

Whether such generally applicable skills are best taught within particular domains remains an interesting question. The evidence concerning the efficacy of meaningful contexts, combined with that concerning the role of inductive processes in learning, would seem to suggest to the present author that children may be best served by being taught to think within a variety of knowledge domains.

Symons et al (1989), in a review of cognitive strategy research, have usefully itemised 8 common elements in the instructional approaches which are emerging from this area of research. First, research suggests children should be taught strategies and, at any one time, be taught a few strategies well rather than a large number superficially. Second, children should be encouraged to check and monitor their performance, and take remedial action when they are in difficulty. Third, it is important children learn when to use particular strategies; this is best accomplished by giving children the experience of using particular strategies across a range of contexts. Fourth, children need to be motivated to use strategies by being made aware of their efficacy for performance. Fifth, strategies are best taught within the contexts of real learning tasks, such as reading or mathematics, rather than as a separate entity (this relates to 'meaningfulness'). Sixth, the use of strategies is greatly enhanced by knowledge. Seventh, the role of the teacher should contingent upon the performance of the child on any particular task, taking more of a directive role where the child is in difficulty, but releasing control where the child is working well independently. Eighth, the teaching of strategies is not a quick fix, but a long-term and extensive business, and needs to be maintained throughout a child's education.

In these 8 common elements Symons et al (1989) have encapsulated much of the current state of knowledge about the ways in which teachers can help young children to become more effective learners and problem-solvers. It is a challenge to which many teachers are only too keen to rise. It is hoped that the present thesis has made a contribution to our developing understandings about the cognitive factors which enable some children to be able to reason, to learn and to solve problems very effectively from an early age. As our understandings improve in relation to these complex processes, it is to be hoped that we will be able to develop instructional practices that will help more children become effective learners, thinkers and solvers of problems.

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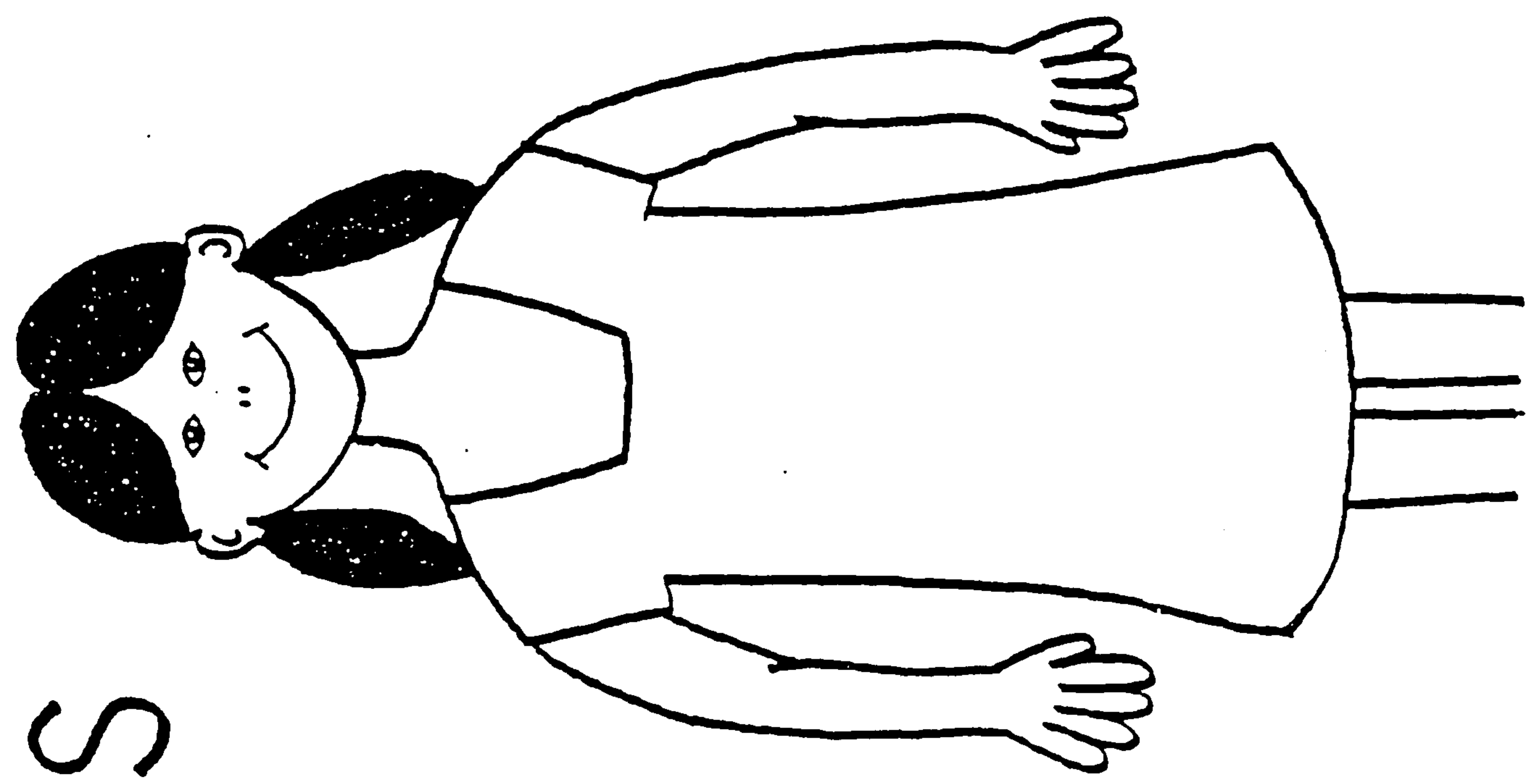
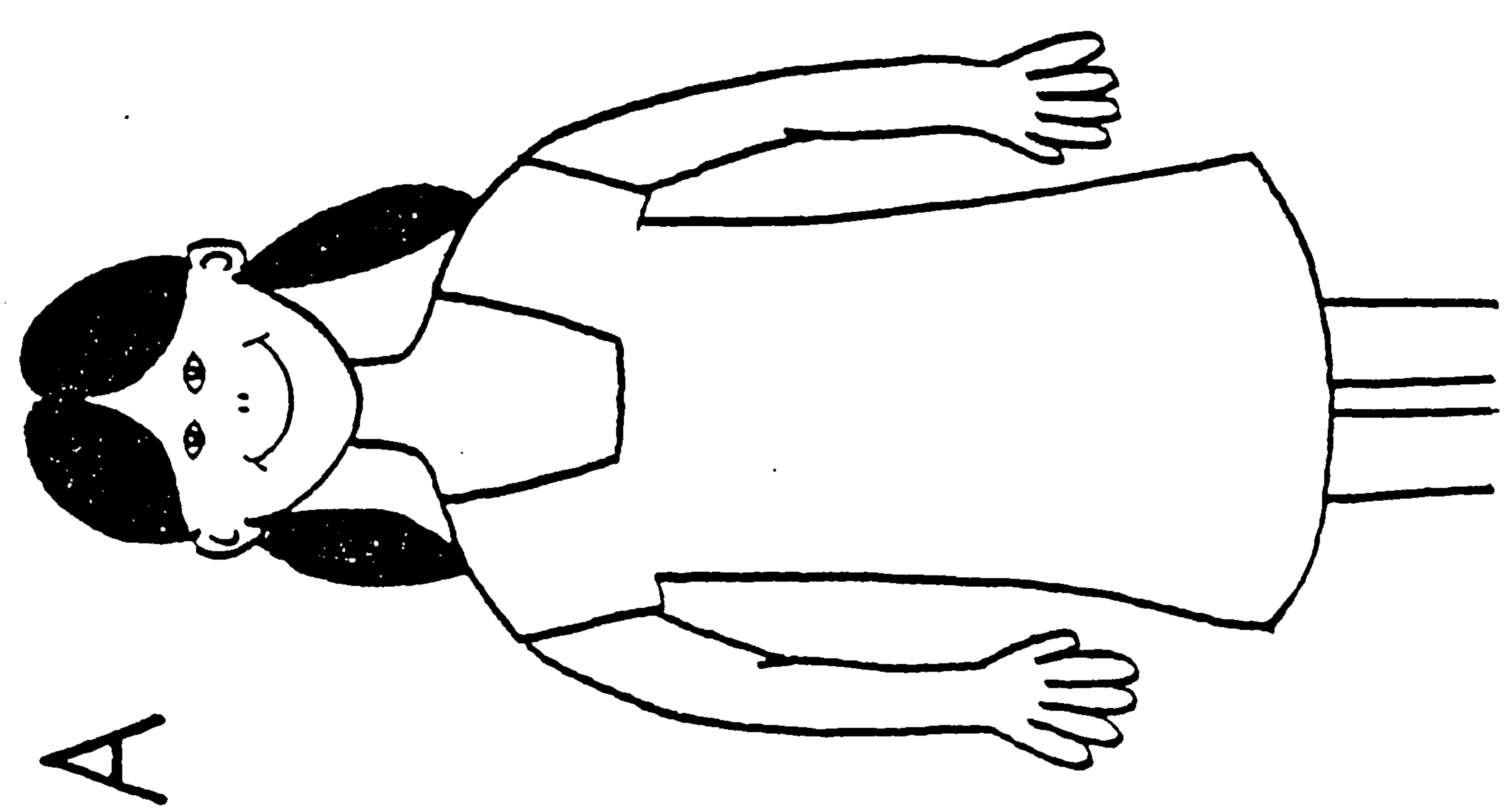
8. APPENDICES

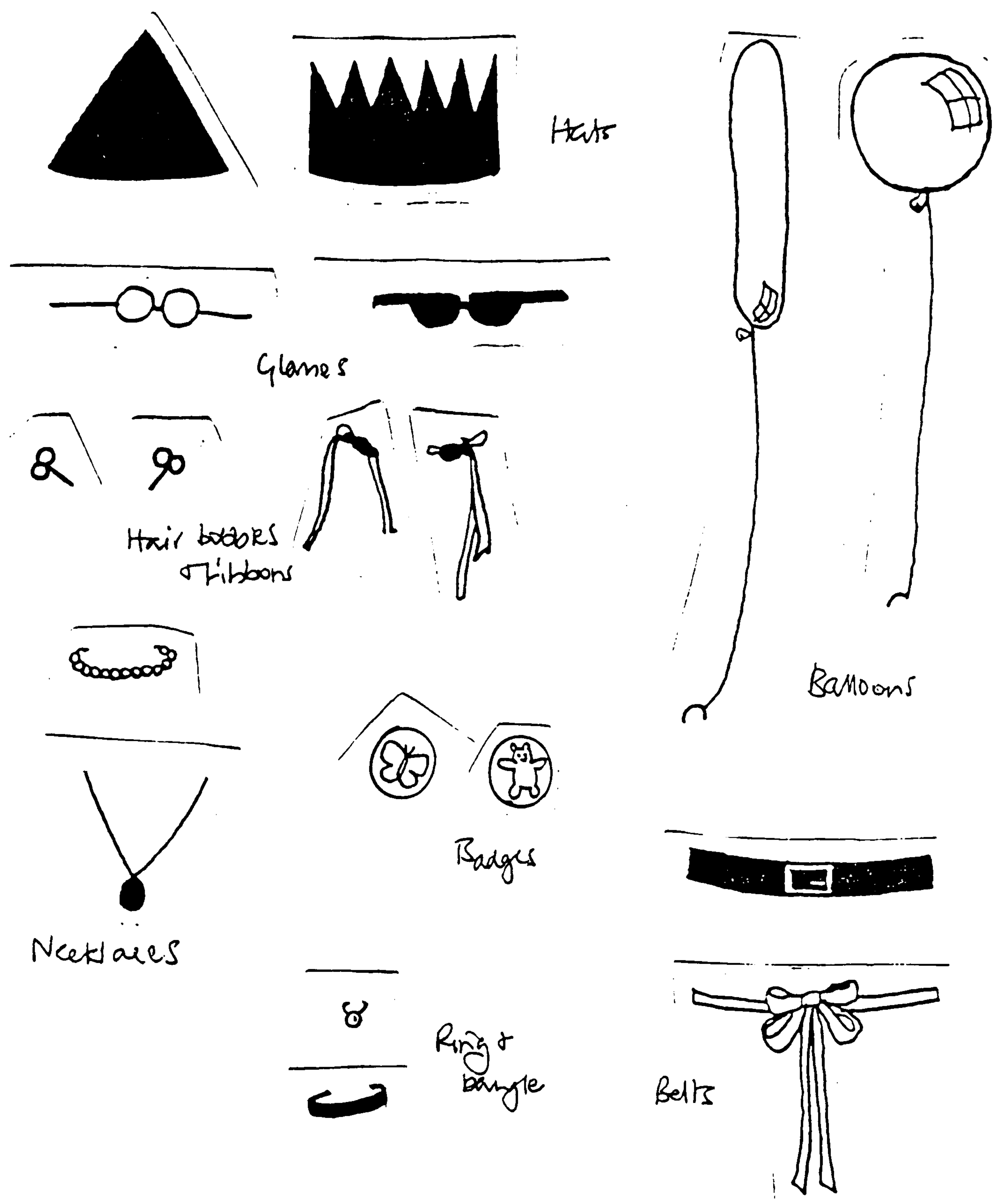
APPENDIX A.1
MDL task: Basic cards & cut-outs

Basic cards



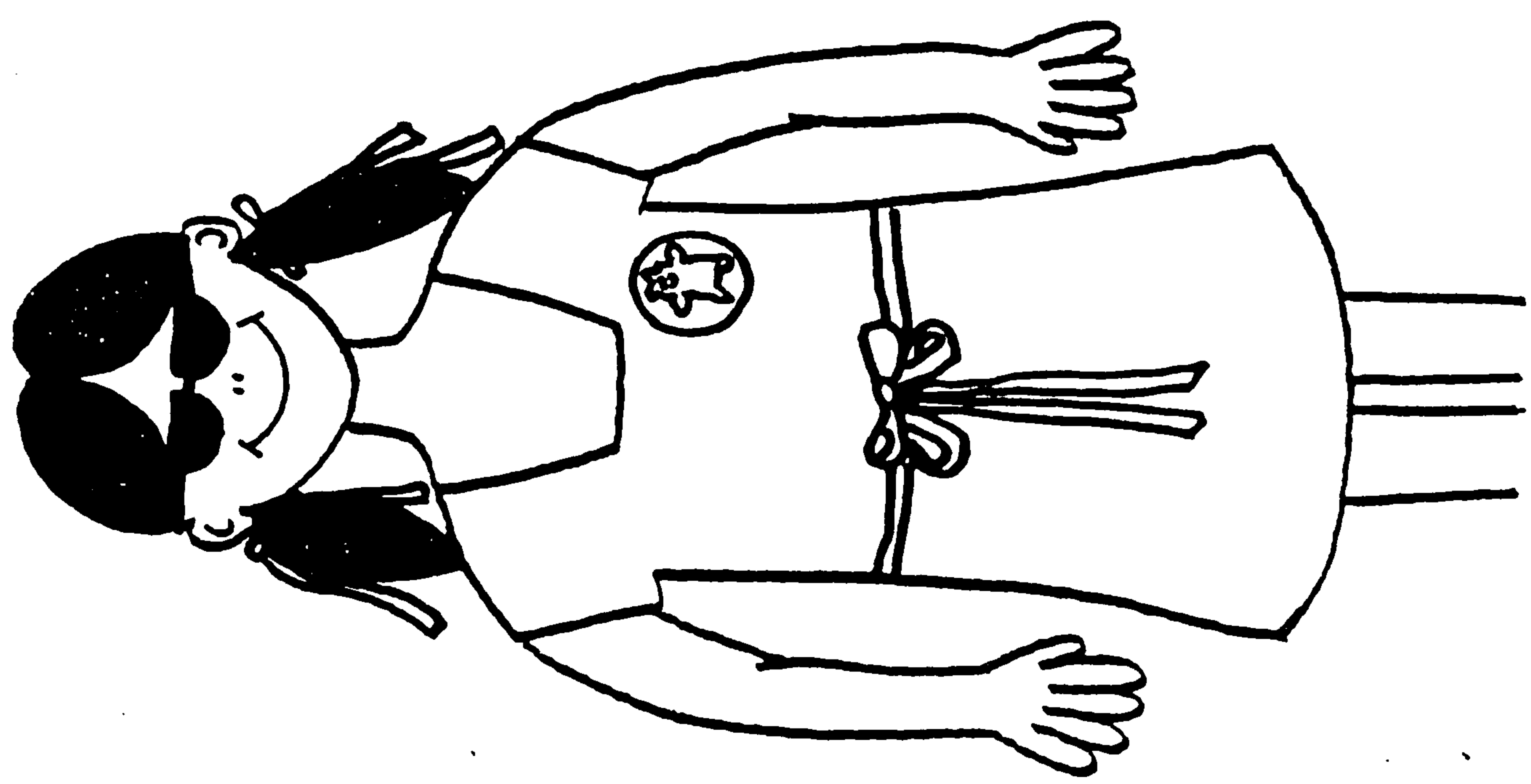


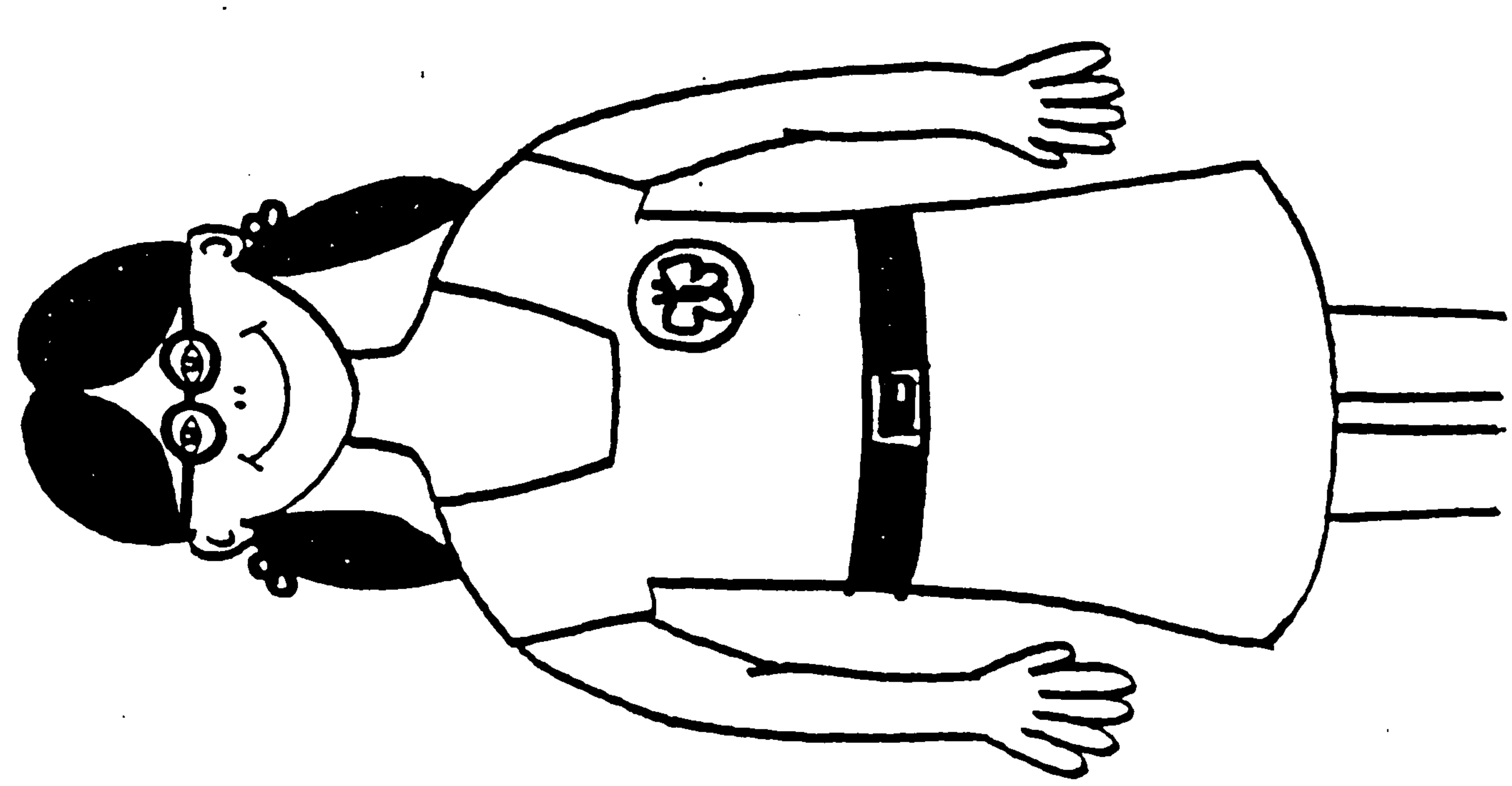
Cut-outs


Hats
Glasses
Hair bobbles & ribbons
Balloons
Badges
Necklaces
Ring & bangle
Belts

APPENDIX A.2

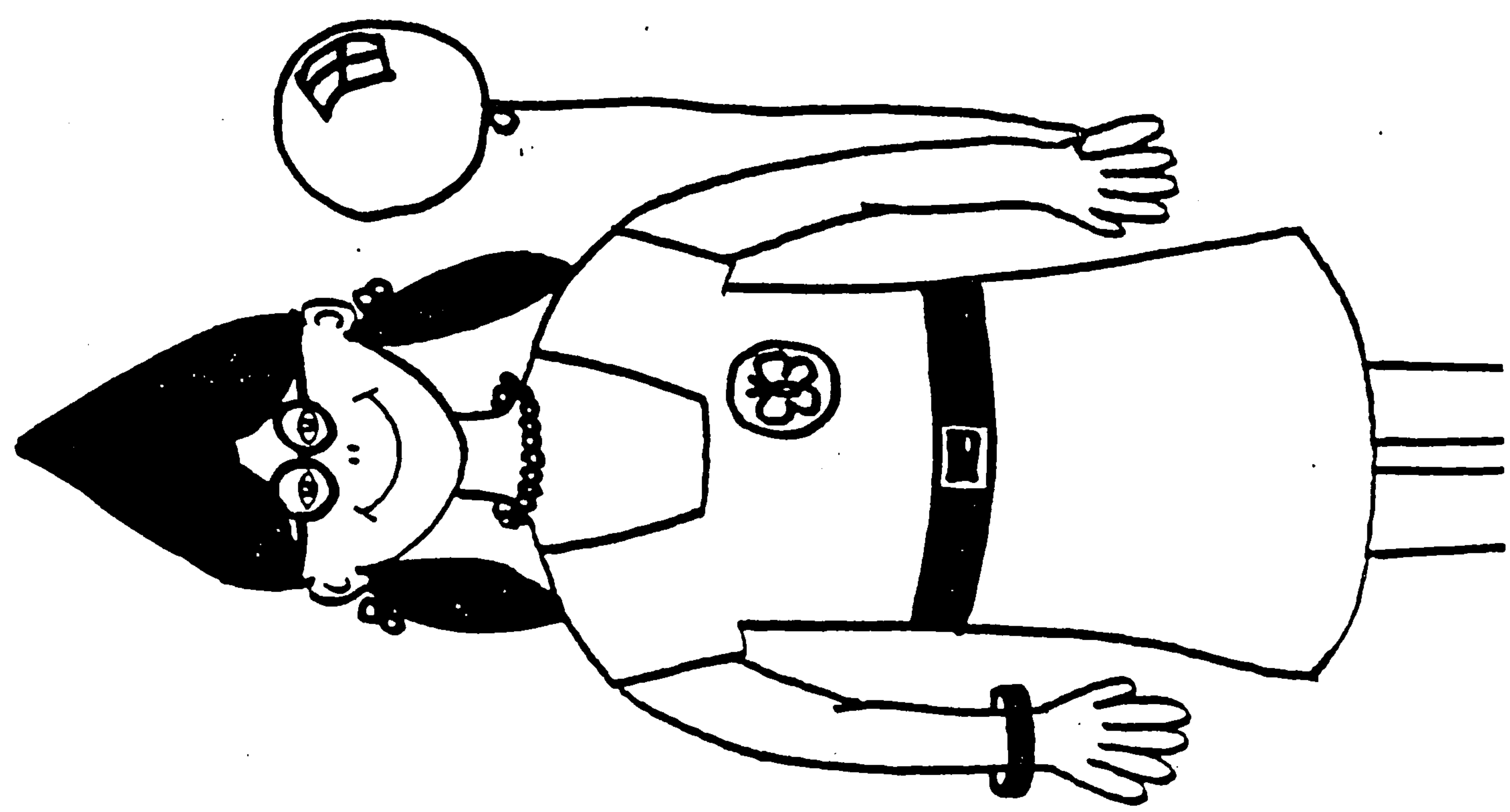
MDL task: Sample cards: 4 dimensions

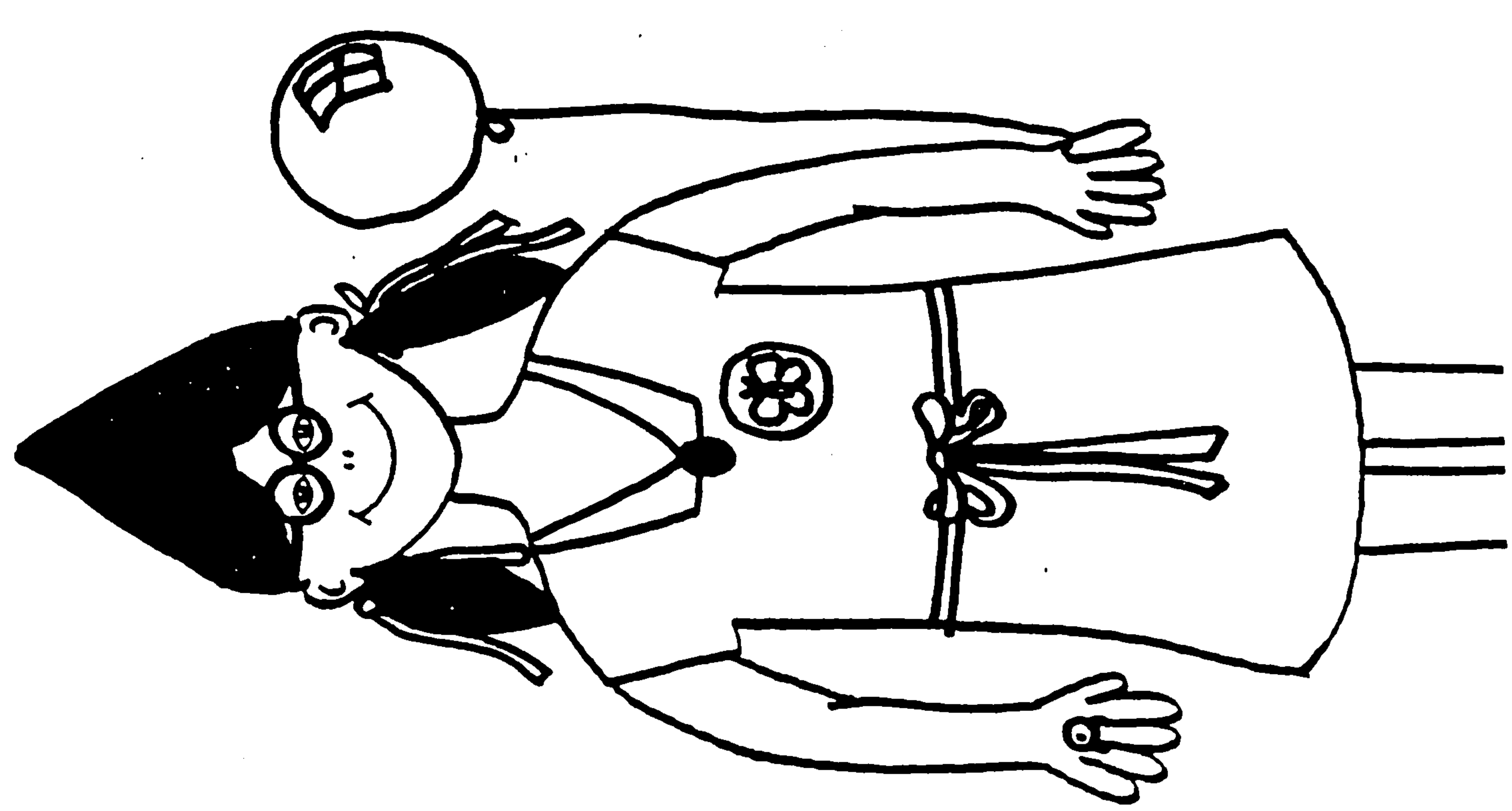




APPENDIX A.3

MDL task: Sample cards: 8 dimensions





APPENDIX A.4
MDL task: Record Card

1. 4 dim standard problem

DL(2) Name James Casey Age 10

Trial	Left	Choice	Right	Choice	Fback	cro	poi	bea	pen	ring	ban	saus	rou
						Hypotheses							
1	cro bea ring saus		(poi pen ban rou)	✓	+		✓		✓		✓		✓
2	poi pen ring saus		cro bea (ban rou)	✓	+						✓		✓
3	poi bea (ban) saus		cro pen ring rou	✓	−						✓		
4	poi pen ban rou	✓	cro bea ring saus		+ ↑						✓		
5	poi bea ring saus		cro pen ban rou	✓	+						✓		
6	poi bea ban rou	✓	cro pen ring saus		+						✓		
7	poi pen ring rou		cro bea ban saus	✓	+						✓		
8	cro pen ban rou	✓	poi bea ring saus		+ ↓						✓		
9	cro bea ban saus		poi pen ring rou										
10	cro bea ring rou		poi pen ban saus										
11	cro pen ring saus		poi bea ban rou										
12	poi pen ban saus		cro bea ring rou										
13	poi bea ring rou		cro pen ban saus										
14	cro pen ring rou		poi bea ban saus										
15	cro bea ban rou		poi pen ring saus										
16	cro pen ban saus		poi bea ring rou										

2. 4 dim problem with -ve information

DL(4) Name James Casey Age 10

Trial	Card Shown	A/S	Feedback	cro	poi	bea	pen	ted	but	buck	bow
				Hypotheses							
1	(buck ted bea cro)	A	+	✓		✓		✓		✓	
2	bow but (bea cro)	S	−	✓		✓					
3	bow ted pen cro	A	−			✓					
4	bow but pen poi	S	+ ↑			✓					
5	bow ted (bea) cro	A	+			✓					
6	bow ted pen poi	S	+			✓					
7	bow but bea poi	A	+			✓					
8	buck but pen poi	S	+ ↓			✓					
9	buck ted pen cro										
10	buck ted bea poi										
11	buck but bea cro										
12	bow but pen cro										
13	bow ted bea poi										
14	buck but bea poi										
15	buck ted pen poi										
16	buck but pen cro										

3. 8 dim problem with irrelevant information

DL(5) Name James Casey Age 10

Trial	Left	Choice	Right	Choice	Fback	Hypotheses Rel.								Irrel.							
						ri	bo	be	pe	bu	bo	ri	ba	kr	po	g	se	ra	bu	[illegible]	ro
1	rib bead buck ring	✓	bob pen bow ban		−		✓		✓		✓		✓								
2	bob pen buck ring		rib bea bow ban	✓	+						✓		✓								
3	bob bea bow ring	✓	rib pen buck ban		+						✓										
4	bob pen bow ban		rib bea buck ring		+ ↑						✓										
5	bob bea buck ring		rib pen bow ban		+						✓										
6	bob bea bow ban		rib pen buck ring		+						✓										
7	bob pen buck ban		rib bea bow ring		+						✓										
8	rib pen bow ban		bob bea buck ring		+ ↓						✓										
9	rib bea bow ring		bob pen buck ban																		
10	rib bea buck ban		bob pen bow ring																		
11	rib pen buck ring		bob bea bow ban																		
12	bob pen bow ring		rib bea buck ban																		
13	bob bea buck ban		rib pen bow ring																		
14	rib pen buck ban		bob bea bow ring																		
15	rib bea bow ban		bob pen buck ring																		
16	rib pen bow ring		bob bea buck ban																		

APPENDIX A.5

MDL task: Sequence of Stimuli Presentation

SEQUENCE OF STIMULI PRESENTATION.

	LEFT.	RIGHT.
1.	ABCD	abcd
2.	abCD	ABcd
3.	aBcD	AbCd
4.	abcd	ABCD
5.	aBCD	Abcd
6.	aBcd	AbCD
7.	abCd	ABcD
8.	Abcd	aBCD
9.	ABcD	abCd
10.	ABCd	abcD
11.	AbCD	aBcd
12.	abcD	ABCd
13.	aBCd	AbcD
14.	AbCd	aBcD
15.	ABcd	abCD
16.	AbcD	aBCd

APPENDIX A.6

MDL task: Scoring Procedures for the 10 Strategy Components

1. Number of Hypotheses per Trial

Total number of Hypotheses divided by number of Trials to criterion (i.e. Trials before 5 consecutive Trials with correct Choices upon which problem is stopped).

2. Hypotheses Consistent with Local Feedback

Percentage of Hypotheses consistent with Feedback on the same Trial. Irrelevant Hypotheses in 8 dimension problems treated as inconsistent.

3. Choice Consistent with Previous Hypothesis

Percentage of Choices on Trial n consistent with Hypotheses on Trial n-1. Choices following multiple Hypotheses allowed where Choice consistent with any Hypothesis. Trials following irrelevant Hypotheses in 8 dimension problems ignored.

4. Lose/Shift Hypothesis

Percentage of Hypotheses on Trial n-1 not repeated on Trial n after negative Feedback. Irrelevant Hypotheses in 8 dimension problems counted on basis of Feedback on Trial n i.e. counted positively if repeated after positive Feedback, and negatively if repeated after negative Feedback.

A 100% score on Component 1 will produce a 100% score on this Component also. A difference will arise where new Hypotheses are produced on Trial n which are not Consistent with Feedback on that Trial. These will reduce the score on Component 1, but not on this Component.

5. Lose/Shift Dimension

Percentage of Dimensions on Trial n-1 not repeated on Trial n after negative Feedback. Irrelevant Hypotheses in 8 dimension problems counted on basis of Feedback on Trial n i.e. counted positively if repeated after positive Feedback, and negatively if repeated after negative Feedback.

6. Win/Stay

Percentage of Hypotheses on Trial n-1 repeated on Trial n after positive Feedback. Irrelevant Hypotheses in 8 dimension problems ignored.

7. Hypothesis Checking

Percentage of Hypotheses on Trial n-1 not repeated on Trials to criterion after negative Feedback. Irrelevant Hypotheses in 8 dimension problems counted on basis of Feedback on subsequent Trials to criterion i.e. counted positively if repeated after positive Feedback, and negatively if repeated after negative Feedback.

8. Dimension Checking

Percentage of Dimensions on Trial n-1 not repeated on Trials to criterion after negative Feedback. Irrelevant Hypotheses in 8 dimension problems counted on basis of Feedback on subsequent Trials to criterion i.e. counted positively if repeated after positive Feedback, and negatively if repeated after negative Feedback.

9. Focusing over 2 Trials

Percentage of Hypotheses on Trial n consistent with Feedback on that Trial and on Trial n-1. Irrelevant Hypotheses in 8 dimension problems treated as inconsistent.

10 Focusing over All Trials

Percentage of Hypotheses on Trial n consistent with Feedback on that Trial and all preceding Trials (after Trial 3 this means consistent with solution). Irrelevant Hypotheses in 8 dimension problems treated as inconsistent.

APPENDIX A.7

MDL task: Scoring Procedures for the 3 Performance Indicators

1. Trial of Last Error

The number of the last Trial at which an incorrect Choice was made i.e. the Trial immediately before the criterion of 5 consecutive correct Choices was achieved, with 3 subtracted (because the Feedback on Trials 1-3 was fixed). A last error on Trials 1-3 scored 0. Failure to solve the problem resulted in a score of 20, which is the last Trial on which a wrong Choice could be made when extra Trials were allowed following a correct Choice on Trial 16.

2. Verbalisation of Correct Hypothesis during Criterion Trials

The number of Criterion Trials on which the correct Hypothesis was verbalised alone. Failure to reach criterion resulted in a score of 0.

3. Number of Hypotheses on Trials 1,2 & 3

Since the "ideal" performance would be a sequence of 4,2,1 Hypotheses on the first three Trials, these numbers of Hypotheses on the appropriate Trial scored 2 points. One Hypothesis more or less on each Trial scored 1 point.

Thus, the number of points scored for different numbers of Hypotheses on Trials 1, 2 & 3 are shown in the following table:

	No. of Hypotheses				
Trial	1	2	3	4	5
1	0	0	1	2	1
2	1	2	1	0	0
3	2	1	0	0	0

APPENDIX B.1
Working Memory Test using MDL Materials

Results of Pilot Study

Subject	Age	WM score
1	6	1
2	6	2
3	6	3
4	8	3
5	8	2
6	8	4
7	10	5
8	10	4
9	10	6

Average WM scores by Age-group:

Age	WM score
6	2
8	3
10	5

APPENDIX B.2
Working Memory Test using MDL Materials

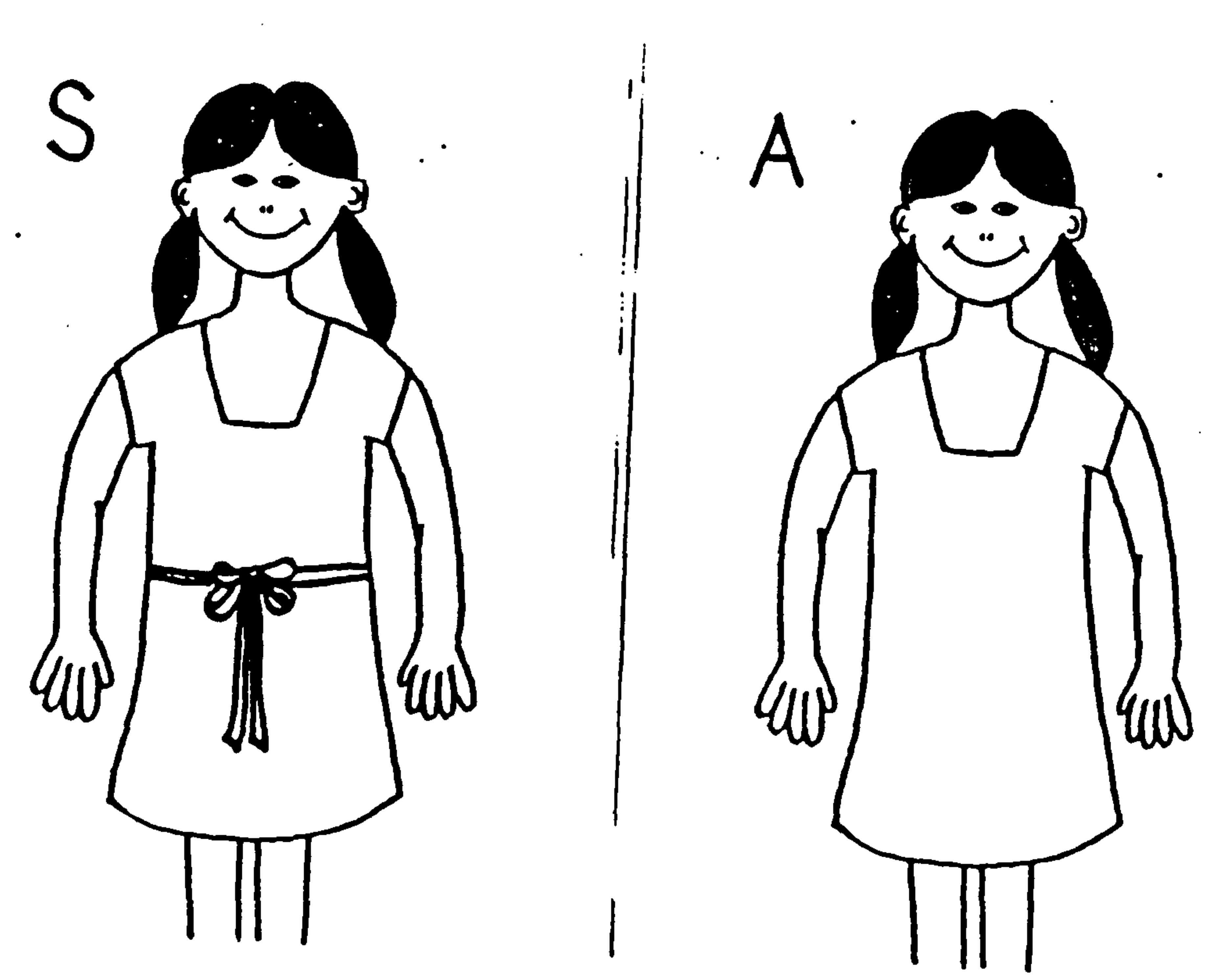
Pre-training arrays

1. bow (S)
   rou (B)
   gl (A)

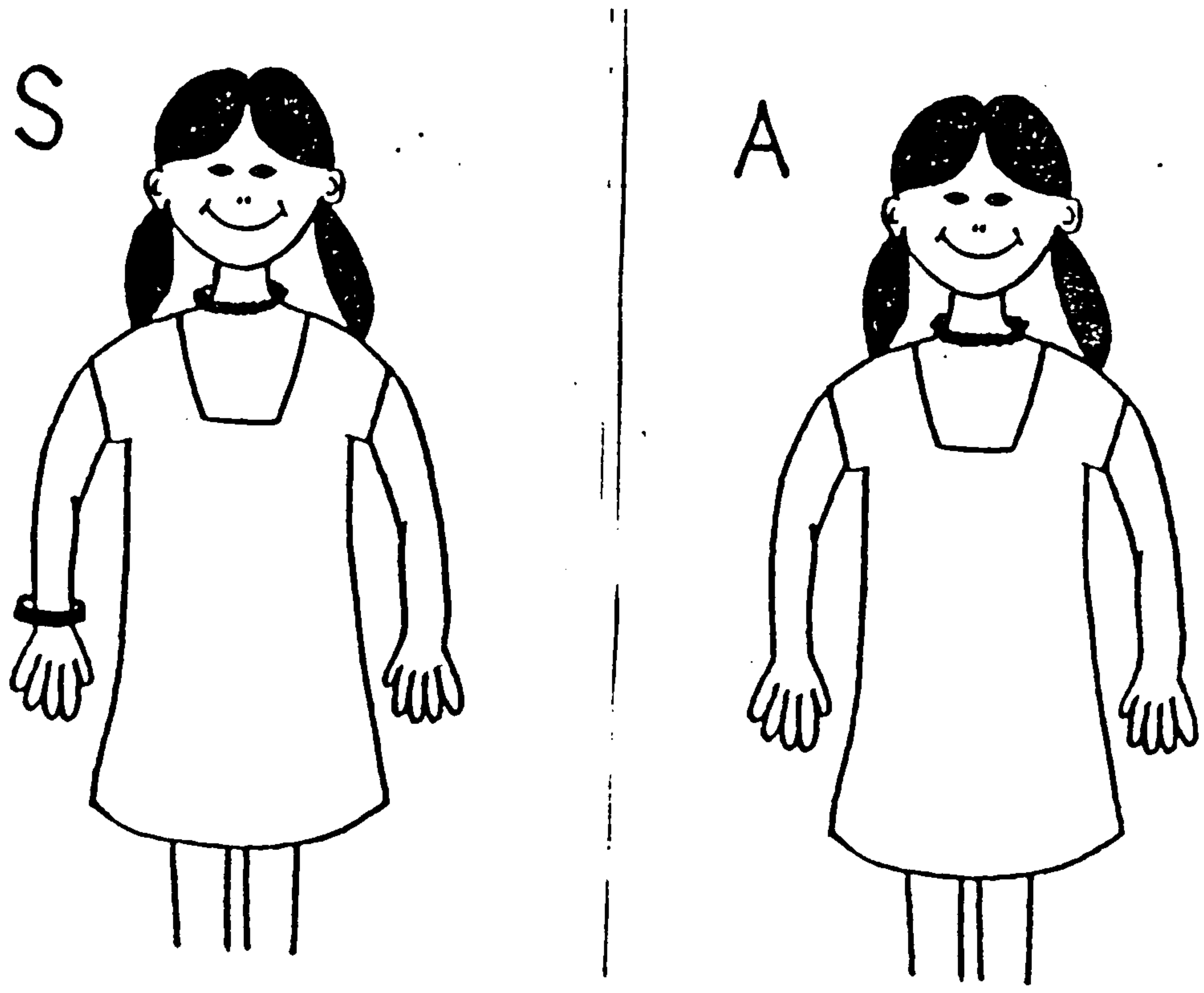
2. ban (S) bea (B)
   poi (A) ted (S)

3. bob (B) buck (A)
   sgl (B) ring (S) pen (S)
   cro (A) rib (A) but (B)

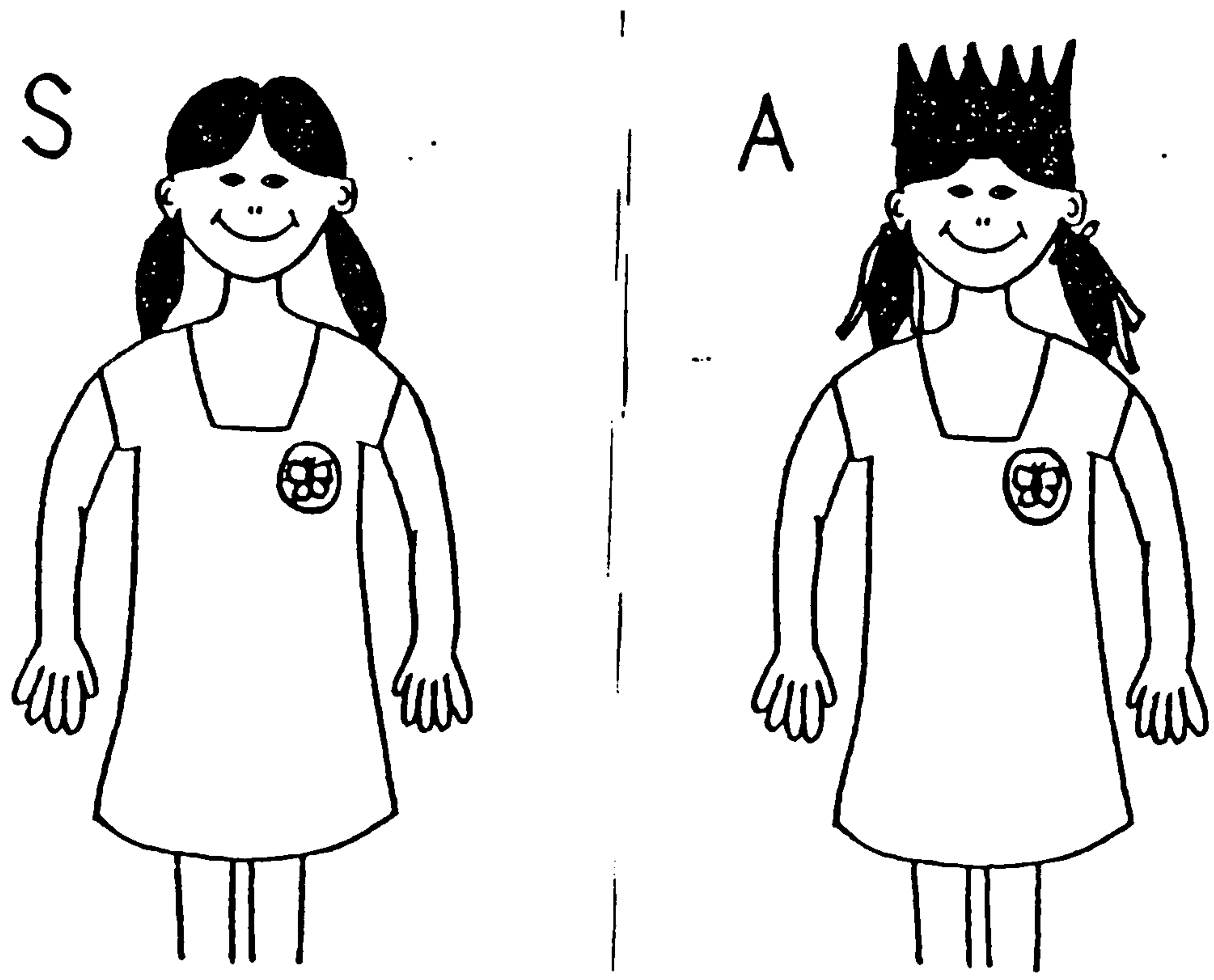
1-dim



2-dim



3-dim



APPENDIX B.3

Working Memory Test using MDL Materials

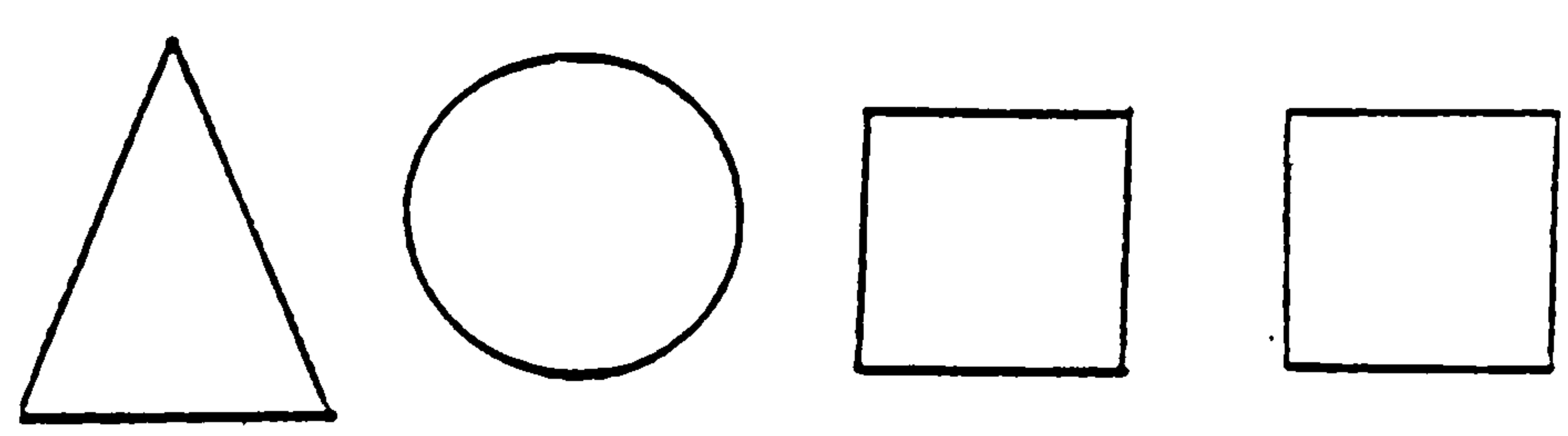
Record sheet and scoring procedure

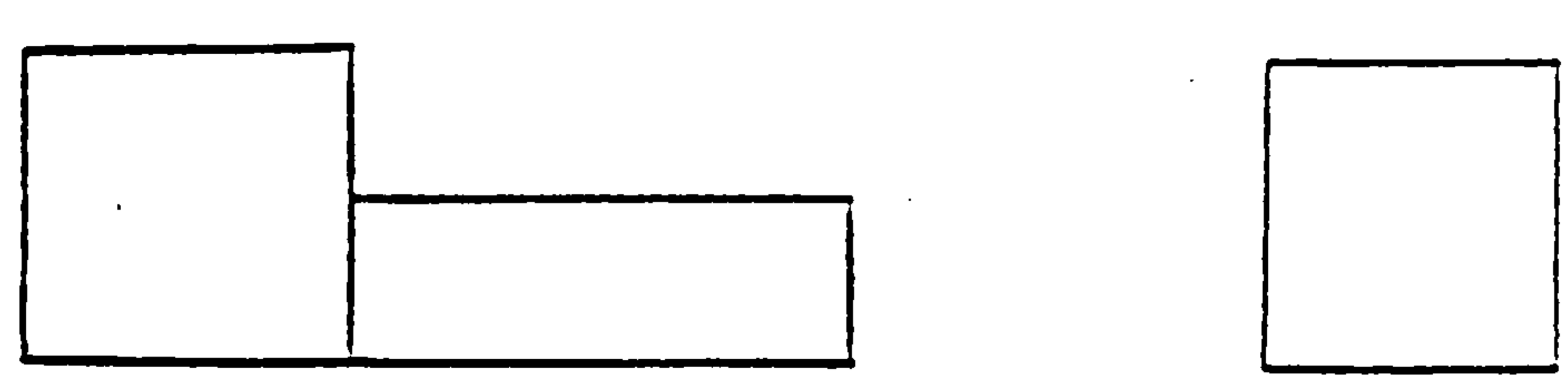
WM	Name James Casey Age 10.11		Recog	Boxed
1	cro(A)✓	(1)	1	1
	but(S)			
	rib(B)			
2	bow(A) rou(S)✓	(1)	2	2
	gl(B) ban(A)			
	bea(S) poi(B)			
3	ted(A)✓ bob(S)✓ buck(B)✓	(1)	3	3
	saus(A) sgl(S) ring(A)			
	pen(B) cro(S) rib(B)			
4	but(A)✓ bow(S)✓ gl(B)✓ bea(A)	(½)	3	3
	rou(S)✓ ban(B) poi(A)✓ bob(S)✓		4	4
	ted(B) buck(A) sgl(S) pen(B)			
5	saus(A)✓ ring(S)✓ cro(B)✓ but(A)✓ gl(S)✗	(½)	5	4
	rib(B)✓ bow(A)✓ bea(S)✓ ban(B)✓ poi(A)✓		5	5
	rou(S) bob(B) buck(A) pen(S) ring(B)			
6	ted(A)✓ sgl(S)✓ saus(B)✓ cro(A)✓ rib(S) bow(B)✓		(5)	(5)
	but(A) gl(S) bea(B) poi(A) bob(A) ring(S)✓		4	4
	ban(S) rou(B)✓ buck(S) pen(B) ted(A)✓ cro(B)✓		(5)	4
7	sgl(A) saus(S) rib(B) but(A) bea(S) ring(B) buck(A)			
	bow(S) gl(B) poi(A) bob(S) ban(B) rou(A) pen(S)			
	ted(B) sgl(A) rib(S) bea(B) buck(A) poi(S) ban(B)			
8	cro(A) saus(S) but(B) ring(A) bow(S) gl(B) bob(A) pen(S)			
	rou(B) ted(A) rib(S) buck(B) ban(A) gl(S) pen(B) poi(A)			
	sgl(S) bea(B) cro(A) but(S) bow(B) bob(A) rou(S) ban(B)			

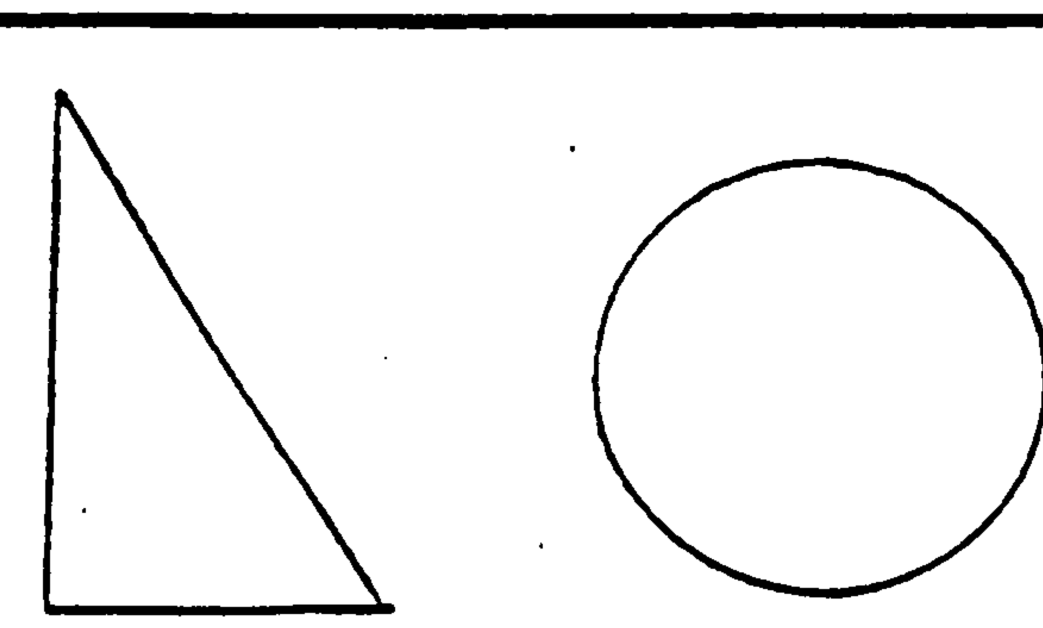
Score (4)

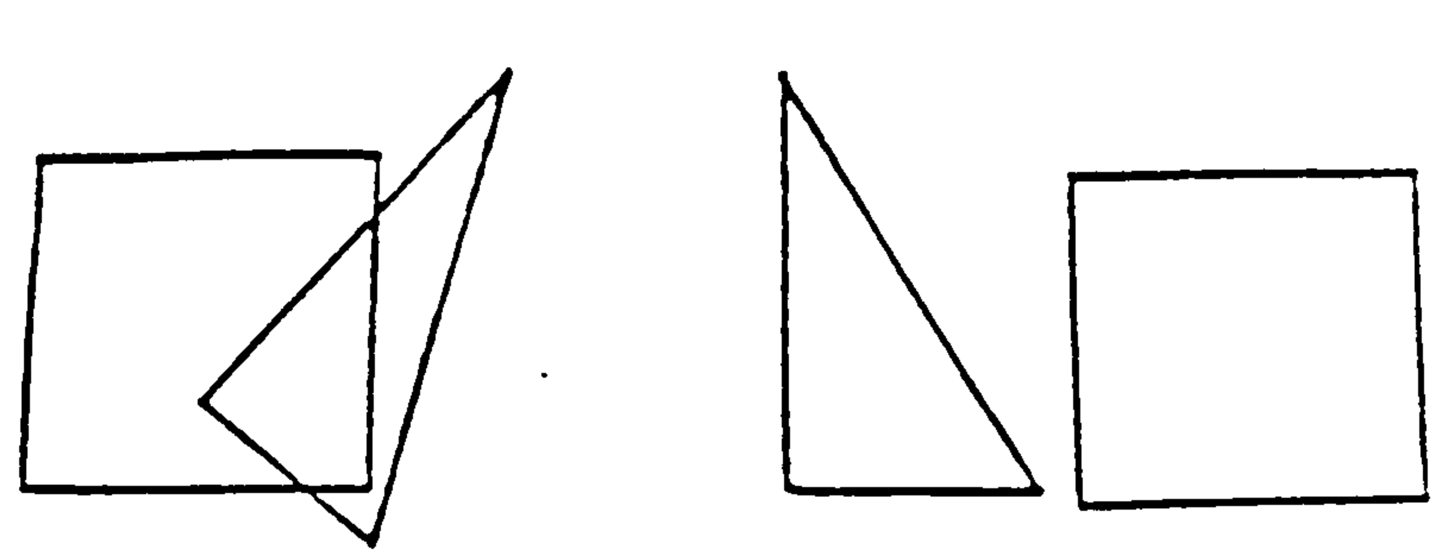
APPENDIX C.1
Figural Intersections Test

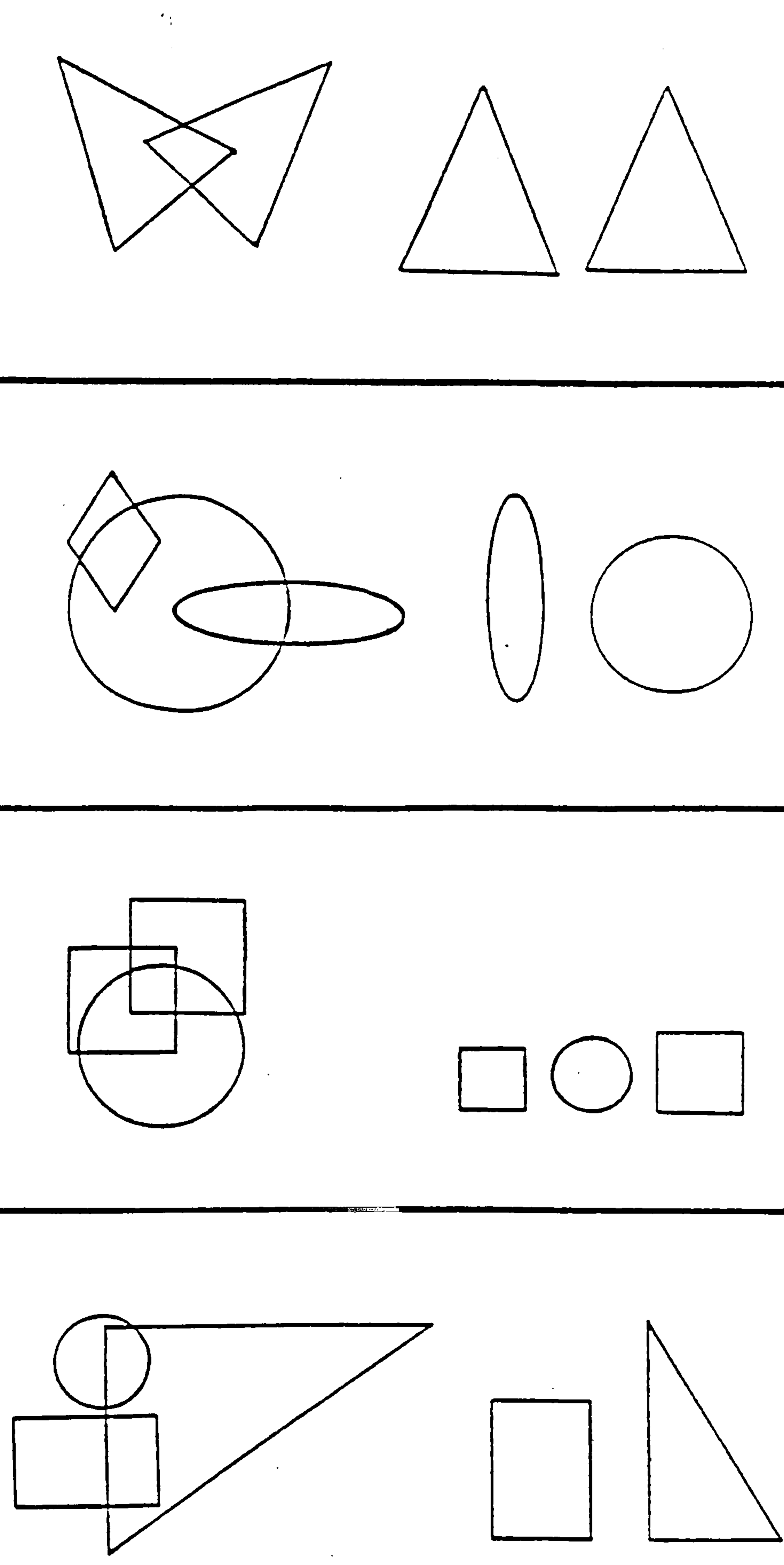
Pre-training items





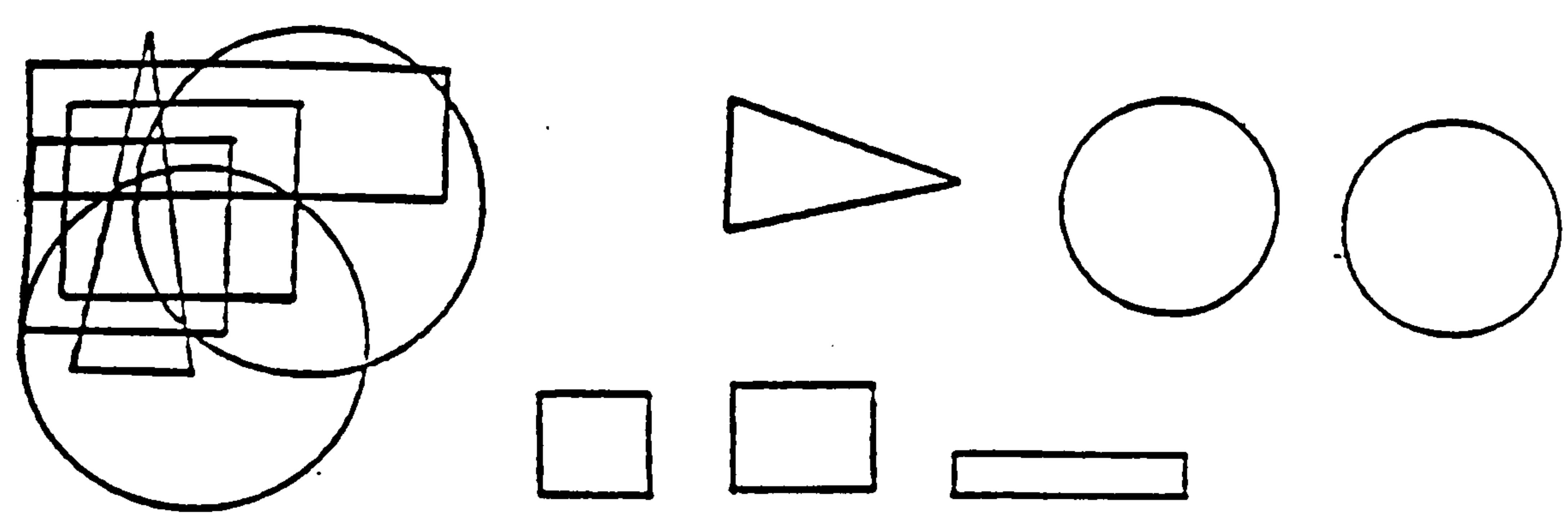


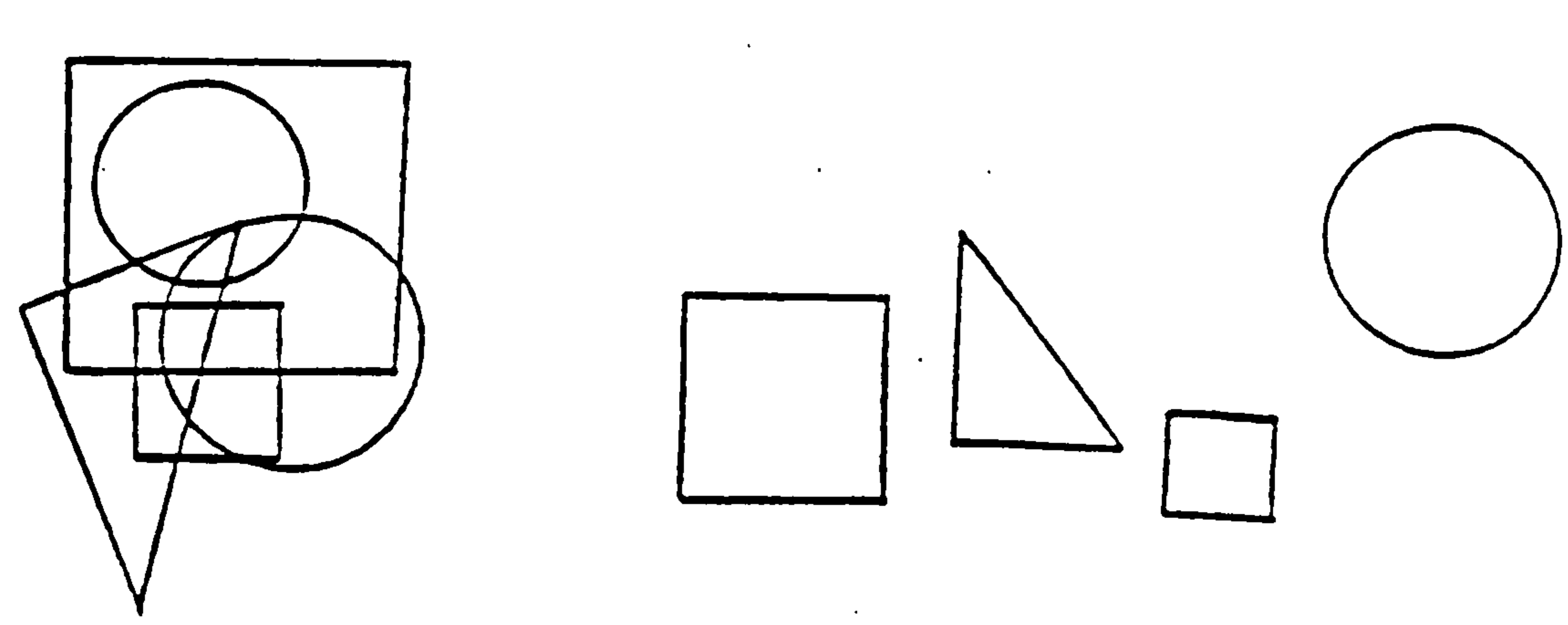




APPENDIX C.2
Figural Intersections Test

Examples of test items





APPENDIX C.3
Figural Intersections Test

Reliability & Validity

From Manual for FIT: Figural Intersections Test
(Juan Pascual-Leone, Dept. of Psychology, York University, Ontario)

RELIABILITY

Reliabilities are available only for earlier forms of FIT. Since most of the items are the same and the test has been slightly expanded the reliability of FIT 752 should be similar. The split-half reliability for the FIT2 score was calculated by taking at random half the items from each class (and discarding one item from classes with odd numbers of items). Subjects for each reliability computation were within a 1 year age range. The reliabilities obtained for the FIT2 score, in each subject group where version A2 or C2 (the versions previous to 752) were used, are given in Table 2. The average is .88, which is quite acceptable. Cronbach's α for each sample is also shown. (Reliabilities are not yet available for the FITC score).

VALIDITY

The construct validity of FIT as a measure of M power (k) may be established by examining the percentage of items of each class which are passed by each of several age groups. The idea behind the FIT is that each additional shape in the test set should require one additional unit of M power (see Task Analysis). The developmental theory of the M operator specifies that one additional unit of M power is available to a child every two years following the age of 3. Therefore, if FIT is a valid measure of M power, the performance level of a given age on a given class of item should be equal to the performance level of that age plus two years on the next higher class. This is so because the older subjects will have one additional unit of M power, and the higher class which has one additional shape requires one additional unit of M power in order to be solved at a level comparable to the lower class.

Table 1 shows the percentage of items of each class which are passed by various ages.[2] The data are taken from several studies. All the studies involve middle class students who were group tested by school grade, and students beyond the normal one year age range for the grade were later excluded. Subjects who failed all items were also excluded. The typical number of observations per point is about 60 student x 5 items.

Table 1 shows the predicted compensation between age and item class. At the 75% performance level, age 7 passes class 3, age 9 passes class 4, age 11 passes class 5, age 13 passes class 6, and age 15 passes class 7. Performance levels other than 75% generally show the same result (viz. each extra shape requires one extra unit of M power) in that the performance level on the higher class is reached by the next two year age group.

TABLE 1

Percentage of items passed as a joint function of age and item class.

AGE	FIT CLASS					
	3	4	5	6	7	8
7	78	50	49	23	16	1
9	86	67	61	37	28	11
11	94	83	70	54	43	30
13	97	94	88	75	61	51
15	99	100	98	90	84	70

TABLE 2

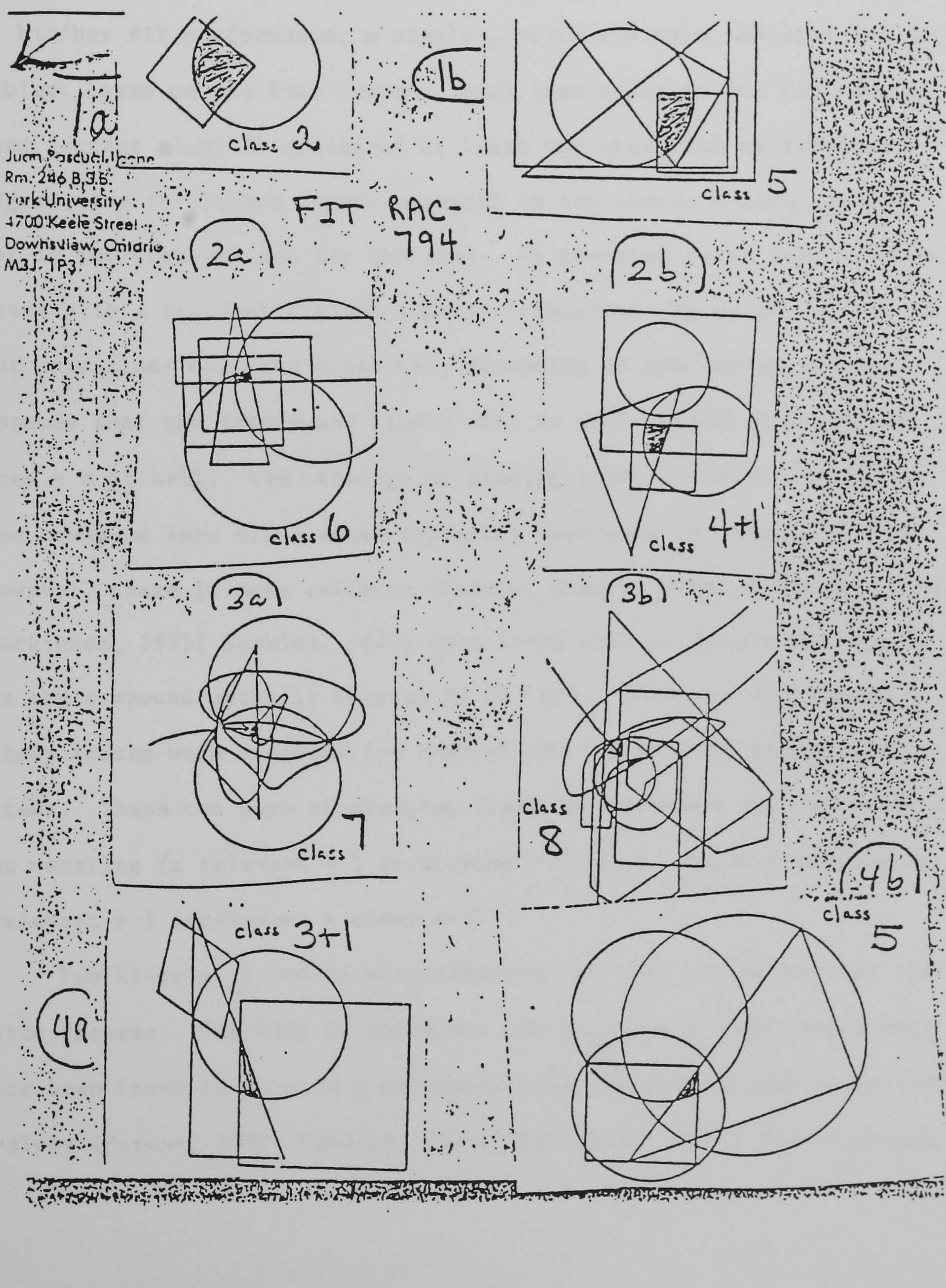
Reliabilites of FIT2 score. (Forms C2 and A2)

Study	Age	Split half	Chronbach's α
R7111	7-8	86	90
R717	9-10	91	93
R7111	9-10	87	90
R7111	11-12	87	-
RM	A	90	84

APPENDIX C.4
Figural Intersections Test

Scoring procedure

Examples of answers for different classes



From Johnson (1982)

APPENDIX C.

Assignment of k Estimates on the Basis of FIT Performance

Four k scores were initially assigned to each subject on the basis of his/her FIT performance; a single k score was then computed for each subject based on the four scores. Each item class in the FIT version used (except class 2) contained at least one item with an irrelevant figure; the irrelevant figure appeared in the compound-form set but not in the discrete set for the item. In grouping items into classes, items with x relevant figures and one irrelevant figure may either be put into class x or into class x+1, depending on whether or not one assumes that the irrelevant figure adds to task demand (i.e., Md of item = x or x+1). The strategy of placing items with x+1 figures in the compound into class x has typically been used in scoring the FIT. However, there is some evidence (Garcia, Aragon, Owen, & Sachse, 1976; Parkinson, 1975; Skakich, 1978) that items with an irrelevant shape in the compound actually have an Md of x+1. Thus, in the present study scores were computed for each of the two ways of classifying items. These two ways of grouping items into classes are referred to as x scaling (x relevant + 1 irrelevant = class x) and x+1 scaling (x relevant + 1 irrelevant = class x+1).

Two kinds of k scores were computed for each way of scaling the item classes. One kind of score was the $K_{.75}$ score which repeatedly has been found to provide k estimates close to theoretically-appropriate values (Furman, 1981; Goodman, 1979b; Parkinson, 1975; Pascual-Leone &

Burtis, 1975; Skakich, 1978; Van Esch, 1978). This score is obtained by grouping the items into classes and obtaining for each class the percentage of items passed in that class. The $K_{.75}$ score is the highest stimulus class at which at least 75% of the items are passed, provided that all (or all but one) of the lower classes also have 75% pass rates (a drop to 60% pass in one lower class is allowed). (This score is sometimes referred to as the $K_{.80}$ score, however, given the number of items in each FIT class, there is no practical difference between using a pass rate of 75% and one of 80%.) This way of scoring yielded two scores: $\underline{K}_{.75}$-$\underline{x}$ and $\underline{K}_{.75}$ - $\underline{x+1}$.

The second kind of $\underline{k}$ score is the S1-theoretical (or S1T) score. This score is based on the strong theoretical assumption that a child will solve all and only those items with class values less than or equal to his/her $\underline{Mp}$ (e.g., if a child has an $\underline{Mp}$ of 3, s/he should solve all class 2 and 3 items, but no items of class 4 or higher). The score is computed by first summing the number of items solved across stimulus classes 2 through 7. One then uses a raw-score distribution to determine what S1T score corresponds to the (summed) raw performance score. Table C-1 lists the distributions for assigning S1T scores for the x and x+1 scaling methods for the FIT version used in the present study. (The distributions were constructed based on the strong theoretical assumption stated above.) I call the S1T scores S1T-x and S1T-x+1.

Pascual-Leone (personal communication, 1982) suggests that the S1T score may be more reliable, because it is based on data from all the

Table C-1

Raw Score Distributions for Assignment of SIT Scores on the Basis of FIT (RAC 794) Performance

SIT	Number of Correct Items (Classes 2 through 7) x scaling	x+1 scaling
1	≤4	≤4
2	5- 9	5- 8
3	10-15	9-13
4	16-20	14-19
5	21-25	20-24
6	26-30	25-29
7	≥31	≥30

No. of items in each class (for K_{75} score)

Class	x-scaling		x+1 scaling			
	Total	75%	60%	Total	75%	60%
2	5	4	3	5	4	3
3	5	4	3	4	3	3
4	6	5	4	5	4	3
5	5	4	3	6	5	4
6	5	4	3	5	4	3
7	5	4	3	5	4	3
8	5	4	3	5	4	3
9				1	1	1

passed items. The $K_{.75}$ score, however, may be more valid, because it is sounder semantically, pegging k at the highest item class that is reliably passed. A single composite FIT-K score for each subject was constructed in the following manner. The four k-estimates for the subject were examined, and if at least three of the four scores had the same value then that majority value was assigned as the FIT-K score (e.g., scores of 3, 3, 3, and 4 yielded a FIT-K of 3). If there was no majority score value, then the mean of the four scores was assigned as the FIT-K score (e.g., scores of 2, 2, 3, 4 yielded a FIT-K of 2.75); decimal values were retained.

APPENDIX D.1

Metacognition

Metacognitive knowledge questions: record and scoring procedures

Record sheet

Metacog Q. Name James Casey Age 10

Q1.	4 dim (E)	8 dim	Card (H)	(2)

Q2.	Easy	1	diff	3	same	4-1	3
	Hard	7	diff	-	same	3	(6)

Q3.	2 diff	2	5	
	2 diff 2 same	3		
	4 diff	4	9	(3)
	4 diff 4 same	5		
	8 diff	7x2 = 14		

Scoring procedures

Question 1

1 point was awarded for each correct assessment to the two parts of this question. The criterion used to establish what was a correct assessment for each child was the number of problems solved of the three different types. Where scores were equal the standard 4 dimension problem type was taken as the easiest, and either of the other two problem types as the hardest.

Question 2

Points were awarded according to the following table:

No. of complimentary items	Points awarded "Easy"	"Hard"
1	4	0
2	3	0
3	2	0
4	1	0
5	0	1
6	0	2
7	0	3
8	0	4

No. of identical items	Points awarded "Easy"	"Hard"
1 or 2	-1/2	+1/2
3 or more	-1	+1

This scoring system could result in negative scores for the "Easy" question. However, the minimum allowable score was 0.

Question 3

In order to award points the suggested number of "swops" were added together for the two complimentary (2 diff) and two complimentary/two identical (2 d/s) pairs of cards, and for the four complimentary (4 diff) and four complimentary/ four identical (4 d/s) pairs. The number of "swops" suggested for the eight complimentary (8 diff) pair was then doubled. The three numbers of total "swops" obtained were then compared and 1 point awarded for each of the following conditions that were met:

4 diff + 4 d/s > 2 diff + 2 d/s

8 diff x 2 > 2 diff + 2 d/s

8 diff x 2 > 4 diff + 4 d/s

APPENDIX D.2

Metacognition

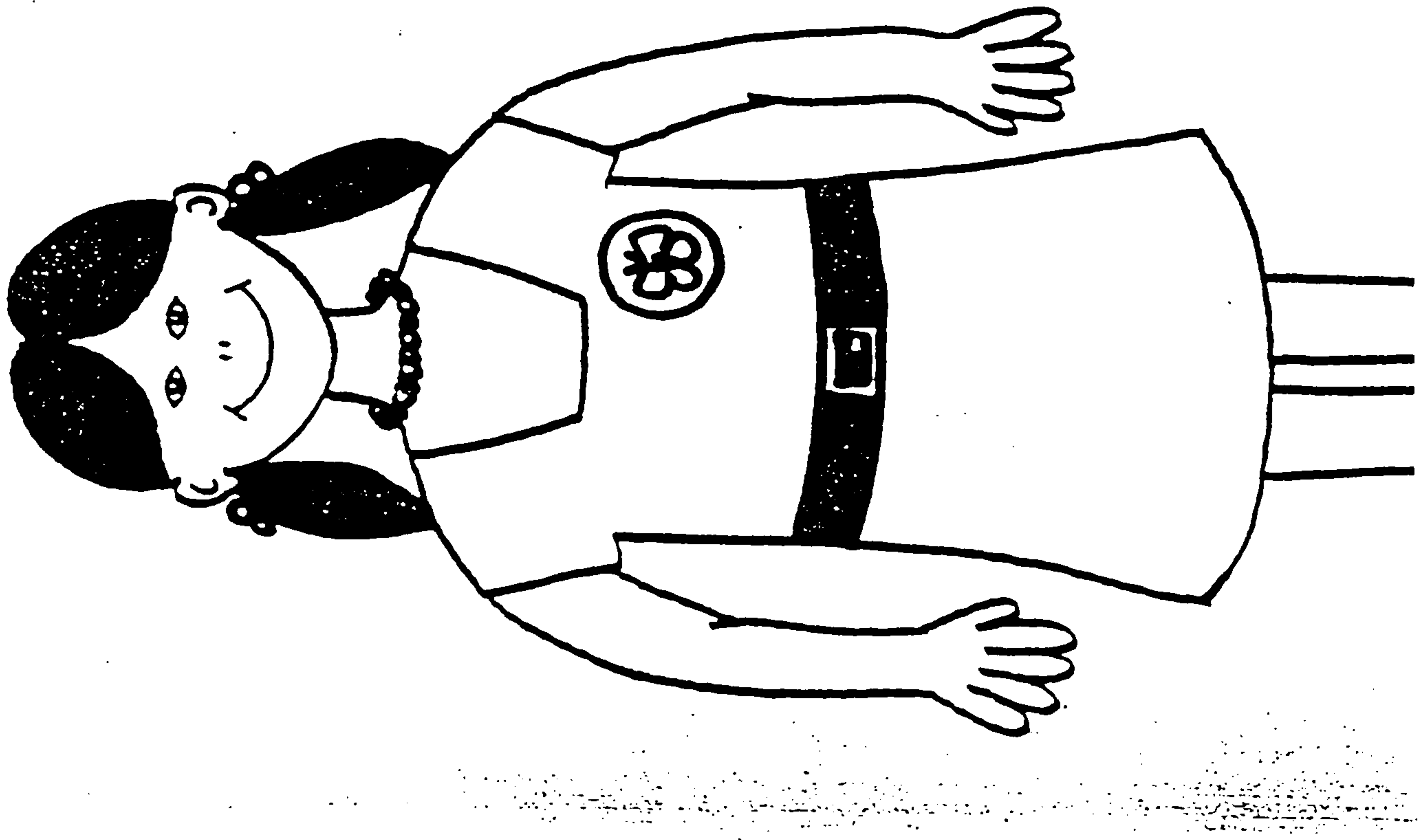
Metacomprehension: photographs

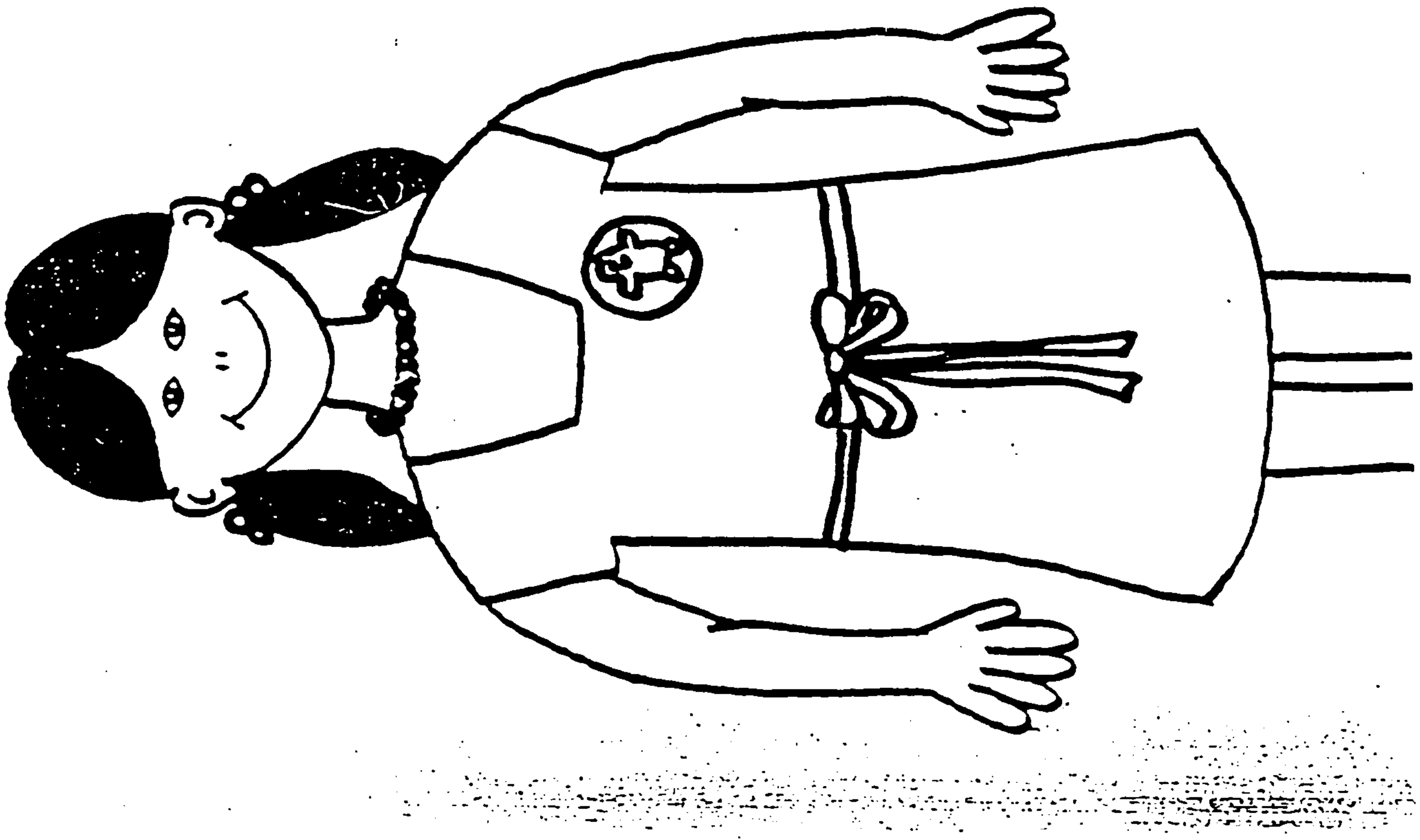
Unsure

Sure

APPENDIX D.3
Metacognition

Strategy Flexibility: example of test card





APPENDIX D.4
Metacognition

Strategy Flexibility: record sheet

Strategy flexibility — Trial (0)

Problem	1	2	3	4	5	6	7	8
1	1	✓ 1	✓ 1	✓ 1	✓ 1	✓ 1	✓ 1	✓ 1
2	1	× 1(2)	✓ 1(2)	× R	R	R	R	R
3	1	× 1(1)	✓ 1(1)	✓ 1(1)	✓ 1(1)	✓ 1(1)	✓ 1(1)	✓ 1(1)
4	1	✓ 1	✓ 1	✓ 1	✓ 1	✓ 1	✓ 1	✓ 1
5	1	× 1(2)	× R	R	R	R	R	R
[illegible]	1	✓ 1	× 1(2)	✓ 1(2)	✓ 1(2)	✓ 1(2)	✓ 1(2)	✓ 1(2)

Strategy flexibility — Trial (1)

Problem	1	2	3	4	5	6	7	8
1	R							
2	1	✓	× 1 2	× R				
3	1	✓	× R					
4	R							
5	R							
6								

Strategy flexibility — Trial (2)

Problem	1	2	3	4	5	6	7	8
1	R	R	R	R	R	R	R	R
2	R	R	R	R	R	R	R	R
3								
4								
5								
6								

APPENDIX E.1
CARALOC

Questionnaire and scoring

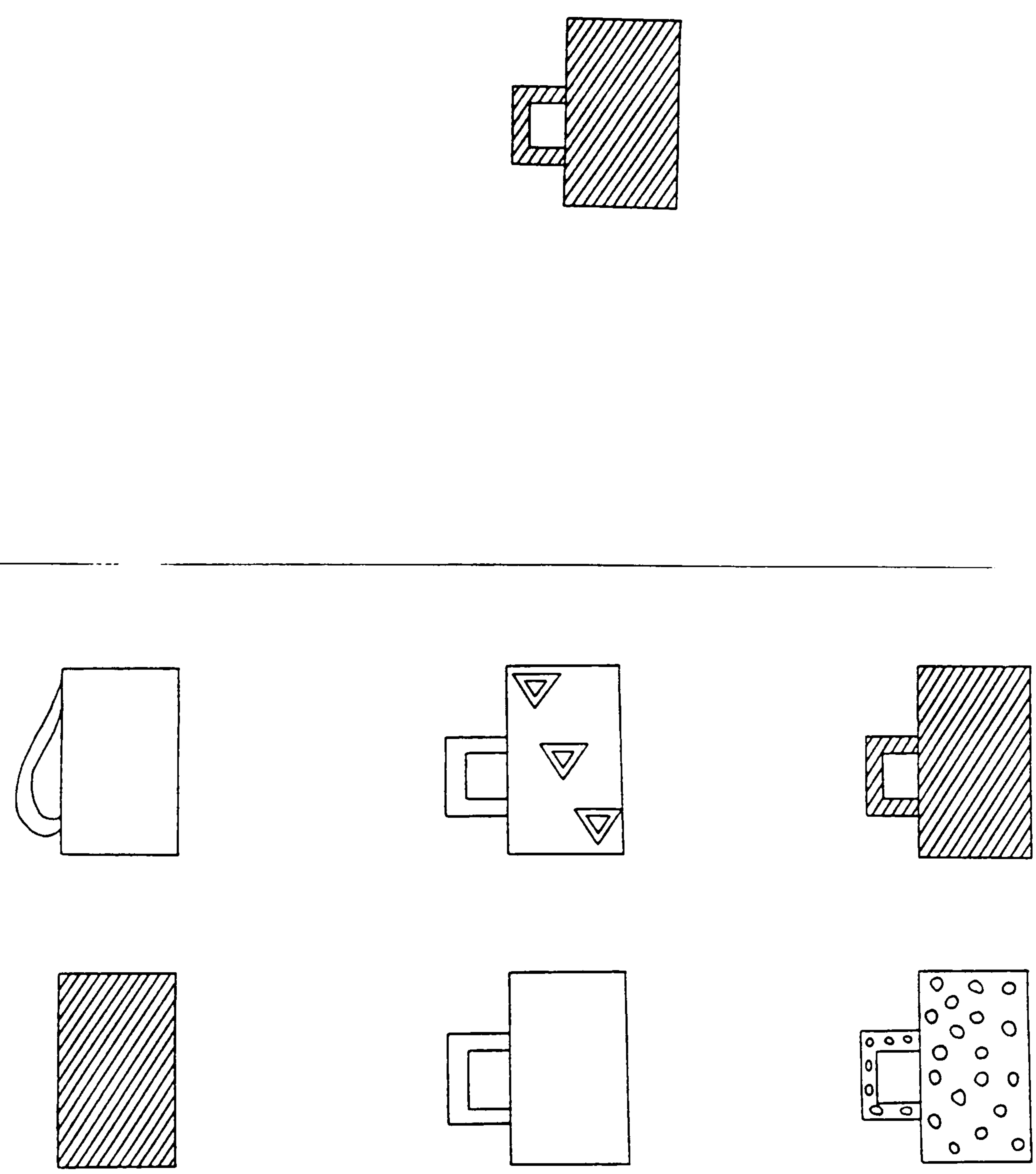
Name ____________

	Yes	No	?
1 Do you feel that most of the time it's not worth trying hard because things never turn out right anyway ?	0	2	1
2 Do you feel that wishing can make good things happen ?	0	2	1
3 Are people good to you no matter how you act towards them ?	0	2	1
4 Do you like taking part in plays or concerts ?	-	-	-
5 Do you usually feel that it's almost useless to try in school because most children are cleverer than you ?	0	2	1
6 Is a high mark just a matter of 'luck' for you ?	0	2	1
7 Are you good at spelling ?	-	-	-
8 Are tests just a lot of guesswork for you ?	0	2	1
9 Are you often blamed for things which just aren't your fault ?	0	2	1
10 Are you the kind of person who believes that planning ahead makes things turn out better ?	2	0	1
11 Do you find it easy to get up in the morning ?	-	-	-
12 When bad things happen to you, is it usually someone else's fault ?	0	2	1
13 When someone is very angry with you, is it impossible to make him your friend again ?	0	2	1
14 When nice things happen to you, is it only good luck ?	0	2	1
15 Do you feel sad when it's time to leave school each day ?	-	-	-
16 When you get into an argument, is it usually the other person's fault ?	0	2	1
17 Are you surprised when your teacher says you've done well ?	0	2	1
18 Do you usually get low marks, even when you study hard ?	0	2	1
19 Do you like to read books ?	-	-	-
20 Do you think studying for tests is a waste of time ?	0	2	1

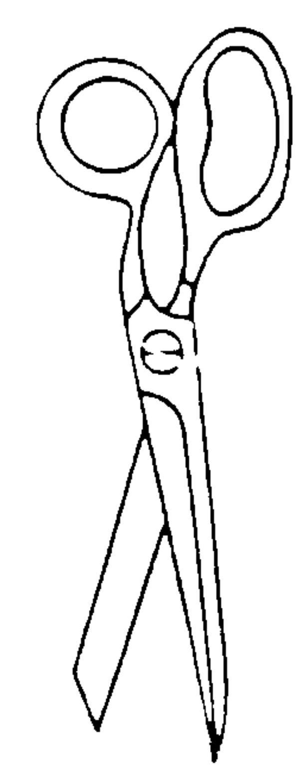
APPENDIX F.1
MFF20

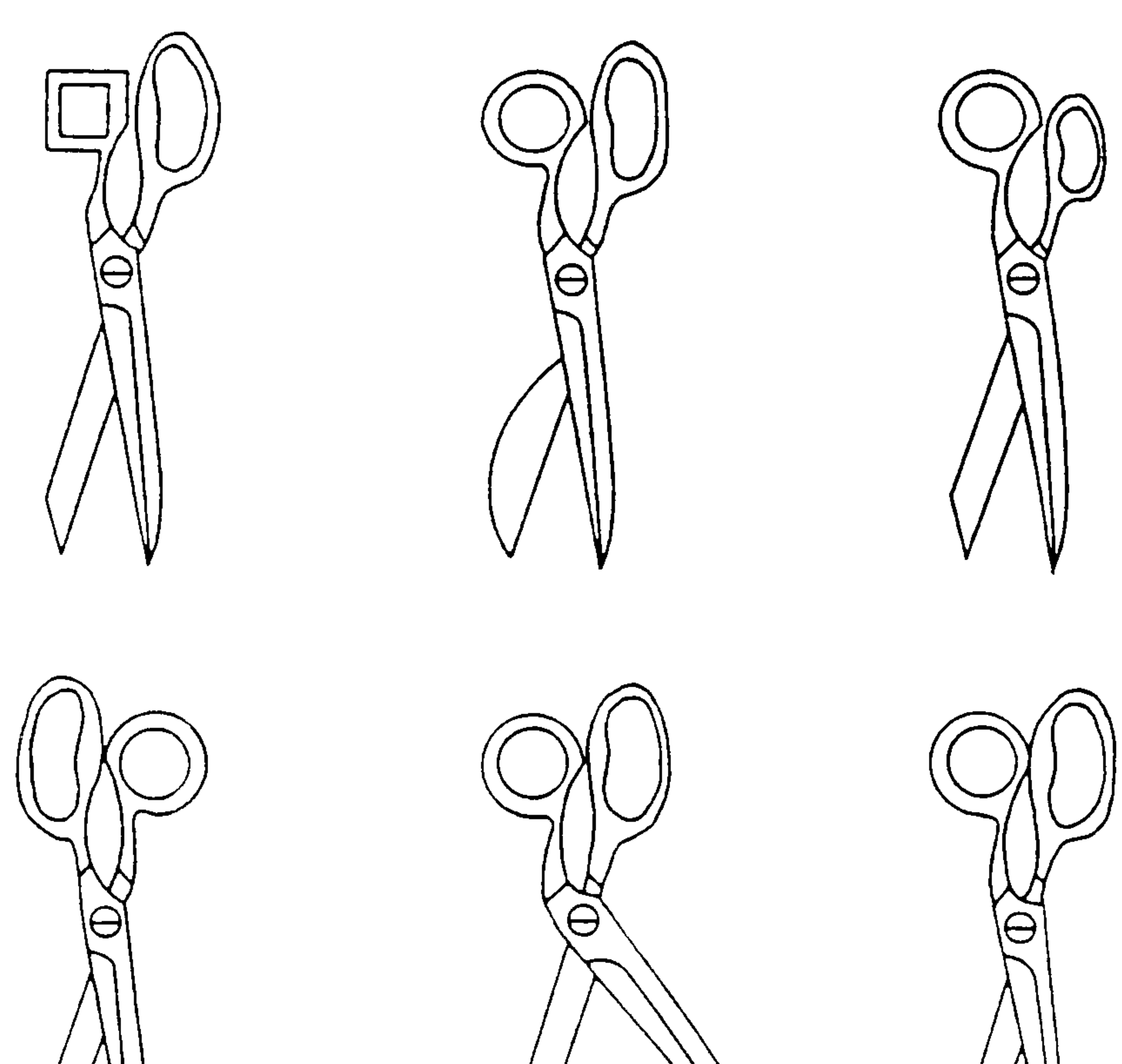
Example of practice and test items

1. Practice item



2. Test item





APPENDIX F.2
MFF20

Record Sheet and Scoring Procedure

Record sheet

MFF20 Name Kelly Morgan (10)

Total errors 17 Latency 12.5

ITEM	TIME	RESPONSES	ITEM	TIME	RESPONSES
1.	7.0	1 2 3 4 5 6	11	10.0	1 2 3 4 5 6
2	7.0	1 2 3 4 5 6	12	20.0	1 2 3 4 5 6
3	15.0	1 2 3 4 5 6	13	11.0	1 2 3 4 5 6
4	6.0	1 2 3 4 5 6	14	25.0	1 2 3 4 5 6
5	6 0	1 2 3 4 5 6	15	31.0	1 2 3 4 5 6
6	15.0	1 2 3 4 5 6	16	18.5	1 2 3 4 5 6
7	5.0	1 2 3 4 5 6	17	11.0	1 2 3 4 5 6
8	10.0	1 2 3 4 5 6	18	11.0	1 2 3 4 5 6
9	21.0	1 2 3 4 5 6	19	12.0	1 2 3 4 5 6
10	6.0	1 2 3 4 5 6	20	7.0	1 2 3 4 5 6

Scoring

From the error and latency scores recorded for each of the children, as illustrated above, their score for Impulsivity was arrived at using the formula devised by Salkind & Wright (1977), as follows:

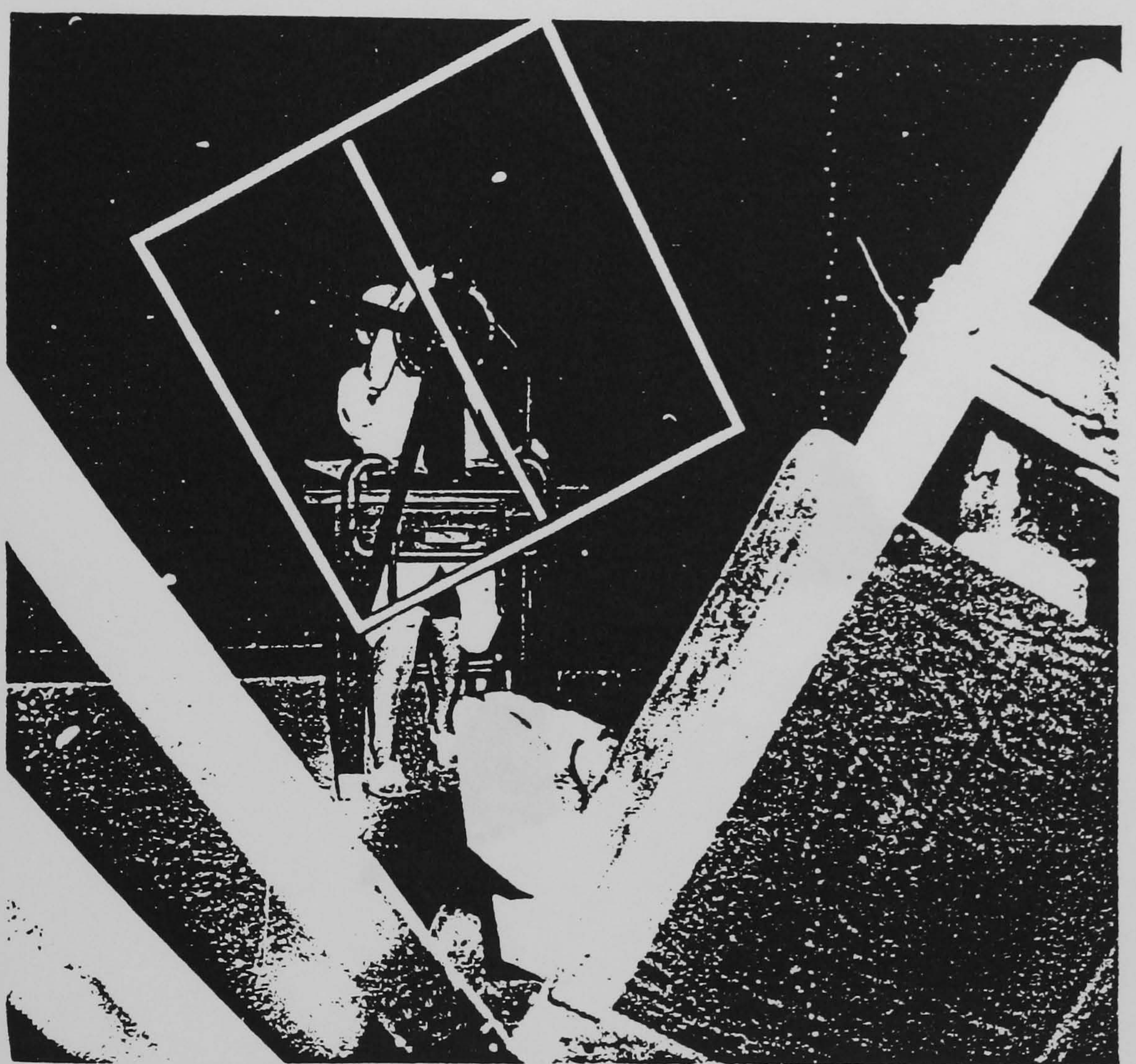
$$I_i = z_{ei} - z_{li}$$

where I_i = impulsivity score for the ith child, z_{ei} = a standard score for the ith child's total errors, and z_{li} = a standard score for the ith child's mean latency.

APPENDIX G.1

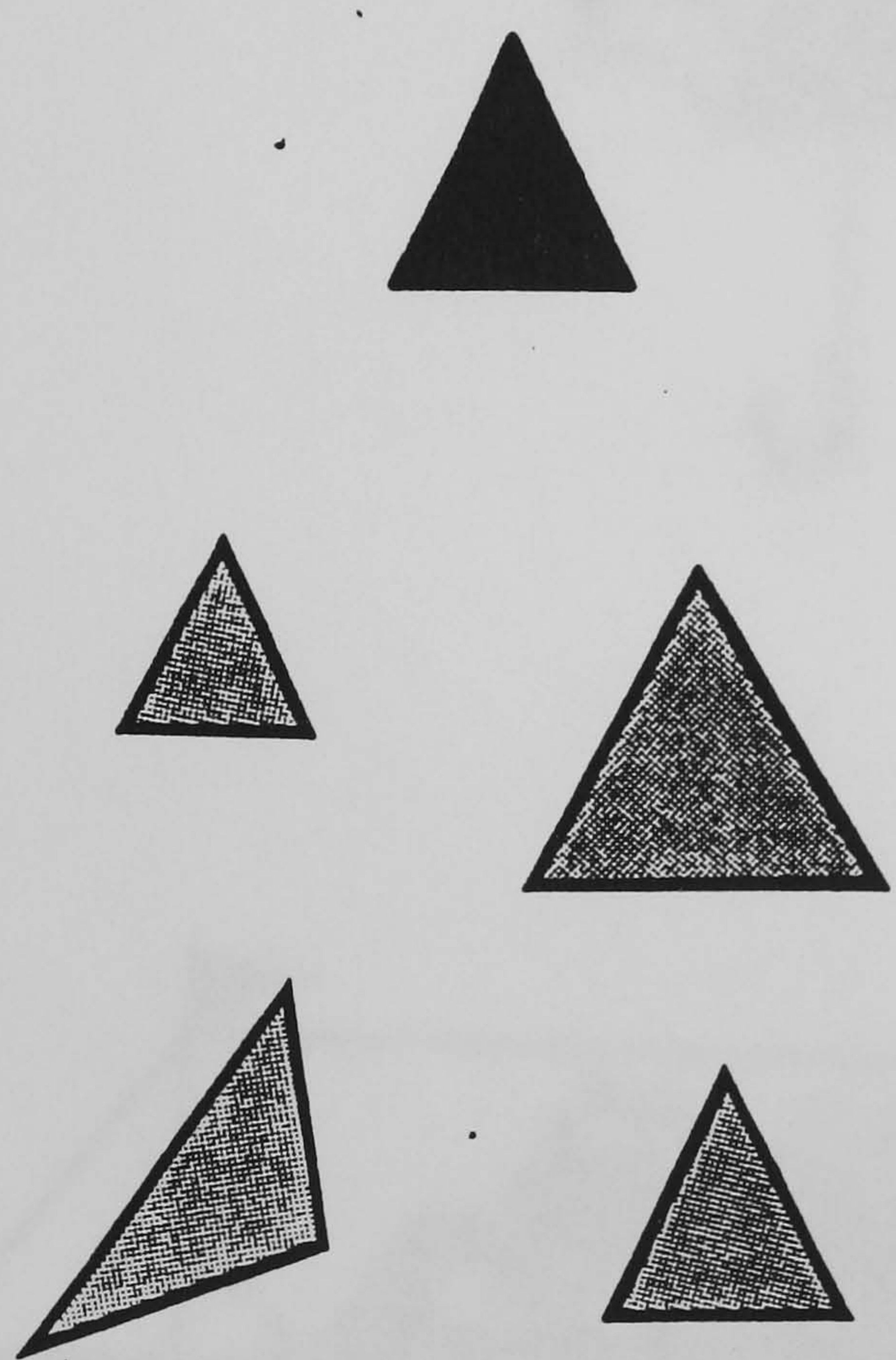
Field Dependence-Independence

Rod & Frame Test: apparatus

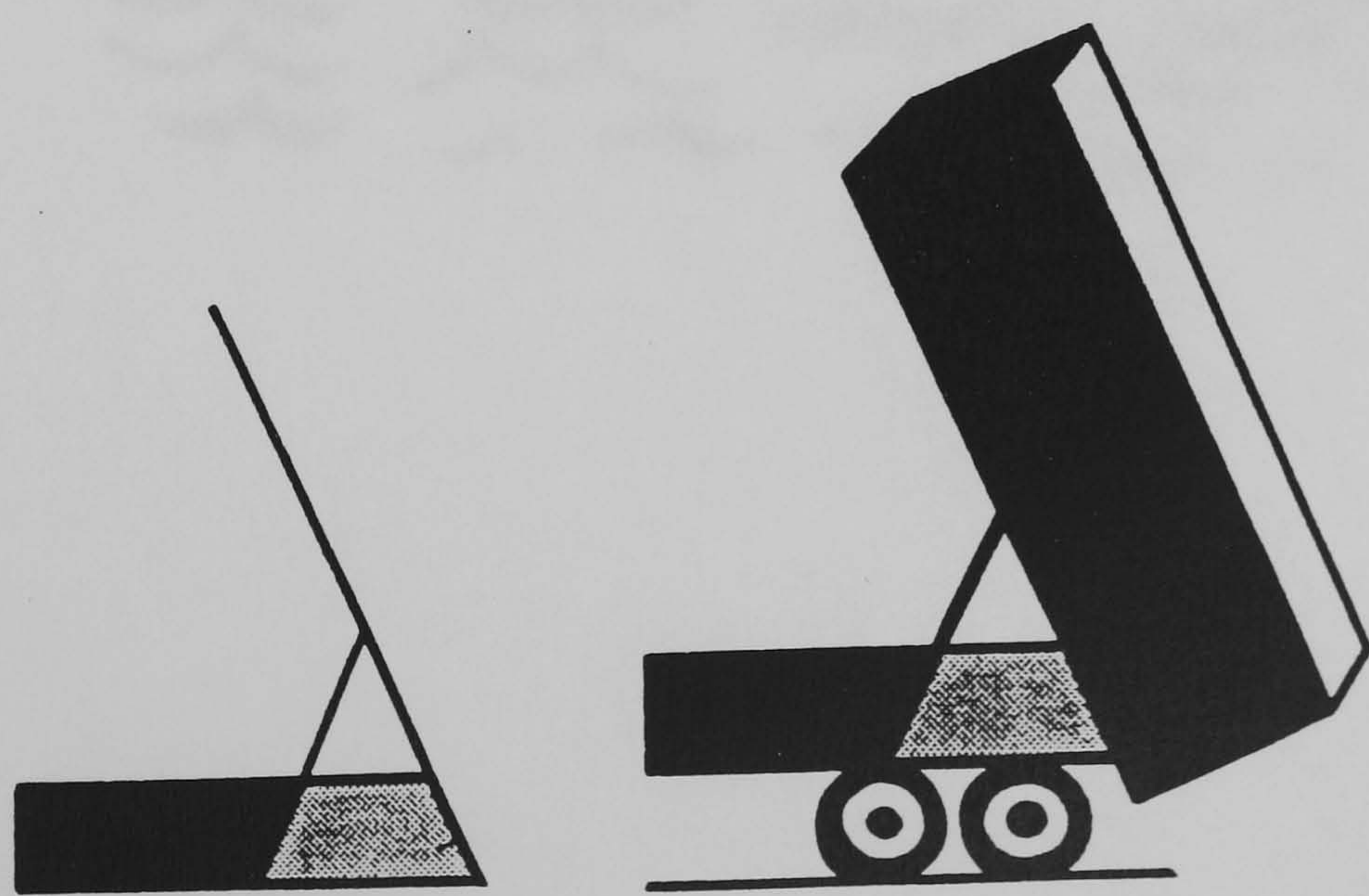


APPENDIX G.2
Field Dependence-Independence

CEFT: example items TENT



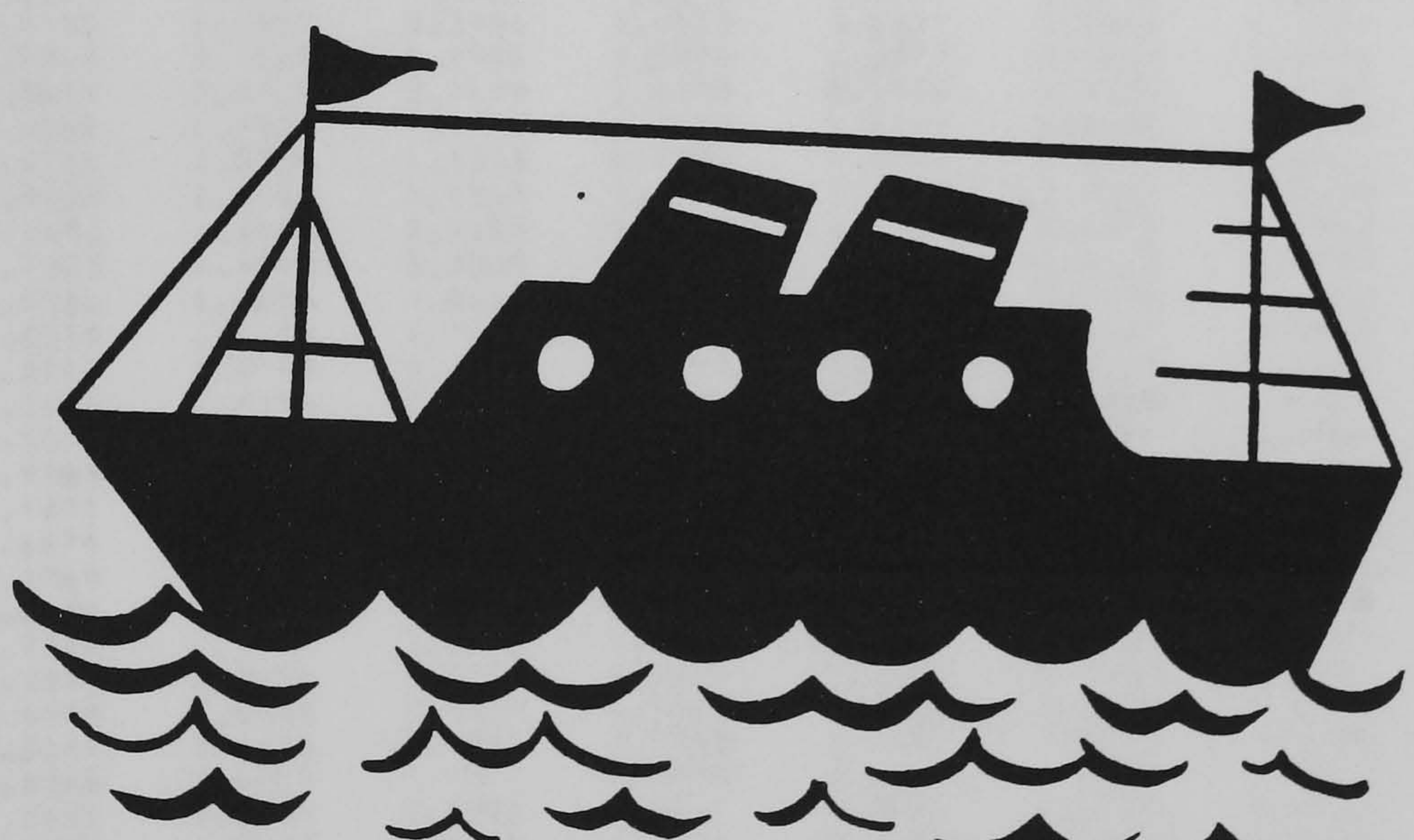
D_1



E_1

P_1

T_1



APPENDIX H.1
Analysis of Central Cases

Case-Cluster Similarity Coefficients

CASE	SIMILARITY WITH CLUSTERS 6	1	3	2	4	7	5
1	4.0452	1.5432	5.7202	3.3678	2.6204	5.0398	4.7959
2	2.8631	3.0807	2.5562	1.1856	2.7711	5.1041	5.4310
3	1.4963	4.4753	0.7007	0.9970	3.8410	2.9795	5.9573
4	1.9895	3.0849	1.2208	1.9283	3.0636	2.7991	6.0532
5	3.9986	1.3046	5.7113	3.5429	1.3285	4.5223	4.7191
6	4.1360	0.9618	5.4576	-3.7452	1.5562	5.1695	4.3946
7	5.3152	3.7843	4.9101	4.1439	1.4911	4.3191	3.1223
8	4.9063	3.5120	4.5671	3.0940	1.2026	5.3798	4.2935
9	2.6725	1.5385	3.1089	1.5200	0.9317	3.6581	4.1102
10	4.8529	3.0019	5.3188	3.3199	0.7482	4.9167	4.2919
11	5.2967	2.3919	5.2248	3.7879	1.1704	5.6417	4.6379
12	2.0773	1.2968	2.6249	1.5032	0.7183	2.7611	4.3091
13	1.0192	1.7566	1.5959	0.3523	1.4919	2.7923	5.0933
14	2.4638	1.3400	3.9437	1.6597	0.9638	4.1934	4.9301
15	2.5509	1.1041	5.1326	3.2605	2.8399	2.8117	4.7446
16	10.5343	7.6552	11.8290	10.1045	7.8955	8.4631	0.0000
17	2.7937	1.9411	4.9265	4.0704	4.3176	4.1412	5.4196
18	1.0066	2.6396	1.9176	2.5304	4.0422	2.0756	6.0517
19	1.7885	0.6764	4.7667	3.0453	3.2988	3.0428	4.3590
20	1.6360	3.5065	1.0482	1.4032	2.4924	1.8275	5.5652
21	2.0089	2.6089	1.9783	1.2573	1.1026	2.9272	5.4497
22	2.9130	1.7995	5.3954	4.0558	3.6857	1.8052	4.5677
23	2.9348	2.9567	2.1984	3.0576	3.0927	2.5682	5.2193
24	4.0431	2.3101	3.7499	2.6933	0.5967	4.1827	4.7284
25	3.0562	4.1507	4.1796	5.3500	5.8967	0.5235	5.7930
26	1.2301	2.0736	1.1338	0.4516	1.6708	2.9193	5.4110
27	1.9688	2.0138	1.1563	1.0412	1.2487	2.9896	5.0779
28	2.5692	4.2148	2.9808	1.3393	3.9905	4.9817	6.7702
29	2.1303	4.6945	0.8069	1.3791	3.2400	2.2323	6.2737
30	2.7384	4.4854	1.0260	2.6439	3.7181	2.1556	5.4408
31	1.8038	2.6429	1.1021	1.1993	1.4994	2.4287	5.2532
32	5.2057	2.6198	5.7353	3.0522	0.9282	6.3763	5.5572
33	2.3445	4.9296	0.7758	1.3932	3.2566	3.0883	6.8421
34	2.3018	1.3137	4.8419	2.6604	3.1393	4.5076	5.3568
35	3.9263	5.1862	3.1208	3.8819	4.4991	2.3491	6.1667
36	1.1275	3.5697	0.2554	0.8111	3.1624	2.4860	6.3491
37	1.6675	3.7867	1.4518	0.9296	2.5922	3.1909	6.5820
38	1.6969	3.5824	1.5565	1.0753	2.6265	2.9912	6.3420
39	0.4485	3.5015	1.0159	1.5518	4.2308	1.6948	6.5949
40	1.4845	2.2942	3.0679	1.4258	2.5618	3.4091	4.9080
41	2.5395	2.9504	2.2583	1.5014	1.3353	3.2505	5.5841
42	2.4799	1.0995	5.1371	2.5897	3.0299	4.0619	4.5786
43	2.0691	5.6253	0.4766	2.2018	4.9577	2.3726	7.1497
44	0.6368	2.4816	1.1011	1.3816	3.3387	2.3122	5.9981
45	2.3453	3.0245	3.3760	1.2441	2.0453	5.0150	5.4237
46	0.9672	3.5420	0.6348	1.7320	3.5496	1.9696	6.4030
47	2.6069	1.7498	2.6689	1.3440	0.4553	3.6040	4.7590
48	1.7487	3.8828	1.0140	1.6776	3.2707	1.6963	5.4023
49	2.9055	6.7175	0.8452	2.6511	5.5483	3.3887	7.6866
50	2.5189	3.9052	1.4143	1.1852	2.4288	4.4385	6.3249
51	1.6674	3.1890	1.3965	0.4685	2.9980	3.7072	6.3257
52	3.2029	6.3810	0.8808	2.5500	5.2099	3.7467	7.6834
53	2.9547	5.7526	0.9753	1.8835	4.2569	3.3037	7.4011
54	2.9792	6.2357	0.7133	2.2342	4.3169	2.3556	7.2394
55	1.2644	3.1379	2.3232	1.9749	3.9270	1.7908	6.3363
56	2.7357	5.5507	0.5984	1.4460	4.2498	3.6923	7.2112
57	1.4129	5.4054	0.8645	1.7172	5.4614	3.1341	7.8095
58	0.9665	3.1128	1.6795	0.8640	3.3299	3.0078	6.3905
59	0.7247	2.5580	1.3629	1.7170	3.6647	0.9795	5.5075
60	1.6423	1.9255	2.9099	2.1581	3.8681	3.6604	6.0897
61	0.8065	2.7973	1.3039	1.3810	2.9224	2.6141	6.0152
62	0.9162	3.7666	2.4047	1.8737	4.4527	3.4169	6.8196
63	0.8784	1.9509	2.3590	2.3278	3.9135	1.7004	5.3678
64	0.8465	3.7632	0.6363	1.3533	3.7373	2.1541	6.7023
65	1.7817	6.2266	1.6074	2.5311	6.4676	3.6036	8.2933
66	3.1359	1.3136	3.6765	2.7062	1.5659	4.1567	5.0436
67	1.4515	3.3373	4.4317	2.7317	5.5783	4.1613	6.8506
68	4.6540	2.1745	5.1718	2.8566	0.6507	5.7531	5.1697
69	0.6252	1.6220	2.0985	0.9923	2.2894	3.0122	5.7524
70	2.3115	4.3821	3.3575	4.6762	6.1524	1.4981	6.4234
71	0.6880	2.7236	1.8020	1.1910	3.2690	2.4708	6.4850
72	1.8979	2.8857	3.4470	2.1668	3.7368	2.1610	5.8652

APPENDIX H.2

Analysis of Central Cases

30 Strategy Components: Raw means and Standard deviations for whole sample

Strat Comp	Prob Type	Mean	S.D.	M+$^1/_2$S.D	M-$^1/_2$S.D
1	a	1.59	0.60	1.89	1.29
	b	1.46	0.57	1.75	1.18
	c	1.83	1.12	2.39	1.27
2	a	96.46	9.87	101.39*	91.52
	b	73.19	17.97	82.17	64.20
	c	77.68	22.06	88.71	66.65
3	a	81.54	18.52	90.80	72.28
	b	70.89	20.43	81.10	60.67
	c	78.31	20.45	88.53	68.08
4	a	99.06	5.95	102.03*	96.08
	b	88.93	14.75	96.30	81.55
	c	90.89	16.43	99.10	82.67
5	a	83.50	20.89	93.94	73.05
	b	77.22	22.60	88.52	65.92
	c	75.78	23.74	87.65	63.91
6	a	72.49	30.04	87.51	57.47
	b	53.35	30.98	68.84	37.86
	c	68.31	33.79	85.20	51.41
7	a	79.31	21.92	90.27	68.35
	b	64.93	23.32	76.59	53.27
	c	67.29	23.28	78.93	55.65
8	a	67.87	29.80	82.77	52.97
	b	48.19	28.55	62.46	33.91
	c	56.36	26.55	69.63	43.08
9	a	74.58	21.53	85.34	63.81
	b	56.93	22.14	68.00	45.86
	c	58.37	24.98	70.86	45.88
10	a	60.60	27.58	74.39	46.81
	b	44.11	25.53	56.87	31.34
	c	45.90	29.38	60.59	31.21

*Since the actual max. score for these variables is 100.00 any case where 100.00 is scored is counted as high.

APPENDIX H.3

Analysis of Central Cases

Performance Indicators: Raw means and Standard deviations for whole sample

Perf. Indicator		Mean	S.D.	$M+^1/_2S.D$	$M-^1/_2S.D$
T. of last error	a	5.06	6.16	8.14	1.98
	b	7.53	6.43	10.74	4.31
	c	6.66	6.85	10.08	3.23
	L	1.92	5.76	4.80	-0.96
Verb. of H. during criterion T's	a	3.49	1.78	4.38	2.60
	b	2.83	1.95	3.80	1.85
	c	3.07	1.94	4.04	2.10
	L	0.45	1.27	1.08	-0.18
No. of H's on T's 1,2, & 3	a	3.75	1.12	4.31	3.19
	b	3.56	0.82	3.97	3.15
	c	3.05	1.03	3.56	2.53
	L	0.27	0.81	0.67	-0.13

Since the Trial of Last Error is a negative indicator (i.e. the best performance = the lowest score) the categories High, Average and Low (for the analysis of Central Cases) are reversed for problem types a,b & c. Learning scores normally as positive scores are derived by subtracting Round 2 scores from Round 1.

APPENDIX H.4

Analysis of Central Cases

Predictor Measures: Raw means and Standard deviations for whole sample

Pred. Measure		Mean	S.D.	$M+{}^{1}/_{2}S.D$	$M-{}^{1}/_{2}S.D$
Wk Mem	WM	2.95	0.80	3.35	2.55
	FIT	3.69	1.18	4.28	3.10
Meta K	Q1	1.31	0.74	1.68	0.94
	Q2	4.11	2.19	5.01	3.01
	Q3	2.13	1.18	2.72	1.54
Meta	M/c	2.93	1.97	3.92	1.94
A&C	SF	0.75	0.92	1.21	0.29
Meta Tot		65.72	26.08	78.76	52.68
L/C		14.82	5.50	17.57	12.07
R-I		1.49	17.73	10.36	-7.38
FDI	RFT	14.08	7.43	17.80	10.36
	CEFT	17.18	4.57	19.47	14.89

Since R-I and RFT are negative indicators (i.e. the best performance = the lowest score) the categories High, Average and Low (for the analysis of Central Cases) are reversed.